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REG-0886
Revision 1

PUREX Storage Tunnels Closing Unit Group 19 Class 3 Permit Modification

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

ch2m

P.O. Box 1600
Richland, Washington 99352

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P.O. Box 1600
Richland, Washington 99352

APPROVED
By Janis D. Aardal at 11:23 am, May 23, 2018

Release Approval | Date

REG-0886
Revision 1

Printed in the United States of America

Certification
for

Permit Application Material for the Plutonium Uranium Extraction (PUREX) Storage Tunnels Closing Unit Group 19

The following certification statement is provided for the submittal of the following revised chapters and addenda for the Plutonium Uranium Extraction (PUREX) Storage Tunnels Closing Unit Group 19 Dangerous Waste Management Units contained in letter 18-AMRP-0106.

- Part A
- Chapter 3, Waste Analysis Plan
- Chapter 4, Process Information
- Chapter 11, Closure and Financial Assurance
- Addendum F, Preparedness and Prevention
- Addendum I, Inspection Requirements
- Addendum J, Contingency Plan

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Doug S. Shoop, Manager
Owner/Operator
U.S. Department of Energy
Richland Operations Office

5/24/18

Date

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L. Ty Blackford, President and CEO
Co-Operator
CHPRC
Richland, Washington

5/23/2018
Date

CHAPTER 1
PART A FORM

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WASHINGTON STATE DEPARTMENT OF ECOLOGY

Dangerous Waste Permit Application
Part A Form

Date Received	Reviewed by:	Date:
Month Day Year	Approved by:	Date:

I. This form is submitted to: (place an "X" in the appropriate box)

☒	Request modification to a final status permit (commonly called a "Part B" permit)
☐	Request a change under interim status
☐	Apply for a final status permit. This includes the application for the initial final status permit for a site or for a permit renewal (i.e., a new permit to replace an expiring permit).
☐	Establish interim status because of the wastes newly regulated on: (Date)
	List waste codes:

II. EPA/State ID Number

W	A	7	8	9	0	0	0	8	9	6	7

III. Name of Facility

U.S. Department of Energy – Hanford Facility

IV. Facility Location (Physical address not P.O. Box or Route Number)
A. Street

Refer to Permit Attachment 2 – Hanford Facility Permit Legal Description

City or Town	State	ZIP Code
Near Richland	WA	

County Code (if			County Name
0	0	5	Benton

B. Land Type	C. Geographic Location Latitude (degrees, mins, secs)	Longitude (degrees, mins, secs)	D. Facility Existence Date Month		Day		Year			
F	Refer to TOPO Map (Section XV).		1	1	1	9	1	9	8	0

V. Facility Mailing Address

Street or P.O. Box

P.O. Box 550

City or Town	State	ZIP Code
Richland	WA	99352

VI. Facility contact (Person to be contacted regarding waste activities at facility)	
Name (last)	**(first)**
Shoop	Doug S.
Job Title	**Phone Number (area code and number)**
Manager	(509) 376-7395

Contact Address		
Street or P.O. Box		
P.O. Box 550		
City or Town	**State**	**ZIP Code**
Richland	WA	99352

VII. Facility Operator Information	
A. Name	**Phone Number**
U.S. Department of Energy Owner/Operator CH2M HILL Plateau Remediation Company Co-Operator for PUREX Storage Tunnels	(509) 376-7395 (509) 373-0293

Street or P.O. Box		
P.O. Box 550 P.O. Box 1600		
City or Town	**State**	**ZIP Code**
Richland	WA	99352
B. Operator Type	F	

C. Does the name in VII.A reflect a proposed change in operator?	☐ Yes ☒ No
If yes, provide the scheduled date for the change:	**Month** / **Day** / **Year**
D. Is the name listed in VII.A. also the owner? If yes, skip to Section VIII.C.	☐ Yes ☒ No

VIII. Facility Owner Information	
A. Name	**Phone Number (area code and number)**
U.S. Department of Energy, Owner/Operator	(509) 376-7395

Street or P.O. Box		
P.O. Box 550		
City or Town	**State**	**ZIP Code**
Richland	WA	99352
B. Owner Type	F	

C. Does the name in VIII.A reflect a proposed change in owner?	☐ Yes ☒ No
If yes, provide the scheduled date for the change:	**Month** / **Day** / **Year**

IX. NAICS Codes (5/6 digit codes)													
A. First							B. Second						
5	6	2	2	1	1	Waste Treatment & Disposal	9	2	4	1	1	0	Administration of Air & Water Resource & Solid Waste Management Programs
C. Third							D. Fourth						
5	4	1	7	1	5	Research & Development in the Physical, Engineering, & Life Sciences	5	6	2	9	1	0	Remediation Services

X. Other Environmental Permits (see instructions)															
A. Permit Type			B. Permit Number												C. Description
	E		A	O	P	0	0	-	0	5	-	0	0	6	Title V Air Operation Permit (AOP) Incorporation of current non-radiological Notice of Construction permits and FF-01 radiological licenses into the AOP may be delayed up to 2 years.

XI. Nature of Business (provide a brief description that includes both dangerous waste and non-dangerous waste areas and activities)

The Plutonium-Uranium Extraction (PUREX) Plant is located in the southeast portion of the 200 East Area. The PUREX Plant was used for the recovery of uranium and plutonium from irradiated reactor fuel. The PUREX Plant was built in 1956 and operated until 1972. It was restarted in 1983 and operated until 1989. The U.S. Department of Energy issued a final shutdown order in December 1992.

Associated with the PUREX Plant is the PUREX Storage Tunnels, Closing Unit Group (CUG) 19. This CUG includes PUREX Tunnels 1 and 2 that are classified as Miscellaneous Units (X99). Each of the tunnels are defined as an individual dangerous waste management unit (DWMU).

PUREX Tunnels 1 and 2 are planned for closure and no new waste will be accepted for placement into the tunnels.

PUREX Tunnel Number 1. The construction of Tunnel Number 1 was completed in 1956. The tunnel is approximately 5.8 meters (19 feet) wide by 6.7 meters (22 feet) high by 109 meters (358 feet) long and provides storage space for eight railcars. The maximum process design capacity for storage in Tunnel Number 1 is approximately 4,129 cubic meters (5,400 cubic yards). The tunnel experienced a partial roof collapse in May 2017. The tunnel was stabilized with grout in October and November 2017.

PUREX Tunnel Number 2. The construction of Tunnel Number 2 was completed in 1964. The usable area in Tunnel Number 2 is approximately 5.8 meters (19 feet) wide by 6.7 meters (22 feet) high by 514.5 meters (1,688 feet) long and provides storage space for 40 railcars. The maximum process design capacity for storage in Tunnel Number 2 is approximately 19,878 cubic meters (26,000 cubic yards). Tunnel Number 2 will be stabilized with grout as an interim closure action.

Process Code X99. The PUREX Storage Tunnels are designated as Miscellaneous Units. Process code X99 is used for storage of mixed waste subject to the requirements of WAC 173-303-680. PUREX

Storage Tunnel Numbers 1 and 2 store waste from the PUREX Plant and other onsite sources. Since being placed into service, mixed waste has been stored in the tunnels on railcars; however, not all material stored in the tunnels contains mixed waste.

The waste stored in the tunnels could include barium(D005), cadmium (D006), chromium (D007), lead (D008), mercury (D009), silver (D011), and light mineral oil (WT02, state-only, toxic, dangerous waste) contained in oil absorption material. The silver is predominately in the form of salts and is considered ignitable (D001) because of the presence of silver nitrate ($AgNO_3$), an oxidizer.

PUREX Tunnel Number 1. Between June 1960 and January 1965, all eight railcar positions were filled and Tunnel Number 1 was sealed. The combined volume of the equipment stored on the eight railcars in Tunnel Number 1 is approximately 596 cubic meters (780 cubic yards).

PUREX Tunnel Number 2. In December 1967, the first railcar was placed in Tunnel Number 2. The last railcar was placed in 1996, for a total of 28 railcars in Tunnel Number 2. The volume of equipment stored on the 28 railcars in Tunnel Number 2 is approximately 2,204 cubic meters (2,883 cubic yards).

EXAMPLE FOR COMPLETING ITEMS XII and XIII (shown in lines numbered X-1, X-2, and X-3 below): A facility has two storage tanks that hold 1200 gallons and 400 gallons respectively. There is also treatment in tanks at 20 gallons/hr. Finally, a one-quarter acre area that is two meters deep will undergo *in situ vitrification*.

Section XII. Process Codes and Design Capacities									Section XIII. Other Process Codes									
Line Number		A. Process Codes (enter code)			B. Process Design Capacity		C. Process Total Number of Units		Line Number		A. Process Codes (enter code)			B. Process Design Capacity		C. Process Total Number of Units	D. Process Description
					1. Amount	2. Unit of Measure (enter code)								1. Amount	2. Unit of Measure (enter code)		
X	1	S	0	2	1,600	G	002	X	1	T	0	4	700	C	001	In situ vitrification
X	2	T	0	3	20	E	001									
X	3	T	0	4	700	C	001									
	1	X	9	9	24,007	C	002		1	X	9	9	24,007	C	002	Tunnel storage
	2								2							
	3								3							
	4								4							
	5								5							
	6								6							
	7								7							
	8								8							
	9								9							
1	0							1	0							
1	1							1	1							

XIV. Description of Dangerous Wastes

Example for completing this section: A facility will receive three non-listed wastes, then store and treat them on-site. Two wastes are corrosive only, with the facility receiving and storing the wastes in containers. There will be about 200 pounds per year of each of these two wastes, which will be neutralized in a tank. The other waste is corrosive and ignitable and will be neutralized then blended into hazardous waste fuel. There will be about 100 pounds per year of that waste, which will be received in bulk and put into tanks.

Line Number			A. Dangerous Waste No. (enter code)				B. Estimated Annual Quantity of Waste	C. Unit of Measure (enter code)	D. Processes (1) Process Codes (enter)									D. Processes (2) Process Description [If a code is not entered in D (1)]
X	1		D	0	0	2	400	P	S	0	1	T	0	1				
X	2		D	0	0	1	100	P	S	0	2	T	0	1				
X	3		D	0	0	2												Included with above
		1	D	0	0	5	454*	K	X	9	9							Includes Debris
		2	D	0	0	6	454*	K	X	9	9							Included with above
		3																
		4	D	0	0	7	454*	K	X	9	9							Included with above
		5	D	0	0	8	8,000*	K	X	9	9							Included with above
		6																
		7																
		8	D	0	1	1	680*	K	X	9	9							Included with above
		9	D	0	0	1		K	X	9	9							Included with above
	1	0	W	T	0	2		K	X	9	9							Included with above
	1	1																
	1	2	D	0	0	9	130*	K	X	9	9							
	1	3																
	1	4																
	1	5																
	1	6																
	1	7																
	1	8																
	1	9																
	2	0																
	2	1																
	2	2																
	2	3																
	2	4																
	2	5																

XV. Map		
Attach to this application a topographic map of the area extending to at least one (1) mile beyond property boundaries. The map must show the outline of the facility; the location of each of its existing and proposed intake and discharge structures; each of its dangerous waste treatment, storage, recycling, or disposal units; and each well where fluids are injected underground. Include all springs, rivers, and other surface water bodies in this map area, plus drinking water wells listed in public records or otherwise known to the applicant within ¼ mile of the facility property boundary. The instructions provide additional information on meeting these requirements.		
XVI. Facility Drawing		
All existing facilities must include a scale drawing of the facility (refer to instructions for more detail).		
XVII. Photographs		
All existing facilities must include photographs (aerial or ground-level) that clearly delineate all existing structures; existing storage, treatment, recycling, and disposal areas; and sites of future storage, treatment, recycling, or disposal areas (refer to instructions for more detail).		

XVIII. Certifications		
I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.		
Operator Name and Official Title (type or print) Doug S. Shoop, Manager U.S. Department of Energy Richland Operations Office	**Signature**	**Date Signed**
Co-Operator Name and Official Title (type or print) L. Ty Blackford President and Chief Executive Officer CH2M HILL Plateau Remediation Company	**Signature** [signature]	**Date Signed** 5/23/2018
Co-Operator – Address and Telephone Number* P.O. Box 1600 Richland, WA 99352 (509) 373-0293		
Facility-Property Owner Name and Official Title (type or print) Doug S. Shoop, Manager U.S. Department of Energy Richland Operations Office	**Signature**	**Date Signed**

1

XV. Map

Attach to this application a topographic map of the area extending to at least one (1) mile beyond property boundaries. The map must show the outline of the facility; the location of each of its existing and proposed intake and discharge structures; each of its dangerous waste treatment, storage, recycling, or disposal units; and each well where fluids are injected underground. Include all springs, rivers, and other surface water bodies in this map area, plus drinking water wells listed in public records or otherwise known to the applicant within ¼ mile of the facility property boundary. The instructions provide additional information on meeting these requirements.

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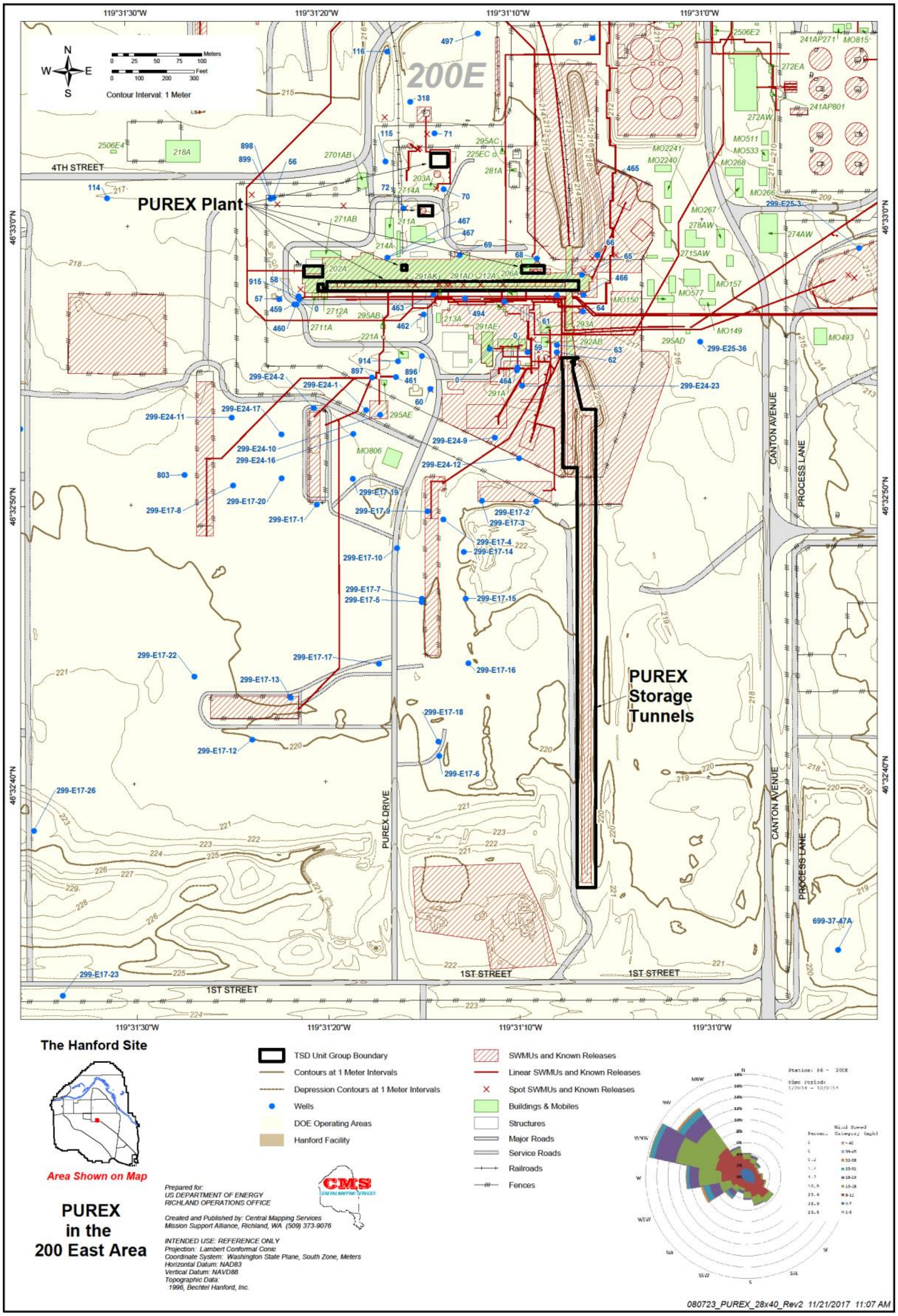
Operator Name and Official Title (type or print)	**Signature**	**Date Signed**
Doug S. Shoop, Manager U.S. Department of Energy Richland Operations Office	Doug S Shoop	5/24/18
Co-Operator Name and Official Title (type or print)	**Signature**	**Date Signed**
L. Ty Blackford President and Chief Executive Officer CH2M HILL Plateau Remediation Company		5/23/2018
Co-Operator – Address and Telephone Number* P.O. Box 1600 Richland, WA 99352 (509) 373-0293		
Facility-Property Owner Name and Official Title (type or print)	**Signature**	**Date Signed**
Doug S. Shoop, Manager U.S. Department of Energy Richland Operations Office	Doug S. Shoop	5/24/18

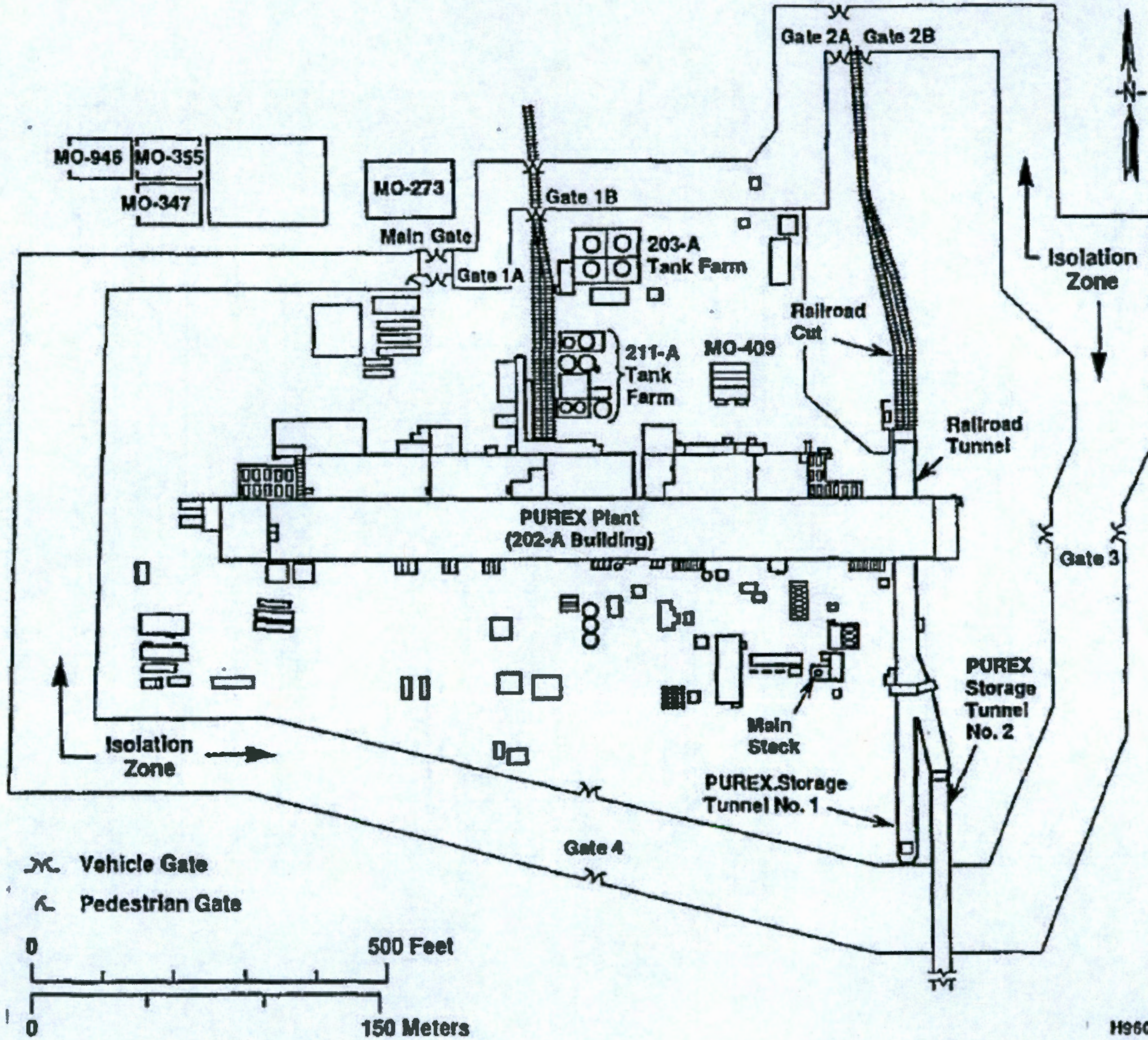
Comments

Section XIV:

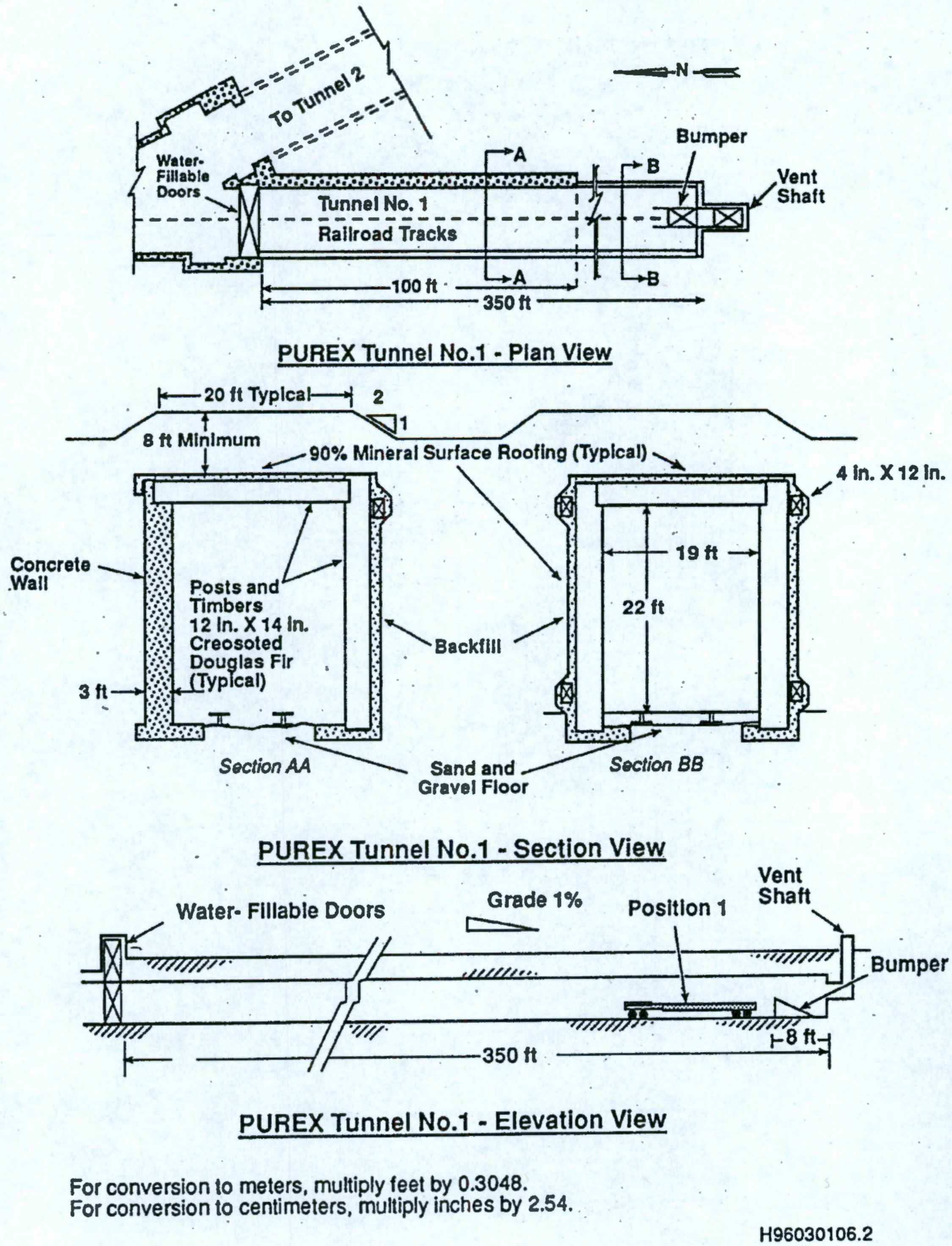
* The values for estimated annual quantity represent the maximum quantity of waste placed in the tunnels in a year. The tunnels no longer receive waste.


200E
PUREX Plant
PUREX Storage Tunnels
4TH STREET
1ST STREET
PUREX DRIVE
CANTON AVENUE
PROCESS LANE
Contour Interval: 1 Meter
The Hanford Site
Area Shown on Map
PUREX in the 200 East Area
TSD Unit Group Boundary
Contours at 1 Meter Intervals
Depression Contours at 1 Meter Intervals
Wells
DOE Operating Areas
Hanford Facility
SWMUs and Known Releases
Linear SWMUs and Known Releases
Spot SWMUs and Known Releases
Buildings & Mobiles
Structures
Major Roads
Service Roads
Railroads
Fences
Prepared for: US DEPARTMENT OF ENERGY RICHLAND OPERATIONS OFFICE
Created and Published by: Central Mapping Services Mission Support Alliance, Richland, WA (509) 373-9076
INTENDED USE: REFERENCE ONLY
Projection: Lambert Conformal Conic
Coordinate System: Washington State Plane, South Zone, Meters
Horizontal Datum: NAD83
Vertical Datum: NAVD88
Topographic Data: 1996, Bechtel Hanford, Inc.
080723_PUREX_28x40_Rev2 11/21/2017 11:07 AM

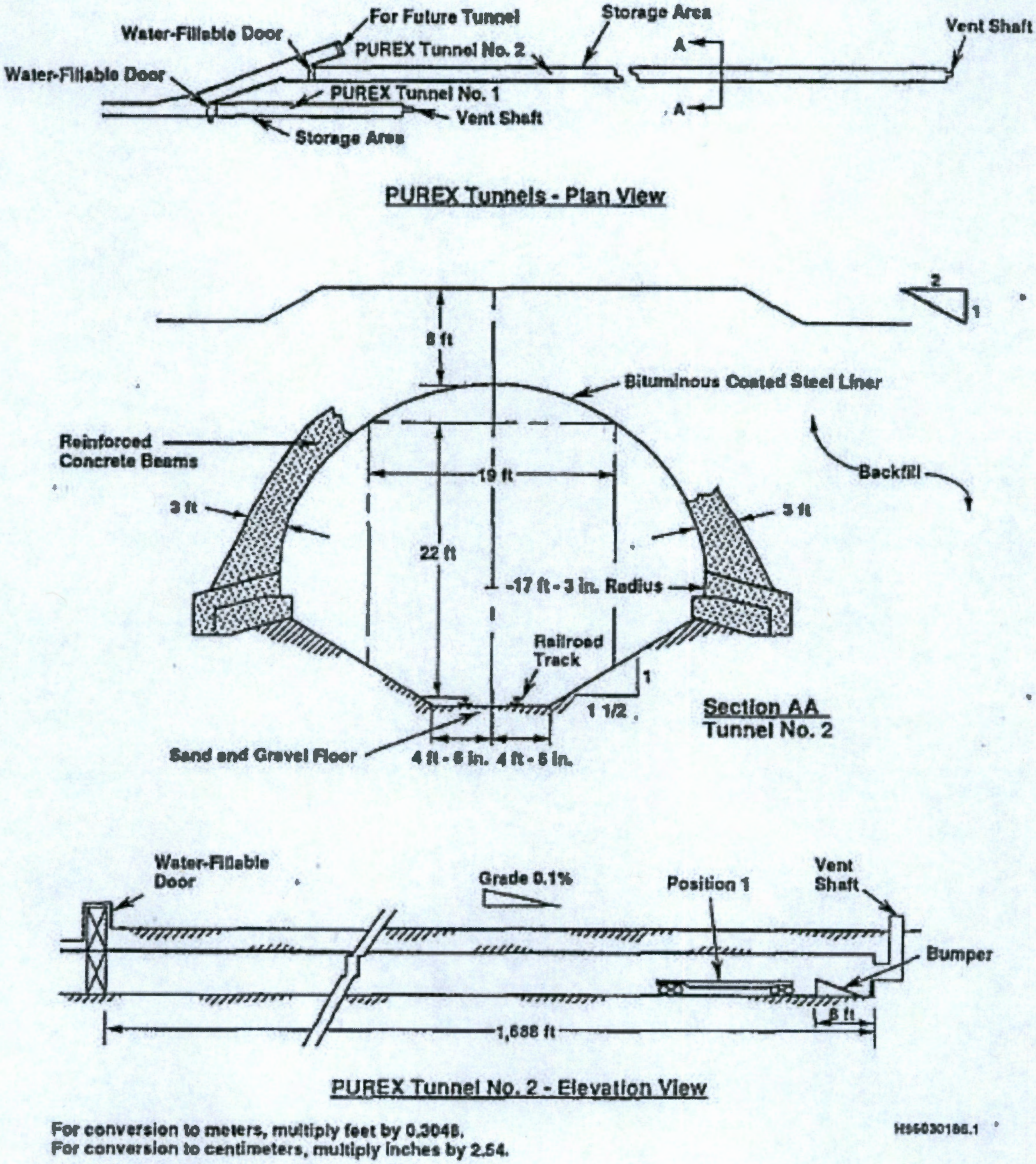
1

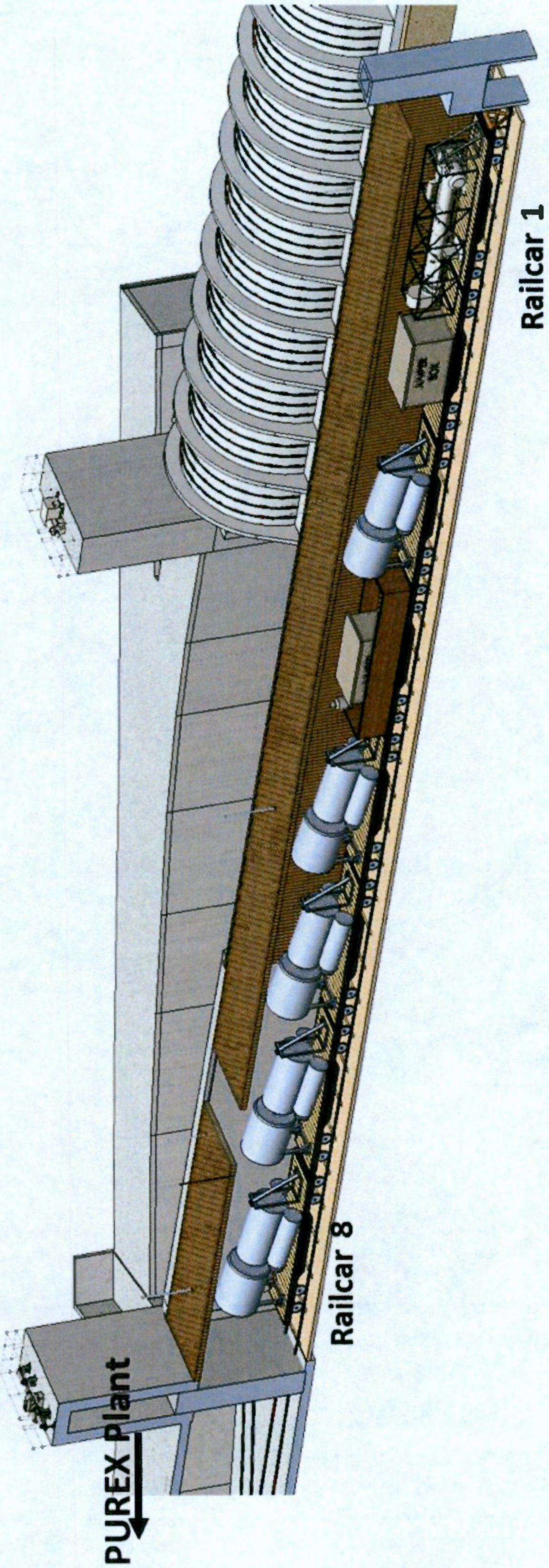

MO-946
MO-355
MO-347
MO-273
Main Gate
Gate 1A
Gate 1B
Gate 2A
Gate 2B
203-A Tank Farm
211-A Tank Farm
MO-409
Railroad Cut
Railroad Tunnel
Isolation Zone
PUREX Plant (202-A Building)
Gate 3
PUREX Storage Tunnel No. 2
Main Stack
PUREX Storage Tunnel No. 1
Gate 4
Isolation Zone
Vehicle Gate
Pedestrian Gate
0
500 Feet
0
150 Meters
N
H96020325.3

PUREX Tunnel No. 1 – Details

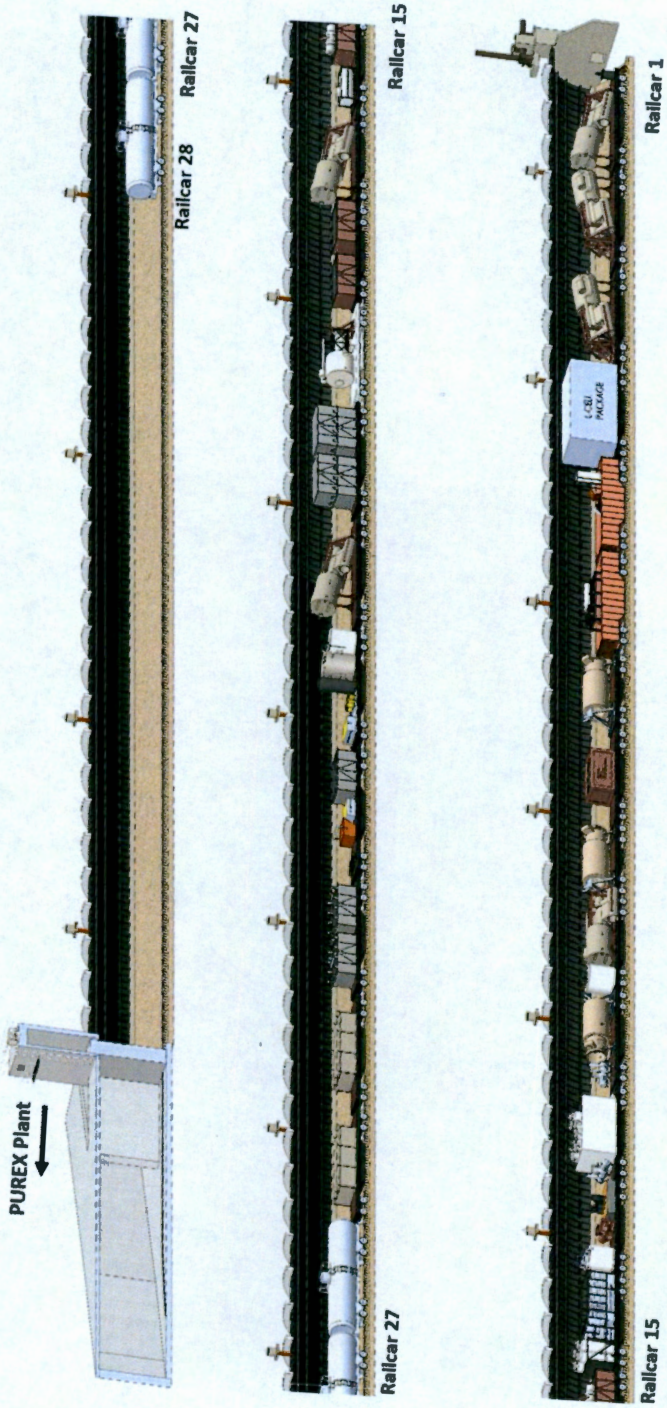


PUREX Tunnel No. 2 – Details

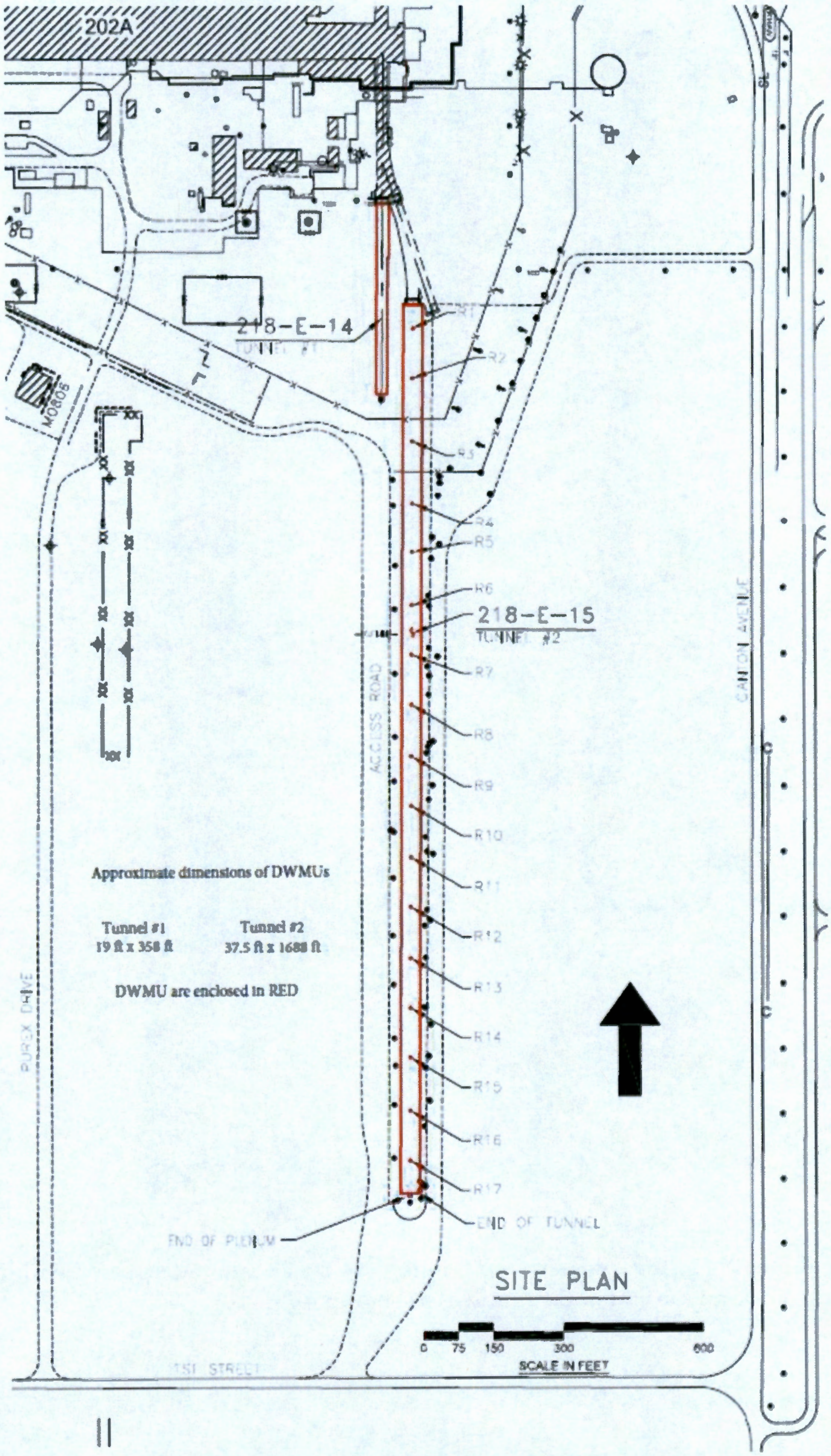




PUREX Tunnel Number 1. The drawing shows a rendition of the eight railroad cars in the tunnel. The water-fillable door is to the left, and the end of the tunnel is to the right.



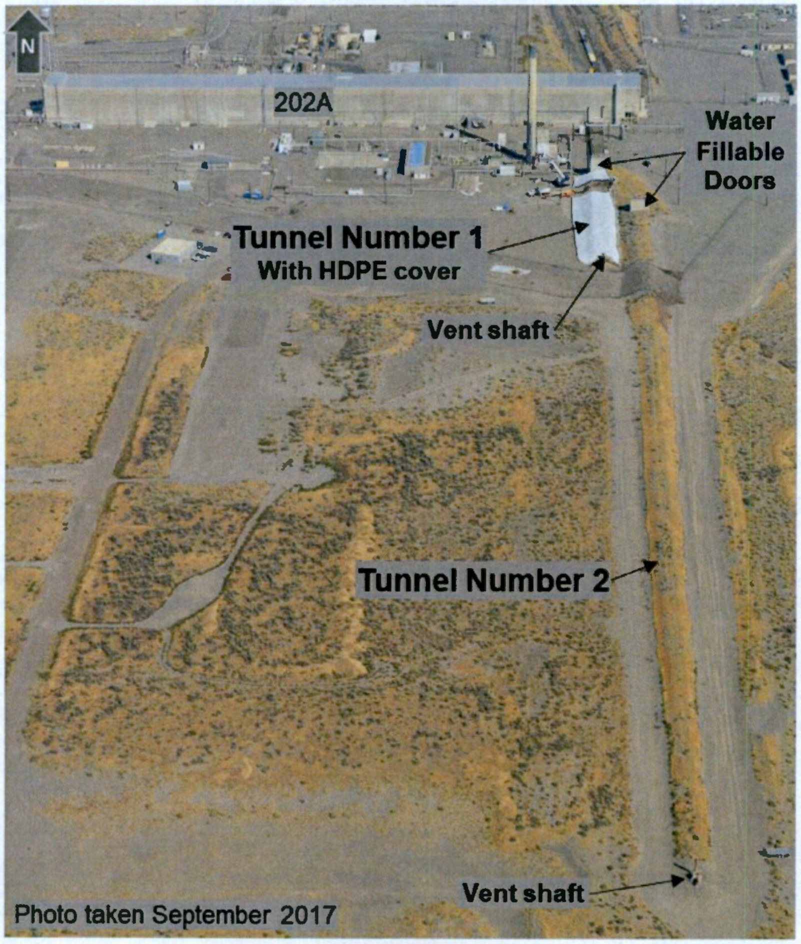
PUREX Tunnel Number 2. The drawing shows a rendition of the 28 railroad cars in the tunnel. The water-fillable door is at top left, and the end of the tunnel is at bottom right.



Dangerous Waste Management Unit Boundary

Chapter 1.16

PUREX Storage Tunnels



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PUREX STORAGE TUNNELS
CHAPTER 3.0
WASTE ANALYSIS PLAN
CHANGE CONTROL LOG

Change Control Logs ensure that changes to this unit are performed in a methodical, controlled, coordinated, and transparent manner. Each unit addendum will have its own change control log with a modification history table. The "**Modification Number**" represents Ecology's method for tracking the different versions of the permit. This log will serve as an up to date record of modifications and version history of the unit.

Modification History Table

Modification Date	Modification Number
10/2006	

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CHAPTER 3.0
WASTE ANALYSIS PLAN

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CHAPTER 3.0
WASTE ANALYSIS PLAN

TABLE OF CONTENTS

TABLE

GLOSSARY

ALARA	as low as reasonably achievable
ECOLOGY	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
pH	negative logarithm of the hydrogen-ion concentration
PUREX	plutonium-uranium extraction
QA/QC	quality assurance and quality control
TSD	treatment, storage, and/or disposal
WAC	Washington Administrative Code
WAP	waste analysis plan

METRIC CONVERSION CHART

The following conversion chart provides the reader an aid in conversion.

Into metric units			Out of metric units		
If you know	Multiply by	To get	If you know	Multiply by	To get
Length			Length		
inches	25.40	millimeters	millimeters	0.0393	inches
inches	2.54	centimeters	centimeters	0.393	inches
feet	0.3048	meters	meters	3.2808	feet
yards	0.914	meters	meters	1.09	yards
miles	1.609	kilometers	kilometers	0.62	miles
Area			Area		
square inches	6.4516	square centimeters	square centimeters	0.155	square inches
square feet	0.092	square meters	square meters	10.7639	square feet
square yards	0.836	square meters	square meters	1.20	square yards
square miles	2.59	square kilometers	square kilometers	0.39	square miles
acres	0.404	hectares	hectares	2.471	acres
Mass (weight)			Mass (weight)		
ounces	28.35	grams	grams	0.0352	ounces
pounds	0.453	kilograms	kilograms	2.2046	pounds
short ton	0.907	metric ton	metric ton	1.10	short ton
Volume			Volume		
fluid ounces	29.57	milliliters	milliliters	0.03	fluid ounces
quarts	0.95	liters	liters	1.057	quarts
gallons	3.79	liters	liters	0.26	gallons
cubic feet	0.03	cubic meters	cubic meters	35.3147	cubic feet
cubic yards	0.76456	cubic meters	cubic meters	1.308	cubic yards
Temperature			Temperature		
Fahrenheit	subtract 32 then multiply by 5/9ths	Celsius	Celsius	multiply by 9/5ths, then add 32	Fahrenheit

Source: *Engineering Unit Conversions*, M. R. Lindeburg, PE, Second Ed., 1990, Professional Publications, Inc., Belmont, California.

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3.0 WASTE ANALYSIS PLAN

This chapter provides information on the chemical, biological, and physical characteristics of the dangerous waste stored in the PUREX Storage Tunnels. Waste in the tunnels is stored and managed as mixed waste. The PUREX Storage Tunnels provide the necessary shielding for the protection of employees and the environment from mixed waste. The PUREX Storage Tunnels are no longer in active operation and will be identified as "closure units."

On May 9, 2017 workers discovered a portion of Tunnel Number 1 had collapsed, prompting an immediate response action to protect workers and the environment. A structural evaluation revealed the threat of further failure of Tunnel Number 1. An interim stabilization measure to fill Tunnel Number 1 with engineered grout was taken under Section J.4.5 of the PUREX Tunnels Contingency Plan and Permit Condition III.2.A.1 of the Hanford Facility RCRA Permit. Grouting in Tunnel Number 1 was completed in November 2017. Filling the tunnel void spaces with grout improved tunnel stability, provided additional radiological protection, and increased durability while not precluding final closure actions.

A structural evaluation revealed the threat of future failure of Tunnel Number 2. To protect stored waste containers from potential damage caused by a tunnel failure event (e.g., puncture of a container by a falling structural member) and to prevent any associated release of dangerous waste constituents to the environment, an interim closure action to cover the stored waste and fill Tunnel Number 2 void spaces around the waste with engineered grout is being taken. The waste analysis plan (WAP) reflects information about the waste currently in storage in the tunnels.

3.1 Chemical, Biological, and Physical Analyses

Regulated material presently stored in the PUREX Storage Tunnels contains the following dangerous waste:

- Lead
- Mercury
- Silver and silver salts
- Chromium
- Cadmium
- Barium
- Mineral oil

In general, dangerous waste is either attached to, contained within, or actually is material removed from the PUREX Plant and other onsite sources. Changes in dangerous waste stored is updated annually in the annual dangerous waste report submitted to Ecology. The PUREX Storage Tunnels are permitted as miscellaneous units under WAC 173-303-680 because the tunnels are not typical containerized storage units. That is, the bulk of the material stored in the tunnels is not placed in a container; rather, this material is placed on a portable device (railcar) used as a storage platform. The mixed waste stored in the PUREX Storage Tunnels is encased or contained within carbon or stainless steel plate, pipe, or vessels that meet the WAC 173-303-040 definition of container. Therefore, the mixed waste normally is not exposed to the tunnel environment.

The only free-liquid dangerous waste stored in the tunnels is elemental mercury. The mercury is contained within thick-walled (0.8-centimeter) thermowells. The amount of mercury per thermowell is less than 1.7 liters.

Other liquid containers, such as large discarded process tanks, are stored in the PUREX Storage Tunnels. These containers are 'empty' [per WAC 173-303-160(2)(a)].

The only stored mixed waste that is designated as either reactive or ignitable (D001) is silver nitrate in the silver reactors [WAC 173-303-090(5)]. There is no mixed waste designated as reactive (D003).

The potential for ignition from this source is considered negligible because this material is dispersed on ceramic packing and is physically isolated from contact with any combustible material or ignition source.

3.2 Tracking System

Documentation of the movement of waste for storage in the PUREX Storage Tunnels will be maintained at the Hanford Facility for a minimum of 5 years following closure of the PUREX Storage Tunnels.

3.3 Facility Description

This WAP has been prepared for the PUREX Storage Tunnels, located on the Hanford Facility, Richland, Washington. This WAP applies to all mixed waste (containing dangerous components) regulated by WAC 173-303 that is contained in the PUREX Storage Tunnels.

The PUREX Storage Tunnels are permitted as miscellaneous units under WAC 173-303-680, but are no longer in active operation and comprise Closing Unit Group 19. The bulk of the waste stored in the PUREX Storage Tunnels is not placed in a typical container; rather, this waste is placed on a portable device (railcar) that is used as a storage platform. In general, the mixed waste stored in the PUREX Storage Tunnels is encased or contained within carbon or stainless steel plate, pipe, or vessels. Therefore, the mixed waste normally is not exposed to the tunnel environment.

The PUREX Facility, located in the 200 East Area, consists of two separate treatment, storage, and/or disposal (TSD) Unit Groups, the PUREX Plant (202-A Building) and the PUREX Storage Tunnels. Access to the PUREX Storage Tunnels is by means of the railroad tunnel.

The PUREX Storage Tunnels branch off from the railroad tunnel and extend southward from the east end of the PUREX Plant. The tunnels are used for storage of mixed waste from the PUREX Plant and from other onsite sources. Each storage tunnel is isolated from the railroad tunnel by a water-fillable shielding door. There are no electrical utilities, water lines, drains, fire detection or suppression systems, or communication systems provided inside the PUREX Storage Tunnels.

Material selected for storage was loaded on railcars modified to serve as both transport and storage platforms. Normally, a remote-controlled, battery-powered locomotive was used to position the railcar in the storage tunnel. In the past, other remote movers, e.g., standard locomotive with a string of railcar spacers, power winch, etc., have or could have been used to position a railcar in the tunnel or to withdraw a car from the tunnel. The railcar storage positions are numbered sequentially, commencing with Position 1 that abuts the rail stop bumper at the south end of each tunnel. Position 2 is the location of the railcar that abuts the railcar in Position 1 and so forth. The railcars and material remain in the storage tunnel until final disposition is determined.

Construction of Tunnel Number 1 was completed in 1956. The Tunnel has three areas, the water-fillable door, the storage area, and the vent shaft. The water-fillable door is located at the north end of Tunnel Number 1 and separates the storage tunnel from the railroad tunnel. The door is 7.5 meters high, 6.6 meters wide, and 2.1 meters thick, and is constructed of 1.3-centimeter steel plate. The door is hollow so that the door could be filled with water to act as a shield when the door is in the down (closed) position. The door does not currently contain water and will not be refilled. Above the door is a reinforced concrete structure in which the door is raised to open the tunnel. Electric hoists used for opening and closing the door are located on the top of this concrete structure.

The storage area is that portion of the tunnel that extends southward from the water-fillable door. Inside dimensions of Tunnel Number 1 are 109.1 meters long, 6.7 meters high, and 5.8 meters wide. Ceiling and walls are 35.6-centimeters thick and constructed of 30.5- by 35.6-centimeter creosote pressure-treated Douglas fir timbers arranged side by side. The first 30.5 meters of the east wall are constructed of 0.9-meter-thick reinforced concrete. A 40.8-kilogram mineral-surface roofing material was used to cover the exterior surface of the timbers before placement of nominally 2.4 meters of earth fill. The earth cover serves as protection from the elements and as shielding. The timbers that form the walls rest on reinforced concrete footings 0.9 meter wide by 0.3 meter thick. The floor consists of a railroad track laid on a gravel bed. The space between the ties is filled to top-of-tie with gravel ballast. The tracks are on a 1.0 percent downward slope to the south to ensure that the railcars remain in their storage position. A railcar bumper is located 2.4 meters from the south end of the tracks to act as a stop. The capacity of the storage area is eight, 12.8-meter-long railcars.

In June 1960, the first two railcars were loaded with a single, approximately 12.5-meter-long, failed separation column and a box containing jumpers (connectors) and placed in Tunnel Number 1. Between June 1960 and January 1965, six more railcars were placed in Tunnel Number 1, filling the tunnel. After the last car was placed in the northern-most storage position (Position 8), the water-fillable door was closed, filled with water, and deactivated electrically. The door was subsequently drained and sealed and will not be refilled.

On May 9, 2017 workers discovered a portion of Tunnel Number 1 had collapsed, prompting an immediate response action to protect workers and the environment. A structural evaluation revealed the threat of further failure of Tunnel Number 1. An interim stabilization measure to fill Tunnel Number 1 with engineered grout was taken under Section J.4.5 of the PUREX Tunnels Contingency Plan and Permit Condition III.2.A.1 of the Hanford Facility RCRA Permit. Grouting in Tunnel Number 1 was completed in November 2017. Filling the tunnel void spaces with grout improved tunnel stability, provided additional radiological protection, and increased durability while not precluding final closure actions.

Construction of Tunnel Number 2 was started and completed in 1964. Like Tunnel Number 1, Tunnel Number 2 consists of three functional areas: the water-fillable door, the storage area, and the vent shaft. Construction of Tunnel Number 2 differs from that of Tunnel Number 1 as follows.

- A combination of steel and reinforced concrete was used in the construction of the storage area for Tunnel Number 2 rather than wood timbers, as used in Tunnel Number 1.
- Tunnel Number 2 is longer, having a storage capacity of five times that of Tunnel Number 1.
- The floor of Tunnel Number 2, outboard of the railroad ties, slopes upward to a height of approximately 1.8 meters above the railroad bed, whereas the floor in Tunnel Number 1 remains flat all the way out to the sidewalls.
- The railroad tunnel approach to Tunnel Number 2 angles eastward then angles southward to parallel Tunnel Number 1. The approach to Tunnel Number 1 is a straight extension southward from the PUREX Plant. Center-line to center-line distance between the two tunnels is approximately 18.3 meters.

The physical structure of the water-fillable door at the north end of Tunnel Number 2 essentially is identical to the water-fillable door for Tunnel Number 1. The water-fillable door for Tunnel Number 2 is approximately 57.9 meters south and 18.3 meters east of the water-fillable door for Tunnel Number 1. As of March 1997, the door was empty and it will not be refilled.

The storage area of Tunnel Number 2 is that portion of the tunnel extending southward from the water-fillable door. Construction of this portion of Tunnel Number 2 consists of a 10.4-meter diameter, steel (0.5 centimeter plate), and semicircular-shaped roof, supported by internal I-beam wales attached to external, reinforced concrete arches. The concrete arches are 0.4 meter thick and vary in width from 0.4 to 1.8 meters. The arches are spaced on 4.8-meter centers. This semicircular structure is supported on reinforced concrete grade beams approximately 1.8 meters wide by 1.2 meters thick (one on each side) that run the full length of Tunnel Number 2. The interior and exterior surfaces of the steel roof are coated with a bituminous coating compound to inhibit corrosion. The entire storage area is covered with nominally 2.4 meters of earth fill to serve as shielding.

The overall inside dimensions of Tunnel Number 2 are 514.5 meters long, 7.9 meters high, and 10.4 meters wide. However, because of the arch-shaped cross-section of Tunnel Number 2 and entry clearance at the water-fillable door, the usable storage area (width and height above top-of-rail) is 6.7 meters high and 5.8 meters wide, the same dimensions as for Tunnel Number 1. The floor consists of a railroad track laid on a gravel bed. The space between ties is filled to top-of-tie with gravel ballast. Commencing at the ends of the 2.4-meter-long ties, the earth floor is sloped upward on a 1 (vertical) to 1 1/2 (horizontal) grade. The tracks are on a 1/10 of 1 percent downgrade slope to the south to ensure the railcars remain in their storage position. A railcar bumper is located 2.4 meters from the south end of the tracks to act as a stop. The capacity of the storage area is 40, 12.8-meter-long railcars.

The first railcar was placed in storage in December 1967. Table 3.1 contains an approximate inventory of waste stored in the PUREX Storage Tunnels.

After Tunnel Number 1 collapsed, a structural evaluation was performed that revealed the threat of future failure of Tunnel Number 2. To protect stored waste containers from potential damage caused by a tunnel failure event (e.g., puncture of a container by a falling structural member) and to prevent any associated release of dangerous waste constituents to the environment, an interim closure action to cover the stored waste and fill Tunnel Number 2 void spaces around the waste with engineered grout is being taken.

3.3.1 Process and Activities

The function of the PUREX Tunnels is to store mixed waste until final disposal. When waste was placed in the storage tunnels, a work plan, describing the overall transfer activities, and a storage tunnel checklist were prepared. The work plan and storage tunnel checklist were routed for review and concurrence by key personnel and forwarded to management for approval. No new waste will be added to the tunnels. The following sections describe processes used when the tunnels were in active operation.

3.3.2 Physical Characterization of Material to be Stored

Physical characterization of waste includes an evaluation of the following physical properties:

- Length, width, and height
- Gross weight and volume
- Preferred orientation for transport and storage
- Presence of dangerous waste constituents

Information sources used in physical characterization include equipment fabrication and installation drawings, operational records, and process knowledge. Physical characterization provides information necessary to describe the waste material. Such information also was used to design and fabricate, if required, supports on the railcar.

Before removal from service, the equipment could be flushed to minimize loss of products, to reduce contamination, and to reduce dangerous waste constituents present in a residual heel to nonregulated levels. When equipment was flushed, analysis of the rinsate was used to determine when these goals were achieved.

3.4 Identification/Classification and Quantities Of Dangerous Waste Managed Within The PUREX Storage Tunnels

Table 3.1 contains an approximation of the total amount of waste stored within the PUREX Storage Tunnels.

3.5 Waste Analysis Parameters

Analytical requirements were selected based on knowledge required for the safe handling and storage of the waste within the PUREX Storage Tunnels, including any operational compliance issues.

3.5.1 Waste Identification

This section provides information on how the chemical and physical characteristics of the mixed waste currently stored in the PUREX Storage Tunnels were determined so that the waste was stored and managed properly.

Regulated material presently stored in the PUREX Storage Tunnels contains the following dangerous waste:

- Lead
- Mercury
- Silver and silver salts
- Chromium
- Cadmium
- Barium
- Mineral oil

Storage of non-PUREX Plant waste was reviewed on a case-by-case basis. Sampling, chemical analysis, process knowledge (as discussed in the following section), and/or inventory information from waste tracking forms provided from other onsite sources were required to confirm the characteristics and quantities of mixed waste to be stored.

3.5.1.1 Lead

Lead stored was used in various capacities during past Hanford Facility operations. Primary functions of lead included use as weights, counterweights, and shielding. Often the lead is encased in steel (carbon or stainless) to facilitate its attachment to various types of equipment.

Lead exhibits the characteristic of toxicity as determined by the toxicity characteristics leaching procedure and is designated D008 [WAC 173-303-090(8)]. The quantity of lead present could produce an extract greater than 500 milligrams per liter should the lead be exposed to a leachate. However, because the bulk of the lead is encased in steel, is stored inside weather-tight structures that are or will be filled with grout to encapsulate the waste, and is elevated above floor level on railcars that isolate the lead from other materials stored, the potential for exposure of bare lead to a leachate is considered negligible.

Sampling and chemical analysis was not performed on lead associated with the material placed in the PUREX Storage Tunnels. Therefore, the accuracy of the estimate on the amount of lead presently stored in each tunnel is limited to the data available from process knowledge. Counterweights on equipment dunnage and lead used for shielding cannot be quantified by existing historical records and are not included for lead listed on Table 3.1.

3.5.1.2 Mercury

Mercury is contained within thermowells that were an integral part of spent reactor fuel dissolvers used at the PUREX Plant. The dissolvers are large 304L stainless steel process vessels that are approximately 2.7 meters in diameter, 7.3 meters tall, and weigh approximately 26,309 kilograms. The outer shell is constructed of a 1-centimeter-thick plate. The dissolvers were used in decladding and dissolving spent reactor fuel in the PUREX Plant.

Approximately 45 kilograms of mercury (less than 1.7 liters) were poured in each of the two thermowells per dissolver following vertical installation of the dissolvers inside the PUREX canyon and before the dissolver was installed in a process cell. The mercury served to transfer heat from the dissolver interior to the thermohm temperature sensor mounted within the thermowell. This mercury remains within the thermowells of discarded dissolvers. In preparation for storage, the thermohms were removed and the upper end of each thermowell was plugged with a 304L stainless steel nozzle plug. In storage, the discarded dissolver rests in an inclined position in a cradle on the railcar. The mercury contained in the thermowells remains in the lower portion of each thermowell and, under normal conditions, is never in contact with the mechanical closure on the nozzle end of the thermowell.

Mercury exhibits the characteristic of toxicity as determined by the toxicity characteristics leaching procedure and is designated D009 [WAC 173-303-090(8)].

The potential for mercury to become exposed to leachate is considered negligible. The PUREX Storage Tunnels are designed and constructed as weather-tight structures that are or will be filled with grout to encapsulate the waste. Further, the mercury is encased in a stainless steel pipe within a stainless steel vessel that is stored on a railcar above the floor level of the tunnels. Therefore, exposure of the mercury stored in the tunnels to leachate is not considered a credible occurrence.

Sampling and chemical analysis was not performed on mercury associated with the dissolvers stored in Tunnel Number 2. The quantity of mercury present in each thermowell is documented on Table 3.1.

3.5.1.3 Silver

Silver, mostly in the form of silver salts deposited on unglazed ceramic packing, is contained within the discarded silver reactors stored in Tunnel Number 2. The silver reactors were used to remove iodine from the offgas streams of the spent reactor fuel dissolvers. The reactor vessel is approximately 1.4 meters in diameter by 4.1 meters tall and is constructed of 1-centimeter 304L stainless steel. The vessel contains two 1.2-meter-deep beds of packing. Each bed consists of a 30.5-centimeter depth of 2.5-centimeter unglazed ceramic saddles topped with a 0.6-meter depth of 1.3-centimeter unglazed ceramic saddles. The two beds are separated vertically by a distance of about 0.6 meter, and each bed rests on a support made of stainless steel angles and coarse screen. The packing was coated initially with 113.4 kilograms of silver nitrate used for iodine retention. Nozzles on the top of the reactor were provided to allow flushing and/or regeneration of the packing with silver nitrate solution as the need arose.

Because of competing reactions, which include conversion of silver nitrate to silver iodide, reduction of silver nitrate to metallic silver, and formation of silver chloride, the packing of a stored silver reactor contains a mixture of silver nitrate, silver halides, and silver fines.

Silver salts exhibit the characteristics of toxicity as determined by the toxicity characteristics leaching procedure and are designated D011 [WAC 173-303-090(8)]. Silver salts exhibit the characteristic of ignitability and are designated as D001 [WAC 173-303-090(5)].

The potential of silver, including silver salts, stored in the PUREX Storage Tunnels to become exposed to leachate is considered negligible. Silver is contained within a stainless steel vessel, stored inside a weather-tight structure that is or will be filled with grout to encapsulate the waste, and elevated above floor level on a railcar. Therefore, exposure of the silver stored in the tunnels to leachate is not considered a credible occurrence. In addition, the contained silver is isolated from contact with any combustibles; therefore, the possibility of ignition is considered extremely remote.

Provisions for taking samples of the packing were not provided in the design of the vessels. Therefore, sampling and chemical analysis were not performed for silver salts before placing a silver reactor in storage. However, for accountability, the total silver content (Table 3.1) is considered silver nitrate, the salt that exhibits the characteristics of both ignitability and toxicity.

The quantity of silver salts contained within a discarded silver reactor is a function of silver nitrate regeneration history. Operating records (process knowledge) of regenerations and flushes were used to estimate the total accumulation of silver within each reactor.

3.5.1.4 Chromium

Presently, chromium stored in Tunnel Number 2 is contained within a failed concentrator removed from the PUREX Plant, and within stainless steel containers received from the 324 Building. The concentrator is a vertical tube structure that was used to concentrate aqueous streams from the final uranium cycle, final plutonium cycles, final neptunium cycles, and condensate from the acid recovery system for recycle. Following service, the concentrator was inspected and found to contain silicate solids with high levels of chromium from the corrosion of stainless steel. The existence of chromium within the 324 Building waste was determined through process knowledge. Chromium exhibits the characteristic of toxicity as determined by the toxicity characteristics leaching procedure and is designated D007 [WAC 173-303-090(8)]. The potential for the chromium stored in Tunnel Number 2 to become exposed to leachate is considered negligible. Tunnel Number 2 is designed and constructed to be weather-tight and will be filled with grout to encapsulate the waste. Further, the chromium is encased within stainless steel vessels and containers that are stored on railcars above the floor level of the tunnel. Therefore, exposure of the chromium stored in the tunnel to leachate is not considered a credible occurrence.

The quantity of chromium within the concentrator was estimated by calculating the volume of silicate solids and the percentage of chromium within the silicate solids. The quantity of chromium in the 324 Building waste was based on process knowledge.

3.5.1.5 Cadmium

Presently, cadmium stored in the PUREX Storage Tunnel Number 2 is associated with shielding and with a dissolver moderator removed from the PUREX Plant, and within stainless steel containers received from the 324 Building. The cadmium was used to shield equipment and consists of sheets of the metal attached to lead, both of which could be encased in steel. The cadmium received from the 324 Building was used in waste technology research and development programs.

The dissolvers are annular vessels that are geometrically favorable for criticality safety. The dissolvers were placed over cadmium lined (neutron absorbers) moderators for additional criticality safety. The moderator is a centrally located, cylindrical, cadmium-jacketed 0.08-centimeter-thick concrete 15.2-centimeter-thick neutron absorber. The moderators are approximately 4.4 meters tall by approximately 1.5 meters outer diameter.

Cadmium exhibits the characteristic of toxicity as determined by the toxicity characteristics leaching procedure and is designated D006 [WAC 173-303-090(8)]. Cadmium lists a lethal concentration (LC50) of 0.0016 mg/L (fish, salmon). Therefore, cadmium is a Toxic Category X [WAC 173-303-100(5)]. Mixed waste on some railcars is assigned the dangerous waste number WT02.

The potential for the cadmium stored in Tunnel Number 2 to become exposed to leachate is considered negligible. Tunnel Number 2 is designed and constructed to be weather-tight and will be filled with grout to encapsulate the waste. Further, the cadmium is stored on railcars above the floor level of the tunnel. Therefore, exposure of the cadmium stored in the tunnel to leachate is not considered a credible occurrence.

3.5.1.6 Barium

Presently, barium is stored in Tunnel Number 2 in stainless steel containers received from the 324 Building. The waste was generated during numerous research and development programs conducted in B-Cell of the Waste Technology Engineering Laboratory (324 Building). The existence of barium within the 324 Building waste was determined through process knowledge.

Barium exhibits the characteristic of toxicity as determined by the toxicity characteristics leaching procedure and is designated D005 [WAC 173-303-090(8)].

The potential for barium stored in Tunnel Number 2 to become exposed to leachate is considered negligible. Tunnel Number 2 is designed and constructed to be weather-tight and will be filled with grout to encapsulate the waste. Further, the barium is encased in steel containers stored on a railcar above the floor level of the tunnel. Therefore, exposure of the barium stored in the tunnel to leachate is not considered a credible occurrence.

3.5.1.7 Mineral Oil

Presently, mineral oil is stored in Tunnel Number 2 in stainless steel containers received from the 324 Building. The mineral oil was used in the B-Cell viewing windows in the 324 Building. Oil leaking from the windows was absorbed on rags and clay absorbent material.

The material safety data sheet for the mineral oil lists a lethal dose (LD50) of 2 grams per kilogram (dermal rabbit). Therefore, the oil designates as a Toxic Category A WT02 [WAC 173-303-100(5)].

The potential for the absorbed mineral oil stored in Tunnel Number 2 to become exposed to leachate is considered negligible. Tunnel Number 2 is designed and constructed to be weather-tight and will be filled with grout to encapsulate the waste. Further, the mineral oil is encased in steel containers stored on a railcar above the floor level of the tunnel. Therefore, exposure of the mineral oil stored in the tunnel to leachate is not considered a credible occurrence.

3.5.1.8 Identification of Incompatible Waste

The next step was to ensure that sufficient information concerning the waste was provided so the waste can be managed properly. This includes identifying incompatible waste. These safety issues primarily were related to prevention of unwanted chemical reactions that could create a catastrophic situation, such as a fire, an explosion, or a large chemical release.

3.5.2 Parameter and Rationale Selection Process

This WAP describes the process to ensure that the dangerous waste components of the material stored in the tunnels were properly characterized and designated so that dangerous and mixed waste was managed properly.

The tunnels no longer receive waste. The parameters considered for waste designation under WAC 173-303-070(3) during operation and the rationale for their application are discussed in the following sections.

3.5.2.1 Discarded Chemical Products

The first category of dangerous waste designation is "Discarded Chemical Products" (WAC 173-303-081). The waste stored in the tunnels does not fit the definitions in WAC 173-303-081 for a discarded chemical product. Therefore, the waste stored in the PUREX Storage Tunnels is not designated as a discarded chemical product.

3.5.2.2 Dangerous Waste Sources

The second category of dangerous waste designation is "Dangerous Waste Sources" (WAC 173-303-082). The waste stored in the tunnels is not listed on the "Dangerous Waste Sources List" (WAC 173-303-9904). Therefore, the waste stored in the PUREX Storage Tunnels is not designated as a dangerous waste source.

3.5.2.3 Dangerous Waste Characteristics

The third category of dangerous waste designation is "Dangerous Waste Characteristics" (WAC 173-303-090). The characteristics are as follows.

- Characteristic of Ignitability – Although the solid silver nitrate has not been tested in accordance with Appendix F of 49 CFR 173, the waste is assumed to be an oxidizer as specified in 49 CFR 173.127(a). Therefore, the silver nitrate waste is assumed to exhibit the characteristic of ignitability under WAC 173-303-090(5) and is designated as D001.
- Characteristic of Corrosivity – Some of the material stored within the tunnels either has contained or has been in contact with corrosive liquids. The standard operating procedure has been to flush vessels with water to recover as much special nuclear material as practical. In addition, flushing removes much of the mixed waste contamination, minimizing the spread of contamination during

handling. The final aqueous rinse was sampled and analyzed to confirm that the pH was greater than 2 and less than 12.5. Therefore, the waste stored in the PUREX Storage Tunnels is not designated as corrosive waste.

- Characteristic of Reactivity – The waste stored in the tunnels does not meet any of the definitions of reactivity as defined in WAC 173-303-090(7). The waste material is not unstable, does not react violently with water, does not form explosive mixtures, or does not generate toxic gases. Therefore, the waste stored in the PUREX Storage Tunnels is not designated as reactive waste.
- Characteristic of Toxicity – Lead, mercury, silver, chromium, barium, and cadmium are identified on the Toxicity Characteristics list. The quantity of these materials stored in the tunnels is sufficient that, should the substances come in contact with a leachate (an event considered unlikely), the concentration of the extract could be above the limits identified in the list. Therefore, this waste is designated D005, D006, D007, D008, D009, and D011.

3.5.2.4 Dangerous Waste Criteria

The fourth category of dangerous waste designation is "Dangerous Waste Criteria" (WAC 173-303-100). The criteria are as follows:

- Toxicity Criteria – Cadmium meets the toxicity criteria in WAC 173-303-100(5) when performing a book designation. Because of the concentrations present, the waste containing these constituents is designated as dangerous waste (DW) and is assigned the dangerous waste number of WT02.
- Persistence Criteria – Currently, no waste stored in the tunnels has been designated as persistent per WAC 173-303-100(6).

3.5.2.5 Waste Designation Summary

The mixed waste currently stored in the PUREX Storage Tunnels is designated as follows:

- Lead – D008; DW
- Mercury – D009; DW
- Silver and silver salts – D001, D011; DW
- Chromium – D007; DW
- Cadmium – D006, WT02; DW
- Barium – D005; DW
- Mineral Oil – WT02; DW

3.5.3 Rationale for Parameter Selection

Refer to Section 3.5.2.

3.5.4 Special Parameter Selection

Refer to Section 3.5.2.

3.5.5 Selection of Sampling Procedures

The following sections discuss the sampling methods and procedures that were used. Sampling usually was performed in accordance with requirements contained in the pertinent sampling analysis plan, procedures, and/or other documents that specify sampling and analysis parameters.

3.5.6 Sampling Strategies and Methods

The only analysis used in support of the PUREX Storage Tunnels operation was a corrosivity check on the final in-place aqueous rinse of discarded vessels before the vessels were released for storage.

The pH was determined by a pH meter using U.S. Environmental Protection Agency (EPA) Test

Method 9040 or 9041 in Test Methods for the Evaluation of Solid Waste: Physical/Chemical Methods (EPA 1986). Resource Conservation and Recovery Act (RCRA) sampling was not performed on any waste currently stored in the PUREX Storage Tunnels.

Process knowledge of the characteristics and the quantities of the dangerous waste stored in the PUREX Storage Tunnels is considered sufficient to properly manage the stored waste.

The waste currently stored in the tunnels is lead, mercury, chromium, cadmium, barium, mineral oil, silver, and silver salts. Sampling and chemical analysis of the lead, mercury, cadmium, barium, mineral oil, or chromium to confirm their presence would not provide additional data beneficial to proper management of the waste and would not comply with As Low As Reasonably Achievable (ALARA) principles. The silver salts are dispersed over a large area on ceramic packing contained within a large stainless steel reactor vessel. Representative sampling of the ceramic packing was not considered to be practical and therefore was not performed.

3.5.6.1 Frequency of Analyses

Because the dangerous waste components of mixed waste stored in the PUREX Storage Tunnels are stable and will remain undisturbed for a long time, the waste designations and quantities present will remain the same as assigned at the time of storage. The stored waste is or will be encapsulated with grout and no further sampling of the PUREX Storage Tunnels is expected until final closure. In the event that sampling is required during the extended closure period, representative sampling methods referenced in WAC 173-303-110 or some other method approved by the Washington State Department of Ecology (Ecology) will be used. The following sections describe practices that were used during operations.

3.5.7 Selection of Sampling Equipment

The only analysis used in support of the PUREX Storage Tunnels operation was for corrosivity on the final in-place aqueous rinse of discarded vessels before the vessels were released for storage. The pH was determined by Method 9040 or 9041 (SW-846). The RCRA sampling methods, as referenced in WAC 173-303-110, were not performed on any waste currently stored in the PUREX Storage Tunnels.

3.5.8 Maintaining and Decontaminating Field Equipment

All RCRA sampling equipment used to collect and transport samples must be free of contamination that could alter test results. Equipment used to obtain and contain samples must be clean. Acceptable cleaning procedures for sample bottles and equipment include, but are not limited to, washing with soap or solvent, and steam cleaning. After cleaning, cleaning residues must be removed from all equipment that could come in contact with the waste. One method to remove these residues would be a solvent (acetone or other suitable solvent) rinse followed by a final rinse with deionized water. Equipment must be cleaned before use for another sampling event.

After completion of sampling, equipment was cleaned as indicated previously. If decontamination of the equipment was not feasible, the sampling equipment was disposed of properly.

3.5.9 Sample Preservation and Storage

Following RCRA sampling, sample preservation follows methods set forth for the specific analysis identified. Preservation is in accordance with the methods stated in SW-846 or any of the test methods adopted by the Hanford Facility that meet WAC 173-303 requirements. No preservation method was used when there were ALARA concerns.

3.5.10 Quality Assurance and Quality Control Procedures

The only test method used in support of the PUREX Storage Tunnels operation was a corrosivity check on the final in-place aqueous rinse of discarded vessels before the vessels were released for storage. The RCRA sampling was not performed on any waste currently stored in the PUREX Storage Tunnels.

Field duplicates, field blanks, trip blanks, and equipment blanks were not taken. Split samples may have been taken at the request of Ecology.

Generally, quality assurance and quality control (QA/QC) requirements for sampling were divided between paperwork requirements, such as chain-of-custody, and sampling and analysis activities. This section addresses sampling QA/QC requirements. Analytical QA/QC is discussed in Section 3.6.

A chain-of-custody procedure was required for all sampling identified by this WAP. At a minimum, the chain of custody included the following: (1) description of waste collected, (2) names and signatures of samplers, (3) date and time of collection and number of containers in the sample, and (4) names and signatures of persons involved in transferring the samples.

3.5.11 Health and Safety Protocols

The safety and health protocol requirements established for the Hanford Site were followed for all RCRA sampling activities required by this WAP.

3.6 Laboratory Selection and Testing and Analytical Methods

The tunnels no longer receive waste. This section discusses laboratory selection and the types of acceptable analytical methods for RCRA samples that were applied during operations.

3.6.1 Laboratory Selection

Laboratory selection was limited as only a few laboratories are equipped to handle mixed waste because of the special equipment and procedures that must be used to minimize personnel exposure to mixed waste. Laboratory selection depended on laboratory capability, nature of the sample, timing requirements, and cost. At a minimum, the selected laboratory had the following:

- A comprehensive QA/QC program (both qualitative and quantitative).
- Technical analytical expertise.
- An effective information management system.

These requirements were met if the selected laboratory followed the pertinent requirements contained in the Hanford Federal Facility Agreement and Consent Order Action Plan, Section 6.5. The selected laboratory also could have met these requirements by having some other type of QA/QC program as long as equivalent data quality was achieved.

3.6.2 Testing and Analytical Methods

The testing and analytical methods for corrosivity used by the various onsite analytical laboratories are outlined in SW-846. These methods in some cases deviate from SW-846 and American Society for Testing and Materials-accepted specifications for holding times, sample preservation, and other specific analytical procedures. These deviations are discussed in Analytical Methods for Mixed Waste Analyses at the Hanford Site (DOE/RL-94-97).

3.7 Waste Re-Evaluation Frequencies

Re-evaluation of waste within the PUREX Storage Tunnels will not occur because the tunnels are or will be filled with grout. The waste is encapsulated and is expected to remain stable until final closure.

3.8 Special Procedural Requirements

The tunnels no longer receive waste. The following sections describe special procedural requirements that were associated with waste in the PUREX Storage Tunnels during operations.

3.8.1 Procedures for Ignitable, Reactive, and Incompatible Waste

The only ignitable, reactive, or incompatible dangerous waste stored in the PUREX Storage Tunnels is the silver nitrate coating on the ceramic packing inside the silver reactors. This material is confined to the interior of a large stainless steel vessel (Section 3.5.1.1) that separates this material from all other waste material stored in the tunnel. The waste is or will be encapsulated with grout, further isolating the silver nitrate from the environment. The requirements in WAC 173-303-395(1)(a) require 'No Smoking' signs be conspicuously placed wherever there is a hazard present from ignitable or dangerous waste. 'No Smoking' signs are not considered appropriate at the PUREX Storage Tunnels because of ALARA principles. Smoking is not allowed in any area with ALARA concerns and rules prohibiting smoking are strictly enforced. This policy serves to achieve the no smoking intent of WAC 173-303-395(1)(a), posting and maintaining 'No Smoking' signs are not considered appropriate.

Ignitable waste storage units are required by WAC 173-303-395(1)(d) to have inspections conducted at least yearly by a fire marshal or professional fire inspector familiar with the requirements of the uniform fire code. However, annual inspection was not feasible during active operations because of the highly radioactive environment and was not justifiable under ALARA guidelines. Personnel entry for inspection is no longer possible in Tunnel Number 1 because of the grout fill and is prohibited in Tunnel Number 2 because of the threat of structural failure. Following the interim closure action, personnel entry into Tunnel Number 2 waste storage area will no longer be possible. The grout fill in Tunnel Number 1 and the grout to be placed in Tunnel Number 2 during the interim closure action encapsulates the waste containers, further isolating the silver nitrate from ignition sources.

3.8.2 Provisions for Complying with Land Disposal Restriction Requirements

The information provided by the generating unit regarding land disposal restrictions (LDR) of dangerous waste was sufficient to operate the PUREX Storage Tunnels in compliance with land disposal restriction requirements. When final disposition of the waste occurs, this information will be passed on for final treatment or disposal of the waste. Grouting macroencapsulates the waste which is an accepted treatment for hazardous debris under 40 CFR 268.45. When determining the final closure decisions, the appropriate LDR treatment standards for waste that is not debris will be considered. If the appropriate LDR treatment standard cannot be achieved due to physical limitations or if treatment is otherwise inappropriate, a petition for variance from the treatment standard will be submitted in accordance with 40 CFR 268.44.

3.8.3 Deviations from the Requirements of this Plan

Management may approve deviations from this plan if special circumstances arise that make this prudent. These deviations must be documented in writing with a copy to be retained by the management.

3.9 Recordkeeping

Records associated with this WAP and waste verification program are maintained on the Hanford Facility. These records will be maintained until closure of the PUREX Storage Tunnels. Records associated with the waste inventory will be maintained for 5 years.

3.10 References

Ecology, EPA, and DOE, 2003, Hanford Federal Facility Agreement and Consent Order, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S Department of Energy, Richland, Washington, amended periodically.

DOE/RL-94-97, Analytical Methods for Mixed Waste Analyses at the Hanford Site, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

EPA, 1986, Test Methods for the Evaluation of Solid Waste: Physical/Chemical Methods, SW-846, 3rd ed., U.S. Environmental Protection Agency, Washington, D.C.

Table 3.1. PUREX Storage Tunnels Inventory

PUREX Tunnel Number 1 (218-E-14)

PUREX Tunnel Number 1 is located at the southeast end of the PUREX Plant and is an extension of the railroad tunnel. The storage area is approximately 109 meters long, 6.7 meters high, and 5.8 meters wide. The tracks have a one percent downgrade toward the south end of the tunnel. The capacity of the Storage Tunnel is eight modified railroad cars, 12.8 meters long. Tunnel Number 1 reached full capacity in January 1965. The tunnel void spaces around the waste have been filled with grout. This improved tunnel stability, provided additional radiological protection, and increased durability while not precluding final closure actions.

Position	PUREX Tunnel Number 1 (218-E-14)
1. & 2.	HA column and miscellaneous jumpers in box placed in Tunnel #1 on 6/60 HA 4,700 Cu. Ft. Jumpers 2,190 Cu. Ft., Pb-~115 Kg
3.	E-F11 #1 (1WW Waste) Concentrator failed 7/24/60. Placed in Tunnel #1 on 7/29/60, 1,900 Cu. Ft.
4.	G-E2 Centrifuge, miscellaneous jumpers in box and two tube bundles. Placed in Tunnel #1 on 12/24/60. (FUG SER# 762) 2,465 Cu. Ft., Pb-~115 Kg.,
5.	E-H4 (3WB) Concentrator failed 1/4/61. Placed in Tunnel #1 on 1/4/61, 2,336 Cu. Ft.
6.	E-F6 (2WW Waste) Original Concentrator failed 4/21/61. Placed in Tunnel #1 on 4/21/61, 2,336 Cu. Ft.
7.	E-F11 (1WW Waste) #2 Concentrator failed 2/1/62. Placed in Tunnel #1 on 2/8/62, 2,336 Cu. Ft.
8.	E-F6 (2WW Waste) #3 Spare Concentrator failed 5/23/64. Placed in Tunnel #1 on 1/22/65 Flat Car 3621, 2400 Cu. Ft.

Table 3.1. PUREX Storage Tunnels Inventory (con't)

PUREX Tunnel Number 2 (218-E-15)

PUREX Tunnel Number 2 storage area is approximately 514.5 meters long, 6.7 meters high, and 5.8 meters wide. The tracks have a 0.1 percent downgrade toward the south end of the tunnel. The capacity of the Tunnel Number 2 is 38-40 modified railroad cars, 12.8 meters long. The tunnel contains 28 cars as of June 1996. The tunnel void spaces around the waste will be filled with grout. Grouting will improve tunnel stability, provide additional radiological protection, and increase durability while not precluding final closure actions.

Position	PUREX Tunnel Number 2 (218-E-15)
1.	E-F6 # (2WW Waste) Concentrator, TK F 15-2, One tube bundle and agitator motors, placed in Tunnel on 12/12/67 on Car 61439. 2,400 Cu. Ft.
2.	E-F6 #5 (E-H4 3WB) Concentrator, two tube bundles placed in Tunnel on 3/26/69. On Car MILW 60883, 2,400 Cu. Ft.
3.	E-F6 #6 (2WW Waste) Concentrator, two tube bundles failed placed in Tunnel on 3/19/70. On Car 3612, 2,400 Cu. Ft.
4.	L Cell Package in a sealed steel box (H2-66012) placed in Tunnel on 12/30/70 on Car MILW 60033, 2,400 Cu. Ft.

Position	PUREX Tunnel Number 2 (218-E-15)
5.	F2 Silver Reactor, F6 Demister, Vessel Vent Line, Steel Catwalk and Guard Rails, placed in Tunnel on 2/26/71. On Gondola Car 4610, 2,400 Cu. Ft., Ag-~625 Kg
6.	Modified A3-1 tower, scrubber, lid, and vapor line placed in Tunnel on 12/12/71. On Gondola Car 4611, 2,400 Cu. Ft.
7.	A3 Dissolver placed in Tunnel on 12/22/71. On 9 Ft. shortened Car B58, 2,400 Cu. Ft., Hg--~45 Kg.
8.	A1W1 Fuel ends in steel liner box and NPR fuel handling equipment. Used with the suspected canisters, on Car 19808. Placed in Tunnel on 8/29/72, 800 Cu. Ft.
9.	C3 Dissolver placed in Tunnel on 9/30/72, on Car 19811, 1590 Cu. Ft., Hg-~45 Kg.
10.	E-H4 (3WB) Concentrator, #61 tube bundle, prototype cooling coil, and F-Fl Filter Tank, placed in Tunnel 8/30/83, on Car CDX-1, 2,400 Cu. Ft.
11.	A3 Dissolver (Vessel #10) and E-A2 Heater (Vessel #6), placed in Tunnel on 1/18/86, on Car 3613, 3960 Cu. Ft. Hg-~40 Kg., Cd-~43 Kg
12.	White box (H-2-58456) containing eight tube bundles; PG-J6 Pulse Generator (#5), Dissolver Lid, 9 Dumping Trunnions. Car 3611 placed in tunnel on 1/201/86; 5,438 Cu. Ft.
13.	J5 Tank (Vessel #30), F-1 condenser (Vessel #13), and F12-B Cell Block, old four-way dumper, disc yoke, and flange plate placed in Tunnel on 1/21/86, on Car 19806, 2,500 Cu. Ft.
14.	L-l Pulser, 2-column cartridges, 1-jumper cutter, storage rack (H-2-96629), 3-jumper alignment tools, 9-exterior dumping trunnions, 10-pumps, 3-agitators, 4-tube bundles, 2-vent jumpers and 7-yokes placed in Tunnel on 11/18/87, on Car PX-10 (10A-19380) . 50 tons, 3,600 Cu. Ft., Pb-~2540 Kg.
15.	Silver Reactor, E-F2 steam heater, and storage liner (H2-65095), full of cut up jumpers placed in Tunnel on 5/13/88, on Car PX-9 (10A-19809) & S/R Cradle SK-GLR-11-2-87. 20 tons, 2,775 Cu. Ft., Cd-~13 Kg., Ag~115 Kg., Pb-~230 Kg.
16.	E-J8-1 Unitized Concentrator Vessel #1 H-2-52477, failed 3/11/89. Placed on storage Car H-2-99608, PX-6 (10A-19028) and in #2 Tunnel 4/6/89 graveyards. Estimated 42 tons, 6,000 Cu. Ft.
17.	North storage liner H-2-65095 containing six pumps, one agitator, and cut up jumper (14 tons). South storage liner H-2-65095 containing one pump, one #15 yoke and cut up jumpers (11.5 tons). Placed on storage Car PX-19 (10A-19030) and in #2 Tunnel on days 8/5/89. Estimated 25.5 tons, 2,574 Cu. Ft.
18.	T-F5 Acid absorber, ID#1-T-F5/F-168713, H2-52535 and H2-52487/488. Placed on storage Car PX-2 and in #2 Tunnel on 4/8/94. Estimated 22 tons, 835 Cu. Ft.
19.	Four metal liner storage boxes H-2-65095-3/H-2-100187 containing failed jumpers and miscellaneous obsolete canyon equipment items. Placed on storage Car PX-23 and in #2 Tunnel 9/16/94. Estimated 60 tons, 4032 Cu. Ft.
20.	E-H4-1 unitized concentrator (H-2-52477/56213)/(E-H4-1) Placed in Tunnel on 1/27/95, on Car PX-28. Estimated 40 tons, 5,760 Cu. Ft., Cr-~8 Kg.

Position	PUREX Tunnel Number 2 (218-E-15)
21.	Tank E-5 (H-2-52453)/(F-166955), lead storage box assembly (H-2-131629)/ (H-2-131629-1), H4 concentrator tower (H-2-58102)/(F-223017-CBT-4), hot shop cover plate (H-2-52222)/("Q"), tube bundle wash capsule (H-2-58647), dissolver charging insert (H-2-75875)/ (H-2-75875-1), lifting yoke #7A (H-2-96837), lifting yoke #9 (H-2-52458). Placed in tunnel on 2/8/95 on Car X-3609. Estimated 44 tons, 3,457 Cu. Ft., Pb-~1930 Kg
22.	Metal liner box (H-2-65095) containing jumpers and failed/obsolete canyon equipment. F7 neutron monitor (H-2-75825), lead storage box (H-2-131629) containing jumper counterweights and miscellaneous lead items, scrap hopper (H-2-57347) containing miscellaneous canyon equipment, canister capping station (H-2-821831), test canister containing various lengths of carbon steel pipe. Placed in Tunnel on 3/11/96, on Car #3616. Estimated weight 22 tons, 1,712 Cu. Ft., Pb-~3232 Kg., Cd-~2 Kg.
23.	Two burial boxes (H-2-100187) containing jumpers and failed/obsolete canyon equipment, lifting yoke (H-2-99652). Placed in Tunnel 3-11-96 on Car #PX-31. Estimated weight 21 tons, 2,116 Cu. Ft.
24.	Concrete burial box (H-1-44980) storing 8 containers of 324 Building, B-Cell waste. For additional details, see PUREX Work Plan WP-P-95-60. Placed in Tunnel on Car #PX-29, on April 26, 1996. Estimated weight 36 tons, 1,890 Cu. Ft. Cd-~10.5 kg., absorbed oil-~8.5 kg., Cr-~1 kg., Ba-~ 3 kg, Pb ~1802 Kg
25.	Concrete burial box (H-1-44980) storing 9 containers of 324 and 325 Building waste. For additional details, see PUREX Work Plan WP-P-96-015. Placed in tunnel on Car #10A-3619, on June 12, 1996. Estimated weight 46.5 tons, 1,890 Cu. Ft. Ba-~4g., Cd-<1g., Cr-~2g., Pb- <1g
26.	20,000-gallon liquid waste tank Car HO-10H-18582, empty per RCRA, placed in Tunnel on June 19, 1996, approximately 30 tons.
27.	20,000 gallon liquid waste tank Car HO-10H-18579, empty per RCRA, placed in Tunnel on June 19, 1996, approximately 30 Tons.
28.	20,000-gallon liquid waste tank Car HO-10H-18580, empty per RCRA, placed in Tunnel on June 19, 1996, approximately 30 tons.

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PUREX STORAGE TUNNELS
CHAPTER 4.0
PROCESS INFORMATION

CHANGE CONTROL LOG

Change Control Logs ensure that changes to this unit are performed in a methodical, controlled, coordinated, and transparent manner. Each unit addendum will have its own change control log with a modification history table. The "**Modification Number**" represents Ecology's method for tracking the different versions of the permit. This log will serve as an up to date record of modifications and version history of the unit.

Modification History Table

Modification Date	Modification Number
10/2006	

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4.0 PROCESS INFORMATION

This chapter discusses the processes involved in the operation of the Plutonium Uranium Extraction Facility (PUREX) Storage Tunnels. The PUREX Storage Tunnels are used for the storage of mixed waste from the PUREX Plant and other onsite sources.

The PUREX Storage Tunnels were designed and constructed to provide a means of protecting personnel and the environment from exposure to mixed waste associated with stored material. The tunnel design also serves to protect personnel and the environment from the dangerous waste component of the mixed waste stored inside the tunnels.

On May 9, 2017 workers discovered a portion of Tunnel Number 1 had collapsed, prompting an immediate response action to protect workers and the environment. A structural evaluation revealed the threat of further failure. An interim stabilization measure to fill Tunnel Number 1 with engineered grout was taken under Section J.4.5 of the PUREX Tunnels Contingency Plan and Permit Condition III.2.A.1 of the Hanford Facility RCRA Permit. Grouting in Tunnel Number 1 was completed in November 2017. Filling the tunnel void spaces with grout improved tunnel stability, provided additional radiological protection, and increased durability while not precluding final closure actions.

A structural evaluation also revealed the threat of future failure of Tunnel Number 2. To protect stored waste containers from potential damage caused by a tunnel failure event (e.g., puncture of a container by a falling structural member) and to prevent any associated release of dangerous waste constituents to the environment, an interim closure action to cover the stored waste and fill Tunnel Number 2 void spaces around the waste with engineered grout is being taken. Until grouting is completed, enhanced surveillance and monitoring measures have been implemented using video equipment to provide daily observation of the tunnel surface as described in Addendum I (Inspection Requirements).

The PUREX Storage Tunnels are permitted as miscellaneous units under Washington Administrative Code (WAC) 173-303-680 and comprise Closing Unit Group 19. The WAC regulations require that miscellaneous unit permit terms and provisions address appropriate requirements provided for other treatment, storage, and disposal (TSD) units. Because the operation and construction of the PUREX Storage Tunnels most closely resemble that of a container storage unit, the appropriate requirements prescribed for a container storage unit are addressed in this chapter.

4.1 Operation of the PUREX Storage Tunnels

The PUREX Storage Tunnels are no longer in active operation. Tunnel Number 1 is filled with grout and will store the existing encapsulated waste until final closure in accordance with Chapter 11, *Closure and Financial Assurance*. No waste has been added to Tunnel Number 2 since 1996 and no waste will be added or removed, nor will personnel entry be permitted prior to grouting because of the threat of structural failure. Following implementation of the interim closure action for Tunnel Number 2, it will also be filled with grout and will store encapsulated waste until final closure in accordance with Chapter 11.

4.1.1 Historical Operations Information

Previous operations of the tunnels were conducted using a remote-controlled battery-powered locomotive to move railcars containing failed equipment from the PUREX Plant or waste from other Hanford Site sources into storage positions in the tunnels to provide a means of protecting workers from exposure to highly radioactive residues within the failed equipment. A water-fillable door on each tunnel isolates the storage area from the PUREX Plant. The doors have been drained, and they will not be refilled.

The ventilation system on Tunnel Number 1 was deactivated after the last railcar was placed in 1965 and was permanently disabled when the tunnel was filled with grout. The ventilation system on Tunnel Number 2 was deactivated after the last railcar was placed in 1996. The tunnel will also be permanently disabled when it is filled with grout as part of the interim closure action.

Waste transferred to the PUREX Storage Tunnels was physically characterized by evaluation of dimensions, weight, volume, orientation for transport and storage, and presence of mixed waste. Information sources used in physical characterization included items such as equipment fabrication and installation drawings, operational records, and process knowledge. Failed equipment from the PUREX Plant to be transferred to the tunnels was flushed before removal from service to minimize loss of products, to reduce contamination, and to reduce to nonregulatory levels the concentration of any dangerous chemicals present in a residual heel.

Railcars were modified to serve as dedicated storage platforms and transporters for material placed in the PUREX Storage Tunnels. The wooden decking on the railcars was removed to minimize the amount of combustible material. The south coupler was disabled or removed to prevent the railcar from coupling to the railcar stored ahead. Brakes were disabled to ensure free movement of the railcar to the storage position. Steel decking, catch pans filled with absorbent, and equipment cradles were provided as needed to modify the railcar for its specific task.

4.2 Containers

This section provides a brief description of the contents and describes the various types of containment used to isolate mixed waste stored in the PUREX Storage Tunnels. The PUREX Storage Tunnels are considered to be miscellaneous units most closely resembling a container storage unit. The mixed waste stored in the PUREX Storage Tunnels is contained and is not considered a risk to human health or to the environment.

Tunnel Number 1 contains eight railcars filled with large equipment items and boxes with smaller components. An artist rendition of how the railcars and waste inventory might look is depicted in Figure **4.1**. The combined volume of the equipment stored on the eight railcars is approximately 596 cubic meters (780 cubic yards). The only dangerous waste constituent in Tunnel Number 1 is lead (waste code D008) contained in counterweights in equipment components and in miscellaneous debris.

Tunnel Number 2 contains 28 railcars filled with large equipment items and boxes with smaller components. An artist rendition of how the railcars and waste inventory might look in Tunnel 2 is depicted in **Error! Reference source not found.**. The combined volume of equipment stored on the 28 railcars is approximately 2,204 m^3 (2,883 yd^3). Dangerous waste constituents in Tunnel Number 2 are barium (D005), cadmium (D006), chromium (D007), lead (D008), mercury (D009), silver (D011), and light mineral oil (WT02, state-only, toxic, dangerous waste) contained in oil absorption material. The silver is predominately in the form of salts and is considered ignitable (D001) because of the presence of silver nitrate ($AgNO_3$), an oxidizer. Cadmium also could be considered state-only, toxic, dangerous waste (WT02). Lead (D008) is present as counterweights in equipment components and miscellaneous debris. Mercury (D009) is present as elemental mercury. Other dangerous waste constituents are present as contaminants on residues contained within equipment components.

Additional details about the waste stored in the tunnels are available in Chapter 3.0, *Waste Analysis Plan.*

4.2.1 Containers with Free Liquids

The only mixed waste stored as a free liquid is elemental mercury in Tunnel Number 2. A small quantity, less than 1.7 liters, of mercury is contained in each of the two thermowells attached to and contained within each dissolver (Chapter 3.0).

Primary containment of the mercury is provided by the all-welded construction of the thermowell itself, which is fabricated from 7.6-centimeter, Schedule 80, 304L stainless steel pipe. The open upper end of the thermowell was plugged with a 304L stainless steel nozzle plug in preparation for storage. The dissolver rests on a cradle on its railcar in an inclined position. This ensures that the mercury remains in the lower portion of the thermowell and is not in contact with the mechanical closure on the nozzle end of the thermowell.

A secondary containment barrier for mercury, should it leak from the thermowell, is provided by the dissolver itself. The dissolver is a 304L stainless steel process vessel constructed from 1-centimeter-thick plate and is approximately 2.7 meters in diameter. The dissolver is of all-welded construction and contains no drains or nozzle outlets in the bottom several feet of its lower section, which contains both thermowells.

The 304L stainless steel used to contain the elemental mercury is both compatible with the waste itself, with the original storage environment, and with the engineered grout used for interim closure. The potential for significant deterioration of either the primary or secondary containment barrier material before final closure is considered to be negligible. Following the interim closure action for Tunnel Number 2 the dissolver vessels will be encapsulated in grout, further isolating the mercury from the environment.

The dissolvers stored within the PUREX Storage Tunnels are not labeled as containing characteristic toxic mercury (D009) [WAC 173-303-090(8)(c)]. Procedures for labeling were not applicable to the tunnels at the time of storage. Personnel access into the storage area for purposes such as labeling was not feasible during active operations because of the highly radioactive environment and was not justifiable under As Low As Reasonably Achievable (ALARA) program guidelines. Personnel access into Tunnel Number 2 is now prohibited because of the threat of structural failure. Therefore, mercury-containing waste presently within the PUREX Storage Tunnels will remain unlabeled. No additional waste will be transferred into the either of the PUREX Storage Tunnels.

4.2.2 Containers without Free Liquids that do not Exhibit Ignitability or Reactivity

Most lead in Tunnel Numbers 1 and 2 is fully contained in all-welded encasements of either carbon steel or 304L stainless steel (refer to Chapter 3.0, Table 1). The encasement serves as support, protection against mechanical damage, and protection of the lead from exposure to the environment. Some lead has been placed in burial boxes of appropriate size. The boxes provide secondary containment for the lead in the unlikely event the primary encasement should fail. Although boxes may be open on the top, the PUREX Storage Tunnels are enclosed; therefore, the containers are protected from the elements.

Both carbon steel and 304L stainless steel used to encase the lead are compatible with the waste and the storage environment. Significant deterioration of either the primary or secondary containment barrier materials before closure is not considered to be credible. The grout fill in Tunnel Number 1 and the grout to be placed in Tunnel Number 2 during the interim closure action encapsulates the lead, further isolating it from the environment. The engineered grout is compatible with lead.

Some of the material that contains lead or that has encased lead attached was not labeled as containing characteristic toxic lead (D008) [WAC 173-303-090(8)], because procedures for labeling had not been identified as applicable at the time of storage. As stated in Section 4.2.1, personnel entry into the tunnel storage area for purposes of labeling was inconsistent with ALARA guidelines and is no longer possible because of grout fill or threat of structural failure. The unlabeled items containing lead will remain unlabeled. No additional waste will be transferred into the either of the PUREX Storage Tunnels.

4.2.3 Protection of Dangerous Waste in Containers

The present amount of mixed waste stored in the PUREX Storage Tunnels is sufficient to characterize this material as dangerous waste. Because the PUREX Storage Tunnels are enclosed totally, protective covering from the elements and from run-on is provided for the storage of dangerous waste. Periodic inspection of the equipment stored in the PUREX Storage Tunnels was not feasible during active operations because of the highly radioactive environment and was not justifiable under ALARA guidelines. Personnel entry for inspection is no longer possible in Tunnel Number 1 because of the grout fill and is prohibited in Tunnel Number 2 because of the threat of structural failure. Following the interim closure action, personnel entry into Tunnel Number 2 waste storage area will no longer be possible. Safe management of this waste during active operations was based on the following considerations.

- The operation of the PUREX Storage Tunnels is passive, i.e., once a storage position was filled, the storage position remains undisturbed until closure.
- The dangerous waste is compatible with its storage container and the storage environment.

The grout fill in Tunnel Number 1 and the grout to be placed in Tunnel Number 2 during the interim closure action encapsulates the waste containers, further isolating waste from the environment. The grout fill is compatible with the containers and with the dangerous waste constituents.

4.2.4 Prevention of Reaction of Ignitable, Reactive, and Incompatible Waste in Containers

There is no reactive or incompatible waste known to be stored in the PUREX Storage Tunnels. The only mixed waste stored in the PUREX Storage Tunnels considered an ignitable waste is the silver nitrate in Tunnel Number 2. The silver nitrate fraction of the silver salts, within the silver reactors, exhibits the characteristic of ignitability as defined in 49 CFR 173-127(a) as an oxidizer. Therefore, the silver salts are managed as an ignitable dangerous waste in accordance with WAC 173-303-395. The risk of fire associated with the storage of silver nitrate in the PUREX Storage Tunnels during active operations was considered to be extremely low. This conclusion is based on the following considerations.

- The operation of the PUREX Storage Tunnels is passive; i.e., once a storage position is filled, the storage position remains undisturbed until closure.
- The silver nitrate is contained within large, heavy-walled stainless steel vessels that isolate the silver nitrate from contact with any combustibles that might be in the tunnels.
- The silver nitrate is dispersed over a large surface area on a ceramic packing substrate and is not conducive to build-up of heat that could lead to spontaneous combustion.
- Personnel access to the stored waste in the tunnels was not permitted, thereby precluding activities that could present a fire hazard (e.g., smoking, flame cutting, welding, grinding, and other electrical activities).

Grout fill added to Tunnel Number 2 will be compatible with the ignitable waste, although it is unlikely to directly contact the waste because the silver nitrate is contained within stainless steel vessels.

Ignitable waste storage units are required by WAC 173-303-395(1)(d) to have inspections conducted at least yearly by a fire marshal or professional fire inspector familiar with the requirements of the uniform fire code. However, annual inspection was not feasible during active operations because of the highly radioactive environment and was not justifiable under ALARA guidelines. Personnel entry for inspection is no longer possible in Tunnel Number 1 because of the grout fill and is prohibited in Tunnel Number 2 because of the threat of structural failure. Following the interim closure action, personnel entry into Tunnel Number 2 waste storage area will no longer be possible. The grout fill in Tunnel Number 1 and the grout to be placed in Tunnel Number 2 during the interim closure action encapsulates the waste containers, further isolating the silver nitrate from ignition sources.

4.3 Safe Storage of Mixed Waste in the PUREX Storage Tunnels

Following the collapse of a portion of Tunnel Number 1, discovered by workers on May 9, 2017, an immediate response action was taken. Uncompacted soil fill was placed through the roof opening at the collapsed area to stabilize the opening and to provide a barrier between contaminated equipment in the tunnel and the environment. A temporary protective cover of water-resistant tarpaulin material was installed over the full length of Tunnel Number 1 to minimize precipitation infiltration into the nominally 2.4-meter-thick soil overburden.

A structural integrity evaluation completed for Tunnel Number 1 (Appendix 4A) indicated that a significant threat of further failure remained. As a result, in a continuation of the response action, an interim stabilization measure to grout Tunnel Number 1 was taken under Section J.4.5 of the PUREX Tunnels Contingency Plan and Permit Condition III.2.A.1 of the Hanford Facility RCRA Permit. Grouting improved tunnel stability, provided additional radiological protection, and increased durability while not precluding final closure actions. This measure mitigates threats to human health and the environment until final disposition is implemented.

A structural integrity evaluation completed for Tunnel Number 2 (Appendix 4B) indicated that a threat of future failure exists. To protect stored waste containers from potential damage caused by a tunnel failure event (e.g., puncture of a container by a falling structural member) and to prevent any associated release of dangerous waste constituents to the environment, an interim closure action to cover the stored waste and fill Tunnel Number 2 void spaces around the waste with engineered grout is being taken.

Grouting was completed in Tunnel Number 1 in November 2017. Grouting in Tunnel Number 2 will be initiated pending completion of planning, design, and permit modification. As a temporary measure, daily walkdowns around the tunnels were performed to conduct visual observations and radiological surveys in the area. Those walkdowns were discontinued when grouting in Tunnel Number 1 was completed. Until grouting is completed in Tunnel Number 2, enhanced surveillance and monitoring measures have been implemented using video equipment to provide daily observation of the tunnel surface as described in Addendum I (Inspection Requirements)

Anomalous conditions (meaning discovery of changes to the exterior conditions of the tunnel that may be the result of structural issues) and changes from previous observations will be evaluated to determine if further action is necessary, such as activation of the contingency plan. If it is determined that further actions are necessary as a result of the anomalous conditions that affect the descriptions, conditions, or processes contained in the permit, a permit modification will be submitted in accordance with WAC 173-303-830.

The structural integrity evaluation of Tunnel Number 1 is contained in Appendix 4A. The structural integrity evaluation of Tunnel Number 2 is contained in Appendix 4B.

4.4 Engineering Drawings

As-built drawings for the PUREX Storage Tunnels:

H-2-55587	218-E-14 Structural Floor Plan and Section (Tunnel Number 1)
H-2-55588	Structural Sections and Details: Disposal Facility for Failed Equipment
H-2-55589	Structural Sections and Details: Disposal Facility for Failed Equipment
H-2-58175	PUREX Tunnel (Tunnel Number 1)
H-2-58193	Architectural Plans
H-2-58194	Structural Sections and Details (Tunnel Number 2)
H-2-58195	Structural Sections and Details– (Tunnel Number 2)
H-2-58208	Sheet 1; Electrical Plans and Details; Sheet 2, Plan – No. 2 Burial Tunnel; Sheet 3; Sections – No. 2 Burial Tunnel
H-2-94665	RR Burial Tunnels 218-E-14, 218-E-15 (Tunnels Number 1 and 2)
H-2-94756	Burial Tunnel #2 Filter Assembly; Sheet 1, Sheet 2
The following engineering drawings depict tunnel components that are no longer functional:	
H-2-55590	Failed Equipment Burial Tunnel Door
H-2-55591	Tunnel Door Hoist Assembly
H-2-55592	Tunnel Door Hoist Details
H-2-55593	PUREX Tunnel Extension Power and Lighting
H-2-55594	Shielding Door Fill and Drain Lines Arrangement: Disposal Facility for Failed Equipment

H-2-55599	Electrical Door Control Plan, Elementary Diagram and Miscellaneous Details: Disposal Facility for Failed PUREX Equipment
H-2-58134	Burial Tunnel #1 and 2 Ventilation Arrangement; Sheet 1, Sheet 2, Sheet 3, Sheet 4
H-2-58206	Piping Plan and Details

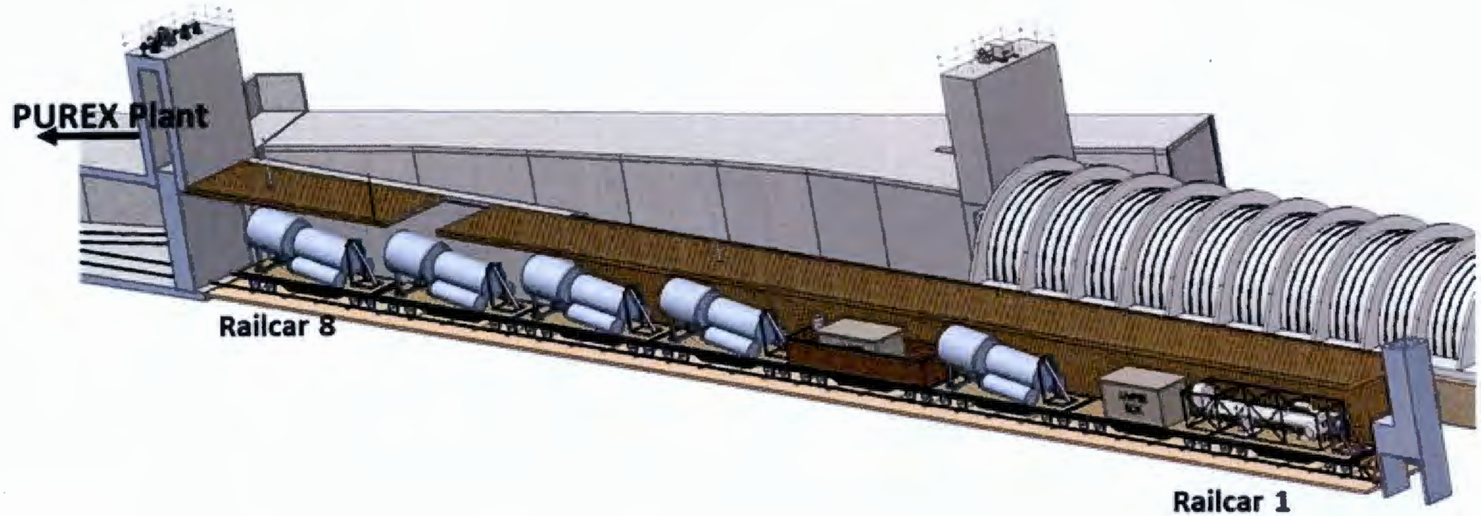

Figure 4.1. Artist Rendition of Waste Storage in Tunnel Number 1

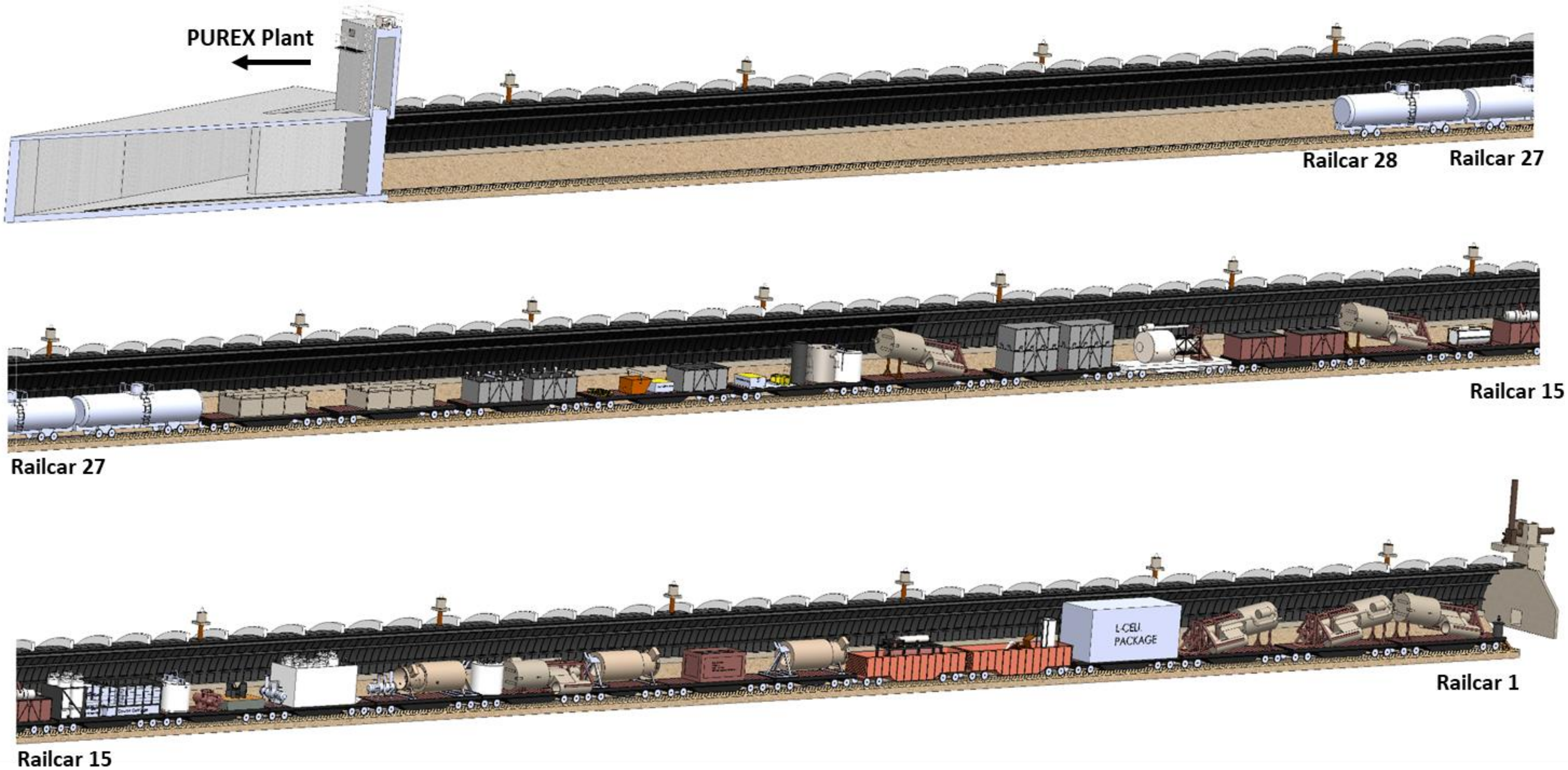

Figure 4.2. Artist Rendition of Waste Storage in Tunnel Number 2

Appendix 4A

PUREX Tunnel 1 Engineering Evaluation
(CHPRC-03364, Revision 0)

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CHPRC-03364
Revision 0

PUREX Tunnel 1 Engineering Evaluation

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

P.O. Box 1600
Richland, Washington 99352

CHPRC-03364
Revision 0

PUREX Tunnel 1 Engineering Evaluation

M. D. Hasty
CH2M HILL Plateau Remediation Company

Date Published
June 2017

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

ch2m

P.O. Box 1600
Richland, Washington 99352

APPROVED
By Lana Perry at 2:54 pm, Jun 27, 2017

Release Approval | Date

CHPRC-03364
Revision 0

Title: *PUREX TUNNEL 1 ENGINEERING EVALUATION*
Project Number 693839

Craig Barrett
Originator:
Craig Barrett, PE
Senior Structural Engineer, CH2M

Signature [signature] Date 6-27-17

Mark Kacmarcik
Mark Kacmarcik. PE
Geotechnical Engineer, CH2M

Signature [signature] Date 6/27/2017

Kent Soelberg
Peer Review:
Kent Soelberg, SE
Senior Structural Engineer, CH2M

Signature [signature] Date 6-27-2017

ch2m	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

1. Purpose

This engineering evaluation of PUREX Tunnel 1 was conducted to:

- Determine the cause of partial roof collapse in PUREX Tunnel 1
- Provide a structural evaluation for PUREX Tunnel 1
- Assess if there is an immediate risk of further failures in PUREX Tunnel 1

It will be submitted to the State of Washington Department of Ecology to fulfill Administrative Order Docket #14156, dated May 10, 2017, Corrective Action 1.

2. Introduction

On May 9, 2017, a portion of the PUREX Tunnel 1 wood timber roof structure was observed to have collapsed into the tunnel resulting in a hole approximately 19 ft wide by 17 ft long. Actual time of the collapse and cause of the failure has not been determined. Potential factors contributing to the collapse are speculated to include heavy rainfall on May 4 and 5, 2017, deterioration of tunnel wood timber structural support members due to prolonged exposure to high levels of radioactivity, and influence of low vibration sources near the site such as local thunderstorms or distant low-magnitude seismic activity. Due to the uncertainty in the condition and structural integrity of the remaining roof and wall timber supports, measures were taken to prevent additional roof loads or personnel from being placed over top of Tunnel 1 and within the roof load zone of influence until permanent stabilization measures can be taken.

Fifty-three truckloads of uncompacted soil fill were placed through the roof opening at the collapsed area to stabilize the tunnel support walls and to cap and seal off the tunnel interior space from further exposure to the atmosphere. A temporary protective cover was installed over the full length of Tunnel 1 to reduce soil loading over the tunnel by minimizing or eliminating rainfall water infiltration into the 8 ft high soil berm over the tunnel timber roof structure. The protective cover consists of water resistant tarpaulin material which has an expected design life on the order of months.

Construction of Tunnel 1 was completed in 1956 as part of the PUREX Plant construction project. The Tunnel 1 consists of three sections, a water-fillable door, a storage area, and a ventilation shaft. The water-fillable door located at the north end of the tunnel is housed in a concrete structure. The water-fillable door is 24.5 ft high, 22 ft wide, and 7 ft deep, constructed of 0.5 inch thick steel plate and hollow to permit filling with water for radiation shielding. The storage area, which is the main portion of Tunnel 1, extends from the water-fillable door south 358 ft to the ventilation shaft and is 22 ft high by 19 ft wide with a 1% grade downward slope from north to south. The roof and walls are constructed of 12 inch by 14 inch rough sawn creosote pressure treated Douglas-Fir wood timbers with the exception that the first 100 ft of the east wall was constructed with 3 ft thick reinforced concrete. Timber wall supports bear on a 1 ft thick by 3 ft wide continuous unreinforced concrete footing. The timber structure is covered with 90 lbs mineral surface roofing material. A minimum depth of 8 ft of uncompacted soil fill was placed over the top of the tunnel. The tunnel floor consists of two railroad track rails supported by 7 inch by 9 inch rough sawn creosote pressure treated Douglas-Fir wood timber railroad ties that extend between the wall footings to brace and support the base of the tunnel walls. Railroad ties are laid on a gravel bed with spaces between ties filled with gravel ballast to the top of members.

ch2m.	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

The ventilation shaft is located at the south end of the tunnel. The shaft is approximately 5 ft by 5 ft in cross section and constructed of reinforced concrete. The ventilation shaft protrudes approximately 1 ft above grade and is capped with a single-stage high-efficiency particulate air filter, an exhaust fan, and a 20 ft tall stack. The ventilation system is not in operation. The tunnel was filled to its capacity in 1965 with eight rail cars, each of 40 to 42 ft in length, containing radioactive process equipment. Tunnel 1 remains in the aforementioned state while the structural evaluation and corrective actions for Tunnel 1 are completed.

3. Design Input

Design input used in the structural evaluation consists of the following:

A. Tunnel 1 Drawings and Specifications
   - H-2-55587 (drawing), Structural Floor Plan & Section, 1955 Tunnel 1
   - H-2-55588 (drawing), Structural Sections & Details, 1955 Tunnel 1
   - H-2-55589 (drawing), Structural Sections & Details, 1955 Tunnel 1
   - HWS-5638, *Specifications for Disposal Facility for Failed Equipment Project CA-513-A*, 1955 Tunnel 1

B. Structure Performance Category = PC-1, General Service in accordance with PRC-PRO-EN-097, *Engineering Design and Evaluation (Natural Phenomena Hazard)*, Rev. 2

C. Soil Design Parameters (see Appendix B):
   - Soil Density = 110 pcf (moist condition)
   - Lateral Earth Pressures (at-rest condition)
     a) At-Rest Lateral Earth Pressure Coefficients
        — Horizontal Ground Surface: $K_O = 0.50$
        — Sloping Ground Surface: $K_{Oi} = K_O*[\ 1+\sin(\theta)\ ]$ where θ = slope of ground surface in degrees
     b) Equivalent fluid pressure at Timber Walls based on geometry and depth of sloped soil backfill, see Appendix B Attachment C for supporting calculations.
        — 44 psf/ft maximum (STA 3+00 East Side) – controlling design evaluation load
        — 34 psf/ft minimum (STA 3+00 West Side)
   - Allowable Bearing Capacity (estimated based on standard practice 3.0 Factor-Of-Safety)
     a) 4,400 psf for Timber Wall concrete footing (3 ft wide)
     b) 5,500 psf for Concrete Wall footing (5 ft wide, east wall at north end of tunnel)

D. Ground Snow Load = 15 psf (PRC-PRO-EN-097)

E. Live Load: None Permitted (includes personnel and equipment)

F. Load and Resistance Factor Design (LRFD) Load Factors: 1.2 Dead (self-weight + vertical soil weight)
   1.6 Snow
   1.6 Lateral Earth Pressures

ch2m	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

G. Wood Timber Properties: Douglas-Fir No. 1, rough sawn (NDS, 2012, *NDS Supplement: Design Values for Wood Construction*, Table 4D)

- Specific Gravity: 0.50
- Modulus of Elasticity (E_w): 1600 ksi (deflection check)
- Modulus of Elasticity (E_{min}): 580 ksi (strength check)
- Bending Stress (F_b): 1350 psi
- Shear Stress (F_v): 170 psi
- Tensile Stress (F_t): 675 psi
- Parallel Compressive Stress (F_c): 1100 psi
- Perpendicular Compressive Stress (F_{cperp}): 625 psi

H. Concrete: 3,000 psi compressive strength at 28 days (per Specification HWS-5638)

I. Reinforcing: Fy = 40 ksi for ASTM A15-52T Intermediate Grade (per Specification HWS-5638)

4. Methodology

Structural evaluation of the Tunnel 1 wood timber structure is based on 2012 International Building Code design standards using LRFD methods when subjected to soil and snow loading conditions. Evaluation did not include potential for structural degradation of wood timber due to long term exposure to high levels of radioactivity and effects of wood decay and insect attack.

The 2008 Light, Data, and Ranging (LIDAR) topographic survey data was utilized to provide an initial estimate of existing grade elevations associated with the Tunnel 1 structure. This information was compared to 1955 design drawing tunnel geometry to determine depth of soil fill and slope configuration for determination of lateral earth pressure load conditions used in the structural evaluation. Field surveys of finish grade and tunnel structure elevations would be required to determine actual soil depth and soil loading conditions that are applied to the structure.

Based on information provided in RHO-RH-34-3, *Geologic and Seismic Investigation of the PUREX Building Site*, there are no known geotechnical investigation or design reports associated with the PUREX facility including Tunnel 1. Estimated geotechnical soil properties for undisturbed native soil and for soil fill placed over the tunnel used in this engineering evaluation were based on best available geotechnical information further described in Appendix B. Sampling and testing of existing soils at or near Tunnel 1 would be required to determine actual soil design properties of soil fill and native soils used in the construction of Tunnel 1.

5. Computations

Calculations are performed in U.S. customary units and are included in the attachments.

6. Computer Software

None

ch2m	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

7. Assumptions

Subsurface soil conditions are similar to those reported by others in the project vicinity. Topography of existing cover soil over Tunnel 1 is consistent with the 2008 LIDAR topographic survey and 1955 Tunnel 1 design drawings listed in Section 12.

8. Results

Comparison of structural support member demand to capacity summarized by individual Design-to-Capacity Ratio (DCR) for each design check are as follows (DCR greater than 1.0 exceed design code requirements). For detailed calculations, see Appendix A.

A. Timber Roof Beams (12 inch x 14 inch rough sawn, Douglas-Fir No. 1):

DCR	Design Check
0.06	Axial Compression
0.78	Bending
0.81	Combined Bending and Axial Compression
0.22	Shear
0.21	Bearing

Deflection (vertical): 0.66 inches long-term, 0.99 inches long-term with creep factor (upper bound)

B. Timber Wall Supports (12 inch x 14 inch rough sawn, Douglas-Fir No. 1):

DCR	Design Check
0.06	Axial Compression
1.43	Bending – EXCEEDS DESIGN CODE LIMITS
1.49	Combined Bending and Axial Compression – EXCEEDS DESIGN CODE LIMITS
0.40	Shear
0.21	Bearing

Deflection (horizontal): 1.34 inches long-term, 2.01 inches long-term with creep factor (upper bound)

C. Railroad Ties (7 inch x 9 inch rough sawn laid flat, Douglas-Fir No. 1, transverse supports along base on tunnel):

DCR	Design Check
0.79	Axial Compression
0.40	Bearing

D. Timber Wall Concrete Footing (unreinforced 12 inch thick x 3 ft wide footing supporting timber walls):

DCR	Design Check
0.15	Bending
0.33	Shear (for plain unreinforced concrete)

E. Foundation Bearing Capacity

DCR	Design Check
0.81	Soil Bearing Capacity At Timber Walls
0.81	Soil Bearing Capacity At Concrete Wall

ch2m	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

9. Cause of Partial Roof Collapse

Due to the potential risk for exposure to high levels of radiation and urgency to close off and seal the roof breach area, insufficient information was obtained to determine the cause of the localized failure and partial collapse of a 17 ft long segment of the Tunnel 1 wood timber roof system. Recent LIDAR topographic survey data analyzed at 6 cross section stations along the length of tunnel indicates the depth of soil berm over the tunnel varied from approximately 7.7 ft to 9.5 ft in depth (compared to 8 ft depth specified on design drawings) with an average depth of 8.2 ft. Structural evaluation calculations included herein, based on a 8 ft soil depth, indicate that the roof timber beams were within design limits when subjected to loading conditions that occurred prior to the collapse. Therefore, potential causes of the partial roof collapse were narrowed down as follows:

- loss of roof beam end bearing (at one or both ends) due to decay and/or deterioration; this reason could be the result of prolonged water infiltration and pooling along a 17 ft length of concrete ledge support that was formed and cast-in-place at the top of concrete wall support along the east side of tunnel; reason is only moderately plausible when considering the tunnel is located within and subjected to overall arid and dry climate conditions.
- wood defects in roof beam timbers near maximum bending stress locations (at or near mid-span); this reason could explain why a small number of roof timbers failed but does not explain the contiguous loss of 17 individual roof timber support members.
- loss of roof beam structural capacity due to thru-roof core drilled holes used to install monitor standpipes and to obtain wood core samples taken in 1980 for testing purpose; this reason could explain why a small number of roof timbers failed but does not explain the contiguous loss of 17 individual roof timber support members.

10. Conclusions

This structural evaluation of Tunnel 1 indicates that structural wood and concrete support members of the size and configuration specified in the 1955 tunnel design drawing are within building code design requirements when subjected to ground snow and estimated soil loading conditions with the exception that vertical timber wall members which support long duration at-rest lateral earth pressures are up to 49% overstressed. Successful structural performance of Tunnel 1 vertical timber wall supports over the last 61-years indicates that the actual bending strength of wood timbers used during original construction are well above industry average for that wood species and are closer to results from the 1980 in-situ testing based on information provided in RHO-CD-1079, *Structural Evaluation of the PUREX No. 1 Burial Tunnel*.

Neither the results from the structural evaluation nor potential increases in bending strength of the timber based on 1980 in-situ wood core sample testing provides any explanation for why there was a 17 ft long partial roof collapse of Tunnel 1 timber roof beams and why the vertical timber wall supports in this area did not immediately or shortly thereafter collapse inward.

ch2m.	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

11. Risk of Future Failure

The Tunnel 1 wood timber structure has been in service for more than 60 years which is beyond the typical design life for similar structures. The risk of future failure of the tunnel (partial or global collapse) is considered high based on significant design overstress of timber wall supports noted in the structural evaluation herein and on the recent partial roof collapse. As a result, the existing Tunnel 1 structure presents an extreme collapse hazard until such time that physical evaluation of remaining timber members and their supports can be performed. For safety purposes (e.g. avoid potential collapse, avoid exposure to high levels of radiation, etc.), placement of personnel and equipment on top of the tunnel and within the roof load zone of influence is not recommended without further evaluation.

12. References

H-2-55587 (drawing), 1980, *Structural Floor Plan & Section, Tunnel No. 1,* Rev. 7, General Electric Company, Richland, Washington.

H-2-55588 (drawing), 1955, *Structural Sections & Details,* Rev. 1, General Electric Company, Richland, Washington.

H-2-55589 (drawing), 1955, *Structural Sections & Details,* Rev. 2, General Electric Company, Richland, Washington.

HWS-5638, 1955, *Specifications for Disposal Facility for Failed Equipment Project CA-513-A*, General Electric Company, Richland, Washington.

PRC-PRO-EN-097, *Engineering Design and Evaluation (Natural Phenomena Hazard)*, Rev 2, Change 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

NDS, 2011, *Supplement National Design Specification, Design Values for Wood Construction*, 2012 Edition, American Wood Council, Leesburg, Virginia. Available at: http://www.awc.org/pdf/codes-standards/publications/nds/AWC-NDS2012-Supplement-ViewOnly-1402.pdf

ASTM A15, 1952, *Standard Specification for Billet-Steel Bars for Concrete Reinforcing,* ASTM International, West Conshohocken, Pennsylvania.

2012 International Building Code (IBC), International Code Council.

FLUOR Hanford LIDAR Digital Elevation Model(s) & Topographic Contour Maps, 2008, prepared by Aero-Metric, Seattle, Washington.

RHO-R-34-3, 1981, *Geologic and Seismic Investigation of the PUREX Building Site*, URS/John A. Blume & Associates, San Francisco, California.

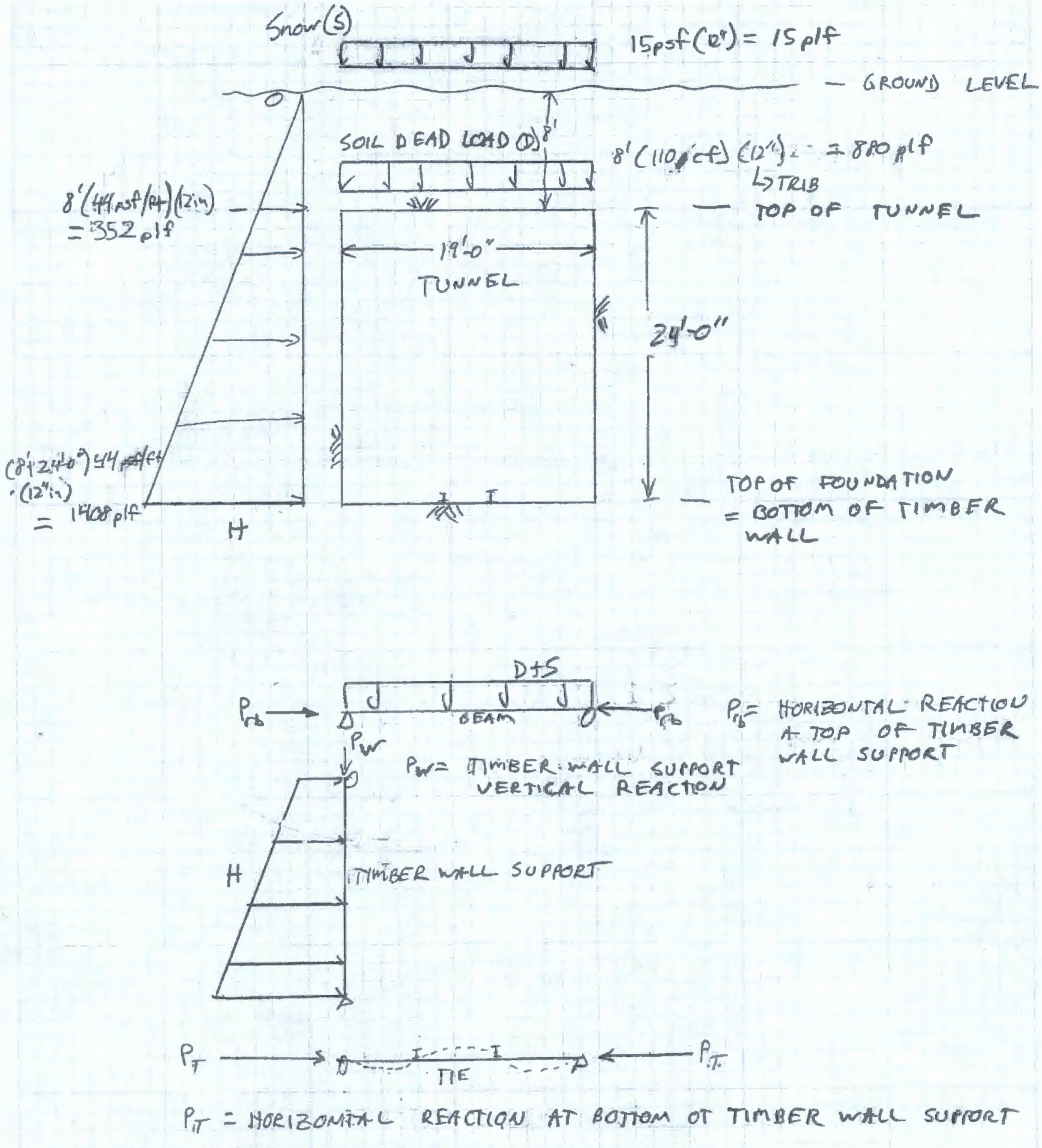
RHO-CD-1079, 1980, *Structural Evaluation of the PUREX No. 1 Burial Tunnel*, Rockwell Hanford Operations, Richland, Washington.

ch2m	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

Appendix A

Calculations

PUREX Tunnel 1
Loading Diagram



Timber Roof Beam Supports

References:

1. 2012 NDS "National Design Specifications for Wood Construction" U.O.N.
2. 2012 NDS Supplement

Notes:
1. LRFD design used for wood members per NDS Section 4.3 including lambda, K.f and phi values.

Design Information

Length of roof beam: $L_{rb} := 19.33ft$

Effective length factor for compression: $K_{ex.rb} := 1.0$ (Table G1)

Effective length for bending: (Fully braced)

Tributary width: $trib_{rb} := 12in$

Depth of overburden soil: $h_s := 8ft$

Overburden Loads:

Moist soil unit weight: $\gamma_s := 110pcf$

Dead Load (soil weight): $w_{DL} := \gamma_s \cdot h_s \cdot trib_{rb} = 880 \cdot plf$ (Moist Soil)

Live Load (ground snow load): $w_{LL} := 15psf \cdot trib_{rb} = 15 \cdot plf$ (Snow)

Lateral Earth Pressures at top of wall:

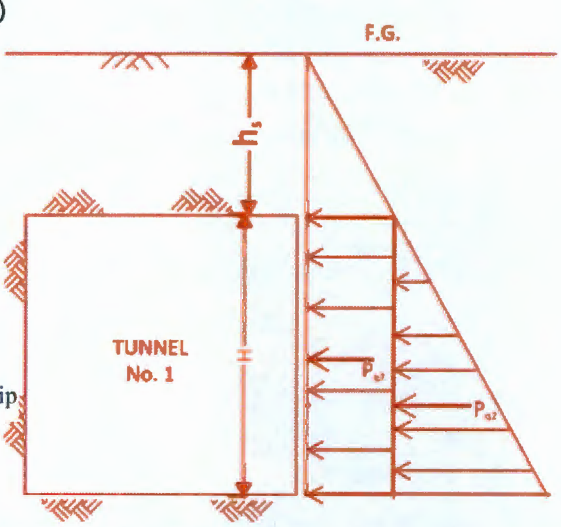
Height of tunnel: $H := 24ft$

Soil (at-rest): $q := 44 \frac{psf}{ft}$

Horizontal loads on tunnel from lateral earth pressure:

$P_{q1} := H \cdot (q \cdot h_s) \cdot trib_{rb} = 8.45 \cdot kip$

$P_{q2} := 0.5 \cdot H \cdot [(H + h_s) \cdot q - h_s \cdot q] \cdot trib_{rb} = 12.67 \cdot kip$



Wood Specific Gravity: $\gamma_{wood} := 0.5$ Douglas-Fir Larch per NDS Supplement Table 4D

Self weight of roof beam: $sw_{rb} := 12in \cdot 14in \cdot 62.4pcf \cdot \gamma_{wood} = 36.4 \cdot plf$ $sw_{u.rb} := 1.2 \cdot sw_{rb} = 44 \cdot plf$ (Factored self weight)

Axial compression force on beam (reaction of horizontal pressures at top of wall member): $P_{rb} := \frac{P_{q1}}{2} + \frac{P_{q2} \cdot \left(\frac{1}{3} H\right)}{H} = 8.45 \cdot kip$

Factored Axial: $P_{u.rb} := 1.6 \cdot P_{rb} = 14 \cdot kip$

Service Moment: $M_{rb} := \frac{\left[\left(w_{DL} + sw_{rb}\right) + w_{LL}\right] \cdot L_{rb}^{2}}{8} = 44 \cdot kip \cdot ft$

Factored Moment: $M_{ux.rb} := \frac{\left[1.2 \cdot \left(w_{DL} + sw_{rb}\right) + 1.6 \cdot w_{LL}\right] \cdot L_{rb}^{2}}{8} = 52 \cdot kip \cdot ft$

Service Shear: $V_{rb} := \frac{\left[\left(w_{DL} + sw_{rb}\right) + w_{LL}\right] \cdot L_{rb}}{2} = 9 \cdot kip$

Factored Shear: $V_{u.rb} := \frac{\left[1.2 \cdot \left(w_{DL} + sw_{rb}\right) + 1.6 \cdot w_{LL}\right] \cdot L_{rb}}{2} = 10.9 \cdot kip$

Wood Species: **Doug-Fir Larch** ***No. 1 Beam and Stringers*** *(Supplement Table 4D)*

Beams are 12x14 rough sawn.

Section Width: $b_{rb} := 12in$ Section Depth: $d_{rb} := 14 \cdot in$

Bearing length: $l_{b.rb} := 4in$

Material properties:

Modulus of Elasticity: $E_w := 1600000 \cdot psi$ $E_{min} := 580000 \cdot psi$

Design Bending Stress: $F_b := 1350 \cdot psi$ Design Shear Stress: $F_v := 170 \cdot psi$

Design Tensile Stress: $F_t := 675psi$ Parallel Compressive Stress: $F_c := 925psi$

Perp. Compressive Stress: $F_{cperp} := 625 \cdot psi$ Wood Specific Gravity: $\gamma_{wood} := 0.5$

Douglas-Fir Larch per NDS Supplement Table 4D

Load Duration Factor: $C_D := 0.9$ Permanent dead load *(Table 2.3.2)*

Wet Service Factor: $C_M := 1.0$ Dry service condition *(Supplement Table 4D)*

Size Factor: $C_{F.rb} := \left(\frac{12in}{d_{rb}}\right)^{\frac{1}{9}}$ $C_{F.rb} = 0.98$ < or = 1.0 *(Supplement Table 4D)*

Time Effect: $\lambda := 0.8$ (1.2D+1.6L)
(Table N.3.3)

Resistance Factors: $\phi_b := 0.85$ $\phi_v := 0.75$ $\phi_c := 0.9$ $\phi_s := \phi_b$ $\phi_t := 0.8$
(Table N.3.2)

Format Conversion Factors: $K_{F\_Fb} := 2.54$ $K_{F\_Fc} := 2.40$
(Table N.3.1)

$K_{F\_Fv} := 2.88$ $K_{F\_E.min} := 1.76$ $K_{F\_Ft} := 2.70$

Design Checks

Compression check (Section 3.6 and 3.7)

$F_{cn} := F_c \cdot K_{F\_Fc}$ $F_{cn} = 2220 \cdot psi$ $E'_{min} := E_{min} \cdot K_{F\_E.min} \cdot \phi_s \cdot C_M$ $E'_{min} = 867.68 \cdot ksi$

$$F_{cE1.rb} := \frac{0.822 \cdot E'_{min}}{\left(\frac{L_{rb} \cdot K_{ex.rb}}{d_{rb}}\right)^2} \qquad F_{cE1.rb} = 2.6 \cdot ksi$$

$F_{cn.star} := F_{cn} \cdot \phi_c \cdot \lambda \cdot C_D \cdot C_M$ $F_{cn.star} = 1439 \cdot psi$ $\alpha := \frac{F_{cE1.rb}}{F_{cn.star}}$ $c := 0.85$ (Rough sawn)
(Sec. 3.7.1)

Column Stability Factor: $C_{P.rb} := \frac{1 + (\alpha)}{2 \cdot c} - \sqrt{\left[\frac{1 + (\alpha)}{2 \cdot c}\right]^2 - \frac{\alpha}{c}}$ $C_{P.rb} = 0.88$ *[Eqn. 3.7-1]*

$C_{P.rb} := \min(C_{P.rb}, C_{F.rb}) = 0.88$

Compressive stress: $f_{c.rb} := \frac{P_{u.rb}}{b_{rb} \cdot d_{rb}} = 80 psi$

Compressive strength: $F'_{c.rb} := \lambda \cdot K_{F\_Fc} \cdot \phi_c \cdot F_c \cdot C_D \cdot C_M \cdot C_{P.rb}$ $F'_{c.rb} = 1.26 \cdot ksi$

Compression only interaction ratio: $DCR_{comp.rb} := \frac{f_{c.rb}}{F'_{c.rb}} = 0.06$

$Check := if(DCR_{comp.rb} < 1.0, ok, ng)$ Check = "OK"

Flexure check

Compression edge supported: $C_{L.rb} := 1.0$

Flexure stress: $f_{b.rb} := \dfrac{M_{ux.rb}}{\left(\dfrac{b_{rb} \cdot d_{rb}^{2}}{6}\right)}$ $\qquad f_{b.rb} = 1606.6 \cdot psi$

$F'_{b.rb} := \lambda \cdot K_{F\_Fb} \cdot \phi_b \cdot F_b \cdot C_M \cdot C_{F.rb} \cdot C_D \qquad F'_{b.rb} = 2.06 \cdot ksi$

Flexure only interaction ratio: $DCR_{flex.rb} := \dfrac{f_{b.rb}}{F'_{b.rb}} = 0.78$

$Check := if\left(DCR_{flex.rb} < 1.0, ok, ng\right) \qquad Check = "OK"$

Combined Bending and Axial Compression Check (Section 3.9.2 Bending and Axial Compression)

$$DCR_{comb.rb} := \left(\frac{f_{c.rb}}{F'_{c.rb}}\right)^{2} + \frac{f_{b.rb}}{F'_{b.rb} \cdot \left[1 - \left(\dfrac{f_{c.rb}}{F_{cE1.rb}}\right)\right]} = 0.81$$

[NDS Eqn. 3.9-3]

$Check := if\left(DCR_{comb.rb} \le 1.0, ok, ng\right) \qquad Check = "OK"$

Compression component of demand

Bending component of demand

Shear Check

Shear Strength: $F'_{v.rb} := \lambda \cdot K_{F\_Fv} \cdot \phi_v \cdot F_v \cdot C_M \qquad F'_{v.rb} = 294\,psi$

For chord to top cord connections $\quad V'_{r.rb} := F'_{v.rb} \cdot b_{rb} \cdot d_{rb} = 49 \cdot kip$

Stress interaction ratio: $DCR_{shear.rb} := \dfrac{V_{u.rb}}{V'_{r.rb}} = 0.22$

$Check := if\left(DCR_{shear.rb} < 1.0, ok, ng\right) \qquad Check = "OK"$

Bearing Check

Bearing factor: $C_{b.rb} := 1.1$ *[Sec. 3.10.4]*

Shear Strength: $F'_{c.rb} := \lambda \cdot K_{F\_Fc} \cdot \phi_c \cdot F_{cperp} \cdot C_M \cdot C_{b.rb} \cdot C_D$ $F'_{c.rb} = 1069\,psi$

Bearing Stress: $f_{c.rb} := \frac{V_{u.rb}}{b_{rb} \cdot l_{b.rb}}$ $f_{c.rb} = 226\,psi$

Bearing interaction ratio: $DCR_{bear.rb} := \frac{f_{c.rb}}{F'_{c.rb}} = 0.21$

$Check := if(DCR_{bear.rb} < 1.0, ok, ng)$ $Check = "OK"$

Deflection Check

NDS suggest using a creep factor in deflection calculations when long-term loading must be limited. Long-term deflection limitations were not an original design criteria. However, due to the life span of the project, the deflections calculated incorporate the creep factor. They have only been provided to serve as a higher range value of what could be observed and are only provided as a reference.

Moment of inertia of roof beam: $I_{x.rb} := \frac{b_{rb} \cdot d_{rb}^3}{12} = 2744 \cdot in^4$

Short term loading deflection: (Snow) $\Delta_{st.rb} := \frac{5(w_{LL}) \cdot L_{rb}^4}{384 \cdot E_w \cdot I_{x.rb}} = 0.01 \cdot in$

Long term deflection of roof beam: (soil loading) $\Delta_{lt.rb} := \frac{5(w_{DL} + sw_{rb}) \cdot L_{rb}^4}{384 \cdot E_w \cdot I_{x.rb}} = 0.66 \cdot in$

Creep factor: $K_{cr} := 1.5$ *[Section 3.5.2]*

Total deflection: $\Delta_{T.rb} := \Delta_{lt.rb} \cdot K_{cr} + \Delta_{st.rb} = 0.99 \cdot in$ *[Eqn. 3.5-1]*

Timber Wall Supports

Design Information

Length of member: $L_w := 24\text{ft} - \frac{14\text{in}}{2} - \frac{4\text{in}}{2} = 23.25\,\text{ft}$

Effective length factor for compression: $K_{ex.w} := 1.0$ *(Table G1)*

Effective length for bending: (Fully braced)

Tributary width: $trib_w := 12\text{in}$

Wood Specific Gravity: $\gamma_{wood} := 0.5$ Douglas-Fir Larch per NDS Supplement Table 4D

Self weight of timber wall support: $sw_w := 12\text{in}\cdot 14\text{in}\cdot 62.4\text{pcf}\cdot\gamma_{wood}\cdot H = 0.87\cdot\text{kip}$

$sw_{u.w} := 1.2\cdot sw_w = 1048\,\text{ft}\cdot\text{plf}$
(Factored self weight)

Service Moment: $M_w := 60.03\text{kip}\cdot\text{ft}$ Loads by analysis, Ref. Loading Diagram

Factored Moment: $M_{ux.w} := 96.04\text{kip}\cdot\text{ft}$

Service Shear: $V_w := 12.3\text{kip}$

Factored Shear: $V_{u.w} := 19.64\text{kip}$

Service Axial at mid height (beam reaction): $P_w := V_{rb} + \frac{sw_w}{2} + h_s\cdot\gamma_s\cdot\left(14\text{in} - \frac{4\text{in}}{2}\right)\cdot trib_w = 10.32\cdot\text{kip}$

Factored Axial at mid height (beam reaction): $P_{u.w} := V_{u.rb} + 1.2\cdot\frac{sw_w}{2} + 1.2\cdot\left[h_s\cdot\gamma_s\cdot\left(14\text{in} - \frac{4\text{in}}{2}\right)\cdot trib_w\right] = 12.4\cdot\text{kip}$

<u>Wood Species:</u> Doug-Fir Larch <u>*Dense No. 1 Beam and Stringers*</u> *(Supplement Table 4D)*

Wall Supports are 12x14 rough sawn.

Section Width: $b_w := 12\text{in}$ Section Depth: $d_w := 14\cdot\text{in}$

Bearing length: $l_{b.w} := 4\text{in}$ at bottom L4x3 support (LLV)

Size Factor: $C_{F.w} := \left(\frac{12\text{in}}{d_w}\right)^{\frac{1}{9}} = 0.98$ < or = 1.0 *(Supplement Table 4D)*

Design Checks

Compression check (Section 3.6 and 3.7)

$$F_{cE1.w} := \frac{0.822 \cdot E'_{min}}{\left(\frac{L_w \cdot K_{ex.w}}{d_w}\right)^2} \qquad F_{cE1.w} = 1.8 \cdot ksi \qquad \alpha := \frac{F_{cE1.w}}{F_{cn.star}} = 1.25$$

Column Stability Factor: $C_{P.w} := \frac{1 + (\alpha)}{2 \cdot c} - \sqrt{\left[\frac{1 + (\alpha)}{2 \cdot c}\right]^2 - \frac{\alpha}{c}} \qquad C_{P.w} = 0.79$ [Eqn. 3.7-1]

$C_{P.w} := \min(C_{P.w}, C_{F.w}) = 0.79$

Compressive stress: $f_{c.w} := \frac{P_{u.w}}{b_w \cdot d_w} = 74\, psi$

Compression strength: $F'_{c.w} := \lambda \cdot K_{F\_Fc} \cdot \phi_c \cdot F_c \cdot C_D \cdot C_M \cdot C_{P.w} \qquad F'_{c.w} = 1.14 \cdot ksi$

Compression only interaction ratio: $DCR_{comp.w} := \frac{f_{c.w}}{F'_{c.w}} = 0.06$

$Check := if(DCR_{comp.w} < 1.0, ok, ng) \qquad Check = "OK"$

Flexure check

Compression edge supported: $C_{L.w} := 1.0$

Compression zone of member is continuously braced by the adjacent members. Members are placed side-by-side and continuous along length of tunnel.

Flexure stress: $f_{b.w} := \frac{M_{ux.w}}{\left(\frac{b_w \cdot d_w^2}{6}\right)} \qquad f_{b.w} = 2940 \cdot psi$

$F'_{b.w} := \lambda \cdot K_{F\_Fb} \cdot \phi_b \cdot F_b \cdot C_M \cdot C_{F.w} \cdot C_D \qquad F'_{b.w} = 2.06 \cdot ksi$

Flexure only interaction ratio: $DCR_{flex.w} := \frac{f_{b.w}}{F'_{b.w}} = 1.43$

$Check := if(DCR_{flex.w} < 1.0, ok, ng) \qquad Check = "No Good"$

Using in-situ test results of F_b= 1,980 psi (Silvan 1980), DCR would be... $DCR_{flex.w} \cdot \frac{F_b}{1980 psi} = 0.97$

Compression/bending ratio

$$DCR_{comb.w} := \left(\frac{f_{c.w}}{F'_{c.w}}\right)^2 + \frac{f_{b.w}}{F'_{b.w} \cdot \left[1 - \left(\frac{f_{c.w}}{F_{cE1.w}}\right)\right]} = 1.49$$ [3.9-3]

$Check := if(DCR_{comb.w} \le 1.0, ok, ng)$ $Check = "No\ Good"$

Using in-situ test results of F_b= 1,980 psi (Silvan 1980), DCR would be... $DCR_{comb.w} \cdot \frac{F_b}{1980 psi} = 1.02$

Shear Check

Shear Strength: $F'_{v.w} := \lambda \cdot K_{F\_Fv} \cdot \phi_v \cdot F_v \cdot C_M$ $F'_{v.w} = 294 psi$

For chord to top cord connections $V'_{r.w} := F'_{v.w} \cdot b_w \cdot d_w = 49 \cdot kip$

Shear Stress: $DCR_{shear.w} := \frac{V_{u.w}}{V'_{r.w}} = 0.4$

$Check := if(DCR_{shear.w} < 1.0, ok, ng)$ $Check = "OK"$

Bearing Check

Bearing factor: $C_{b.w} := 1.13$ [Sec. 3.10.4]

Shear Strength: $F'_{c.w} := \lambda \cdot K_{F\_Fc} \cdot \phi_c \cdot F_{cperp} \cdot C_M \cdot C_{b.w} \cdot C_D$ $F'_{c.w} = 1098 psi$

Bearing Stress: $f_{c.w} := \frac{V_{u.w}}{b_w \cdot l_{b.w}}$ $f_{c.w} = 409 psi$

Bearing interaction ratio: $DCR_{bear.rb} := \frac{f_{c.rb}}{F'_{c.rb}} = 0.21$

$Check := if(f_{c.w} < F'_{c.w}, ok, ng)$ $Check = "OK"$

Deflection Check

NDS suggest using a creep factor in deflection calculations when long-term loading must be limited. Long-term deflection limitations were not an original design criteria. However, due to the life span of the project, the deflections calculated incorporate the creep factor. They have only been provided to serve as a higher range value of what could be observed and are only provided as a reference.

Moment of inertia of member: $I_{x.w} := \frac{b_w \cdot d_w^3}{12} = 2744 \cdot in^4$

Short term loading deflection: $\Delta_{st.w} := 0in$ No short term horizontal loading is applied to vertical wall supports

Long term deflection: (soil loading) $\Delta_{lt.w} := \frac{5(h_s \cdot q \cdot trib_w) \cdot L_w^4}{384 \cdot E_w \cdot I_{x.w}} + \frac{0.013 \cdot \left[0.5 \cdot H \cdot \left[\left[(H + h_s) \cdot q - h_s \cdot q\right] \cdot trib_w\right]\right] \cdot L_w^3}{E_w \cdot I_{x.w}} = 1.34 \cdot in$

Total deflection: $\Delta_{T.w} := \Delta_{lt.w} \cdot K_{cr} + \Delta_{st.w} = 2.01 \cdot in$ *[Eqn. 3.5-1]*

Timber Railroad Ties

Design Information

Length of tie: $L_t := 19\text{ft} - 1.92\text{ft} = 17.08\,\text{ft}$

Effective length factor for compression: $L_{x.t} := 6\text{ft}$ $K_{ex.t} := 1$ (Table G1)

Effective length for bending: $l_{ex.t} := 6\text{ft}$

Car Rails brace beam in the horizontal direction and weight of cars braces beam in the vertical direction

Tributary width: $trib_t := 1.83\text{ft}$

Factored Moment: $M_{ux.t} := 0\text{kip}\cdot\text{ft}$ Bending due to car weight is resisted by at-grade soil below

Factored Shear: $V_{u.t} := 0\text{kip}$

Factored Axial (horizontal reaction at bottom of timber wall support): $P_{u.t} := V_{u.w}\cdot\frac{trib_t}{1\text{ft}} = 36\cdot\text{kip}$

24 kips is load per foot of length at bottom of timber wall support

Wood Species: resisted Larch Dense No. 1 Beam and Stringers (Supplement Table 4D)

Ties are 9x7 rough sawn laid with 9" dimension horizontal

Section Width: $b_t := 9\text{in}$ Section Depth: $d_t := 7\cdot\text{in}$

Size Factor: $C_{F.t} := 1.0$ (Supplement Table 4D)

Design Checks

Compression check (Section 3.6 and 3.7)

$$F_{cE1.t} := \frac{0.822\cdot E'_{min}}{\left(\frac{L_t\cdot K_{ex.t}}{d_t}\right)^2} \qquad F_{cE1.t} = 0.83\cdot\text{ksi} \qquad \alpha := \frac{F_{cE1.t}}{F_{cn.star}} = 0.58$$

Column Stability Factor:

$$C_{P.t} := \frac{1 + (\alpha)}{2\cdot c} - \sqrt{\left[\frac{1 + (\alpha)}{2\cdot c}\right]^2 - \frac{\alpha}{c}} \qquad C_{P.t} = 0.5 \qquad \text{[Eqn. 3.7-1]}$$

$$C_{P.t} := \min\left(C_{P.t}, C_{F.t}\right) = 0.5$$

Compressive stress:

$$f_{c.t} := \frac{P_{u.t}}{b_t\cdot d_t} = 570\,\text{psi}$$

Compression strength: $F'_{c.t} := \lambda \cdot K_{F\_Fc} \cdot \phi_c \cdot F_c \cdot C_D \cdot C_M \cdot C_{P.t}$ $F'_{c.t} = 0.72 \cdot ksi$

Compression interaction ratio: $DCR_{comp.t} := \frac{f_{c.t}}{F'_{c.t}} = 0.79$

$Check := if(DCR_{comp.t} < 1, ok, ng)$ $Check = "OK"$

Bearing Check

Shear Strength: $F'_{c.t} := \lambda \cdot K_{F\_Fc} \cdot \phi_c \cdot F_c \cdot C_M \cdot C_D \cdot C_{F.t}$ $F'_{c.t} = 1439 psi$

Bearing Stress: $f_{c.t} := \frac{P_{u.t}}{b_t \cdot d_t} = 570.5\ psi$

Bearing interaction ratio: $DCR_{bear.t} := \frac{f_{c.t}}{F'_{c.t}} = 0.4$

$Check := if(DCR_{bear.t} < 1, ok, ng)$ $Check = "OK"$

Wall Footing Design

References:

1. ACI 318-11 "Building Code Requirements for Structural Concrete"

Assumptions:

1. Analysis is per foot of wall length
2. Eccentricity of loads are measured from the center of footing

Design Information

Dimensional Information

Thickness of foundation: $t_f := 1ft$

Heel of foundation: $L_{toe} := \frac{L_f - t_w}{2} = 11 \cdot in$

Thickness of wall: $t_w := 14in$

Total length of footing: $L_f := 3ft$

Density of Concrete: $\gamma_c := 145pcf$

Density of Water: $\gamma_w := 62.4pcf$

Soil unit weight: $\gamma_s := 115pcf$

Loading

Service Load: $P_f := P_w + \frac{sw_w}{2} = 10.76 \cdot kip$

Includes the lower half of the wall timber support self weight

Factored Load: $P_{u.f} := P_{u.w} + 1.2 \cdot \frac{sw_w}{2} = 12.96 \cdot kip$

No applied moment at base as the post hast a pin reaction: $M_f := 0kip \cdot ft$

Allowable bearing pressure: $q_a := 4400psf$

Concrete compressive strength: $f'_c := 3000psi$

Bearing Pressure Analysis

Applied bearing pressure: $q_f := \dfrac{P_f}{1ft \cdot L_f} = 3585 \cdot psf$

Demand capacity ratio: $DCR_{q.f} := \dfrac{q_f}{q_a} = 0.81$

$Check := if(DCR_{bear.t} < 1, ok, ng)$ $\quad Check = "OK"$

Flexure in footing analysis
(Analysis is done for plain concrete as the original plans do not indicate any reinforcement)

Moment from bearing pressure: $M_f := q_f \cdot \left[1ft \cdot \dfrac{\left(\dfrac{L_f}{2} - \dfrac{t_w}{2}\right)^2}{2} \right]$ $\quad M_f = 1.51\, ft \cdot kip$

Cracking moment of section: $M_{cr} := 7.5 \cdot \sqrt{f'_c \cdot psi} \cdot \dfrac{1ft \cdot t_f^{\,2}}{6}$ $\quad M_{cr} = 9.86 \cdot kip \cdot ft$ *[Ref. Eqn. 9-10]*

Footing does not contain any rebar. Therefore, the moment capacity is the cracking moment

Demand capacity ratio: $DCR_{f.m} := \dfrac{M_f}{M_{cr}} = 0.15$

$Check := if(DCR_{f.m} < 1, ok, ng)$ $\quad Check = "OK"$

One Way Shear Check

$V_{u.f} := 1.2 q_f \cdot 12in \cdot L_{toe} = 3.94 \cdot kip$ **(1.2 factor for controlling load case)**

Reduction factor for shear: $\phi_v := 0.75$ *[Section 9.3.2.3]*

Capacity of concrete: $\phi V_{c.f} := \phi_v \cdot 2 \cdot \sqrt{f'_c \cdot psi} \cdot 12in \cdot t_f = 11.83 \cdot kip$ *[Eqn. 11-3]*

Demand capacity ratio: $DCR_{f.s} := \dfrac{V_{u.f}}{\phi V_{c.f}} = 0.33$

$Check := if(DCR_{f.s} < 1, ok, ng)$ $\quad Check = "OK"$

Concrete Wall Footing Analysis

References:

1. ACI 318-11 "Building Code Requirements for Structural Concrete"

Assumptions:

1. Analysis is per foot of wall length
2. Eccentricity of loads are measured from the center of footing

Design Information

Dimensional Information

Thickness of foundation: $t_{cf} := 1ft$ Thickness of wall: $t_{cw} := 3ft$

Total length of footing: $L_{cf} := 5ft$

Loading

Service Load: $P_{cf} := V_{rb} + t_{cw} \cdot h_s \cdot \gamma_s \cdot ft + t_{cw} \cdot H \cdot \gamma_c \cdot 1ft = 22.2 \cdot kip$

Roof beam reaction + soil above wall+wall sw

Factored Load: $P_{u.cf} := V_{u.rb} + 1.2t_{cw} \cdot h_s \cdot \gamma_s \cdot ft + 1.2t_{cw} \cdot H \cdot \gamma_c \cdot 1ft = 26.7 \cdot kip$

No applied moment at base as the post hast a pin reaction: $M_{cf} := 0kip \cdot ft$

Allowable bearing pressure: $q_a := 5500psf$

Bearing Pressure Analysis

Applied bearing pressure: $q_{cf} := \frac{P_{cf}}{1ft \cdot L_{cf}} = 4440 \cdot psf$

Ultimate bearing pressure: $q_{u.cf} := \frac{P_{u.cf}}{1ft \cdot L_{cf}} = 5340 \cdot psf$

Demand capacity ratio: $DCR_{q.cf} := \frac{q_{cf}}{q_a} = 0.81$

$Check := if(DCR_{bear.t} < 1, ok, ng)$ $Check = "OK"$

Flexure in footing analysis

Moment from bearing pressure:

$$M_{cf} := q_{cf} \cdot \left[1ft \cdot \frac{\left(\frac{L_{cf}}{2} - \frac{t_{cw}}{2} \right)^2}{2} \right]$$

$M_{cf} = 2.22 \, ft \cdot kip$

Footing has #5@12" o.c. transverse bars. Moment capacity of footing is adequate by inspection. Reference wall footing design.

Check for shear capacity

Design 'd':

$$d := t_{cf} - 3in - 0.5 \cdot \frac{5}{8} in = 8.69 \cdot in$$

Critical Shear:

$$V_{u.cf} := q_{u.cf} \cdot \left(\frac{L_{cf}}{2} - \frac{t_{cw}}{2} - d \right) \cdot 1ft$$

$V_{u.cf} = 1.47 \cdot kip$

Capacity of concrete:

$$\phi V_c := \phi_v \cdot 2 \cdot \lambda \cdot \sqrt{f'_c \cdot psi} \cdot 1ft \cdot d$$

$\phi V_c = 6.85 \cdot kip$

Demand capacity ratio:

$$DCR_{f.s} := \frac{V_{u.cf}}{\phi V_c} = 0.22$$

$Check := if\left(DCR_{f.s} < 1, ok, ng\right)$ $Check = "OK"$

ch2m:	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

Appendix B

Soil Design Parameters

Geotechnical Soil Design Parameters for Engineering Evaluation of PUREX Tunnel 1

PREPARED FOR:	Pete Hopkins/CH2M
COPY TO:	Craig Barrett/CH2M
	Mark Hasty/CH2M
PREPARED BY:	Mark Kacmarcik/CH2M
DATE:	June 23, 2017
PROJECT NUMBER:	693839.BS
REVISION NO.:	0
REVIEWED BY:	Nason McCullough/CH2M

Introduction

Geotechnical soil design parameters are presented herein for use in structural evaluation of PUREX Failed Equipment Storage Tunnel No. 1, Facility 218-E-14 (hereinafter described as Tunnel 1). Structure-specific geotechnical data is not available for the Tunnel. This memorandum describes the methodologies employed to develop tunnel soil geometry, geotechnical engineering properties of soils, earth pressures on tunnel roof and walls, and bearing capacity of footings. Geotechnical analysis of the progressive failure of roof timbers is also provided.

Limitations

At the time of issue of this report, site-specific geotechnical data was not available for use in the evaluation of Tunnel 1. Available geotechnical information generally consists of historical photographs, regional geologic studies, or site-specific studies for other facilities in the project vicinity. All evaluations and recommendations provided herein are derived from interpretation of data reported by others. As such, errors or misrepresentation of site information by others would affect our recommendations. In the event that additional geotechnical data is made available, or subsurface investigation programs are performed, analysis results should be updated accordingly.

Geotechnical Properties of Cover Soil

Geotechnical properties of Tunnel 1 cover soils were estimated for use in evaluation of soil loading on the roof and walls of the structure. At this time, there is no known geotechnical investigation data which characterizes the Tunnel 1 cover soil, and original design calculations for the tunnel are not available.

Soil properties were estimated considering review of as-built drawings, construction specifications, construction photographs, previous geotechnical investigation results in the vicinity of Tunnel 1, regional geologic studies, and other investigations performed by others. As can be seen in Exhibit 1, it is interpreted that the cover soil was not placed in lifts and compacted as specified, but was placed loosely with a bulldozer, and was not compacted in lifts as specified. It is unknown whether the cover soils over the roof of the tunnel were compacted in lifts.

Exhibit 1 – Backfill operations at Tunnel 1; note placement of fill against Tunnel walls during winter conditions using a bulldozer

We recommend cover soil properties for Tunnel 1 as follows, based on our experience in the area, existing nearby information, and typical properties:

- Unified Soil Classification System (USCS) classification: Silty Sand with Gravel (SM)
- Moist unit weight, γ_m = 110 pcf (Expected range: 105 to 115 pcf)
- Internal friction angle, ϕ' = 30 degrees
- Cohesion, c' = 0 psf

The selection of soil parameters for the cover soils is complicated due to the lack of clear documentation of material properties or fill placement methods. Variability in the dry density of the soil, the in-situ moisture content, and material gradation are expected to contribute to variations in moist unit weight of the soil. The soil unit weight may change seasonally in response to seasonal weather patterns, variations with depth and location are likely. Discussion of the selection of these parameters is included in Attachment A.

Cover Soil Geometry

The geometry of the Tunnel 1 cover soil was evaluated by comparing the existing site topography to the as-built geometry of the tunnel. Light, Data, and Ranging (LiDAR) topographic survey data was collected in 2008 for the Central Plateau of the Hanford site by AeroMetric, Inc. of Seattle, Washington.

The collected data for the Central Plateau is arranged in 343 tiles arranged across the site. Tiles 153, 154, 177, and 178 overlap the PUREX Storage Tunnel 1 and Tunnel 2 and were provided to CHPRC by MSA of Richland, Washington for use in the analysis. The LiDAR survey data in the provided tiles consisted of a "bare earth" digital elevation model (DEM) processed by Aero-Metric to remove projections from the ground surface such as structures and vegetation as well as a "first return" DEM which includes all data points regardless of impacted surface. An excerpt from the LiDAR topography developed for the site is shown in Exhibit 2, detailed topography and cross sections are shown in Attachment B.

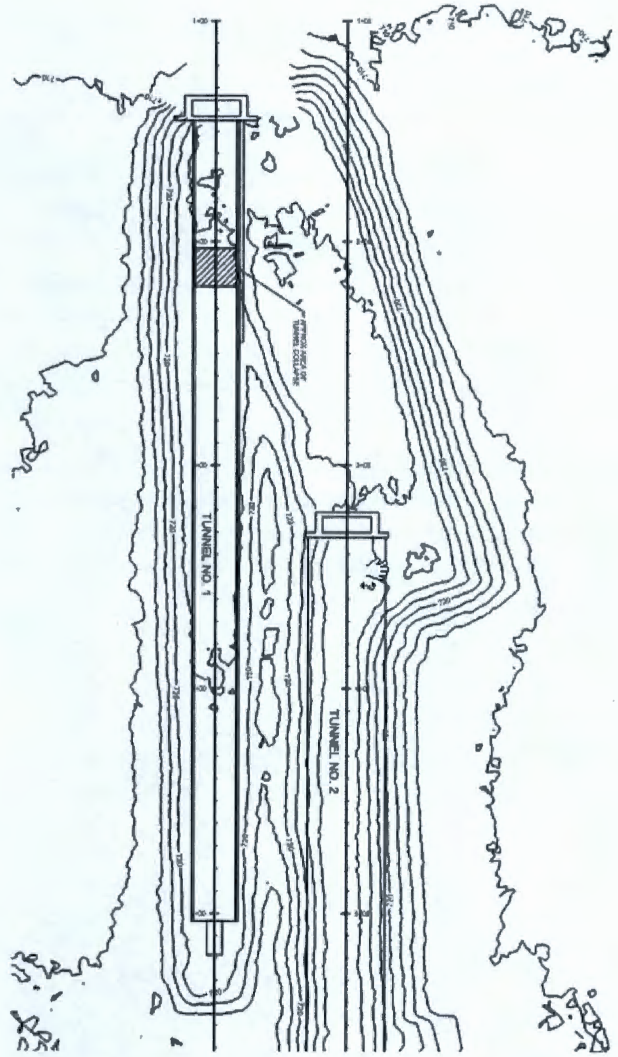


Exhibit 2 – Plan view showing of LIDAR topography and as-built geometry of Tunnel 1. North is up.

The horizontal coordinate system for the LiDAR data is State Plane, NAD83, Washington South Zone, meters. The vertical elevation system was NAVD88, meters. The LiDAR data was converted from the original coordinate system to match the 200E survey datum using survey monument data for brass-cap Monument 2E-41. This conversion allows direct comparison of topographic survey data to the as-built plan and elevation of the Tunnel 1 structure. An example is shown in Exhibit 3. The results of the LiDAR analysis, including site topography, tunnel profile, and tunnel cross sections are included in Attachment B.

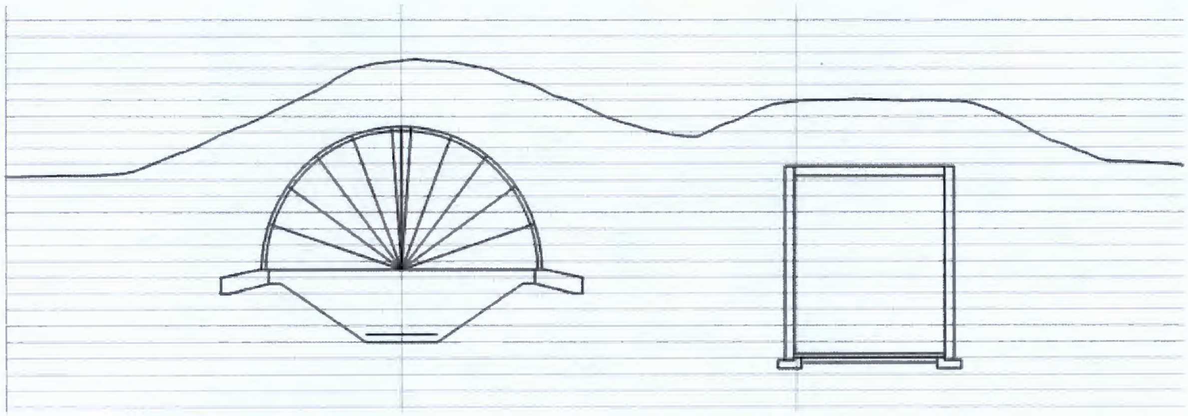


Exhibit 3 – Cross Section at STA 4+00 showing geometry of Tunnel 1, Tunnel 2, and Tunnel Cover Soils

At this time, no known recent confirmation survey data is available to confirm the horizontal or vertical position of the tunnel or the cover soil. The LiDAR data was collected in 2008, and at the time of this analysis was greater than 9 years old. It is possible that changes in the ground surface may have occurred since the data was collected. The geometry of Tunnel 1 was reproduced from horizontal and vertical coordinates shown on the 1955 as-built drawings. Plan, profile, and cross-sections of Tunnel 1 were then generated for evaluation of cover soil geometry as shown in Attachment B. Considering the age of the data, it is emphasized that the elevations and locations developed for this study are approximate.

To investigate the accuracy of the tunnel and cover soil geometries, "first return" LiDAR elevation data for the exposed portions of the Tunnel 1 and Tunnel 2 water-filled door structures was compared to the as-built design elevations of the structures reported in 1955 and 1962, respectively. First-return elevation data was found to generally be within 0.3 feet of the as-built elevation of the water-filled door structures. To our knowledge, the elevation of the water filled door structures have not been recently surveyed to confirm the as-built elevations; some movement of these structures over time is possible.

The LiDAR elevation data is expected to be the best-available topographic data for the site. The agreement between the LiDAR data and as-built water-filled door elevation supports the use of these two data sources to evaluate earth pressures on the tunnel with reasonable accuracy. If improved topography or tunnel geometry data becomes available, the cover soil geometry should be re-evaluated and incorporated into revised earth pressure calculations.

Earth Pressures

Earth pressures were estimated for the tunnel roof and the vertical walls of the tunnel. Earth loads were estimated using the 2008 LiDAR cover soil topography, the as-built tunnel geometry, and the estimated geotechnical properties of the cover soils. Estimation of roof pressures and lateral earth pressures are described below.

Roof Pressure

Soil pressures on the tunnel roof were estimated by taking scaled measurements of the cover soil height over the tunnel roof. Measurements were taken at the eastern edge, the centerline, and the western edge of the tunnel roof. Soil heights over the tunnel roof were found to vary from 7.8 to 9.5 feet, with an average of 8.3 feet. The soil height was multiplied by the estimated moist unit weight of the cover soil. The design snow load (15 psf) was added to the roof pressure. A summary of expected soil and snow loading on the tunnel roof is shown in Exhibit 4 for 6 cross sections along the tunnel. The locations of these cross sections can be seen in Attachment B.

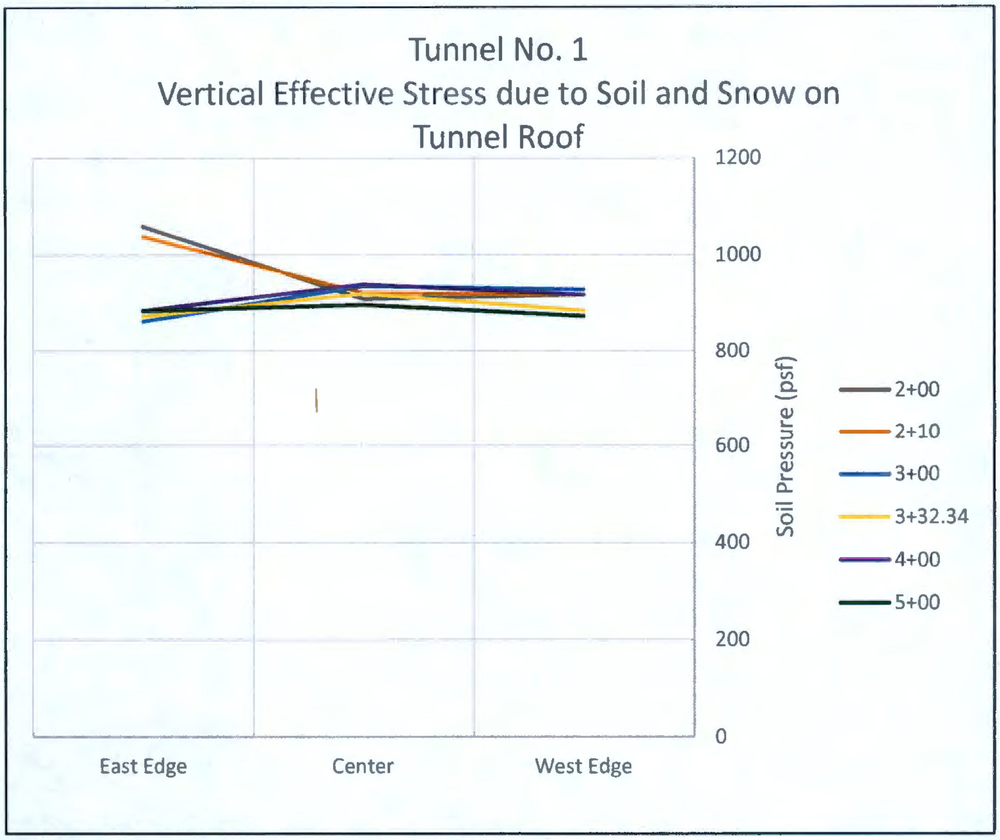


Exhibit 4 – Estimated vertical stress on tunnel roof for 6 cross-sections of Tunnel 1

Lateral Earth Pressures

Lateral earth pressures for the tunnel walls were estimated at the top and bottom of the tunnel walls for 6 cross-sections assuming at-rest lateral earth pressures act against the structure, and that pressures vary linearly along the height of the wall.

The at-rest lateral earth pressure coefficient was estimated using the material properties described herein and adjusted to account for sloping ground surface.

At-rest Earth Pressure Coefficient, $K_O = 1 - \sin(\phi')$

Adjusted At-Rest Earth Pressure Coefficient, $K_{Oi} = K_O \cdot (1 + \sin(i))$

where:

ϕ' is the drained internal friction angle of the soil

i is the slope of the ground surface in degrees

The average slope of the cover soils adjacent to the tunnel walls was estimated using the geometry shown in Exhibit 5. The adjusted lateral earth pressure coefficient was multiplied by the estimated vertical effective stress at the top and bottom of the wall to obtain a lateral earth pressure. The design snow load (15 psf) was included in the lateral earth pressure estimation. The estimated lateral earth pressures for each section are shown in Exhibits 6 and 7. Detailed lateral earth pressure calculations are included in Attachment C.

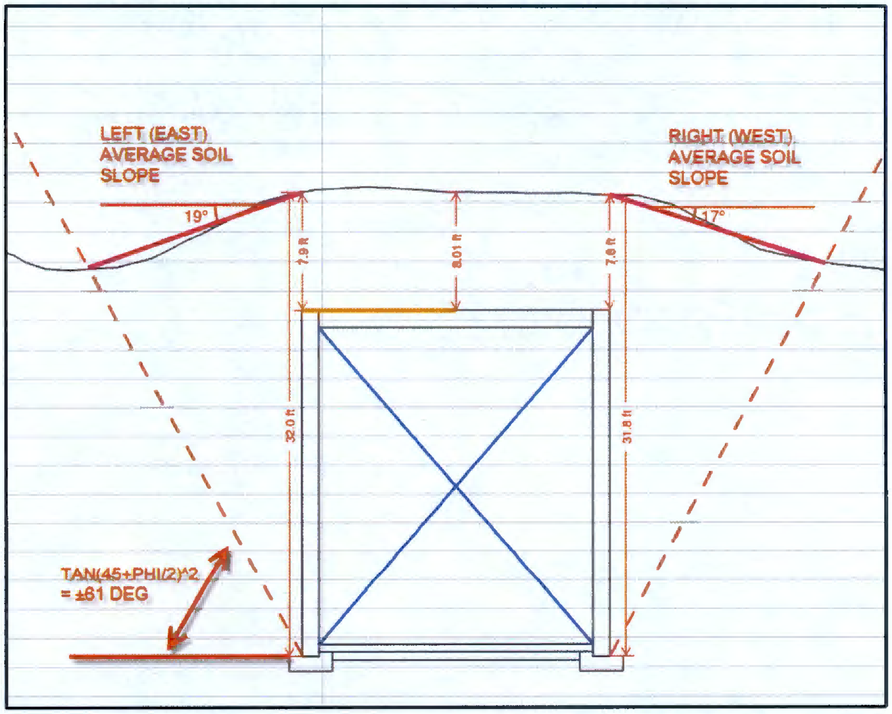


Exhibit 5 – Geometry used for evaluation of lateral earth pressures at Tunnel 1.

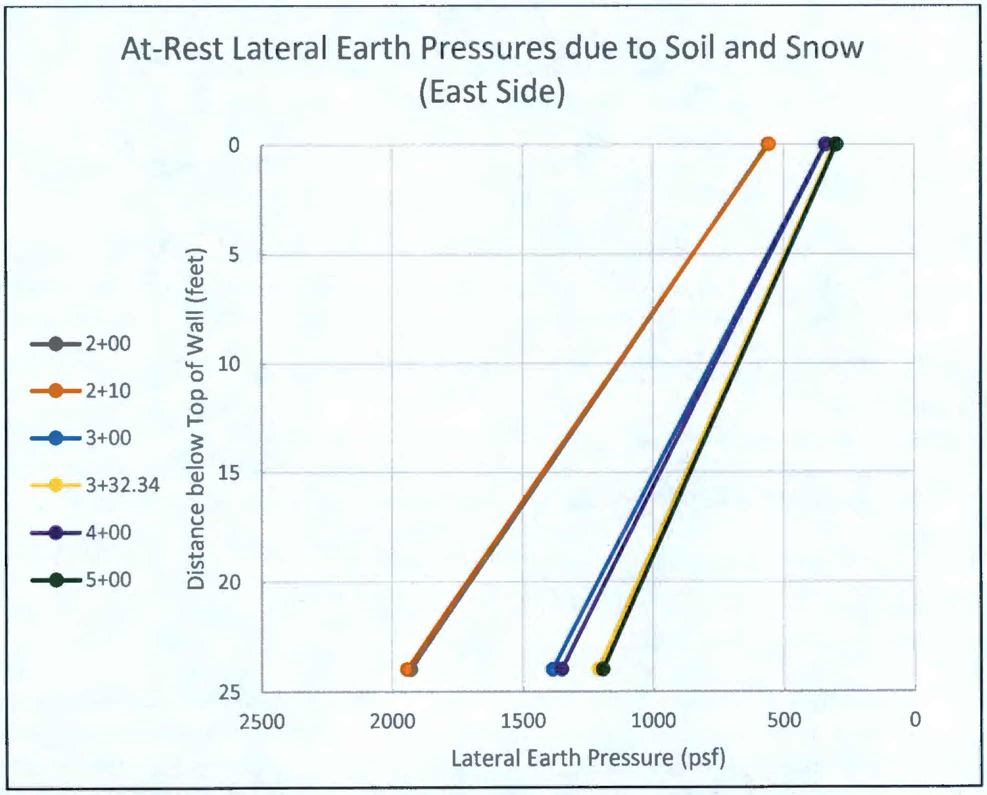


Exhibit 6 – Estimated Lateral Earth Pressures on East wall of Tunnel 1 due to soil and snow loads

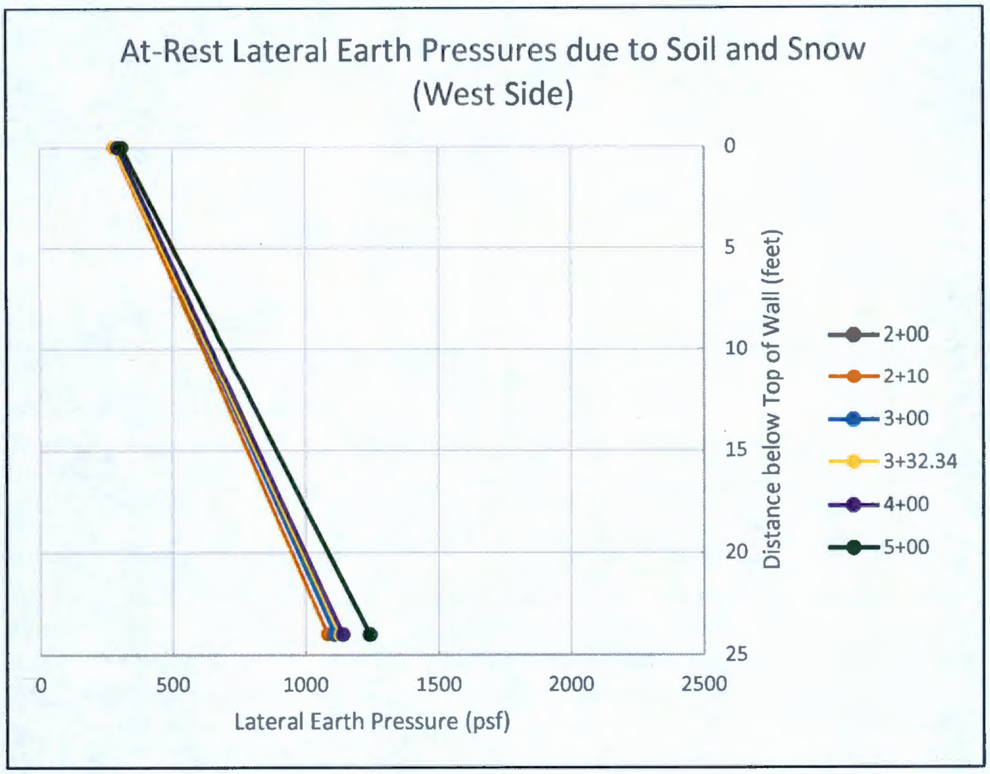


Exhibit 7 - Estimated Lateral Earth Pressures on West wall of Tunnel 1 due to soil and snow loads

Footing Bearing Capacity

The ultimate bearing capacity of the Tunnel 1 footings was estimated using Vesic's extended bearing capacity equation. Ultimate bearing capacity was estimated considering two continuous strip footing geometries: the 5-foot-wide footings beneath the concrete wall on the east side of Tunnel 1, and the 3-foot-wide footings located beneath the timber walls. The footings support vertical loadings and bear upon horizontal ground on the inside of the tunnel.

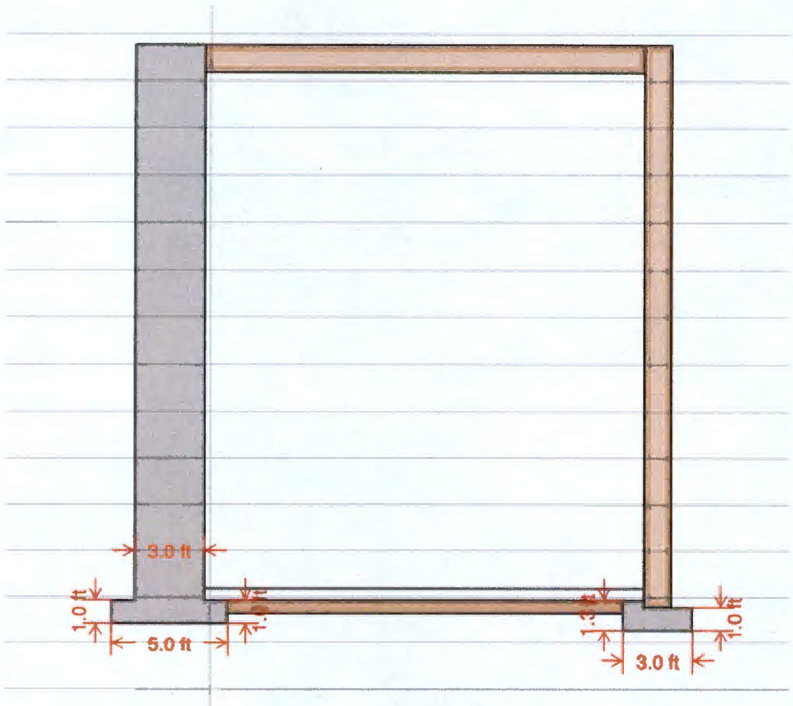


Exhibit 8 –Geometry used in Evaluation of Ultimate Bearing Capacity of Tunnel 1 Footings

The footing subgrade was assumed to be relatively undisturbed native material with an internal friction angle of 34 degrees, a cohesion of 0 psf (recommended by Dames & Moore, 1984), and a unit weight of 125 pcf as recommended by Shannon & Wilson (2015). Groundwater is greater than 300 feet deep below the project site as noted by URS/Blume (1981).

The geotechnical strength parameters adopted from Dames & Moore (1984) were originally prepared for Process Facility Modification Project located approximately 0.25 miles west of the PUREX storage tunnels. These strengths are believed to be conservative considering that Shannon & Wilson later provided a range of recommended strengths for the Hanford Formation as a friction angle of 38 to 54 degrees with zero cohesion. Review of construction photographs of exposed material in the subgrade and experience with similar materials suggests that the strengths provided by Dames & Moore are conservative.

Using the as-built footing geometry and Dames & Moore's (1984) recommended strength results in the following ultimate bearing capacity estimates:

$q_{ultimate,concrete}$ = 16,600 psf (footing on the left in Exhibit 8)

$q_{ultimate,wood}$ = 13,100 psf (footing on the right in Exhibit 8)

The standard of practice for conventional geotechnical design is to incorporate a factor of safety of 3.0 into the development of allowable bearing capacities. Larger factors of safety could be justified considering the uncertainty in subsurface conditions and the consequences of failure.

$q_{allowable,concrete}$ = 5,500 psf

$q_{allowable,wood}$ = 4,600 psf

Factor of Safety = 3.0

These bearing pressures are expected to be conservative considering the relatively low strength used in the calculation, the additional bracing provided by the timbers in the tunnel floor, and the weight of the rail cars and equipment within the tunnel. Soil bearing capacity calculations are included in Attachment D.

Progressive Failure of Roof Timbers

A soil mechanics review was performed to assess the mechanisms of roof collapse for Tunnel 1. The review was conducted to determine if a single roof timber collapse could be attributed to the development of the 17-foot-wide roof collapse observed on May 9, 2017. The premise for the review was the consideration that, if a single timber collapsed, the overburden soil loading on the tunnel roof would be expected to be redistributed to adjacent timbers and cause a corresponding increase in stress. This stress, if sufficient to cause failure of the adjacent timbers, could result in a progressive failure mechanism and additional timber failure. The progressive failure would continue until the soil is unable to arch over the void, and collapses into the opening, thereby reducing the additional weight on the adjacent timbers.

The soil mechanics review was inconclusive; however, the general finding was that the 17-foot-wide collapse cannot be readily explained by soil mechanics principles of a simplified progressive failure mechanism. The loss of a single timber is expected to result in a re-distribution of tunnel stresses which, if sufficient to cause timber failure with 8 feet of cover soil, could open to a width of 4 to 5 feet before the soil arch would collapse into the opening.

Additional factors, such as the apparent cohesion provided by negative pore pressures in the moist cover soils, the "reinforcement" provided by plant roots, three-dimensional effects from the sloping and adjacent cover soils, or disturbance caused by the 1980 RHO investigations of the Tunnel 1 roof timbers, may provide partial explanation for the collapse. Further study may be warranted using numerical methods and by assigning spring constants to individual timbers and investigating the loss of individual timber members.

References

CHPRC-03241 Revision 0. PUREX Burial Tunnels, dated March 2017, prepared for the U.S. Department of Energy Assistant Secretary for Environmental Management, prepared by M. A. Maloof CH2M HILL Plateau Remediation Company.

FLUOR Hanford LiDAR Digital elevation Model(s) & Topographic Contour Maps, prepared by Aero-Metric, Seattle, dated 2008

Geotechnical Engineering Study (Rev2) West Replacement Footings for 324 Building 'B' Cell Excavation Hanford Reservation, Washington. 22-1-03078-010. Submitted to Kurion, Inc., dated February 27, 2015, prepared by Shannon & Wilson.

H-2-55587 (drawing), Structural Floor Plan & Section, 1955 Tunnel 1.

H-2-55588 (drawing), Structural Sections & Details, 1955 Tunnel 1.

H-2-55589 (drawing, Structural Sections & Details, 1955 Tunnel 1.

HWS-5638, Specification for Disposal Facility for Failed Equipment, dated April 25, 1955 (Tunnel 1), Project CA-513-A.

Report of Soils Investigation, Proposed Process Facility Modification Project, PUREX Plant, Hanford, Washington for US Department of Energy, dated January 4, 1984, prepared by Dames & Moore.

RHO-CD-1079, Structural Evaluation of the PUREX No. 1 Burial Tunnel, dated September 1980, by Silvan, G.R.

RHO-R-34-3, Geologic and Seismic Investigation of the PUREX Building Site near Richland, Washington, prepared for Vitro Engineering Corporation, Richland Washington, dated March 1981, prepared by URS/John A. Blume & Associates, Engineers.

ch2m	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

Attachment A

Cover Soil Parameters

Geotechnical Properties of Tunnel 1 Cover Soil

PREPARED FOR:	Project File
COPY TO:	Craig Barrett/CH2M
	Pete Hopkins/CH2M
	Mark Hasty/CH2M
PREPARED BY:	Mark Kacmarcik/CH2M
CHECKED BY:	Youssef Bougataya/CH2M
DATE:	June 23, 2017
PROJECT NUMBER:	693839.BS
REVISION NO.:	0

This memorandum documents the development of recommended geotechnical properties for the Tunnel 1 Cover soils for use in structural evaluation of Tunnel 1. Specifically, this memorandum briefly summarizes the available information and provides recommended strength and unit weight values.

Review of Available Subsurface Information

There is very limited geotechnical information available for Tunnel 1. Collection of site-specific geotechnical data was beyond the scope of this evaluation. Recommendations provided herein are derived from interpretation of geotechnical data reported by others. Much of the available data is fragmentary or otherwise developed for other purposes. No responsibility can be taken for errors or misrepresentation of site information by others.

Construction Drawings (1955)

Original construction drawings are available for Tunnel 1. The drawings include limited information on the cover soils. The following are noted from review of the drawings:

1. Tunnels were to be constructed with minimum 8'-0" of soil cover
2. The width of the soil cover is 28'-0"
3. Side slopes for the soil cover were to be constructed at 2H:1V

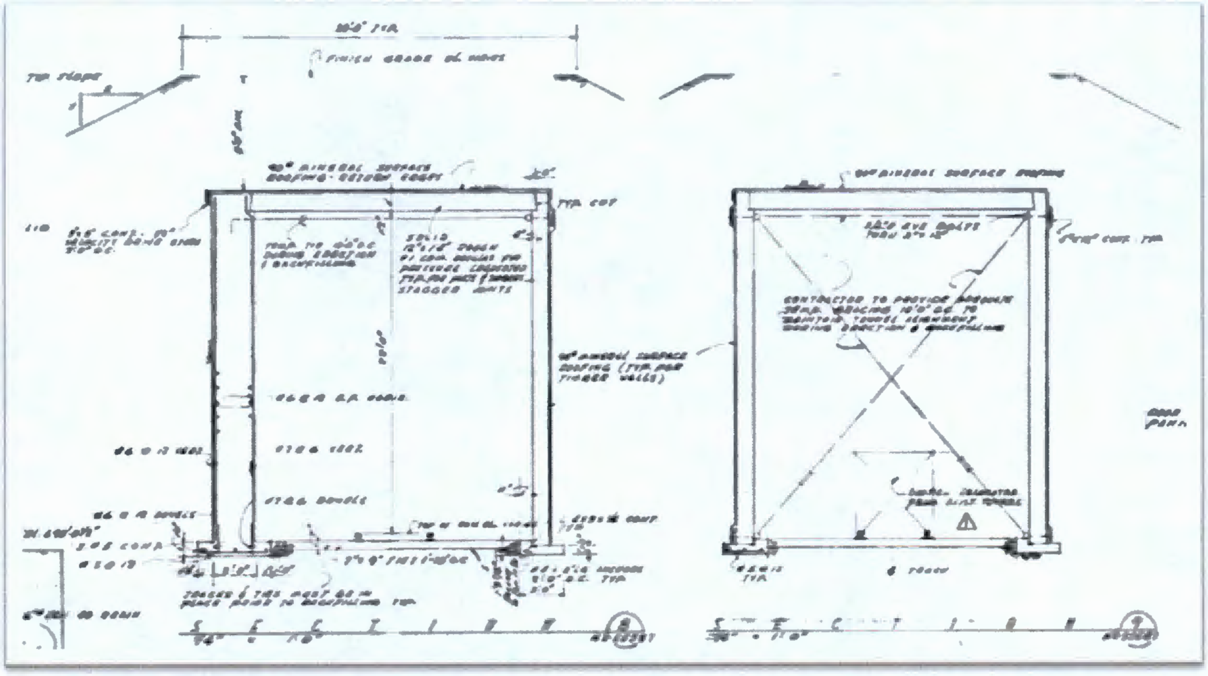


Exhibit 1 – Design Cross section of Tunnel 1 showing proposed finish grade relative to tunnel structure

Construction Specifications (1955)

Original construction specifications for Tunnel 1 were available for review. Review of the available construction photos (discussed hereinafter) makes it difficult to discern the extent to which these specifications were enforced during construction of the tunnel. The following were included in the specifications:

1. Frozen fill materials were not to be used; however placement of fill in wintertime is visible in several photos.
2. Materials were to be screened to remove particles larger than 8 inches; large particles were not discernable in construction photos.
3. Fill materials were to be free from vegetable matter or trash. Tumbleweeds are visible in tunnel excavations, it is unclear whether these materials were removed prior to fill placement.
4. Fill materials were to be placed in maximum 24-inch loose lifts and thoroughly compacted. A compaction specification, method specification, or density was not specified. Construction photos suggest that this material was not placed in horizontal lifts as specified.
5. Compaction methods were not specified, except as to prohibit sluicing or flooding. There is no compaction equipment visible in the photos, it is unclear if cover soils were compacted.
6. Fill placement was to avoid excessive loads on walls, unbalanced loads, or construction of walls out of verticality.
7. The tunnel roof was to receive 6 inches of clean sand fill over the 90# mineral surface roofing. The presence or absence of this material cannot be ascertained from the available photos.

6. BACKFILL

a. Additional embankment material, if required in addition to material excavated under these specifications, shall be obtained from the borrow area designated by the Commission.

b. Only selected material free of frozen particles, stones greater than 8 inches in any dimension, vegetable matter and trash shall be used in any backfill.

c. Trash shall not be allowed to accumulate in spaces to be backfilled.

d. Material for load bearing backfill, such as that under stairwell and pump house, shall be placed in level layers not to exceed 12 inches loose measurement, wetted and thoroughly compacted.

HWS-5638

Exhibit 2a – Backfill specifications for Tunnel 1

e. Material for non-load-bearing backfill and embankment shall be placed in layers not to exceed 24 inches loose measurement unless otherwise specified herein, and thoroughly compacted. Compaction by loaded scrapers and/or tractors will be considered adequate for non-load-bearing compaction subject to the restrictions specified in Section 3-c. above.

f. A compacted sand cushion at least 4 inches thick shall be placed under lines in trenches where such lines pass through rocky soil or as directed by the Commission.

g. After necessary line testing has been accomplished, backfill for piping shall be carefully placed around pipe before covering with a minimum of 12 inches of compacted sand. Common backfill material shall then be placed as noted in items above.

h. Care shall be exercised during backfilling to prevent excessive loads on walls and to insure balanced loading on opposite walls.

All necessary precautions shall be exercised to insure vertical walls upon completion of backfilling.

i. Six inches of clean sand free from stones over 1 inch in diameter shall be placed over tunnel roofing material prior to placing embankment material.

j. Backfilling by means of sluicing or flooding will not be permitted.

Exhibit 2b – Backfill specifications for Tunnel 1 (continued)

Design Documentation

At this time, no design documentation, design calculations, design reports, or related materials are known to exist.

Construction Photographs (various)

Tunnel 1 construction photographs documented in CH2M (2017) were reviewed. The following observations were made:

- Tunnel 1 was constructed and backfilled in winter conditions, with visible snow on ground, possible placement of frozen materials.
- Tunnel excavation geometry (i.e. trench) does not appear to allow adequate access for compaction of backfill soils in lifts against tunnel walls. Photos suggest that material may have been pushed into the trench using a bulldozer or similar equipment. It is unknown if small walk-behind compaction equipment was used to compact material in 24-inch lifts as specified. It is unknown how material was placed on the roof of the tunnel.
- Internal guy wires are visible inside tunnel as shown on drawings.
- Wooden cleats are visible on outside of tunnel.
- Backfill material generally appears to be fine or sandy in nature, there are very few cobbles, gravels, or coarse materials visible in the photos.

Exhibit 3 – Construction photo of Tunnel 1. Note stockpiled backfill and timbers, concrete wall, and footing formwork.

Exhibit 4 – Construction of Tunnel 1. Note snow, steep-walled trench adjacent to tunnel walls, internal guy wires, external timber cleats.

Exhibit 3 – Tunnel 1 construction aerial view. Note snow and relatively even placement of fill material in narrow trench against tunnel walls by construction equipment.

Studies by Others

1.0 Rockwell Hanford Operations Structural Evaluation of Tunnel 1 (1980)

Rockwell Hanford Operations (RHO) performed a structural evaluation of Tunnel 1 in 1980. The following items were noted from the archived report:

- Rockwell International completed a structural evaluation of Tunnel 1, including sampling and evaluation of 4-1/8" diameter cores of roof timbers from 3 locations along the tunnel in May 1980.
- "Location Number 2" was approximately 54 feet south of the water filled door and 4 feet west of the tunnel centerline. This location is very close to the observed tunnel roof collapse. This location (similar to the other locations sampled) was selected because it appeared to have received the greatest amount of radiation exposure.

- To obtain the cores, the cover soil was excavated with a clamshell to expose the roof of the tunnel.
- Although no references or methodology is cited, the following geotechnical parameters for the cover soils were used:
  - Unit weight = 110 pcf
  - Active Earth Pressure Coefficient, *Ka* = 0.4 **Note that the use of *Active* lateral earth pressures in this 1980 evaluation is inappropriate, considering the top of the wall is restrained against rotation away from the backfill by the roof timbers. *At-Rest* earth pressures are more appropriate.**
- Visible in the report photographs are sandy fill material with small to medium gravels. Silt content is not readily apparent. The presence or absence of 6 inches of clean sand above the tunnel roof is not discernable.
- The method for backfilling the investigation holes is not described, although it is noted that the backfilling was delayed approximately 6 days due to equipment delays resulting from ash from the May 18, 1980 eruption of Mt. St. Helens.

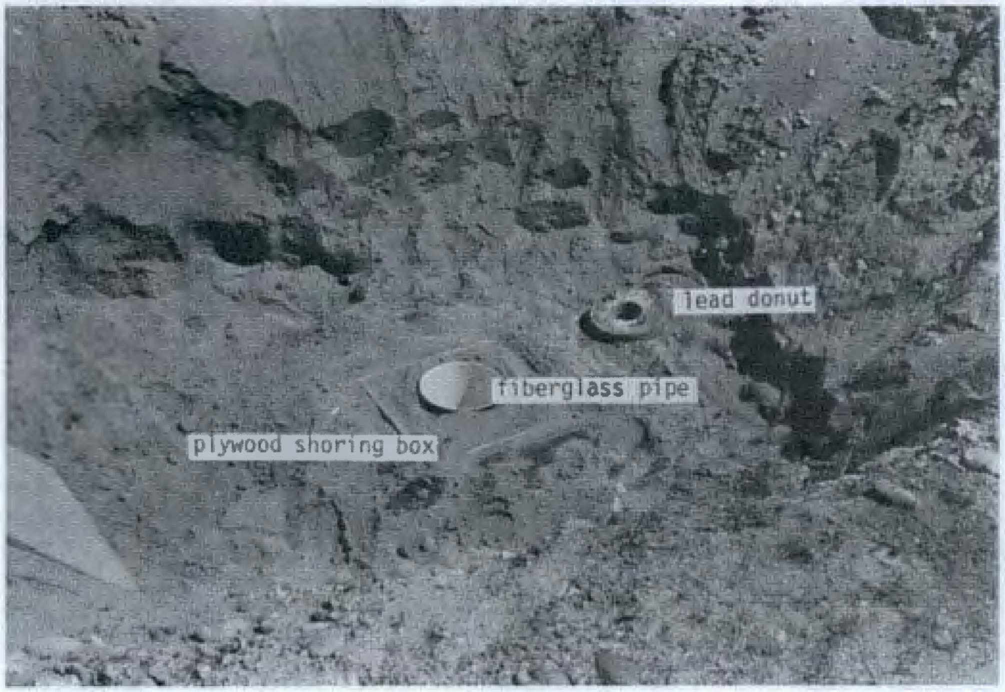


Figure 4: Typical Sample Site

Exhibit 4 – View of excavation into Tunnel 1 cover soils for sampling of roof timbers

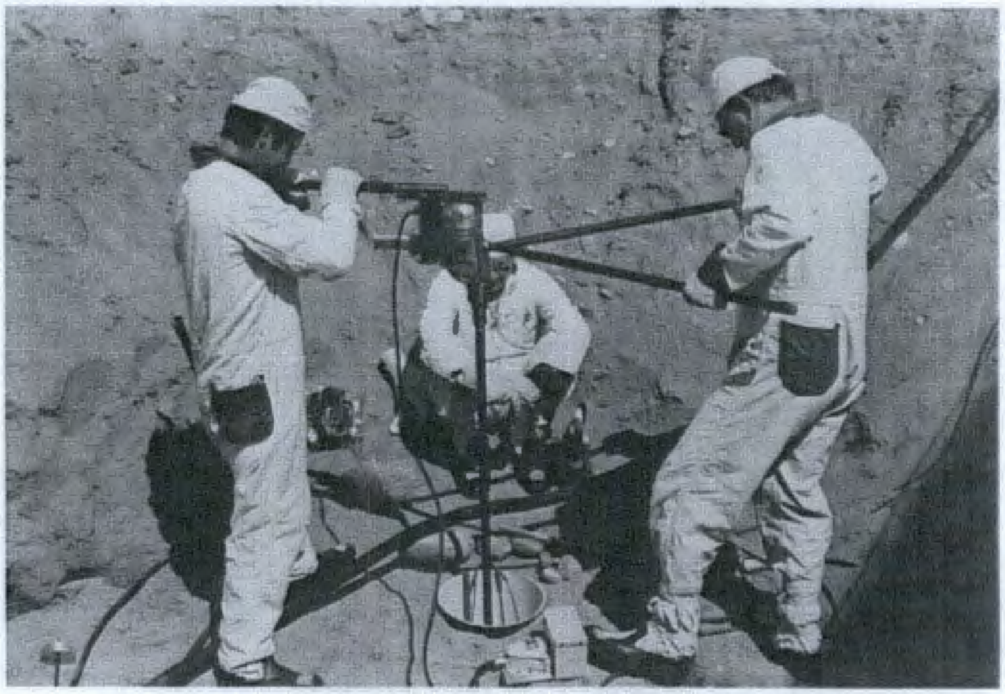


Figure 6: Drill Motor in Use

Exhibit 5 – Alternate view of sampling of roof timbers, note soil sandy soil with fine to medium gravels visible in background.

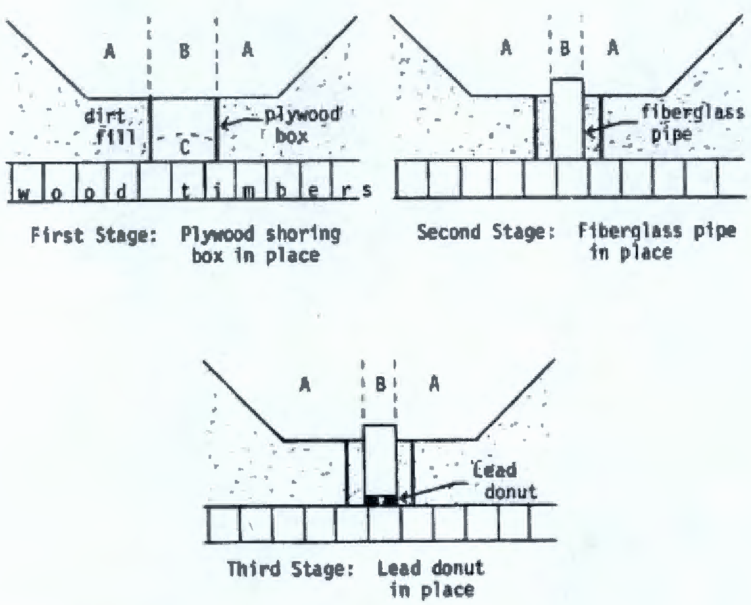


Exhibit 6 – General configuration and sequencing of timber sampling locations on Tunnel 1

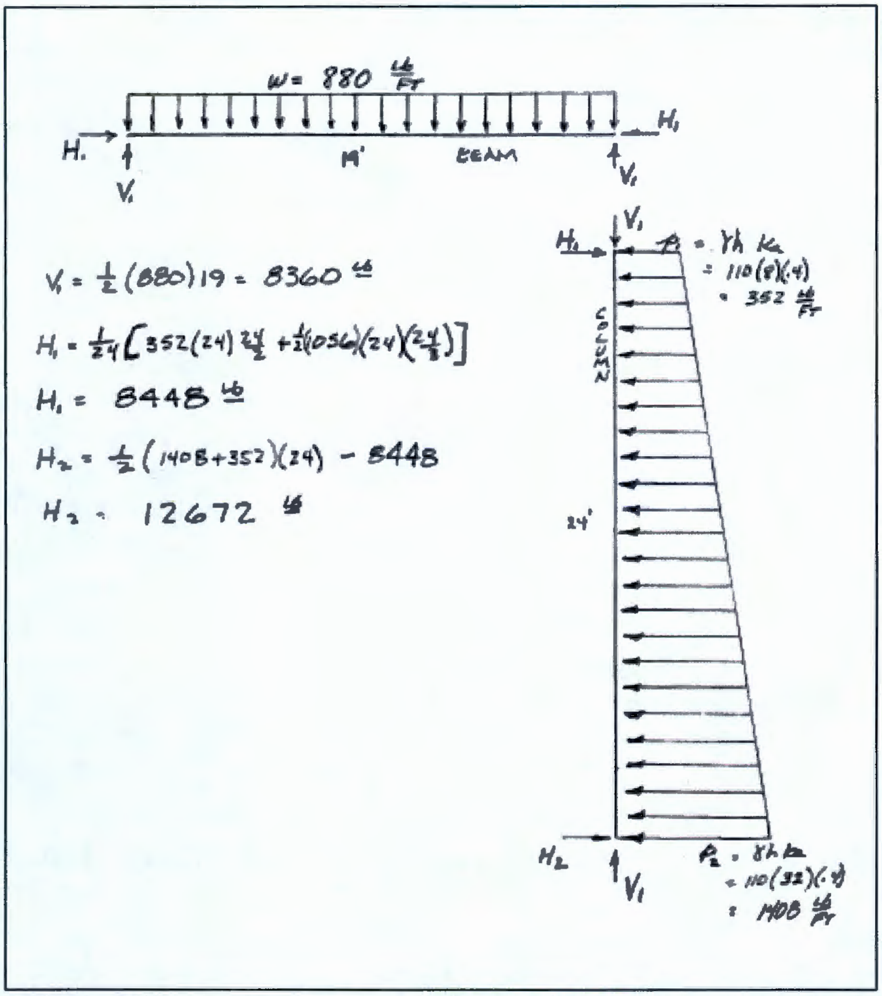


Exhibit 7 – Soil loading used in structural evaluation of Tunnel 1. Note 110 pcf unit weight of soil and Active (Ka) earth pressure coefficient of 0.4 noted. Use of Active lateral earth pressures is inappropriate for this evaluation due to the bracing of the top of the tunnel provided by the roof timbers.

2.0 Report of Soils Investigation for Proposed Process Facility Modification Project (1984)

Dames & Moore submitted a soil investigation report for a proposed Process Facility Modification at the PUREX plant site in January 1984. Four boreholes were advanced for the facility and geotechnical design parameters were developed. The facility was never constructed and the report was never finalized. URS (1981) noted that no known direct subsurface investigations were performed for the design or construction of the PUREX facility. As such, the Dames & Moore (1984) investigation is thought to represent the best available subsurface information in the vicinity of the PUREX Storage Tunnels. It is assumed that subsurface conditions at the PUREX Storage Tunnels are similar to those encountered by Dames & Moore (1984).

The following notes were made from this report:

1. **4 boreholes were advanced for this study. Boreholes were located approximately 1,230 to 1,350 feet west of PUREX Tunnel 1. Borehole were advanced with rotary hollow-stem auger methods and sampled using Dames & Moore proprietary U-type sampler.**

   B-1, Total depth = 54.5 feet

B-2, Total depth = 19.5 feet

B-3, Total depth = 59.5 feet

B-4, Total depth = 19.5 feet

2. Field classifications and laboratory testing were performed on selected samples to support evaluating shear strength, moisture content, density, grain-size distributions, resistivity, and pH.

3. The following geotechnical engineering parameters were recommended for use in design of the proposed facility:

Angle of Internal Friction, ϕ = 34 degrees

Cohesion, c′ = 0 psf

Mass Density, γ = 110 pcf

Poisson's ratio, μ = 0.25

Coefficient of Active Earth Pressure, Ka = 0.28

Coefficient of At-Rest Earth Pressure, Ko = 0.44

Coefficient of Passive Earth Pressure, Kp = 3.5

4. Lateral earth pressures:

Active Equivalent Fluid Unit Weight = 30 pcf

At-Rest Equivalent Fluid Unit Weight = 50 pcf

*At-Rest Pressure for relatively rigid structures (psf) = 26*H (where H is the height of the wall in feet)*

Passive Equivalent Fluid Unit Weight = 250 pcf (includes FS=1.5)

5. General Soil Description:

The near-surface soils generally consist of a thin fill layer of gravelly sand (SW) to sandy gravel (GW). This fill was probably placed at the time that the subject area was temporarily used during construction of the nearby PUREX plant. Under this fill and down to depths ranging from 3.5 to 6 to 7 feet, all borings encountered a layer of loose silty fine sand (SM) containing variable amounts of coarser sand and fine gravel with depth. In each of the shallow borings (B-2 and B-4), about 4 to 5 feet of medium dense to dense fine to coarse sands with occasional gravel (SW) were encountered below the silty fine sand (SM); however, this well-graded sandy material was not encountered in either of the deeper borings (B-1 and B-3).

Below a depth ranging from 3.5 to approximately 6 to 7 feet, all borings encountered medium dense to dense poorly graded sands (SP). These soils generally appear to grade back and forth between the limits of a fine to medium sand with a trace of silt to a medium to coarse sand with variable amounts of fine gravel. ... It is believed that this stratum of poorly graded sand with varying amounts of silt and fine gravel can be assumed to extend under the entire project site to depths in excess of 60 feet. This assumption is based on our field engineer's inspection of a 64-foot-deep excavation to elevation 622 that exists approximately 2300 feet to the northeast of the subject area. This tank farm excavation was made in soils consisting of interbedded sands and gravelly sands overlying poorly graded sands that are similar to those encountered in our exploratory borings.

No groundwater was encountered in any of the four borings. Based on previous geologic and seismic investigations at the PUREX building site, it is believed that the water table is at a depth of approximately 300 feet beneath the subject area.

6. Applicability to PUREX Tunnel Evaluation

Although the boreholes are located nearly 0.25 miles west of the PUREX storage tunnels, Dames & Moore (1984) noted that similar materials were observed in a tank farm excavation nearly 2,300 feet northeast of the boreholes and surmised that conditions could be expected to be relatively similar between this area, which approximately includes the PUREX storage tunnels.

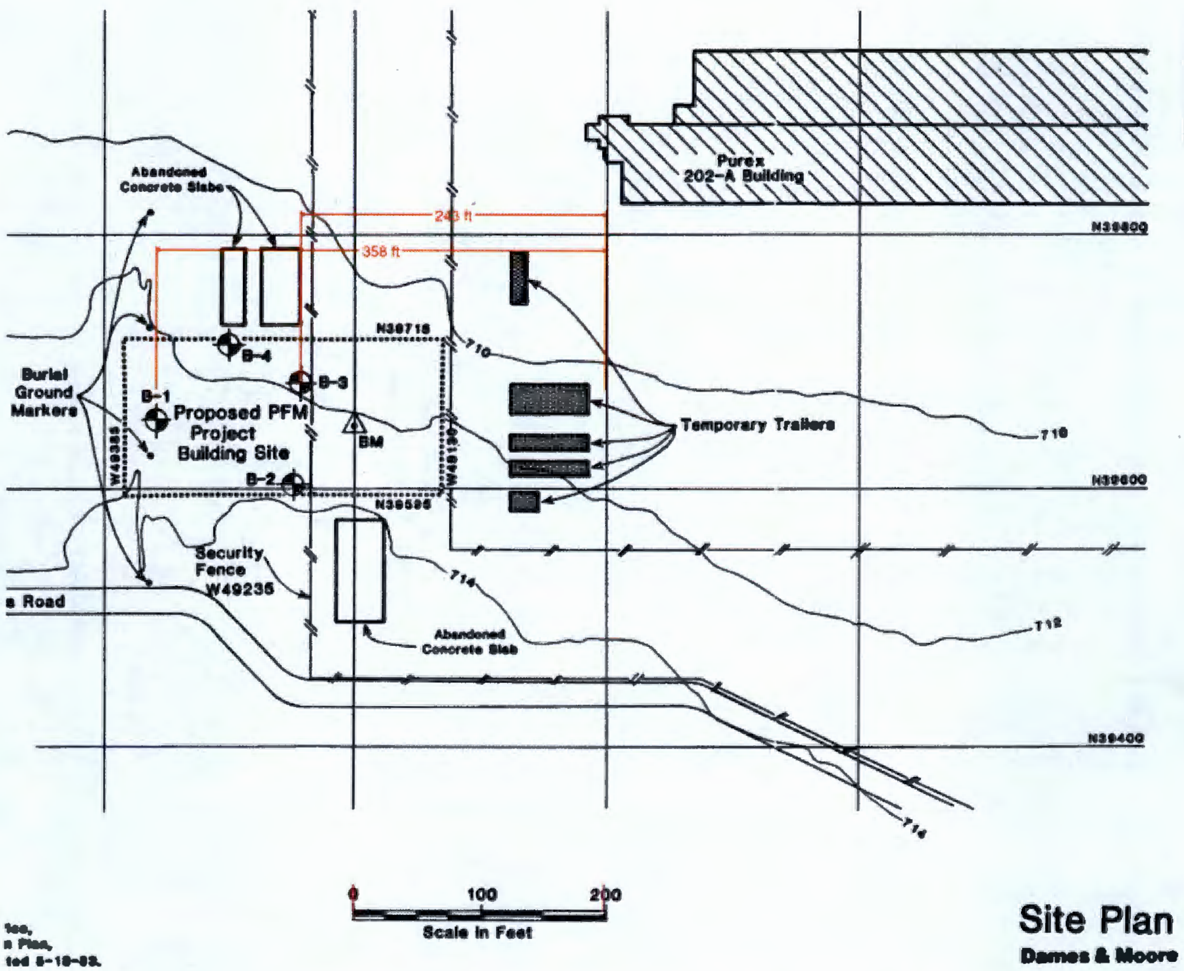


Exhibit 8 – Dames & Moore Site Plan Showing Borehole Locations relative to PUREX Facility. Purex storage tunnels are not shown in this view.

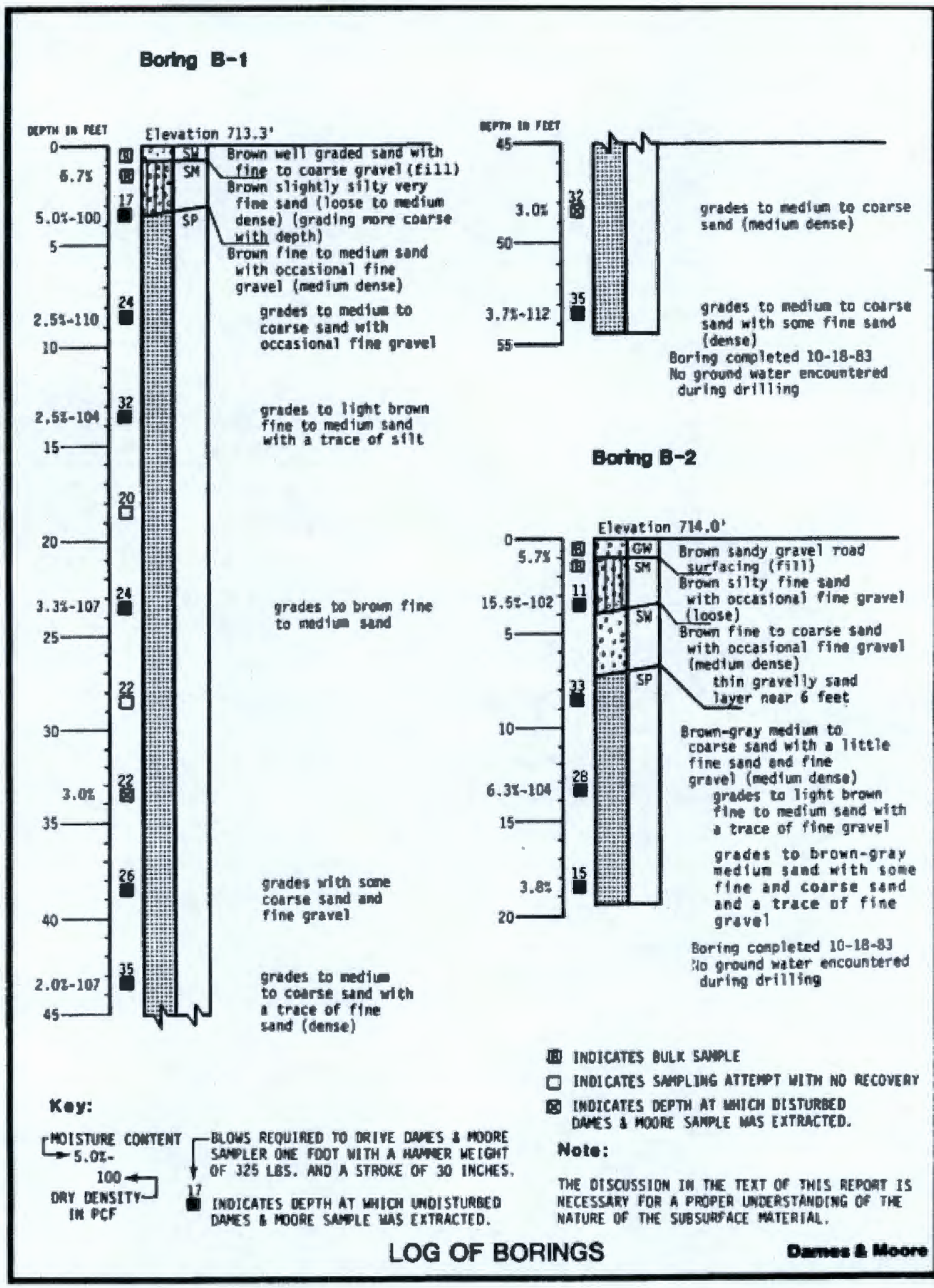


Exhibit 9 – Log of Borings B-1 and B-2

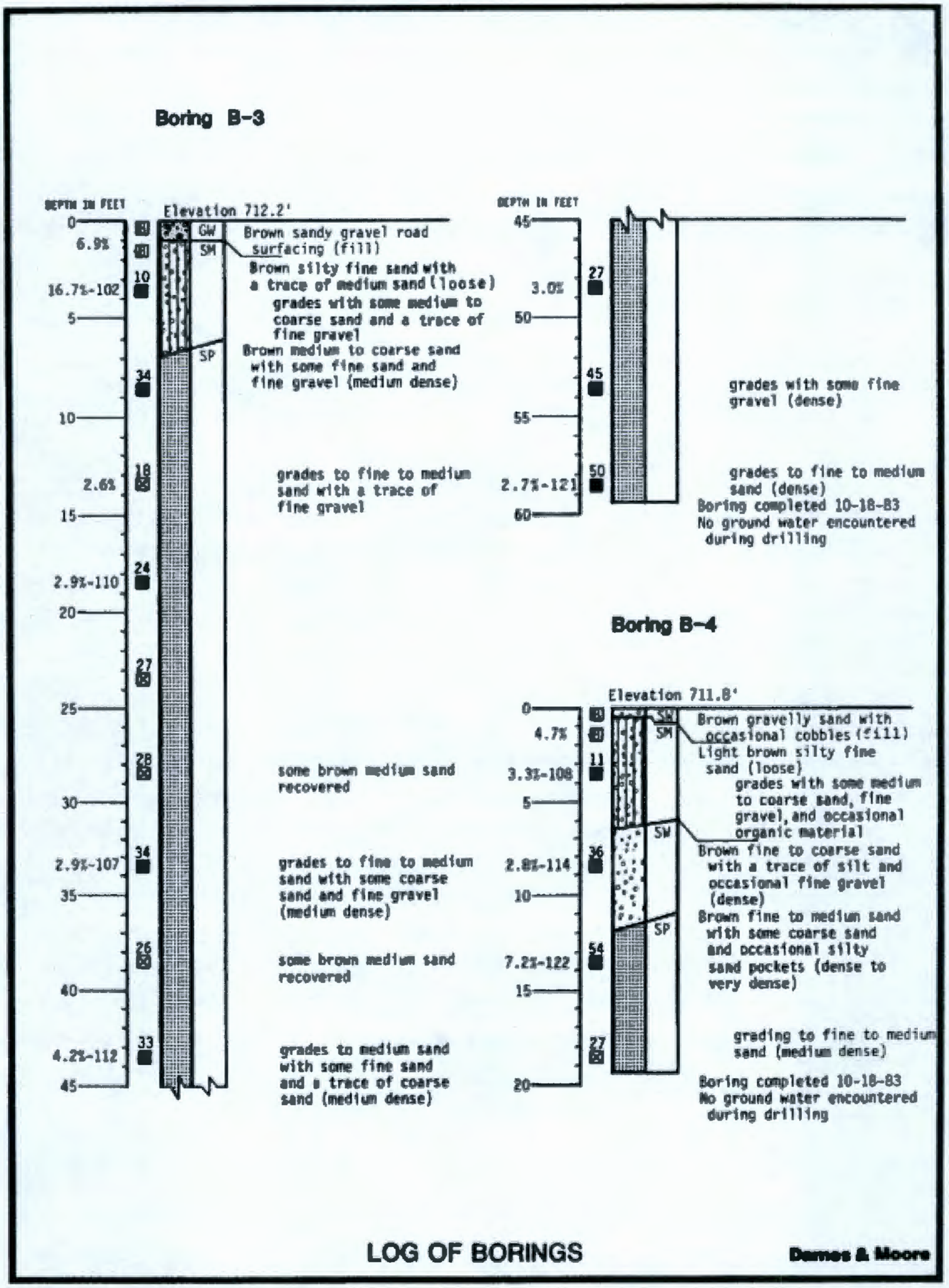


Exhibit 10 – Log of Borings B-3 and B-4

3.0 Geologic and Seismic Investigation of the PUREX Building Site (URS, 1981)

URS (1981) prepared a discussion of the regional geology setting the PUREX facility. This information provides a relevant geologic context for comparison to available geotechnical data, primarily for purposes of confirming expected extents and continuity of site materials.

The project site is underlain by three major geologic units:

1. *The Pasco (glaciofluvial) gravels and associated sediments of the late Pleistocene age at the ground surface* [also known as the Hanford Formation]
2. *Pleistocene-age Ringold formation*
3. *Basaltic lavas and intercalated sediments of the Columbia River basalt group.*

The Pasco basin was formed by downwarping and downfaulting of the basalt flows that underlie the basin. The basin then became the site of deposition of Pliocene sediments of the Ringold Formation and Pleistocene glaciofluvial deposits. The ground surface of the Pasco basin is now largely covered by windblown sand.

Deposition of the Ringold Formation ceased in late Pliocene time, one to two million years ago. Later, ice sheets of the Pleistocene glacial stages advanced from the north but stopped before reaching the Pasco basin. At the close of glaciation, while the ice sheets were retreating, great quantities of water were suddenly released. These huge floods scoured vast areas of basalt terrain in northeastern Washington, swept across the Hanford Reservation area, and crossed the Horse Heaven Hills anticline at Wallula Gap.

...

Locally, within the Pasco Basin, zones of medium-dense to loose sands and gravels, probably resulting from rapid accumulation during glacial floods, are encountered.

The Pasco Gravels are compact, though uncemented, deposits of late Pleistocene and early Recent times. They were laid down by glacial meltwaters and glacial lake floodwaters between about 100,000 and 10,000 years ago. Evidence suggests that in some places the sediments were buried by perhaps an additional 200 feet of gravel that was later swept away.

The Pasco Gravels occur at the surface, or under a thin cover of loessal materials. The water table is controlled by the Columbia River elevation. The Ringold formation occurs near the river level. The [Pasco] gravels, therefore, are typically unsaturated.

Within the 200-East area, where PUREX Building 202-A is located, the uppermost sands and silts were largely reworked during construction activities []. Although the soils beneath the PUREX building have been explored using seismic refraction, other direct exploration methods, such as drilling and sampling, have not been employed.

The water table is at a depth of about 300 feet beneath the plant; there is no liquefaction hazard.

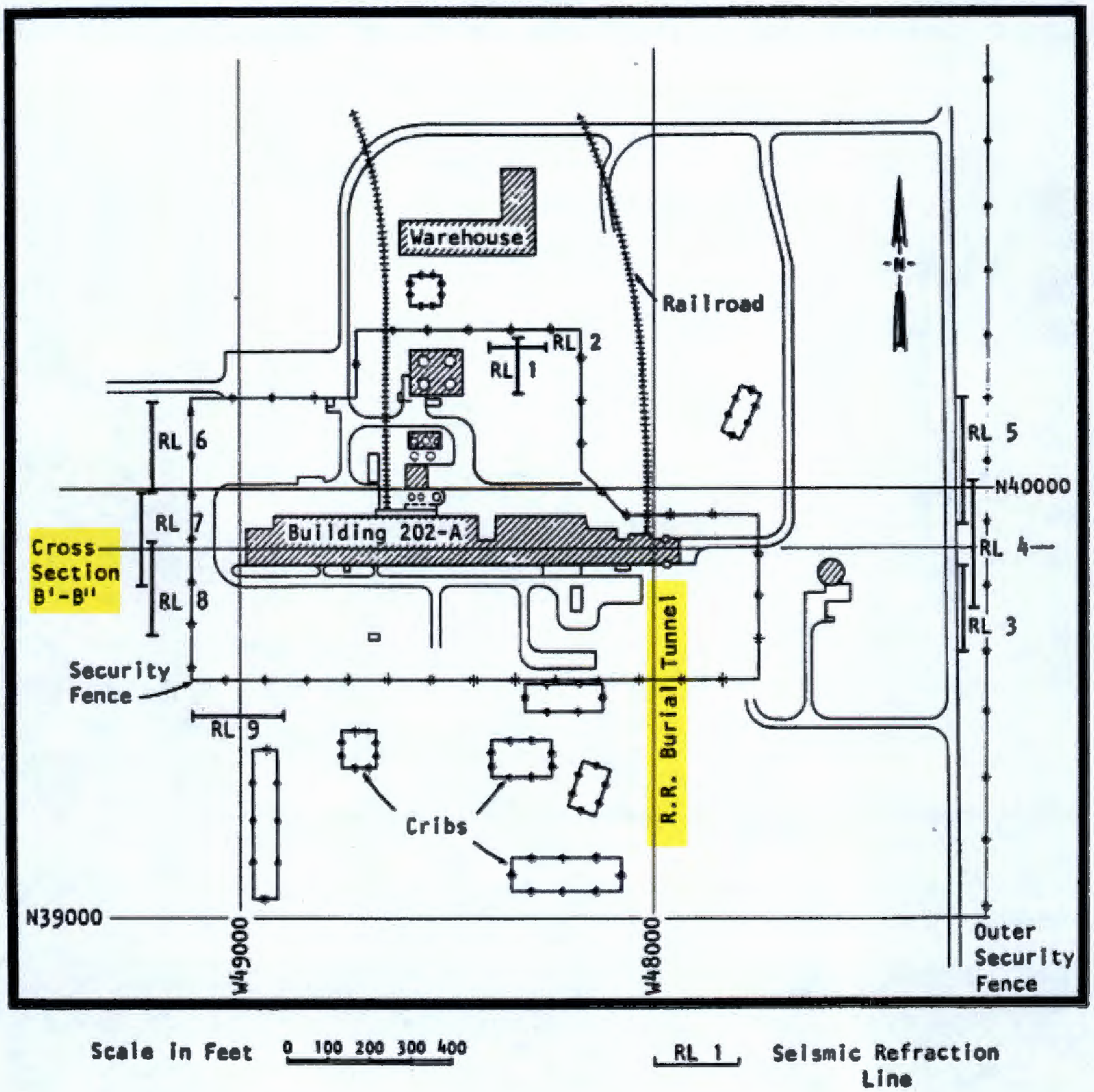


FIGURE 5 PUREX BUILDING SITE PLAN AND SEISMIC REFRACTION LINE LOCATIONS

Exhibit 11 – Site Plan showing location of Cross Section B'-B", located near the northern extent of Tunnel 1

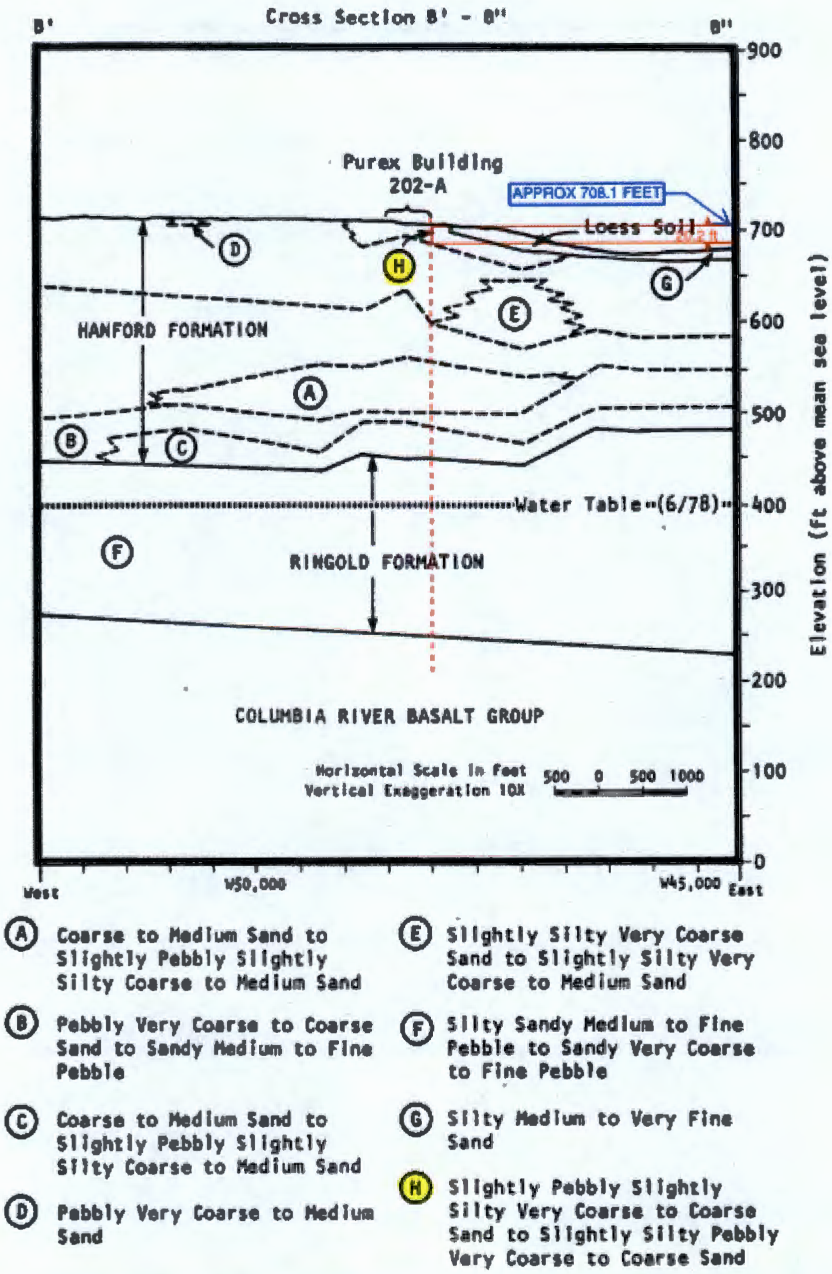


FIGURE 4 GENERALIZED GEOLOGIC CROSS SECTION SHOWING FORMATION NAMES AND SOIL CLASSIFICATION (adapted from Tallman et al., 1979)

Exhibit 12 – Cross Section B'-B". Note descriptions and relative depths of materials and groundwater underlying the PUREX facility. The red dashed line indicates the approximate alignment of the PUREX Storage Tunnels.

Interpretation

Cover soils materials placed over Tunnel 1 were derived from local site soils and processed to remove organic materials and coarse materials larger than 8 inches in diameter.

Project specifications indicate that cover soils were to be "thoroughly compacted," however, no measurable reference density, method specification, moisture condition requirement, or relative compaction is specified. Experience with similar soils suggests that 24-inch lift size does not promote thorough compaction of soil. From the available construction photos, it is believed that the space between the tunnel walls and the tunnel excavation walls was relatively narrow, backfilled from the top using a bulldozer, and not did not permit the use of propelled compaction equipment. Compaction equipment was not visible in the available photos. It appears that the tunnel was constructed from north to south, and backfill was placed behind the advancing tunnel face. It is unknown whether soils placed above the tunnel roof were compacted.

It is assumed that the material placed against the tunnel walls is silty sand material with occasional gravel as described in the boring logs (Dames & Moore, 1984), geologic descriptions of the Hanford Formation / Pasco Gravels (URS, 1981), and construction photographs (CHPRC, 2017), and roof timber sampling photos (Rockwell, 1980). The Tunnel 1 bottom is approximately 20 to 25 feet below existing grade.

Assuming that boring logs from Dames & Moore (1984) are similar to the materials at PUREX Tunnel 1, and that the materials are reasonably well mixed, the fill material is assumed to be as described in the following sections.

4.0 Soil Classification

- The Tunnel 1 cover soils are fill materials obtained from the Tunnel 1 excavation.
- The USCS classification of the soils is Silty Sand with Gravel (SM).
- Fines are expected to be non-plastic.
- Sand is primarily fine to medium size.
- Gravel is fine to medium, subrounded to rounded as visible in photos.

5.0 Specific Gravity

The specific gravity of solid soil particles is assumed to be 2.65.

6.0 Moisture Content

The in-situ moisture content of site soils was estimated by selecting the average in-situ moisture content for 17 samples collected by Dames & Moore (1984) in the top 25 feet of the soil profile. For the reported measurements, the maximum water content observed was 16.7 percent and the minimum was 2.5 percent. The **average in-situ moisture content for the 17 samples was 6 percent** and is recommended for use in tunnel evaluations. Note that actual moisture contents are expected to vary with depth, season, and location along the tunnel alignment.

7.0 Dry Unit Weight

The unit weight of the fill material is difficult to estimate due to the uncertainties in fill placement. Dames & Moore (1984) measured the in-situ dry density of site soils near the PUREX facility. For the 11 field measurements of density taken in the upper 25 feet of the soil profile, the minimum was 100 pcf, the maximum was 122 pcf, and the average was 108 pcf.

Based on a review of site photographs, it is assumed that the cover soils were not well compacted during construction. As such, **the recommended dry unit weight of the loosely placed cover soil is 100 pcf.**

8.0 Moist Unit Weight

The moist unit weight of the Tunnel 1 soil can be estimated using the dry unit weight and the moisture content, using the following fundamental relationship:

$$\gamma_{moist} = \gamma_d \cdot (1 + w\%/100)$$

where:

- γ_m is the moist unit weight,
- γ_d is the dry unit weight,
- w(%) is the in-situ water content, as a percent

Substituting 100 pcf for the dry unit weight, and 6% for the moisture content, gives 106 pcf

Substituting 108 pcf for the dry unit weight and 6% for the moisture content gives 114 pcf.

For structural evaluation of the tunnel, it is recommended that moist unit weights varying from 105 to 115 pcf be considered, with an expected average value of 110 pcf. This recommendation is in general agreement with calculations performed by Rockwell (1980) which used 110 pcf in soil loading calculations.

9.0 Shear Strength

The shear strength of the cover soil was estimated using the published charts in the 1986 Naval Facilities Engineering Command (NAVFAC) Foundations and Earth Structures Design Manual 7.02. Assuming a dry unit weight of 100 pcf and a relative density of 25 to 30 percent for uncompacted soils, **the angle of internal friction, ϕ' is estimated to be approximately 30 degrees. The soil is assumed to be cohesionless (c' = 0psf).** Drained (effective stress) conditions are expected to govern all loading short term and long term loading scenarios.

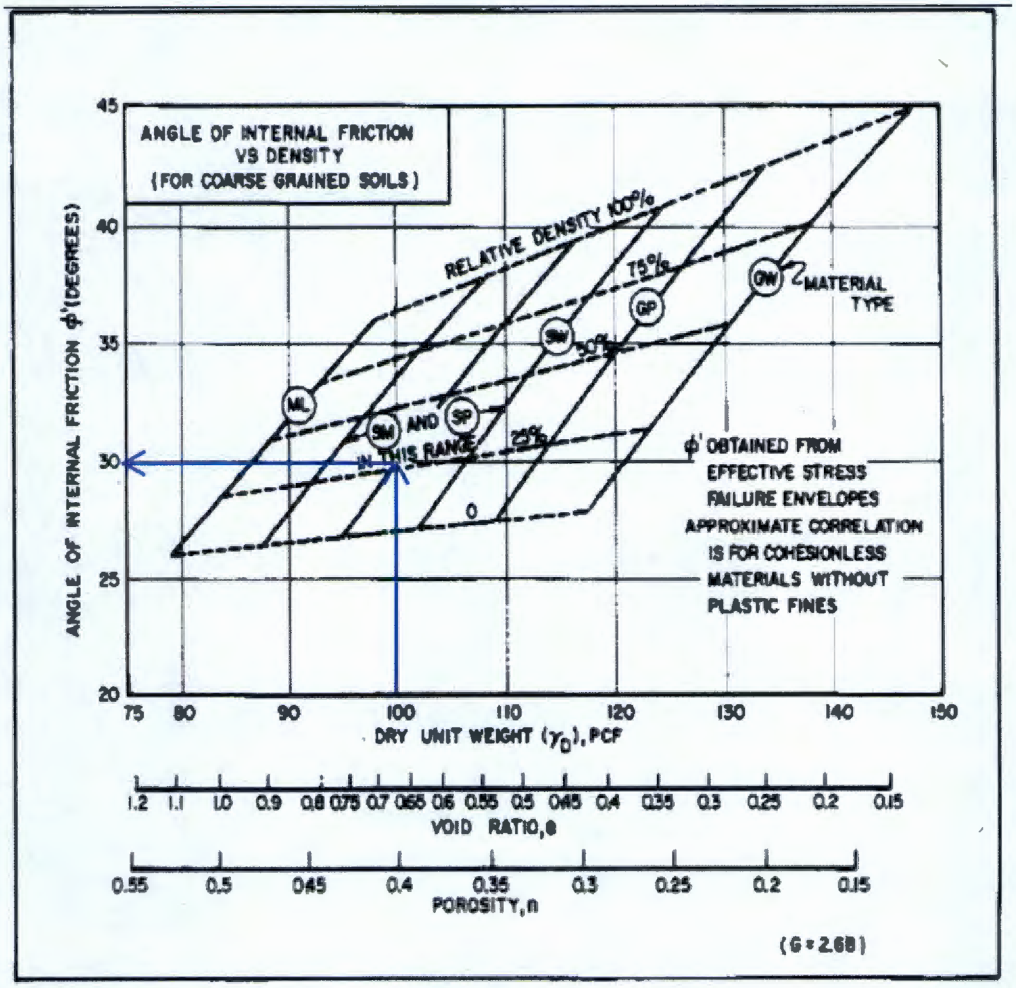


FIGURE 7
Correlations of Strength Characteristics for Granular Soils

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Dames & Moore (1984) Report of Soils Investigation: Proposed Process Facility Modification Project, Purex Plant, Hanford Washington. Prepared for U.S. Department of Energy. 10805-136-05. January 4.

General Electric Company (1955) *HWS-5638 Specifications for Disposal Facility for Failed Equipment*. Project CA-513-A. April 25.

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URS/John A. Blume & Assoc. (1981) *Geologic and Seismic Investigation of the PUREX Building Site near Richland, Washington.* Prepared for Vitro Engineering Corporation. March.

ch2m	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

Attachment B

LIDAR Topography Results

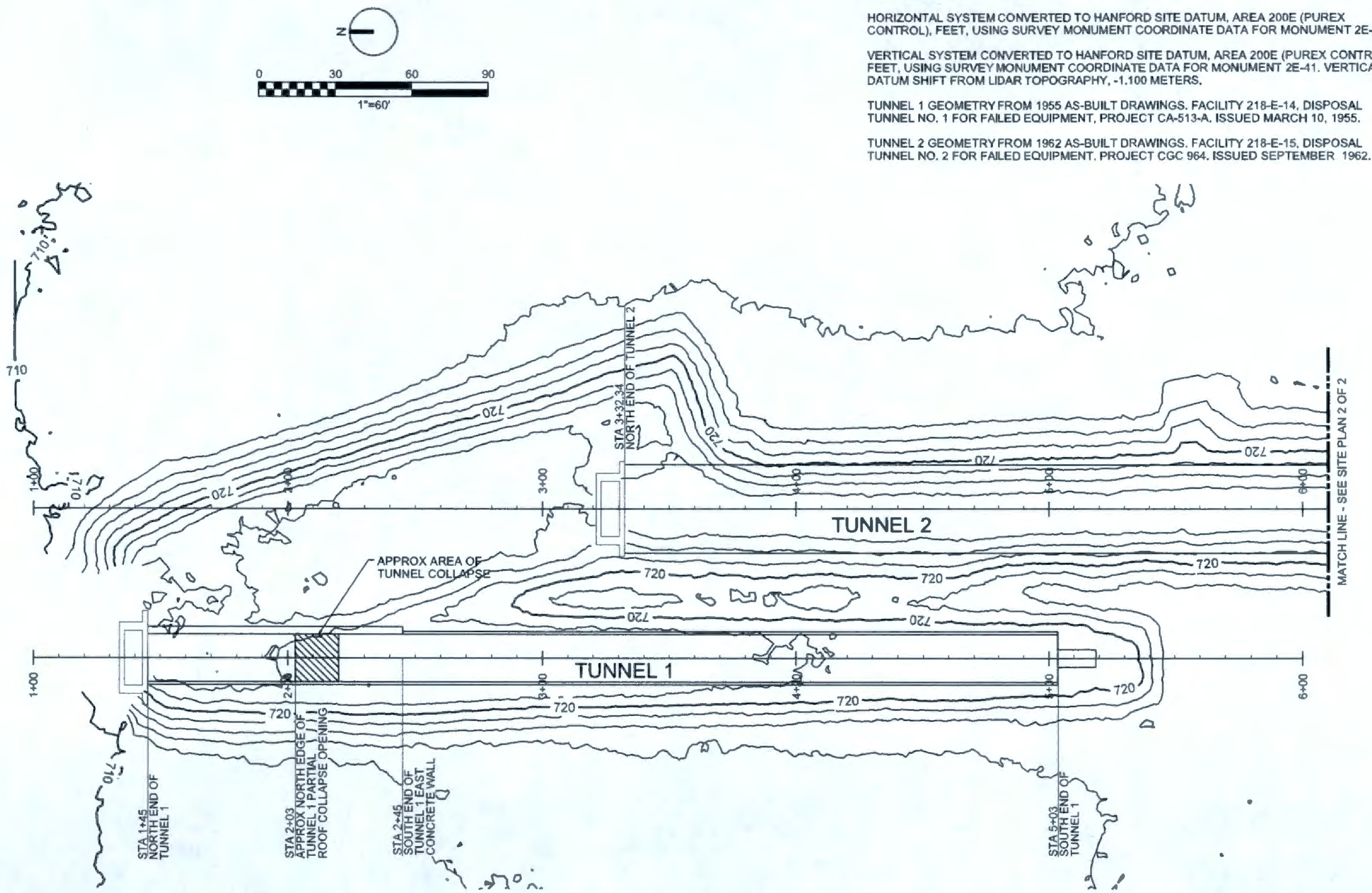
TOPOGRAPHY FROM 2008 *LIDAR CENTRAL PLATEAU REPORT* PREPARED BY AERO-METRIC FOR FLUOR HANFORD. DATA ACQUISITION APRIL 13, 2008. HORIZONTAL DATUM: STATE PLANE NAD83, WASHINGTON SOUTH ZONE, METERS. VERTICAL DATUM: NAVD88, METERS.

HORIZONTAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41.

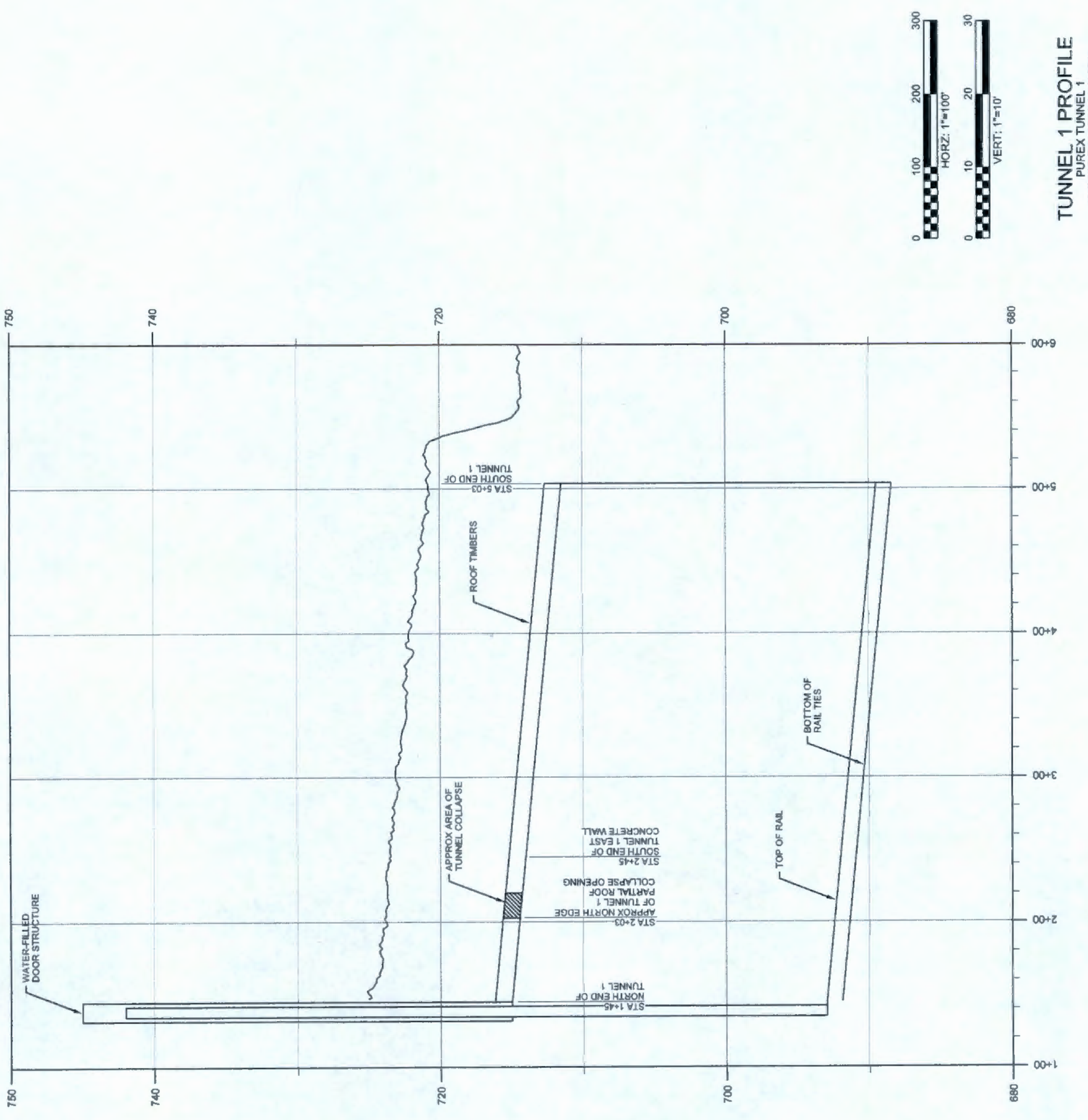
VERTICAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41. VERTICAL DATUM SHIFT FROM LIDAR TOPOGRAPHY, -1.100 METERS.

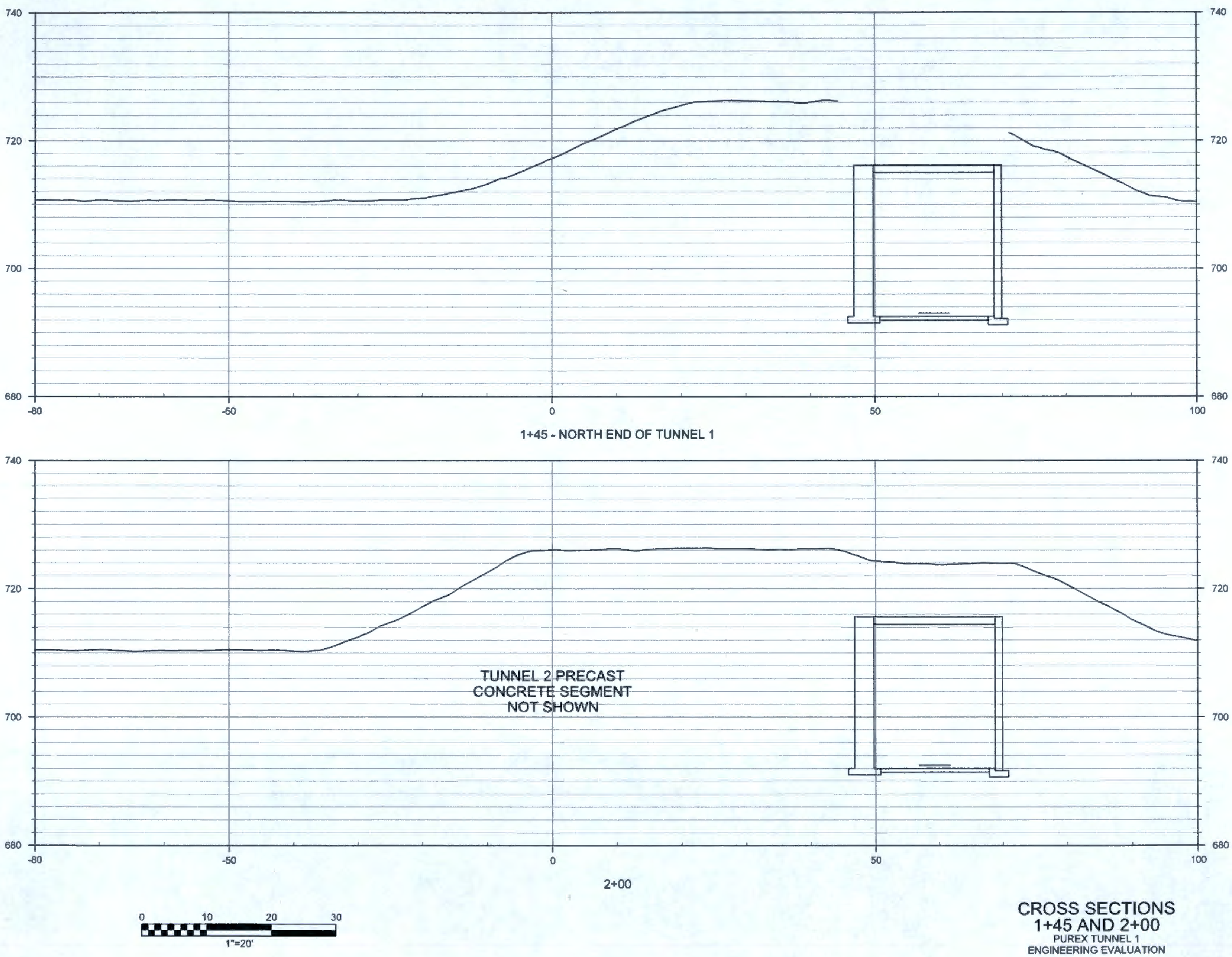
TUNNEL 1 GEOMETRY FROM 1955 AS-BUILT DRAWINGS. FACILITY 218-E-14, DISPOSAL TUNNEL NO. 1 FOR FAILED EQUIPMENT, PROJECT CA-513-A. ISSUED MARCH 10, 1955.

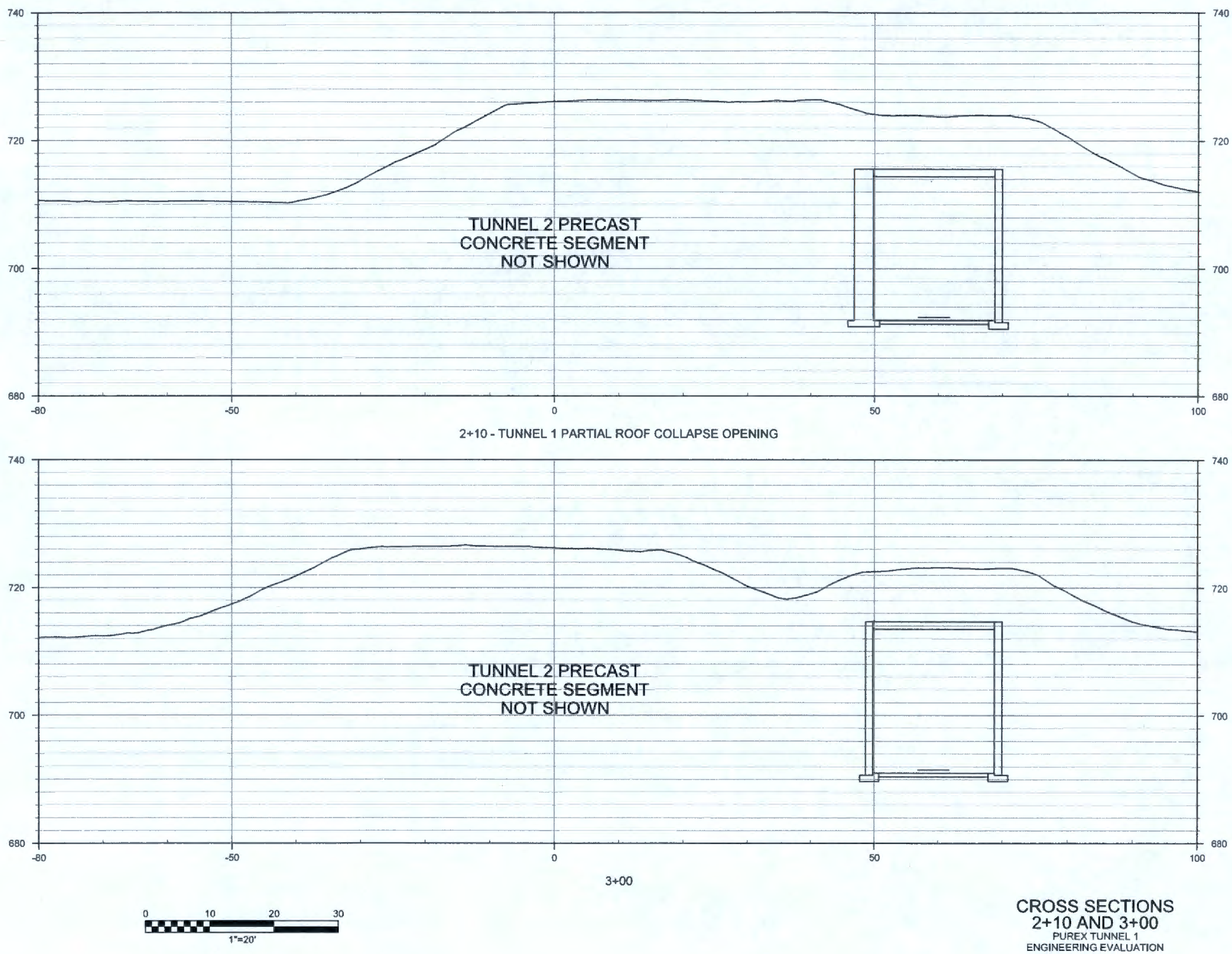
TUNNEL 2 GEOMETRY FROM 1962 AS-BUILT DRAWINGS. FACILITY 218-E-15, DISPOSAL TUNNEL NO. 2 FOR FAILED EQUIPMENT, PROJECT CGC 964. ISSUED SEPTEMBER 1962.

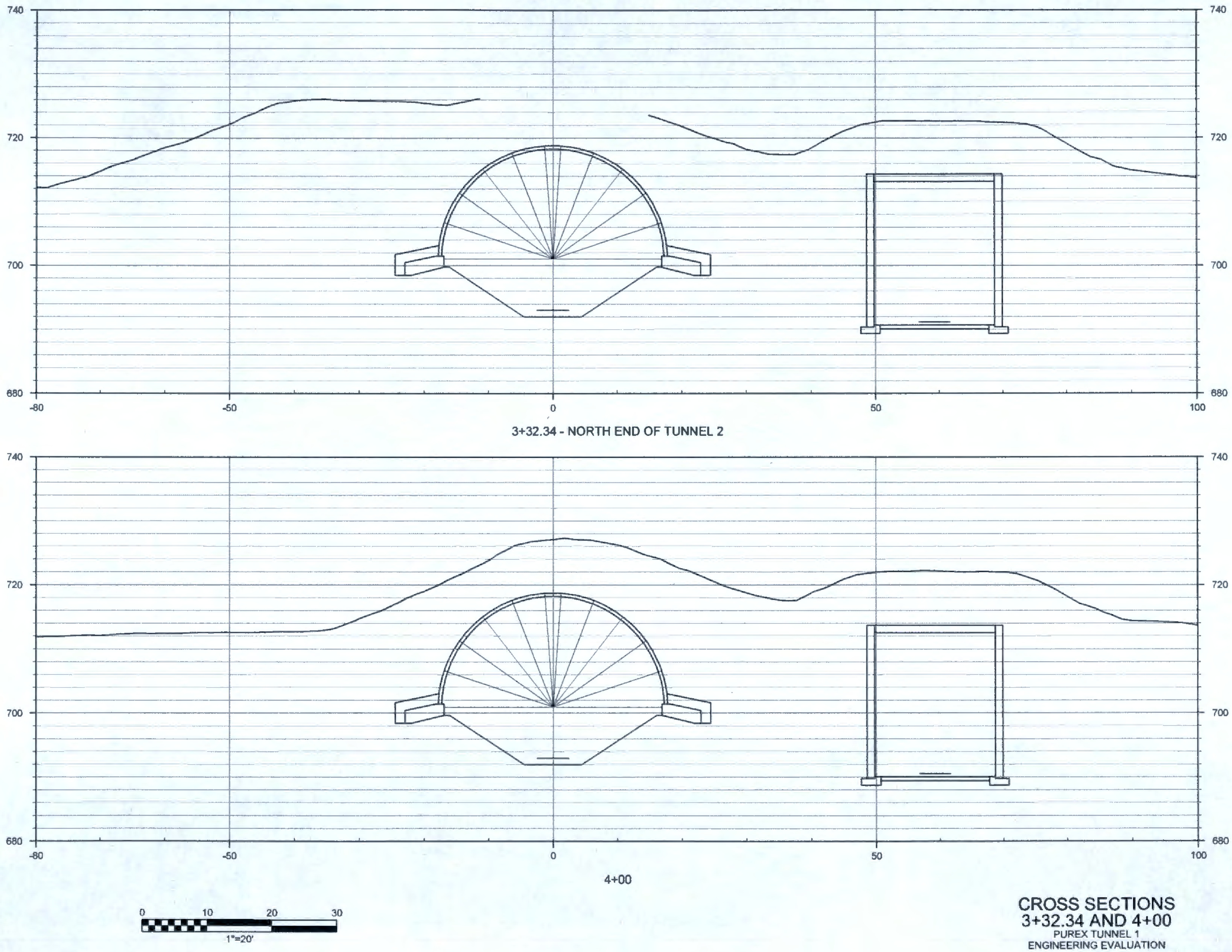


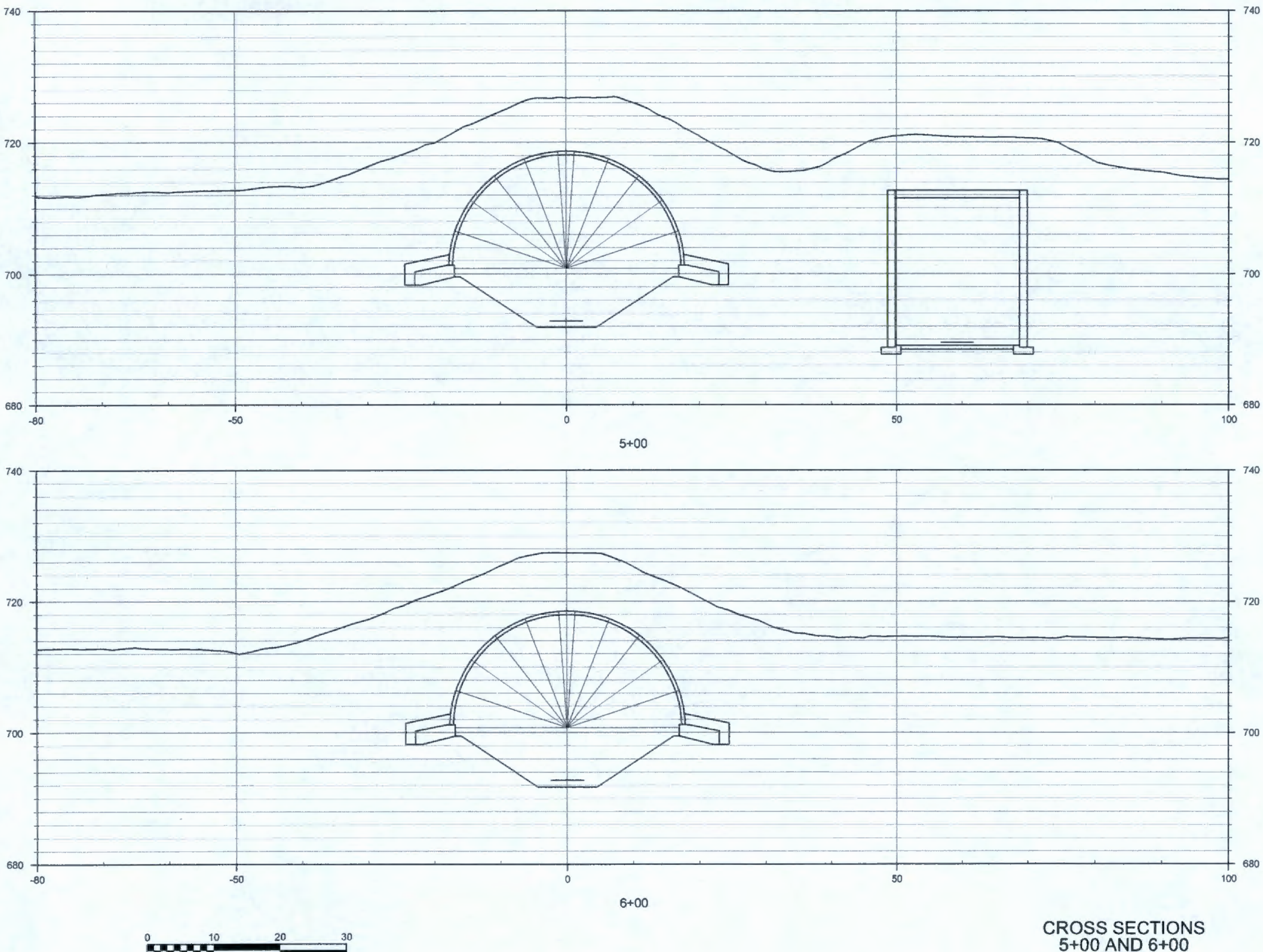
TOPOGRAPHIC SITE PLAN
1 OF 2
PUREX TUNNEL 1
ENGINEERING EVALUATION


WATER-FILLED DOOR STRUCTURE
APPROX AREA OF TUNNEL COLLAPSE
ROOF TIMBERS
STA 1+45 NORTH END OF TUNNEL 1
STA 2+03 APPROX NORTH EDGE OF TUNNEL 1 PARTIAL ROOF COLLAPSE OPENING
STA 2+45 SOUTH END OF TUNNEL 1 EAST CONCRETE WALL
STA 5+03 SOUTH END OF TUNNEL 1
TOP OF RAIL
BOTTOM OF RAIL TIES
750
740
720
700
680
1+00
2+00
3+00
4+00
5+00
6+00
0 100 200 300
HORZ: 1"=100'
0 10 20 30
VERT: 1"=10'
TUNNEL 1 PROFILE
PUREX TUNNEL 1
ENGINEERING EVALUATION


740
720
700
680
-80
-50
0
50
100
1+45 - NORTH END OF TUNNEL 1
TUNNEL 2 PRECAST
CONCRETE SEGMENT
NOT SHOWN
2+00
0
10
20
30
1"=20'
CROSS SECTIONS
1+45 AND 2+00
PUREX TUNNEL 1
ENGINEERING EVALUATION


740
720
700
680
TUNNEL 2 PRECAST
CONCRETE SEGMENT
NOT SHOWN
-80
-50
0
50
100
2+10 - TUNNEL 1 PARTIAL ROOF COLLAPSE OPENING
TUNNEL 2 PRECAST
CONCRETE SEGMENT
NOT SHOWN
3+00
0
10
20
30
1"=20'
CROSS SECTIONS
2+10 AND 3+00
PUREX TUNNEL 1
ENGINEERING EVALUATION


740
720
700
680
-80
-50
0
50
100
3+32.34 - NORTH END OF TUNNEL 2
4+00
0
10
20
30
1"=20'
CROSS SECTIONS
3+32.34 AND 4+00
PUREX TUNNEL 1
ENGINEERING EVALUATION



CROSS SECTIONS
5+00 AND 6+00
PURFX TUNNEL 1
ENGINEERING EVALUATION

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FLUOR HANFORD

LiDAR Digital elevation Model(s)
&
Topographic Contour Maps

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1 Project Area & Synopsis

- This contract consists of obtaining DEM and contour data for the Central Plateau of the Hanford Site. Under a separate contract with Washington Closure Hanford, Aero-Metric completed a LiDAR data acquisition for the entire Hanford site and included most of the Central Plateau. See Exhibit A for project limits. The project area consists of approximately 38,000 acres.
- Aero-Metric obtained Airborne LiDAR data at sufficient density and accuracy to allow for the generation of 0.5m posting DEM grids and 0.3m contours.
- LiDAR survey was supported by on-board Airborne GPS and IMU observations.
- Rogers Surveying was responsible for the ground observations on two base stations during all aerial missions. Aero-Metric was responsible for the computations for the ABGP and IMU measurements.
- Rogers Surveying surveyed and computed the coordinates for approximately 234 vertical points along six profiles and well distributed within the entire Hanford area and representing different terrain types. These points served as true check points to further analyze and correct biases in the LiDAR data.
- See Exhibit B for location of the six selected profiles.

1.1 Coordinate System

- Horizontal system: State Plane NAD83, Washington South Zone, Meters
- Vertical system: NAVD88, Meters

2 LiDAR Survey

2.1 Flight Specifications – See exhibit C for Flight Line Coverage

- Sensor: Optech ALTM.
- Date of data acquisition: April 13, 2008
- Flying Height: 800m / 2634 ft above ground.
- Overlap between flight lines: 50% (100% double coverage)
- System Frequency: 100 KHz
- Scan Frequency: 65 Hz
- Scan Angle: net 24 degrees (12deg on each side)
- Air Speed: 135 kts
- Number of Flight lines: 145
- Geo-Referencing: ABGPS, IMU, and nine ground targets
- Nominal ground resolution: 0.4m
- Mission length: About seven days

2.2 QA/QC Profiles

- See exhibit B for location of the selected QA/QC point profiles.
- See Exhibit D for Point Residual Listing
- About 234 QA/QC points to support analysis and correction to LiDAR data.
- Survey work by Rogers Surveying.

2.3 LiDAR Data Post-Flight / Pre-Processing

- All ABGPS and IMU data, and GPS-obserevations on two base stations are integrated within the computation of the final geo-referencing of each of the flight lines.
- All discrepancies between flight lines are minimized through a number of post-processing algorithms.
- QA/QC points coordinates are used to verify the final accuracy of the derived LiDAR products as described earlier.
- Software used: Optech DASHMAP, Microstation Version 8, TerraSolids TMATCH and TSCAN packages.

2.4 LiDAR Data Editing and Contour Generation

- Post-processed LiDAR data is reduced to 750m by 750m tiles. See exhibit E for Tile Layout and Numbering.
- Classified LiDAR data is visually checked, analyzed, and re-classified if needed. Erroneous points are eliminated.
- After the completion of all editing steps, a LiDAR QC specialist reviewed all data to ensure completeness, conformity to standards, and the accuracy of the data.
- Software used: MicroStation version 8, Terrasolids TSCAN, TMODEL, and TMATCH packages.

3 Final Packaging and Delivery

- The final products are checked against a deliverable list to ensure product completeness. All data used for the project has been archived on permanent archival media for future use if needed by the client.
- The following products are delivered along with this report.
    - Contour data in Microstation Version 8 format.
    - Contour data in Digital Exchange Format (DXF)
    - Contour data in Arc Shapefile format
    - LiDAR data in ASCII .xyz format (All points, First return, Ground, Non-Ground)
    - LiDAR data in .las format
    - DEM Grids in Arc Grid format (All points, First return, Ground, Non-Ground)
    - This LiDAR report including the QA/QC points residuals

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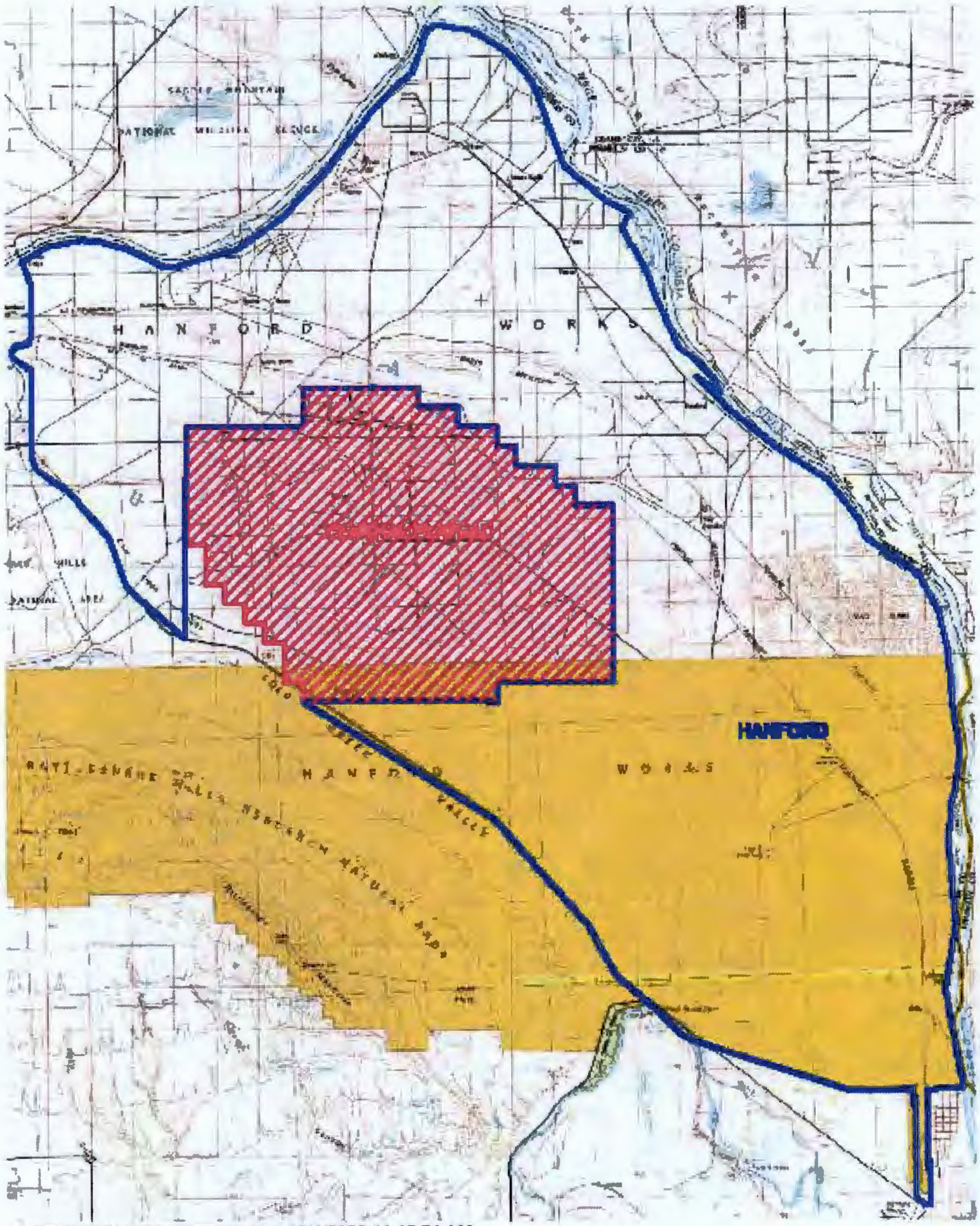
EXHIBIT A – PROJECT AREA



...\2008\080711 FLUOR\Fluor.dgn 12/4/2008 11:15:54 AM

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EXHIBIT B – QA/QC LiDAR PROFILES LOCATION

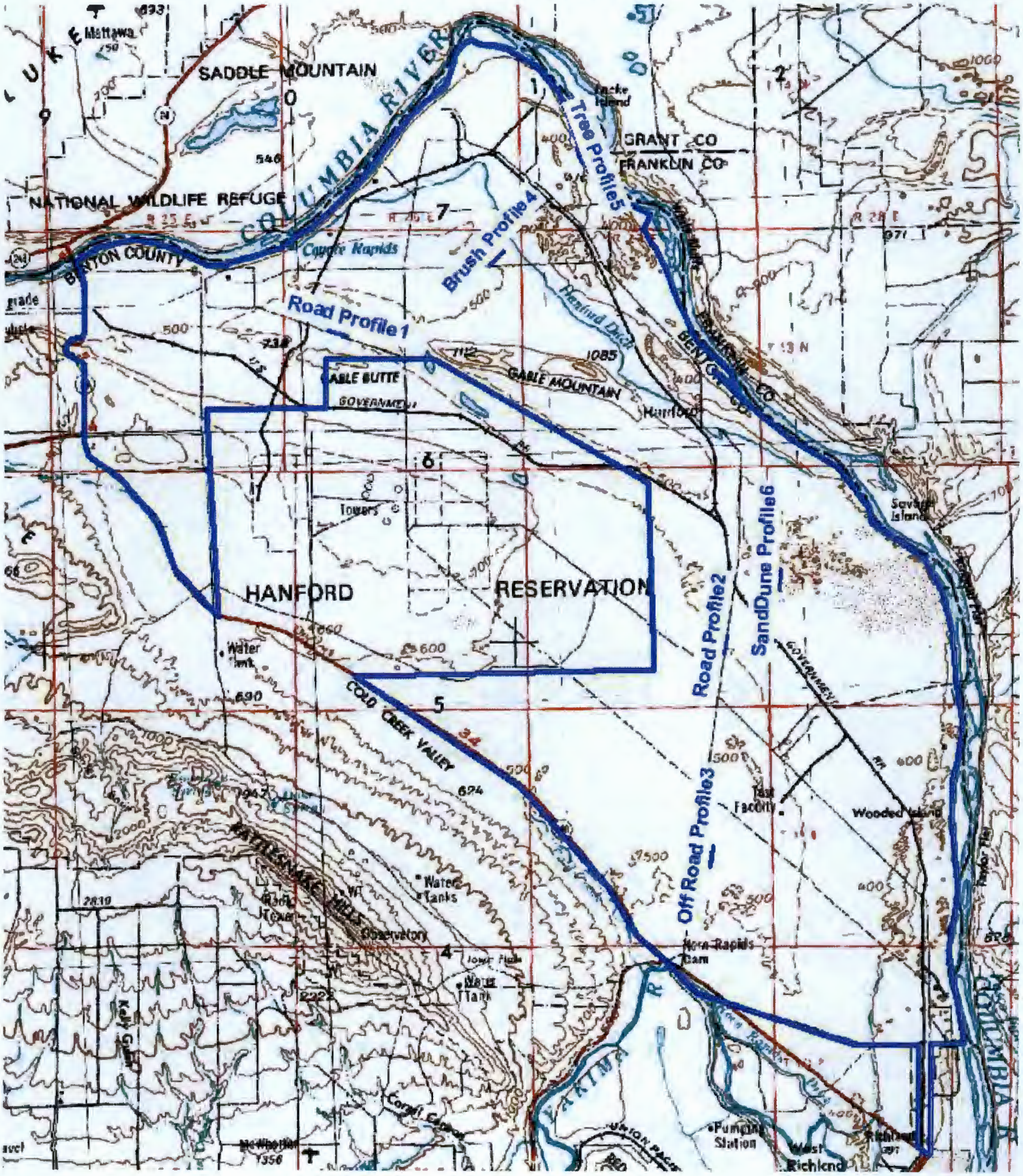

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EXHIBIT C – LiDAR FLIGHT LINE COVERAGE

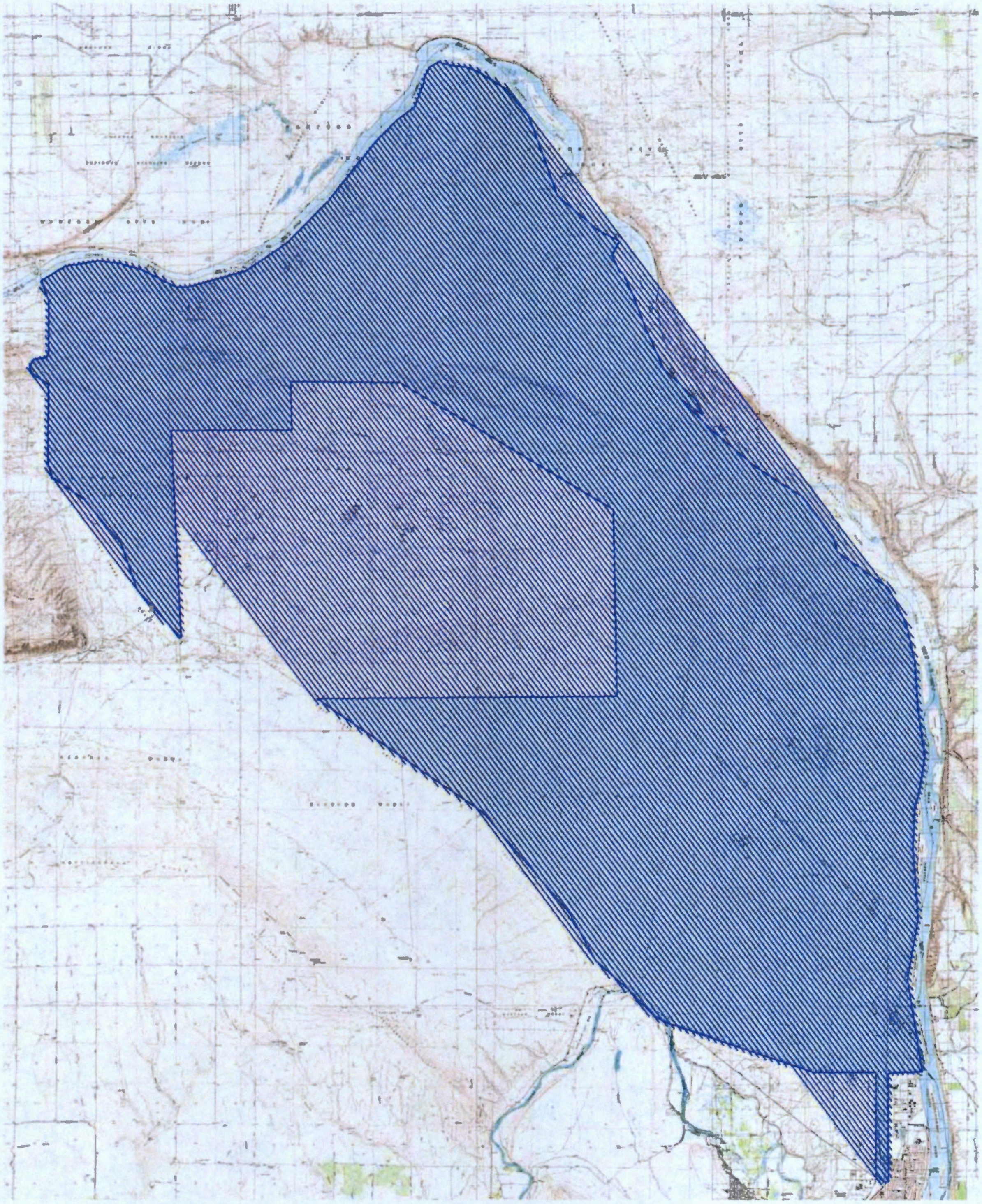

EXHIBIT D – GROUND SURVEYED QA/QC POINTS RESIDUALS (LiDAR minus Survey)

Number	Easting	Northing	Known Z	Laser Z	Dz
1060	587475.238	132228.964	143.798	144.280	+0.482
1249	579340.993	149856.447	118.679	118.970	+0.291
1251	579354.060	149816.955	117.872	118.140	+0.268
1257	579398.173	149685.686	117.363	117.580	+0.217
1250	579348.422	149834.166	118.097	118.270	+0.173
1256	579373.489	149694.794	118.975	119.140	+0.165
1258	579408.160	149654.826	118.016	118.160	+0.144
1263	579450.924	149526.348	117.780	117.920	+0.140
1247	579321.640	149916.351	119.914	120.050	+0.136
1260	579429.732	149589.940	118.158	118.280	+0.122
1259	579419.576	149621.120	118.200	118.310	+0.110
1205	575725.372	145382.413	153.510	153.610	+0.100
1206	575734.716	145392.197	153.144	153.240	+0.096
1235	576160.150	145857.677	140.360	140.450	+0.090
1029	585334.472	130096.641	145.601	145.690	+0.089
1242	579280.772	150039.035	120.312	120.400	+0.088
1084	587531.404	132654.877	148.093	148.180	+0.087
1046	585393.347	130504.843	140.355	140.440	+0.085
1229	576067.969	145757.301	143.657	143.740	+0.083
1074	587504.092	132451.257	144.460	144.540	+0.080
1225	576008.265	145692.311	144.430	144.510	+0.080
1111	584732.979	121081.044	161.161	161.240	+0.079
1106	584722.465	120983.923	162.562	162.640	+0.078
1037	585356.787	130251.641	142.384	142.460	+0.076
1252	579358.353	149803.759	117.784	117.860	+0.076
1063	587481.152	132273.435	144.935	145.010	+0.075
1107	584723.326	120993.677	162.786	162.860	+0.074
1043	585381.737	130425.046	139.898	139.970	+0.072
1104	584718.804	120948.671	160.868	160.940	+0.072
1127	584775.960	121488.399	162.498	162.570	+0.072
1047	585397.229	130530.652	140.739	140.810	+0.071
1090	587543.694	132745.898	144.630	144.700	+0.070
1238	576207.541	145909.804	139.670	139.740	+0.070
1209	575781.473	145443.937	152.011	152.080	+0.069
1239	579254.962	150117.591	120.811	120.880	+0.069
1033	585345.655	130173.495	143.872	143.940	+0.068
1087	587535.486	132683.870	143.213	143.280	+0.067
1241	579270.765	150068.564	120.543	120.610	+0.067
1234	576143.187	145839.927	140.815	140.880	+0.065

Number	Easting	Northing	Known Z	Laser Z	Dz
1105	584720.514	120966.552	161.768	161.830	+0.062
1034	585348.104	130190.540	143.500	143.560	+0.060
1044	585385.662	130451.978	139.930	139.990	+0.060
1013	585285.770	129762.754	159.731	159.790	+0.059
1113	584737.235	121121.823	160.511	160.570	+0.059
1203	575697.710	145352.397	154.161	154.220	+0.059
1068	587493.500	132364.239	147.042	147.100	+0.058
1119	584755.026	121290.156	162.702	162.760	+0.058
1079	587517.153	132544.162	143.644	143.700	+0.056
1233	576126.535	145821.649	141.154	141.210	+0.056
1048	585400.833	130555.520	141.045	141.100	+0.055
1067	587490.288	132341.425	143.815	143.870	+0.055
1202	575684.795	145338.702	154.425	154.480	+0.055
1031	585339.057	130128.201	144.916	144.970	+0.054
1129	584780.205	121525.340	162.716	162.770	+0.054
1058	587470.086	132193.265	145.097	145.150	+0.053
1056	587468.194	132178.359	147.378	147.430	+0.052
1246	579311.631	149944.598	119.948	120.000	+0.052
1262	579444.609	149546.715	117.958	118.010	+0.052
1200	575649.474	145299.913	155.988	156.040	+0.052
1065	587485.476	132308.395	144.339	144.390	+0.051
1240	579262.006	150095.471	120.599	120.650	+0.051
1032	585343.442	130157.930	144.230	144.280	+0.050
1243	579289.207	150013.874	120.320	120.370	+0.050
1244	579297.440	149987.930	120.431	120.480	+0.049
1040	585369.572	130340.238	140.922	140.970	+0.048
1092	587549.771	132792.058	145.612	145.660	+0.048
1095	587555.680	132838.165	145.482	145.530	+0.048
1039	585365.902	130314.026	141.343	141.390	+0.047
1224	575993.975	145676.430	144.603	144.650	+0.047
1248	579330.740	149888.793	119.423	119.470	+0.047
1054	587466.279	132160.286	146.184	146.230	+0.046
1078	587515.376	132531.208	144.984	145.030	+0.046
1254	579351.470	149761.925	120.035	120.080	+0.045
1053	585417.062	130667.336	141.175	141.220	+0.045
1219	575922.100	145597.732	147.805	147.850	+0.045
1066	587486.884	132318.500	143.376	143.420	+0.044
1024	585322.692	130014.839	147.557	147.600	+0.043
1109	584729.398	121043.603	161.517	161.560	+0.043
1226	576025.399	145710.966	143.857	143.900	+0.043
1101	587570.353	132945.220	146.418	146.460	+0.042
1208	575766.562	145427.564	152.239	152.280	+0.041
1006	585262.488	129602.806	162.470	162.510	+0.040

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Number	Easting	Northing	Known Z	Laser Z	Dz
1035	585352.545	130221.264	142.901	142.940	+0.039
1030	585336.726	130112.466	145.282	145.320	+0.038
1228	576052.502	145740.052	143.252	143.290	+0.038
1110	584730.962	121062.110	161.533	161.570	+0.037
1253	579341.285	149792.516	120.363	120.400	+0.037
1064	587483.223	132290.597	143.904	143.940	+0.036
1094	587552.304	132812.394	145.675	145.710	+0.035
1207	575750.411	145409.761	152.525	152.560	+0.035
1227	576037.938	145724.396	143.285	143.320	+0.035
1216	575856.934	145526.814	149.476	149.510	+0.034
1073	587502.724	132438.206	147.827	147.860	+0.033
1210	575796.525	145460.724	151.277	151.310	+0.033
1237	576190.571	145891.082	139.908	139.940	+0.032
1080	587519.405	132561.432	143.929	143.960	+0.031
1100	587568.481	132936.009	146.499	146.530	+0.031
1245	579303.030	149972.045	120.070	120.100	+0.030
1261	579438.794	149564.664	118.360	118.390	+0.030
1026	585327.239	130047.124	146.662	146.690	+0.028
1028	585331.994	130079.151	145.972	146.000	+0.028
1108	584725.530	121014.277	161.683	161.710	+0.027
1017	585301.952	129873.589	153.884	153.910	+0.026
1204	575711.747	145367.563	153.994	154.020	+0.026
1236	576176.449	145875.905	140.004	140.030	+0.026
1036	585354.638	130236.508	142.604	142.630	+0.026
1052	585414.120	130646.630	141.215	141.240	+0.025
1083	587529.062	132635.560	145.155	145.180	+0.025
1218	575900.312	145574.535	148.485	148.510	+0.025
1220	575937.207	145614.189	147.205	147.230	+0.025
1093	587551.306	132802.381	145.146	145.170	+0.024
1077	587512.095	132506.571	145.116	145.140	+0.024
1214	575834.228	145501.400	149.636	149.660	+0.024
1115	584744.477	121190.555	160.397	160.420	+0.023
1221	575952.192	145630.292	146.527	146.550	+0.023
1015	585293.665	129816.196	156.978	157.000	+0.022
1021	585313.338	129950.528	149.899	149.920	+0.021
1062	587478.885	132256.844	144.919	144.940	+0.021
1004	585257.252	129565.131	162.220	162.240	+0.020
1022	585316.063	129969.702	149.060	149.080	+0.020
1075	587507.324	132472.236	142.870	142.890	+0.020
1096	587559.724	132865.958	145.550	145.570	+0.020
1009	585271.984	129666.647	162.731	162.750	+0.019
1217	575878.912	145550.191	149.131	149.150	+0.019
1027	585329.591	130063.183	146.312	146.330	+0.018

Number	Easting	Northing	Known Z	Laser Z	Dz
1223	575985.550	145667.458	145.123	145.140	+0.017
1011	585278.672	129712.912	161.833	161.850	+0.017
1019	585308.711	129919.113	151.453	151.470	+0.017
1116	584747.972	121223.200	160.274	160.290	+0.016
1038	585361.199	130281.578	141.915	141.930	+0.015
1076	587510.869	132493.952	143.015	143.030	+0.015
1137	584797.178	121687.712	161.266	161.280	+0.014
1222	575968.795	145648.424	146.196	146.210	+0.014
1000	585246.671	129492.270	161.737	161.750	+0.013
1102	587571.431	132954.897	147.827	147.840	+0.013
1213	575831.101	145497.699	149.727	149.740	+0.013
1117	584751.321	121255.658	160.448	160.460	+0.012
1042	585377.796	130397.331	140.069	140.080	+0.011
1005	585259.702	129583.398	162.299	162.310	+0.011
1128	584777.534	121507.256	162.779	162.790	+0.011
1061	587478.126	132249.504	143.640	143.650	+0.010
1141	584805.858	121768.837	160.970	160.980	+0.010
1122	584760.344	121339.695	163.011	163.020	+0.009
1134	584790.705	121626.756	164.801	164.810	+0.009
1255	579363.387	149725.734	119.651	119.660	+0.009
1057	587468.520	132182.242	147.091	147.100	+0.009
1215	575835.194	145502.674	149.841	149.850	+0.009
1230	576084.177	145775.166	143.871	143.880	+0.009
1192	569862.857	142446.807	162.902	162.910	+0.008
1232	576114.464	145808.402	142.592	142.600	+0.008
1098	587566.081	132914.210	147.343	147.350	+0.007
1201	575671.847	145324.480	155.603	155.610	+0.007
1010	585275.209	129689.221	162.454	162.460	+0.006
1097	587564.037	132898.331	146.784	146.790	+0.006
1126	584772.523	121455.126	161.684	161.690	+0.006
1140	584804.218	121751.800	161.454	161.460	+0.006
1050	585407.594	130601.992	141.325	141.330	+0.005
1086	587533.314	132667.314	147.765	147.770	+0.005
1199	569932.756	142401.189	163.135	163.140	+0.005
1088	587536.923	132696.760	143.995	144.000	+0.005
1023	585320.291	129998.692	148.027	148.030	+0.003
1125.	584768.839	121420.448	162.887	162.890	+0.003
1124	584766.584	121399.722	164.638	164.640	+0.002
1211	575812.652	145478.706	150.638	150.640	+0.002
1091	587548.132	132778.387	145.349	145.350	+0.001
1041	585373.808	130368.986	140.440	140.440	+0.000
1114	584740.801	121155.878	160.291	160.290	-0.001
1045	585389.520	130478.627	140.093	140.090	-0.003

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Number	Easting	Northing	Known Z	Laser Z	Dz
1089	587540.288	132723.323	142.843	142.840	-0.003
1003	585254.801	129548.103	162.133	162.130	-0.003
1025	585324.996	130030.991	147.073	147.070	-0.003
1071	587498.852	132409.974	143.704	143.700	-0.004
1008	585268.861	129644.743	162.734	162.730	-0.004
1049	585404.251	130579.220	141.234	141.230	-0.004
1007	585265.531	129623.343	162.595	162.590	-0.005
1103	587573.207	132968.568	147.715	147.710	-0.005
1130	584783.234	121555.343	162.065	162.060	-0.005
1131	584784.841	121571.940	163.065	163.060	-0.005
1018	585306.447	129903.713	152.287	152.280	-0.007
1138	584800.327	121720.404	162.597	162.590	-0.007
1002	585251.722	129525.940	161.938	161.930	-0.008
1118	584753.793	121272.855	161.348	161.340	-0.008
1133	584788.533	121609.581	164.980	164.970	-0.010
1051	585410.866	130624.061	141.312	141.300	-0.012
1139	584802.055	121733.653	162.622	162.610	-0.012
1014	585289.664	129788.968	158.363	158.350	-0.013
1177	569628.397	142530.490	163.243	163.230	-0.013
1012	585282.180	129737.468	160.914	160.900	-0.014
1191	569848.162	142452.023	162.914	162.900	-0.014
1069	587494.380	132371.971	147.055	147.040	-0.015
1135	584792.679	121646.923	163.746	163.730	-0.016
1112	584735.214	121104.017	162.159	162.140	-0.019
1070	587495.528	132385.484	142.999	142.980	-0.019
1182	569706.150	142502.735	163.059	163.040	-0.019
1136	584794.917	121668.615	161.131	161.110	-0.021
1020	585311.009	129934.725	150.683	150.660	-0.023
1123	584763.534	121367.574	162.844	162.820	-0.024
1212	575830.018	145496.613	149.854	149.830	-0.024
1231	576097.714	145790.088	142.735	142.710	-0.025
1016	585297.757	129844.389	155.466	155.440	-0.026
1179	569658.787	142519.618	163.147	163.120	-0.027
1121	584758.670	121323.442	163.868	163.840	-0.028
1195	569908.362	142430.497	162.828	162.800	-0.028
1072	587501.372	132428.969	147.999	147.970	-0.029
1082	587527.493	132623.357	145.660	145.630	-0.030
1099	587567.080	132924.839	149.243	149.210	-0.033
1173	569566.925	142552.223	163.494	163.460	-0.034
1193	569878.215	142441.384	162.844	162.810	-0.034
1178	569643.461	142525.105	163.186	163.150	-0.036
1180	569674.172	142514.127	163.112	163.070	-0.042
1132	584786.451	121589.690	164.235	164.190	-0.045

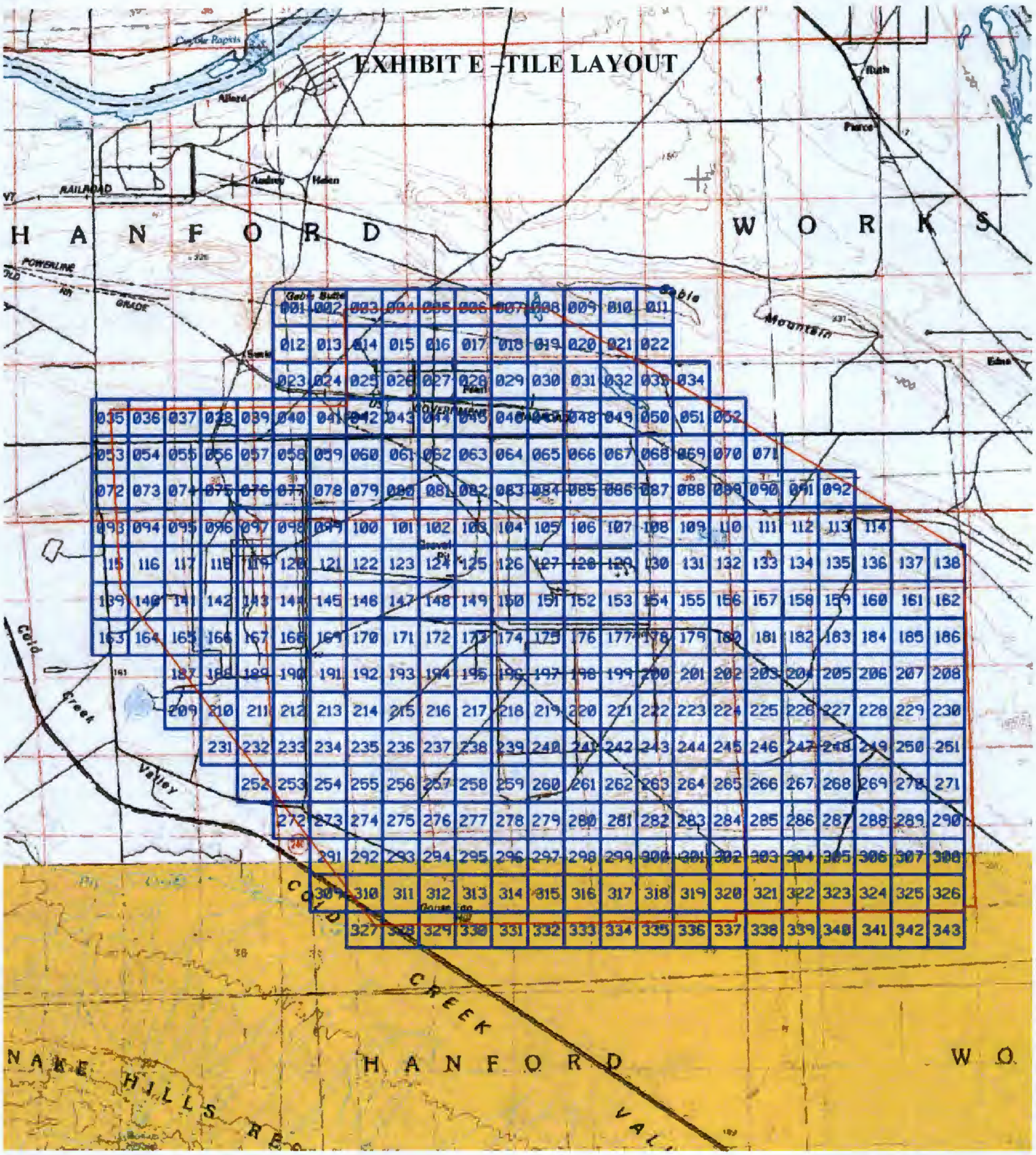
Number	Easting	Northing	Known Z	Laser Z	Dz
1196	569923.688	142425.157	162.775	162.730	-0.045
1001	585248.956	129507.996	161.826	161.780	-0.046
1197	569938.539	142419.792	162.706	162.660	-0.046
1188	569801.879	142468.503	162.889	162.840	-0.049
1120	584756.750	121307.326	163.880	163.830	-0.050
1194	569893.434	142436.026	162.820	162.770	-0.050
1181	569689.956	142508.539	163.101	163.050	-0.051
1168	569487.341	142580.612	163.714	163.660	-0.054
1198	569953.261	142414.648	162.647	162.590	-0.057
1161	569375.906	142620.454	164.080	164.020	-0.060
1163	569406.553	142609.476	163.960	163.900	-0.060
1185	569752.675	142486.048	162.983	162.920	-0.063
1183	569722.146	142497.138	163.018	162.950	-0.068
1186	569770.259	142479.803	162.948	162.880	-0.068
1174	569581.657	142547.040	163.420	163.350	-0.070
1184	569736.533	142491.981	162.964	162.890	-0.074
1164	569425.572	142602.690	163.896	163.820	-0.076
1172	569550.840	142558.164	163.559	163.480	-0.079
1158	569330.482	142636.593	164.052	163.970	-0.082
1190	569831.975	142457.913	162.892	162.810	-0.082
1153	569246.648	142666.541	164.233	164.150	-0.083
1151	569216.008	142677.606	164.225	164.140	-0.085
1150	569200.706	142683.108	164.215	164.130	-0.085
1176	569612.442	142536.096	163.326	163.240	-0.086
1148	569169.730	142694.183	164.237	164.150	-0.087
1165	569440.403	142597.353	163.857	163.770	-0.087
1169	569502.527	142575.177	163.697	163.610	-0.087
1170	569518.665	142569.451	163.660	163.570	-0.090
1081	587523.830	132593.560	146.301	146.210	-0.091
1159	569345.229	142631.411	164.051	163.960	-0.091
1167	569471.549	142586.268	163.791	163.700	-0.091
1171	569534.668	142563.805	163.611	163.520	-0.091
1160	569360.614	142625.943	164.082	163.990	-0.092
1156	569300.130	142647.349	164.125	164.030	-0.095
1146	569138.005	142705.530	164.279	164.180	-0.099
1143	569092.588	142721.835	164.329	164.230	-0.099
1189	569816.997	142463.222	162.890	162.790	-0.100
1154	569262.345	142660.946	164.172	164.070	-0.102
1157	569314.751	142642.178	164.092	163.990	-0.102
1055	587467.086	132172.439	149.014	148.910	-0.104
1162	569391.019	142614.984	164.016	163.910	-0.106
1166	569456.249	142591.751	163.830	163.720	-0.110
1149	569185.447	142688.599	164.214	164.100	-0.114

AERO-METRIC
SEATTLE

Number	Easting	Northing	Known Z	Laser Z	Dz
1145	569123.233	142710.848	164.295	164.180	-0.115
1085	587532.544	132661.711	148.386	148.270	-0.116
1175	569596.356	142541.784	163.387	163.270	-0.117
1144	569108.301	142716.259	164.329	164.210	-0.119
1187	569786.206	142474.105	162.944	162.820	-0.124
1147	569153.788	142699.953	164.268	164.140	-0.128
1152	569230.707	142672.242	164.238	164.100	-0.138
1155	569282.224	142653.724	164.129	163.990	-0.139
1059	587473.812	132219.970	148.368	148.180	-0.188

Average dz	+0.011
Minimum dz	-0.188
Maximum dz	+0.482
Average magnitude	0.051
Root mean square	0.072
Std deviation	0.071

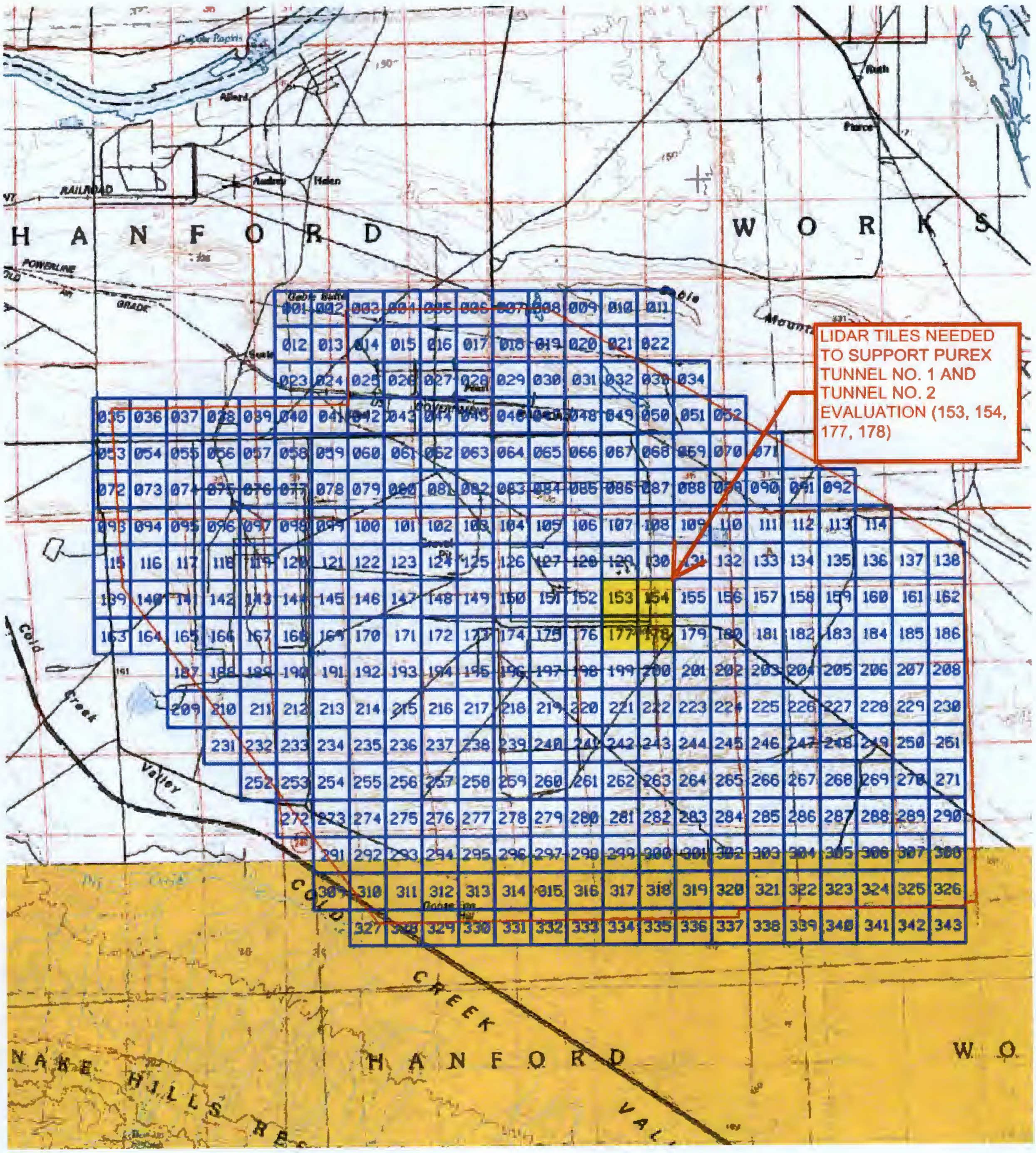
AERO-METRIC
SEATTLE



- **Number of Tiles within project area: 343**
- **Tile size: 750m**

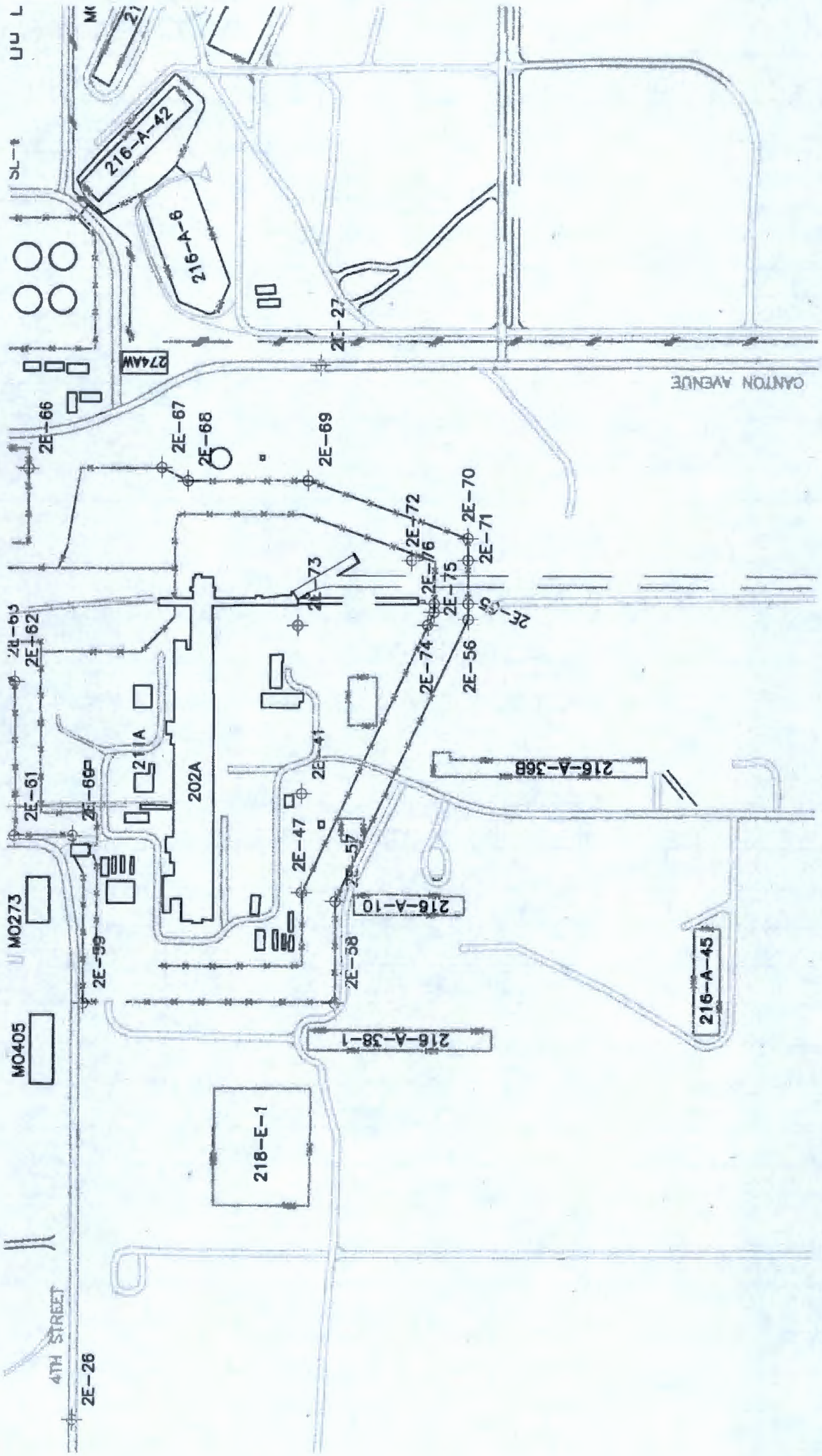
AERO-METRIC
SEATTLE

EXHIBIT E –TILE LAYOUT



- **Number of Tiles within project area: 343**
- **Tile size: 750m**

CHPRC-03364, REV. 0



CHPRC-03364, REV. 0

SURVEY MONUMENT DATA

STATION: 2E-41			LOCATION CODE: 200E	
HORIZONTAL			VERTICAL	
DATUM	COORDINATES		DATUM	HEIGHTS
	LATITUDE	LONGITUDE		ELLIPSOIDAL
NAD83(1991)	46°32'54.878454"	119°31'15.333733"	NAD83(1991)	196.737 m
	NORTHING	EASTING		ORTHOMETRIC
WCS83S(1991)	135,539.989 m	575,080.970 m	NAVD88	218.115 m
	N	W		ORTHOMETRIC
200E AREA (PUREX CONTROL)	39,557.00	48,600.00	NGVD29	712.216 usft
				ORTHOMETRIC
			200E (STAMPED)	711.99

DESCRIPTION

BRASS CAP MONUMENT ON SOUTH SIDE PUREX BLDG 202-A, INSIDE PUREX YARD FENCE. SOUTHEAST OF PIPEFITTERS SHOP, SOUTH OF STEAMLINE.

HORIZONTAL CONTROL

DATUM	INST./METHOD	MONUMENTS USED	LENGTH	MISCLOSURE	ADJUST
NAD 83/91	GPS/NETWORK	USACE GPS NET			TRIMNET
WCS83S/91	"	"			"
200E	— HELD STAMPED VALUES FOR PUREX CONTROL — NOT TIED TO 200E NETWORK				

VERTICAL CONTROL

DATUM	INST./METHOD	MONUMENTS USED	LENGTH	MISC.(mm/√k)	ADJUST
NAVD 88	NA-2/ 3-WIRE	USACE VERTICAL NET			TRIMNET
NGVD29	"	"			"

REFERENCE

DATUM	FILE NO.	REQ. NO.	BERNOULLI	OTHER
NAD 83/91	2ESE-087	962-108		
200E (H&V)	HELD STAMPED VALUES FOR PUREX CONTROL			
NAVD 88	2ESE-087 2EXX-001	971-032	PROJ1 200E 88	L-272
NGVD29	"	"	" 74 200E 29	"

ch2m	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

Attachment C

Earth Pressure Recommendations

Tunnel No. 1
Lateral Earth Pressures and Roof Loads

Prepared by: M. Kacmarcik 6/12/2017
Checked by: Y. Bougataya 6/13/2017

γ_{moist}	110	pcf	*Range is 105 to 115 pcf*
ϕ	30	deg	
c	0	psf	
KO	0.50	--	
SNOW	15	psf	

LEFT (EAST) SIDE

STA	Soil Height Over Footing (feet)	Average Soil Slope (deg)	SOIL + SNOW: Vertical Effective Stress at Wall Top (psf)	SOIL + SNOW: Vertical Effective Stress at Wall Bot (psf)	Inclined At-Rest Coefficient (Koi)	Adjusted Equivalent Fluid Unit Weight (pcf/LF)	SOIL + SNOW: At-Rest Lateral Earth Pressure at Wall Top (psf)	SOIL + SNOW: At-Rest Lateral Earth Pressure at Wall Bot (psf)
1+45	*33.5*	*0*	*1104*	*3700*	*0.50*	*55*	*552.0*	*1850.0*
2+00	*33.2*	*3*	*1060*	*3667*	*0.53*	*58*	*557.7*	*1929.5*
2+10	*32.9*	*4*	*1038*	*3634*	*0.53*	*59*	*555.2*	*1943.7*
3+00	31.7	-12	862	3502	0.40	44	341.4	1386.9
3+32.34	31.7	-18	873	3502	0.35	38	301.6	1209.9
4+00	32.0	-13.6	884	3535	0.38	42	338.1	1351.9
5+00	32.0	-19	884	3535	0.34	37	298.1	1192.1

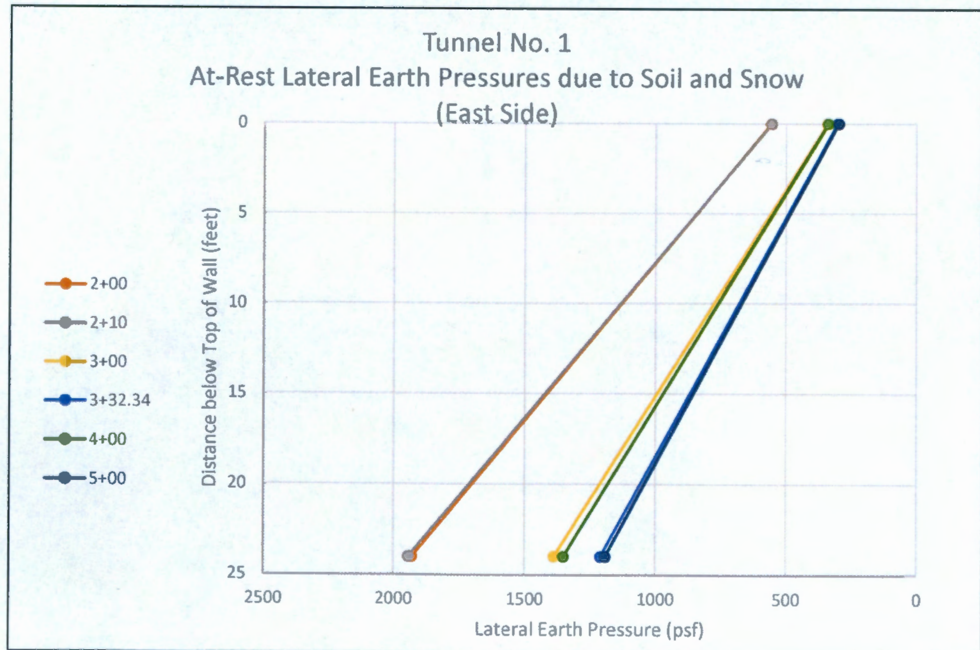
ROOF

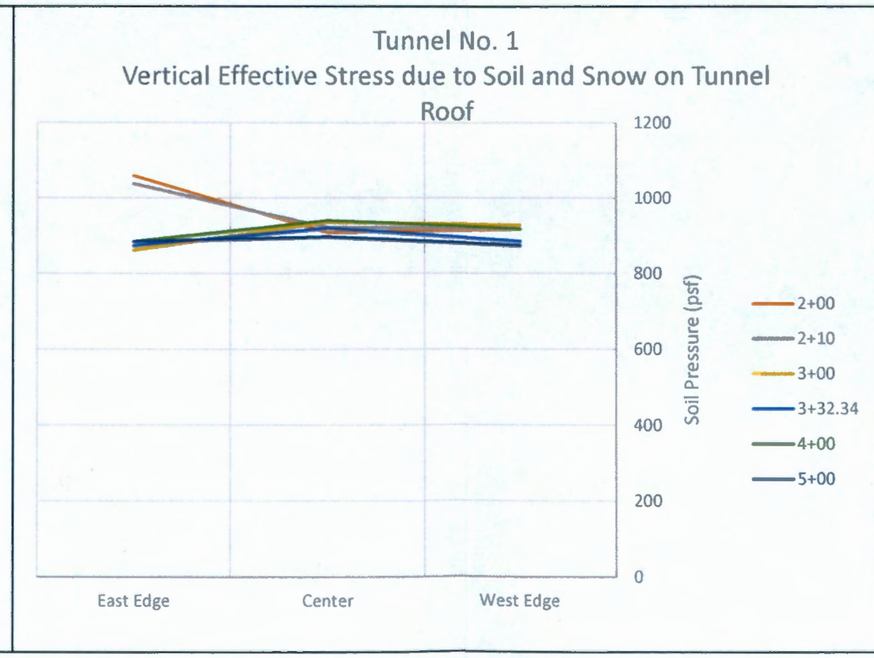
STA	SOIL HEIGHT (FEET): East Edge	SOIL HEIGHT (FEET): Center	SOIL HEIGHT (FEET): West Edge	VERTICAL SOIL + SNOW LOAD (PSF): East Edge	VERTICAL SOIL + SNOW LOAD (PSF): Center	VERTICAL SOIL + SNOW LOAD (PSF): West Edge
1+45	9.9	9.8	5.6	1104	1096.3	631
2+00	9.5	8.1	8.2	1060	908.2	917
2+10	9.3	8.2	8.2	1038	921.4	917
3+00	7.7	8.4	8.3	862	935.7	928
3+32.34	7.8	8.2	7.9	873	919.2	884
4+00	7.9	8.4	8.2	884	939	917
5+00	7.9	8.0	7.8	884	896.1	873

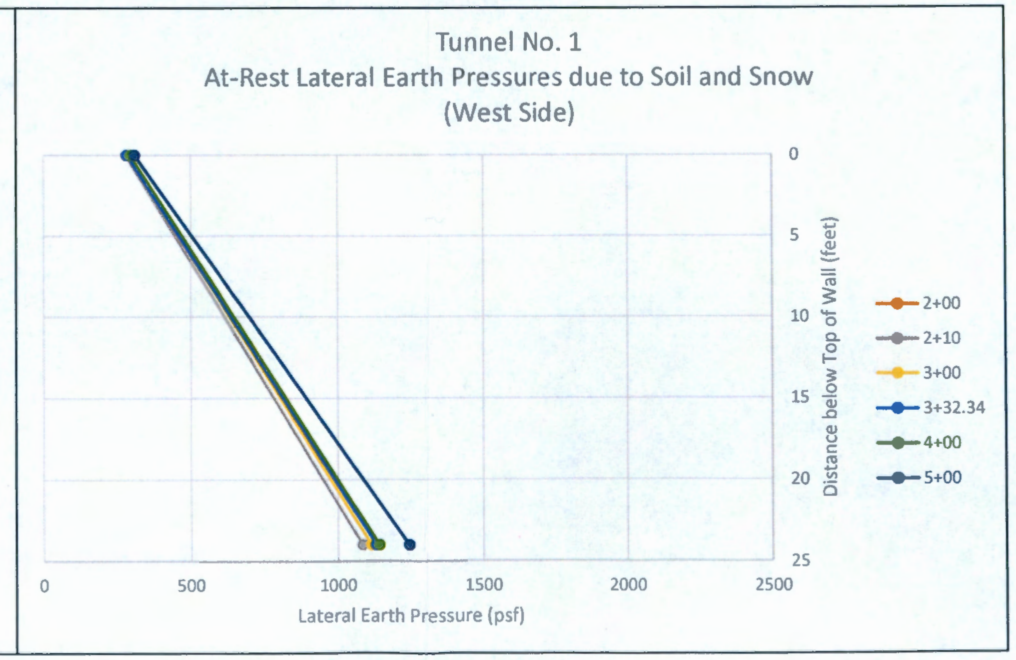
RIGHT (WEST) SIDE

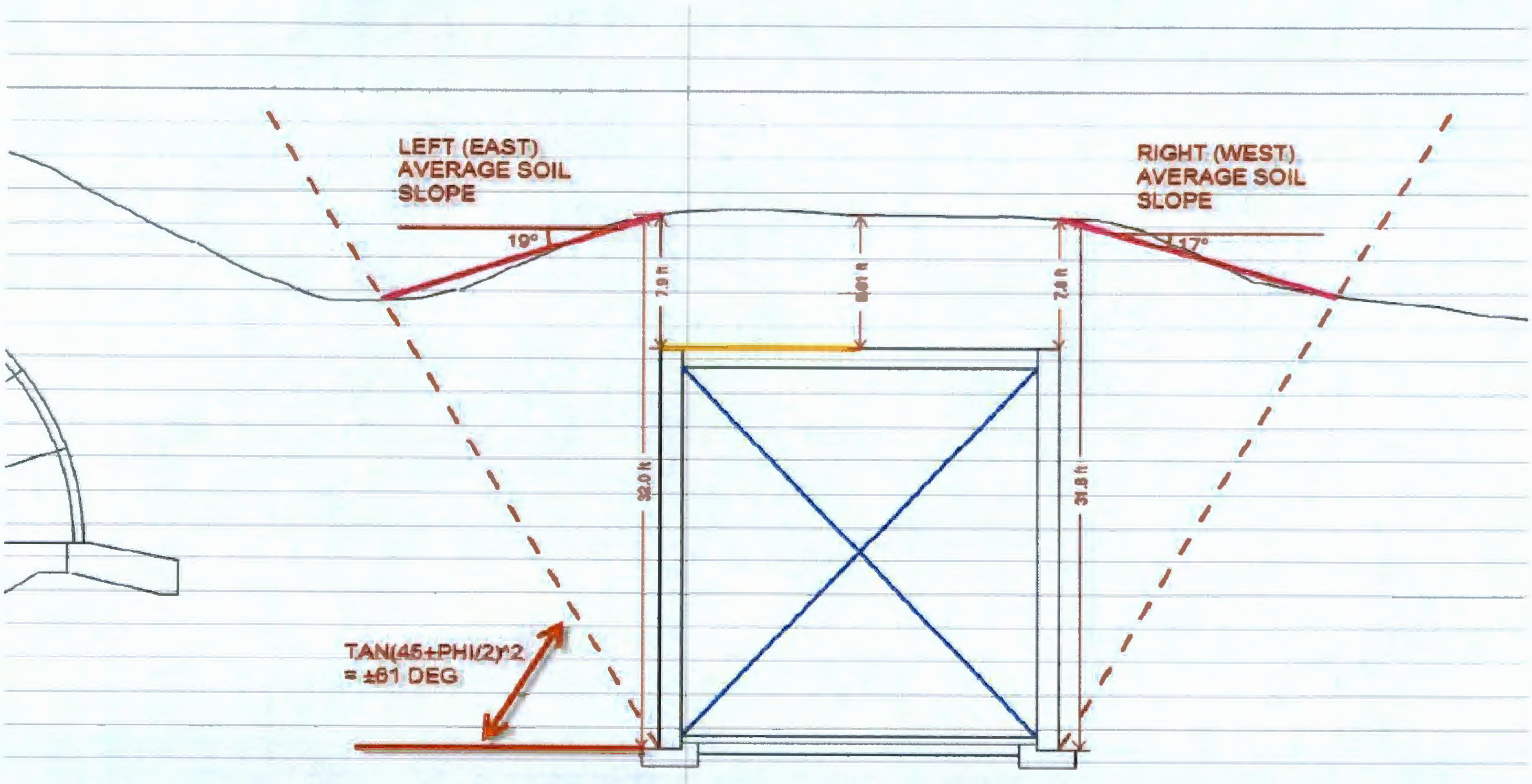
STA	Soil Height Over Footing (feet)	Average Soil Slope (deg)	SOIL + SNOW: Vertical Effective Stress at Wall Top (psf)	SOIL + SNOW: Vertical Effective Stress at Wall Bot (psf)	Inclined At-Rest Coefficient (Koi)	Adjusted Equivalent Fluid Unit Weight (pcf/LF)	SOIL + SNOW: At-Rest Lateral Earth Pressure at Wall Top (psf)	SOIL + SNOW: At-Rest Lateral Earth Pressure at Wall Bot (psf)
1+45	29.6	-25	631	3271	0.29	32	182.2	944.3
2+00	32.2	-21	917	3557	0.32	35	294.2	1141.1
2+10	32.2	-23	917	3557	0.30	34	279.3	1083.6
3+00	32.2	-22	928	3557	0.31	34	290.2	1112.3
3+32.34	31.9	-21	884	3524	0.32	35	283.6	1130.6
4+00	32.2	-21	917	3557	0.32	35	294.2	1141.1
5+00	31.8	-17	873	3513	0.35	39	308.9	1242.9

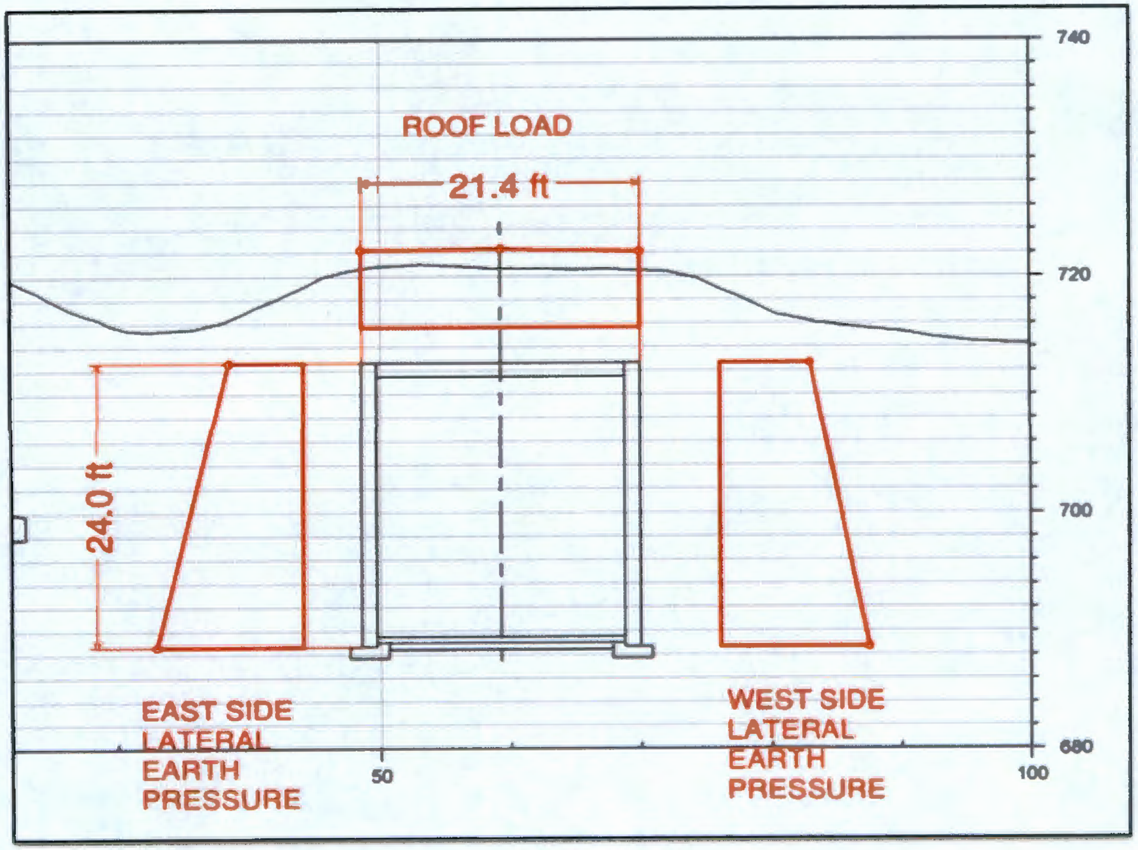
NOTES:
Earth pressure values reported for left (east) side, STA 1+45, 2+00, and 2+10, shown in *red italics*, act against concrete wall. All other earth pressures act against wood timber wall.
Soil pressure profile at STA 1+45 is approximate at edge of LIDAR topography at Tunnel No. 1 Water Filled Door. Not included in summary plots due to uncertain topography.
At-Rest Lateral earth pressure coefficients are adjusted for sloping ground surface at each sections following recommendations of Brooker and Ireland.
STA 2+10 is located at the May 9, 2017 breach of Tunnel No. 1

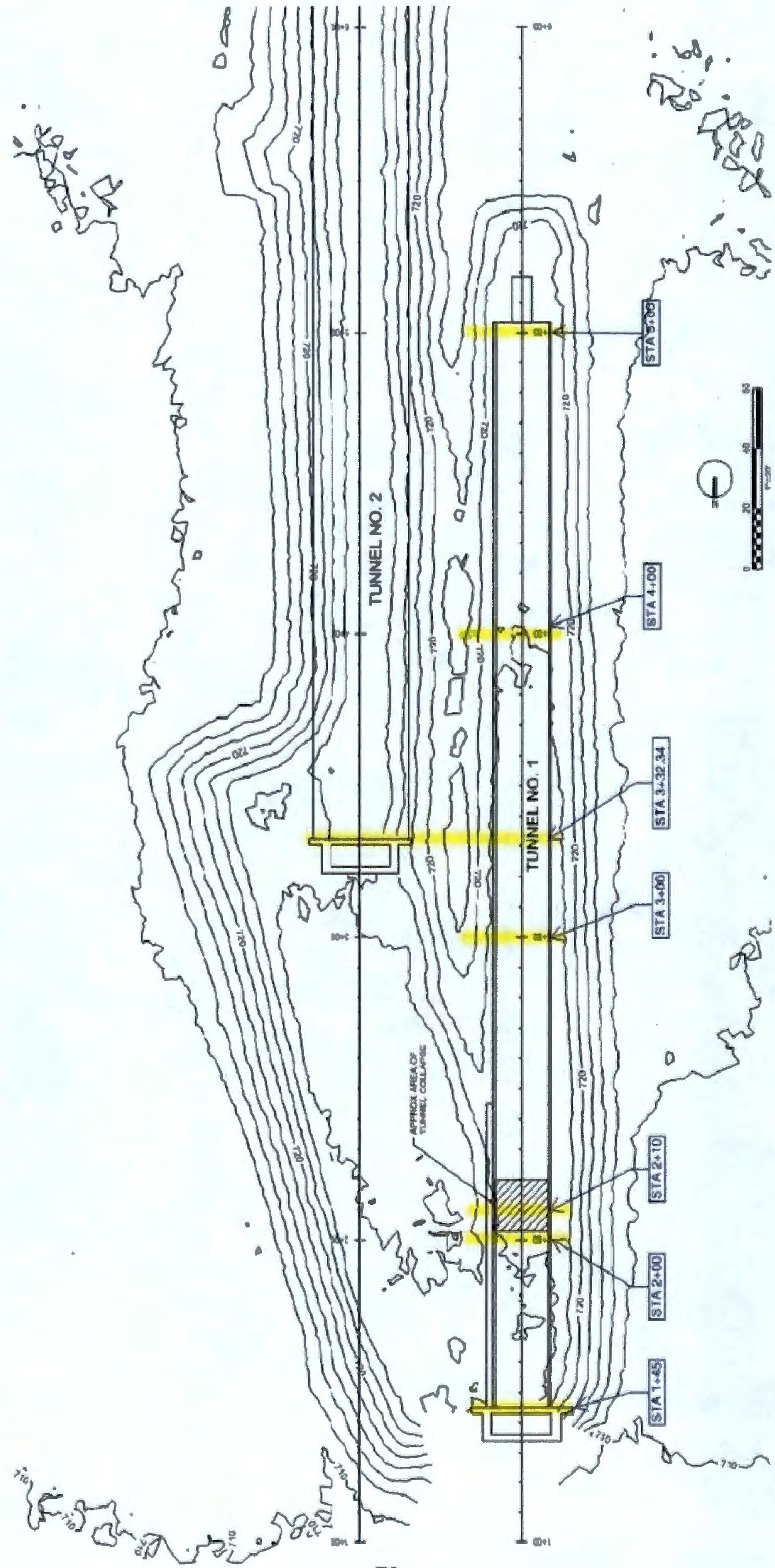







LEFT (EAST)
AVERAGE SOIL
SLOPE
19°
RIGHT (WEST)
AVERAGE SOIL
SLOPE
17°
TAN(45+PHI/2)^2
= ±61 DEG


740
ROOF LOAD
21.4 ft
720
24.0 ft
700
EAST SIDE
LATERAL
EARTH
PRESSURE
WEST SIDE
LATERAL
EARTH
PRESSURE
680
50
100


TUNNEL NO. 2
TUNNEL NO. 1
APPROX AREA OF TUNNEL COLLAPSE
STA 1+45
STA 2+00
STA 2+10
STA 3+00
STA 3+32.34
STA 4+00
STA 5+00
720
710

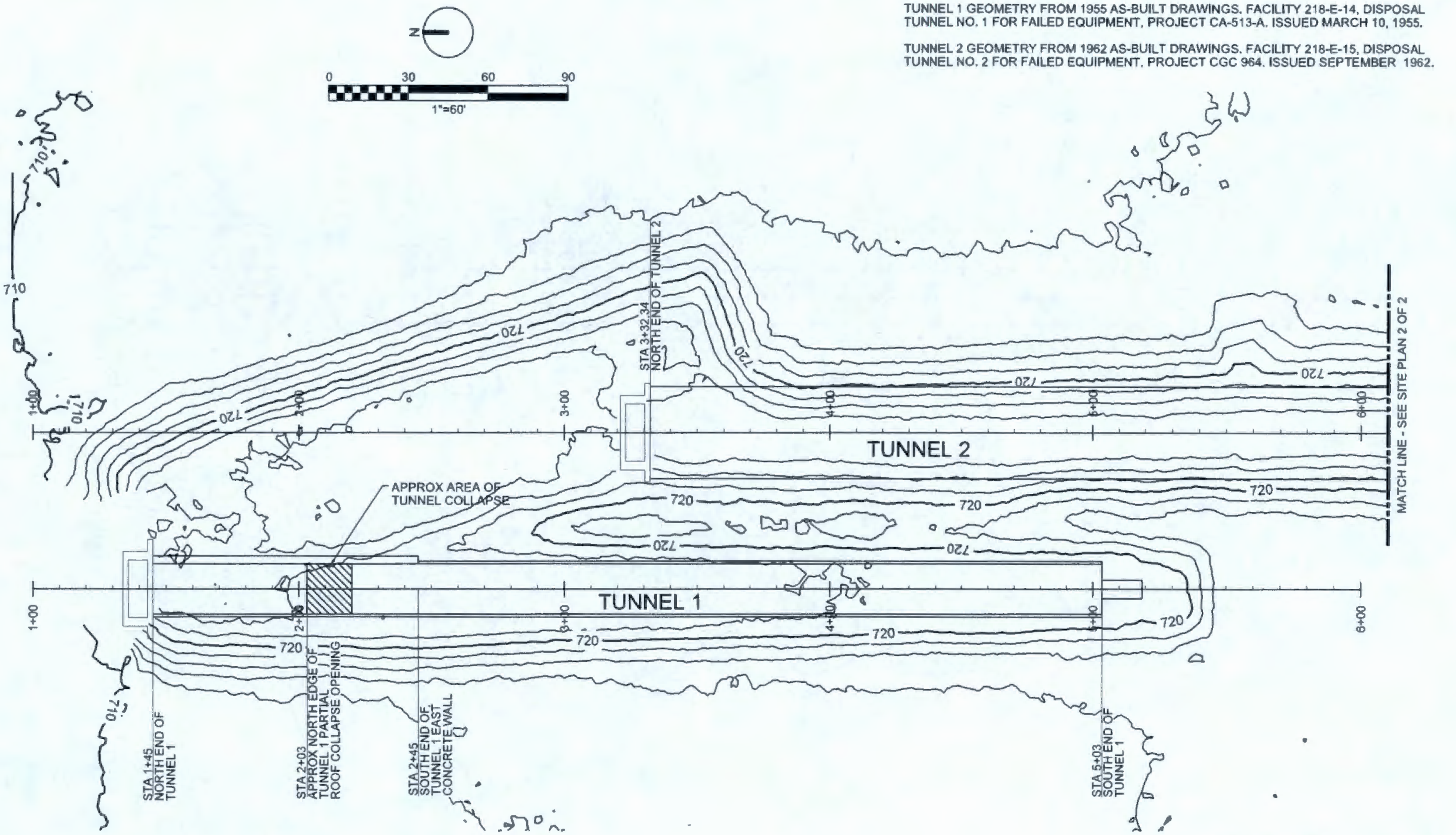
TOPOGRAPHY FROM 2008 *LIDAR CENTRAL PLATEAU REPORT* PREPARED BY AERO-METRIC FOR FLUOR HANFORD. DATA ACQUISITION APRIL 13, 2008. HORIZONTAL DATUM: STATE PLANE NAD83, WASHINGTON SOUTH ZONE, METERS. VERTICAL DATUM: NAVD88, METERS.

HORIZONTAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41.

VERTICAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41. VERTICAL DATUM SHIFT FROM LIDAR TOPOGRAPHY, -1.100 METERS.

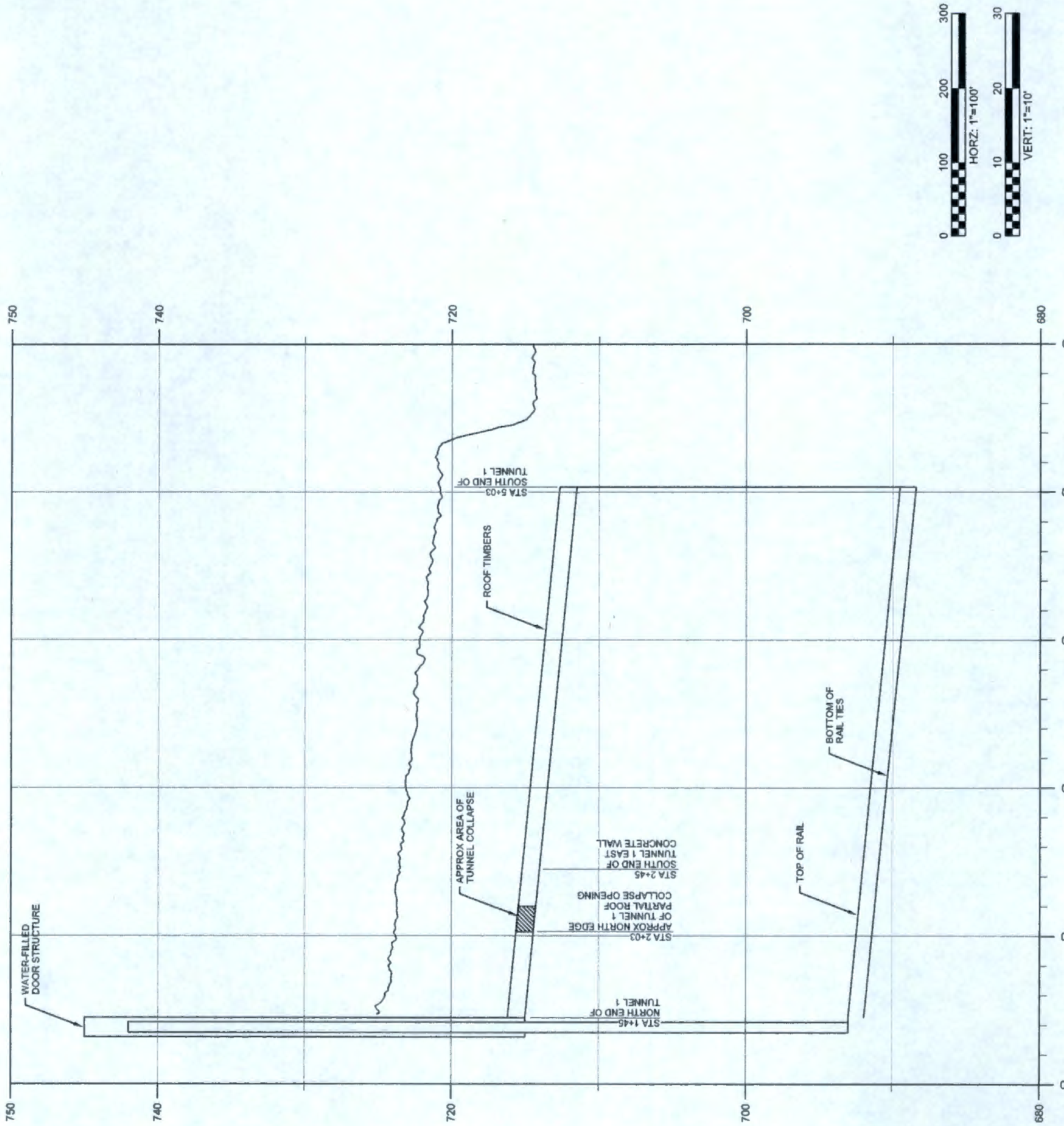
TUNNEL 1 GEOMETRY FROM 1955 AS-BUILT DRAWINGS. FACILITY 218-E-14, DISPOSAL TUNNEL NO. 1 FOR FAILED EQUIPMENT, PROJECT CA-513-A. ISSUED MARCH 10, 1955.

TUNNEL 2 GEOMETRY FROM 1962 AS-BUILT DRAWINGS. FACILITY 218-E-15, DISPOSAL TUNNEL NO. 2 FOR FAILED EQUIPMENT, PROJECT CGC 964. ISSUED SEPTEMBER 1962.

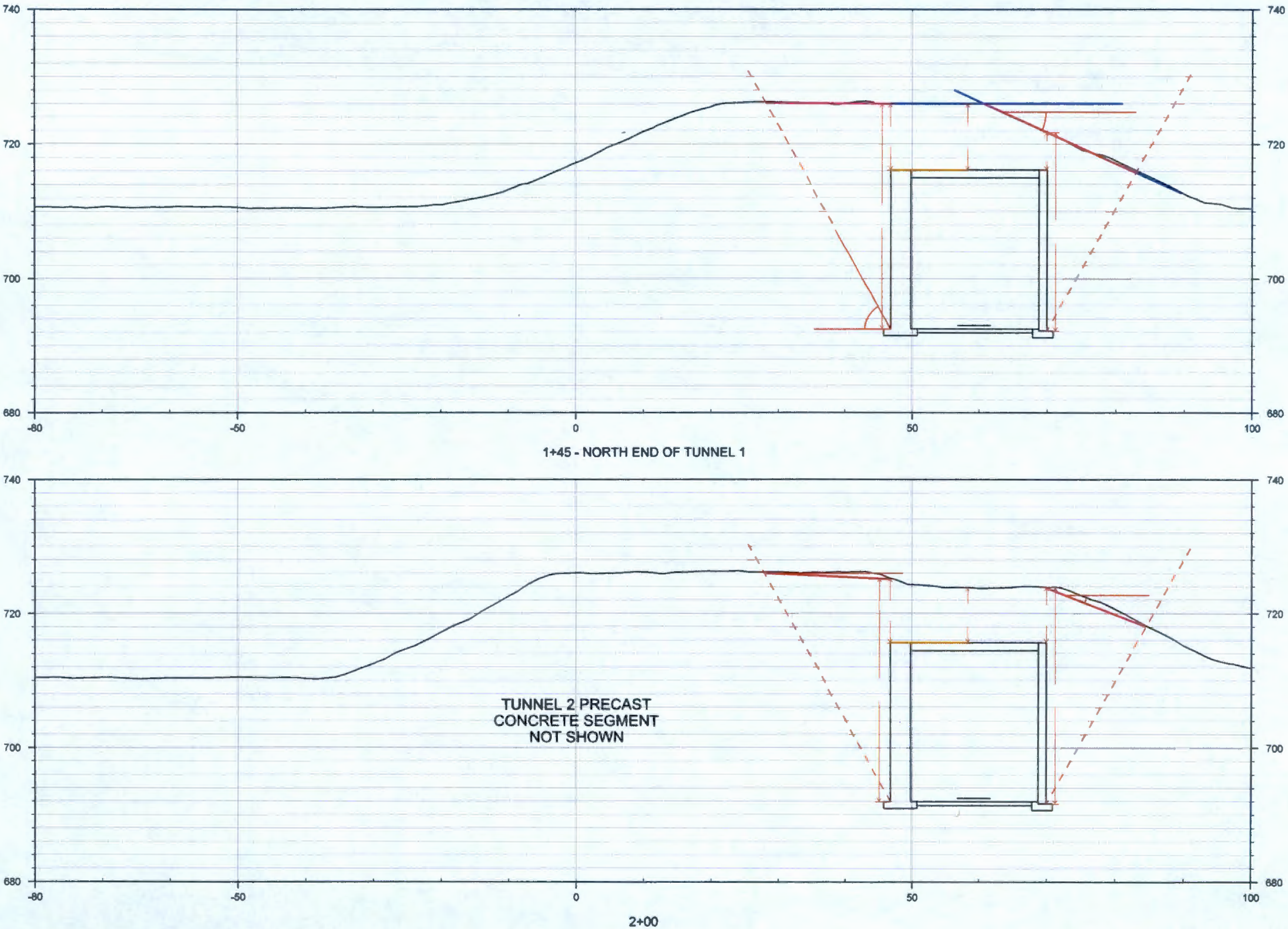


TOPOGRAPHIC SITE PLAN

PUREX TUNNEL 1
ENGINEERING EVALUATION

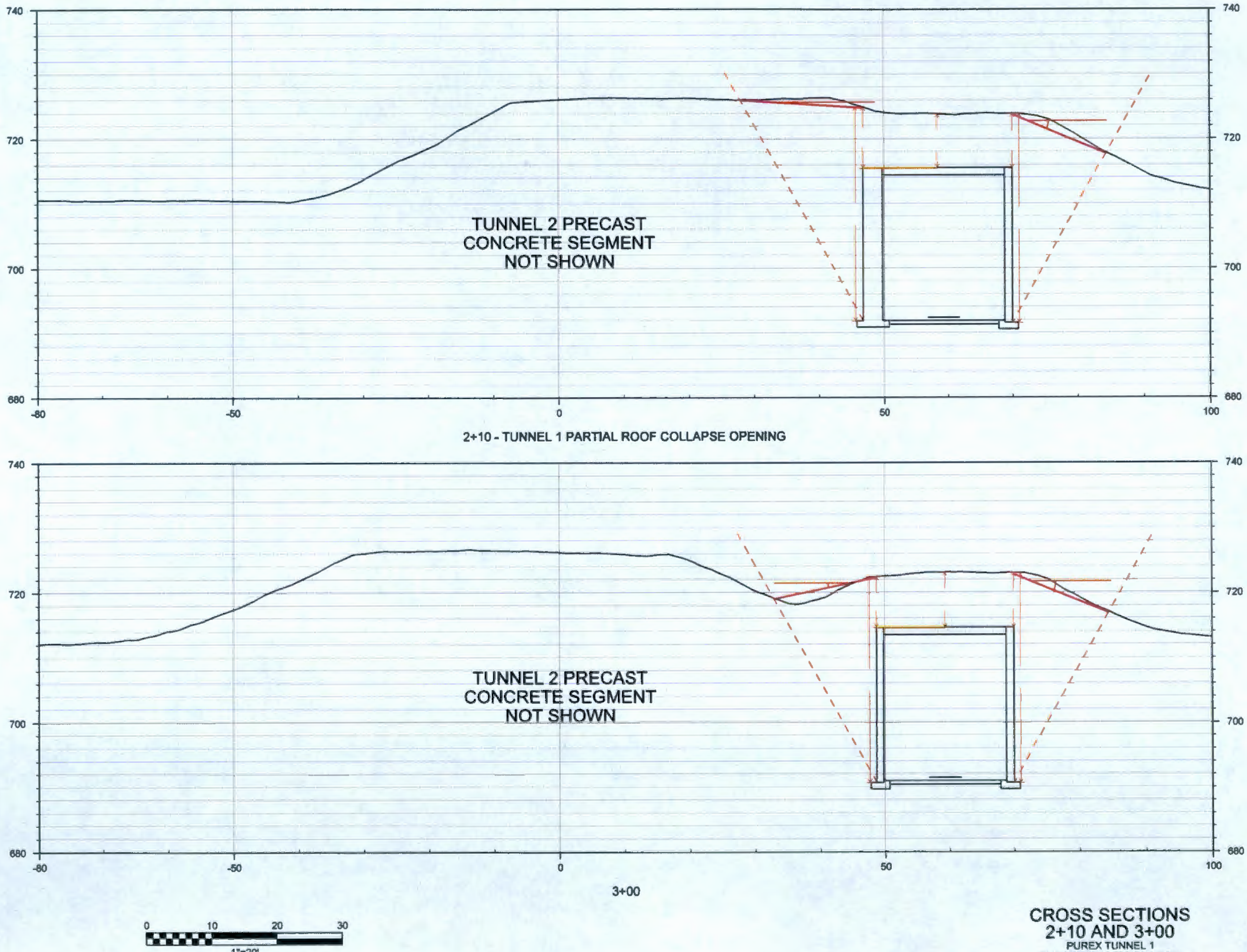


TUNNEL 1 PROFILE
PUREX TUNNEL 1
ENGINEERING EVALUATION

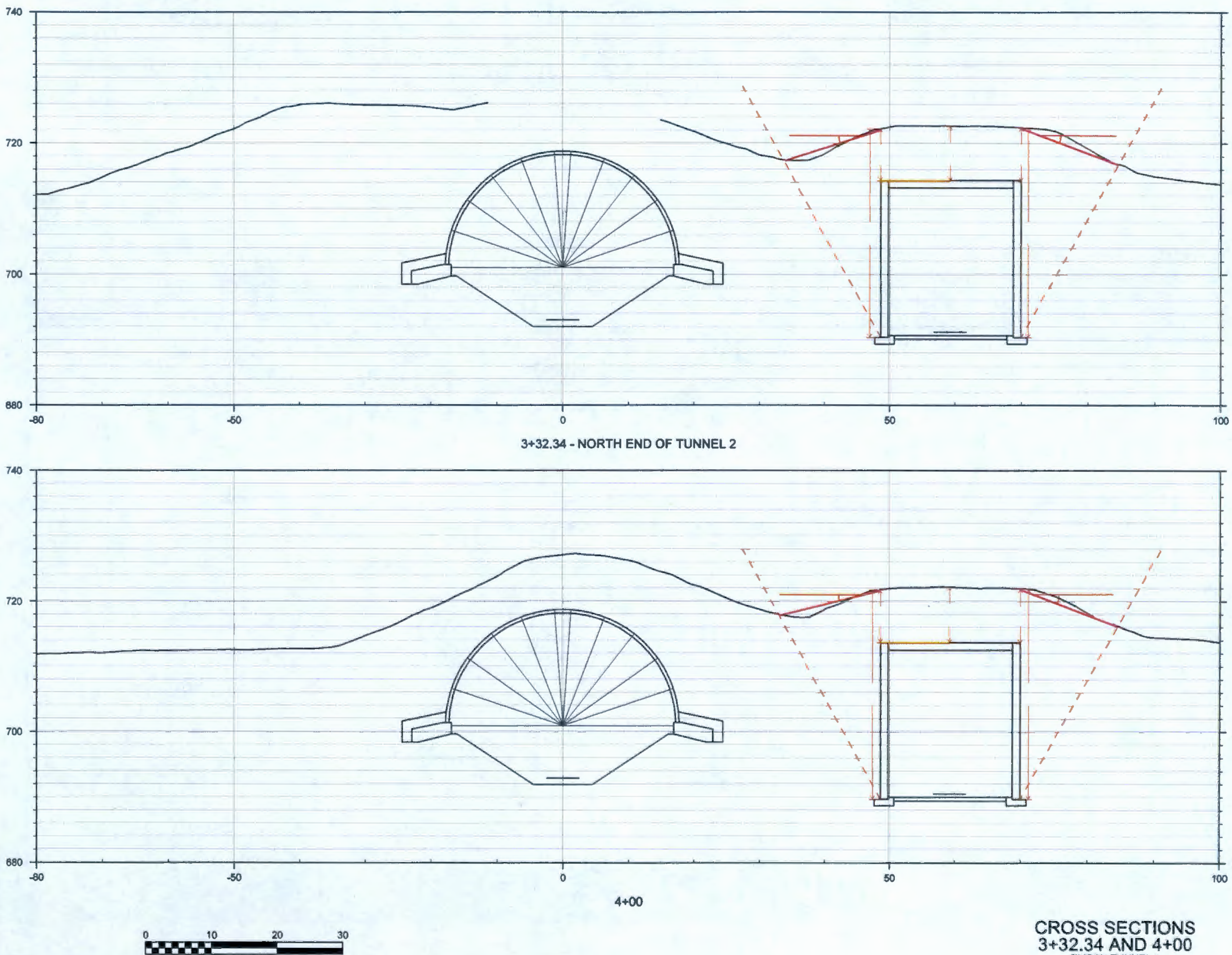


0 10 20 30
1"=20'

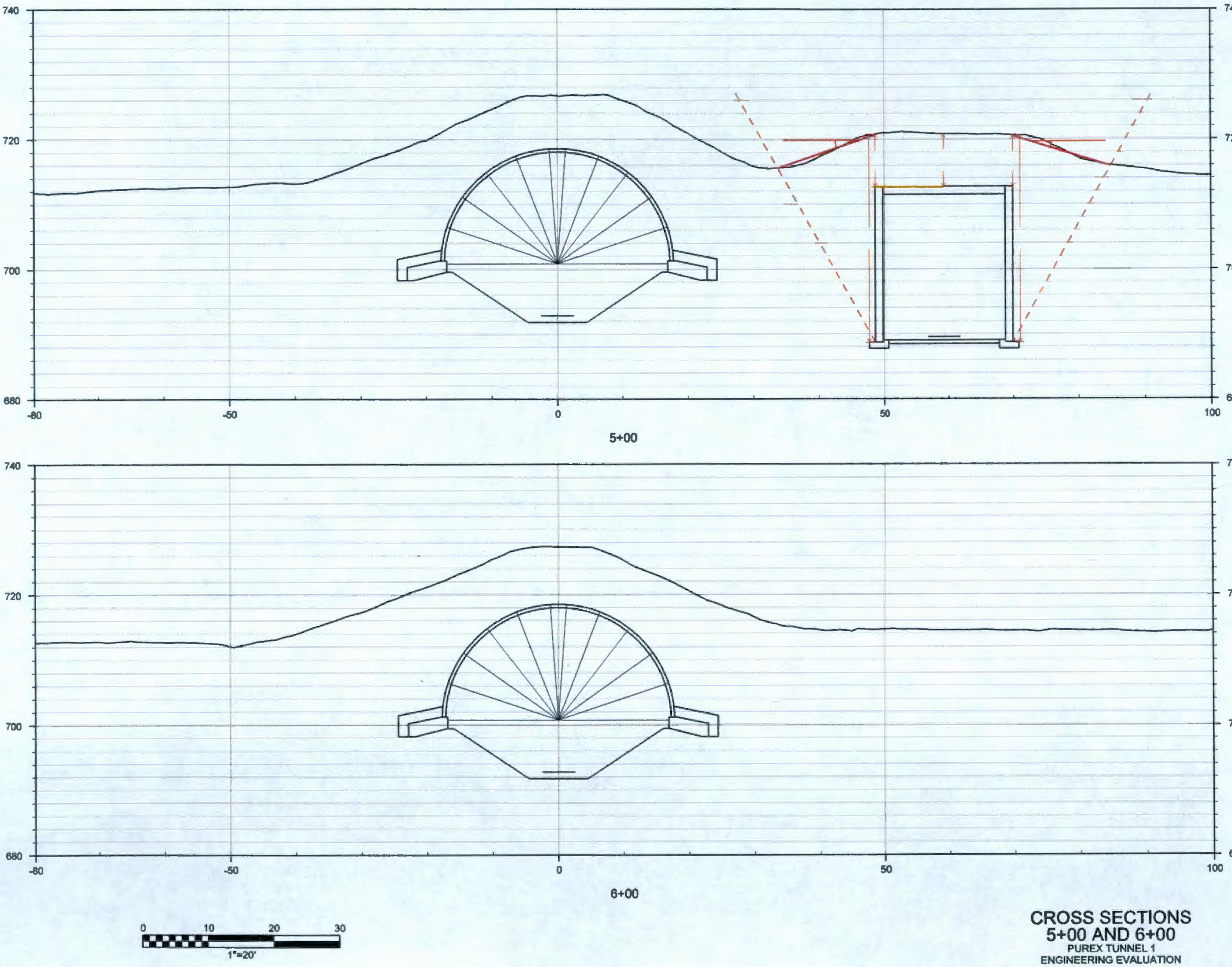
**CROSS SECTIONS
1+45 AND 2+00**
PUREX TUNNEL 1
ENGINEERING EVALUATION



CROSS SECTIONS
2+10 AND 3+00
PUREX TUNNEL 1
ENGINEERING EVALUATION



CROSS SECTIONS
3+32.34 AND 4+00
PUREX TUNNEL 1
ENGINEERING EVALUATION



CROSS SECTIONS
5+00 AND 6+00
PUREX TUNNEL 1
ENGINEERING EVALUATION

ch2m:	Calculation Title: PUREX Tunnel 1 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 1 Client: CHPRC

Attachment D

Foundation Bearing Pressure Evaluation

Bearing Capacity Evaluation

ch2m:

PROJECT: Hanford PUREX Tunnel 1 Evaluation
PROJECT#: 693839.BS
CREATED BY: Mark Kacmarcik/CVO **DATE:** 6/2/2017 **MODIFIED:** 6/23/2017
REVIEWED BY: Youssef Bougataya/CVO **DATE:** 6/12/2017

Given: Tunnel No. 1 Design Drawings
Tunnel No. 1 Construction Specification
Tunnel No. 1 Historical Photos

Find: Estimated Ultimate Bearing Capacity of Tunnel 1 Strip Footings
Allowable Bearing Capacity of Tunnel 1 Strip Footings

Assumptions: Footing geometry is as shown in 1955 as-built drawings for Tunnel 1
Footing subgrade is relatively undistrubed
Factor of Safety of 3.0 is appropriate for estimation of allowable bearing pressures
others as noted below in calculation.

References:

- Coduto, D. *Foundation Design*. Prentice Hall. New Jersey. 2000.
- McCarthy, D. 2002. Essentials of Soil Mechanics and Foundations. 6th Ed. Prentice Hall.
- Dames & Moore (1984) Report of Soils Investigation: Proposed Process Facility Modification Project, Purex Plant, Hanford Washington. Prepared for U.S. Department of Energy. 10805-136-05. Jan. 4.
- Shannon & Wilson (2015) Geotechnical Engineering Study (Rev 2) West Replacement Footings for 324 Building 'B' Cell Excavation, Hanford Reservation, Washington. Submitted to Kurion, Inc. 22-1-03078-010. Feb. 27.

1.0 Soil Properties

At this time, there is no site specific geotechnical data available. Soil properties are based uon the interpretation of construction photographs, and from a 1984 Dames & Moore report which provides foundation recommendations for a proposed Process Facility Modifications approximately 0.25 miles west of the PUREX storage tunnels, in similar subsurface materials.

Original Tunnel 1 Construction Photograph showing construction of Tunnel 1 footings

Subsurface Properties:
From construction photos, undisturbed earth appears to be dense fluvial/glaciofluvial deposits of the Hanford Formation as noted in Dames & Moore (1984). Excavation walls stand vertical to near vertical in many places, with some ravelling to angle of repose possibly due to drying of moist soil. There is no apparent shoring used. There is neither groundwater nor dewatering infrastructure visible, and groundwater is noted to be deep at the PUREX facility. Detail photos of footing subgrade are not available. It is assumed that the material beneath the footings is similar to the material visible at and above the footings. Properties assumed herein should be checked against available geologic literature and available geotechnical studies in similar materials, if available.

$\phi := 34deg$ Assumed internal friction angle of soils, from 1984 Dames & Moore Report

$c := 0psf$ Assumed effective stress cohesion, from 1984 Dames & Moore Report

$\gamma_{moist} := 125pcf$ Assumed average moist unit weight of in-situ soils, average value reported by Shannon and Wilson (2015).

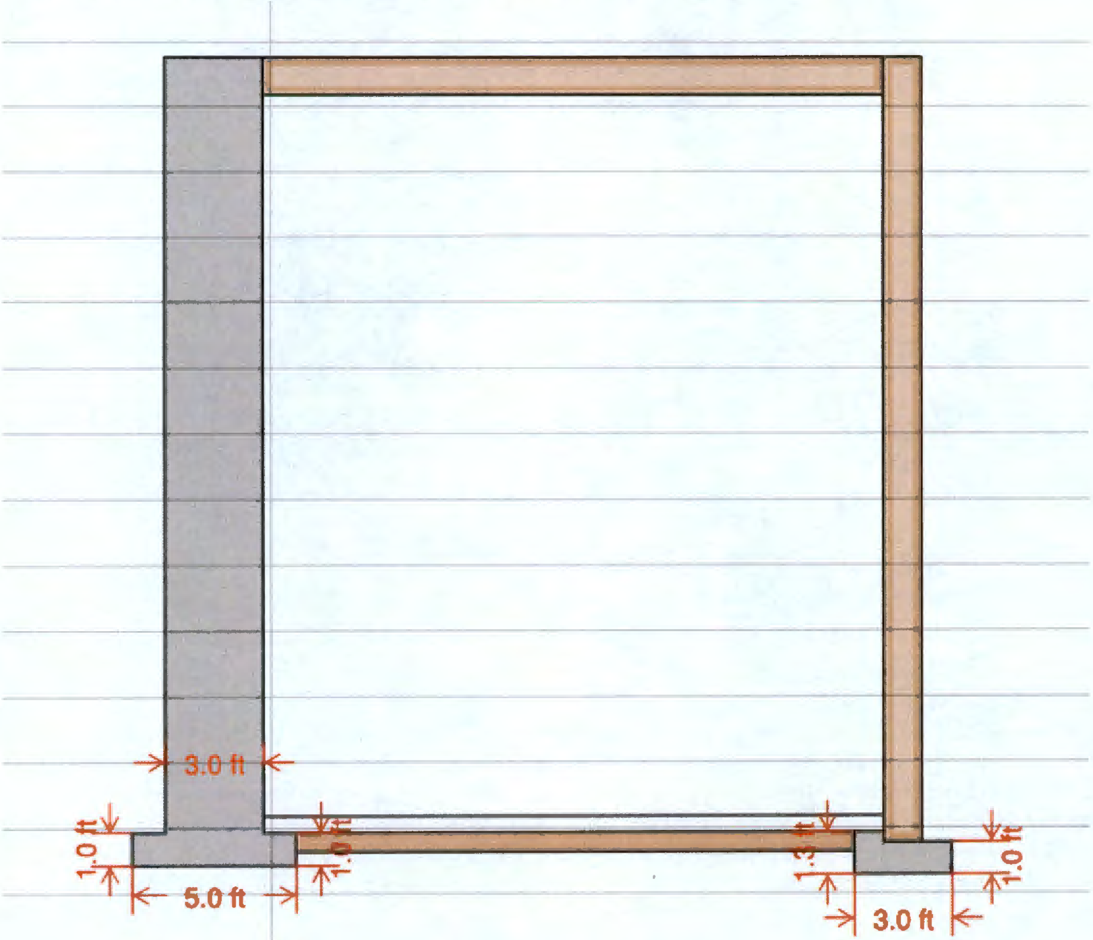
$\gamma_{water} := 62.4pcf$ Unit weight of water, assumed.

2.0 Subsurface Profile

The subsurface profile is assumed to be uniform within the depths of stress influence beneath the footings.
Groundwater is assumed to be significantly deeper than the footings, and total stresses are equal to effective stresses.

3.0 Footing Geometry

The footings for Tunnel 1 consist of two parallel strip footings.
Footings beneath the concrete wall (100 feet long) are 5 feet wide and 1 foot below grade in tunnel.
Footings beneath the timber walls are 3 feet wide and 1.3125 feet below grade in tunnel.



$\alpha := 0deg$ Footing inclination (0 indicates horizontal footings)

$B_{conc} := 5ft$ Width of footing beneath concrete wall

$B_{timber} := 3ft$ Width of footings beneath timber walls

$L_{conc} := 100ft$ Footing length, beneath concrete wall

$L_{timber} := 358ft$ Footing length, beneath timber wall

$\beta := 0deg$ Transverse slope inside tunnel is horizontal

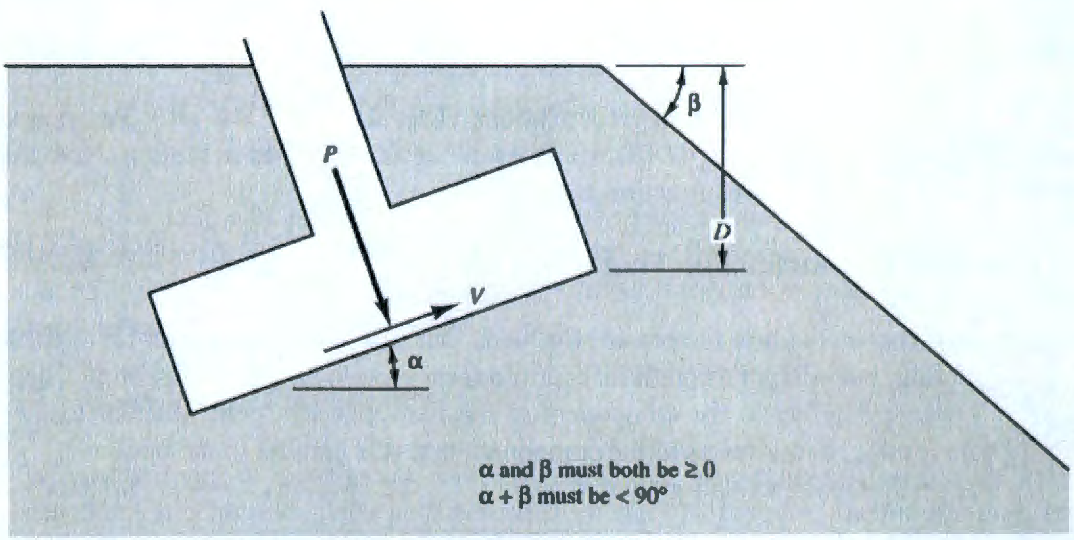
$D_{conc} := 1.0ft$ Footing depth below concrete wall

$D_{timber} := 1ft + 3.75in = 1.313\,ft$ Footing depth below timber walls

$\sigma_{zD.conc} := D_{conc} \cdot \gamma_{moist} = 125 \cdot psf$ In-situ vertical effective stress at depth, D

$\sigma_{zD.timber} := D_{timber} \cdot \gamma_{moist} = 164 \cdot psf$ In-situ vertical effective stress at depth, D

6.2 Estimate Bearing Capacity Using Vesic's Bearing Capacity Formula:



Footing Parameters for Vesic's Bearing Capacity Formula (adapted from Coduto (2001) Figure 6.8).

$$q_{ult} := c \cdot N_c \cdot s_c \cdot d_c \cdot i_c \cdot b_c \cdot g_c + \sigma_{zD}(D_{ftg}) \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot b_q \cdot g_q + 0.5 \cdot \gamma \cdot B \cdot N_\gamma \cdot s_\gamma \cdot d_\gamma \cdot i_\gamma \cdot b_\gamma \cdot g_\gamma$$

where: s_c, s_q, s_γ = shape factors
d_c, d_q, d_γ = depth factors
i_c, i_q, i_γ = load inclination factors
b_c, b_q, b_γ = base inclination factors
g_c, g_q, g_γ = ground inclination factors

Bearing Capacity Factors:

$$N_q := e^{\pi \tan(\phi)} \tan\left(45 \cdot deg + \frac{\phi}{2}\right)^2 \qquad N_q = 29.44$$

$$N_c := \begin{cases} 5.14 & \text{if } \phi = 0 \\ \dfrac{N_q - 1}{\tan(\phi)} & \text{otherwise} \end{cases} \qquad N_c = 42.164$$

$$N_\gamma := 2(N_q + 1)\tan(\phi) \qquad N_\gamma = 41.064$$

Footing Shape Factors

$$s_c(B,L) := 1.0 + \left(\frac{N_q}{N_c}\right)\left(\frac{B}{L}\right) \qquad s_{c.conc} := s_c(B_{conc}, L_{conc}) = 1.035$$
$$s_{c.timber} := s_c(B_{timber}, L_{timber}) = 1.006$$

$$s_q(B,L) := 1.0 + \left(\frac{B}{L}\right)\cdot\tan(\phi) \qquad s_{q.conc} := s_q(B_{conc}, L_{conc}) = 1.034$$
$$s_{q.timber} := s_q(B_{timber}, L_{timber}) = 1.006$$

$$s_\gamma(B,L) := 1.0 - 0.4\cdot\left(\frac{B}{L}\right) \qquad s_{\gamma.conc} := s_\gamma(B_{conc}, L_{conc}) = 0.98$$
$$s_{\gamma.timber} := s_\gamma(B_{timber}, L_{timber}) = 0.997$$

Depth Factors:

$$k_{conc} := \frac{D_{conc}}{B_{conc}} = 0.2 \qquad k_{timber} := \frac{D_{timber}}{B_{timber}} = 0.437$$

$$d_c(k) := 1 + 0.4\cdot k \qquad d_{c.conc} := d_c(k_{conc}) = 1.08$$
$$d_{c.timber} := d_c(k_{timber}) = 1.175$$

$$d_q(k) := 1 + 2\cdot k\cdot\tan(\phi)\cdot(1 - \sin(\phi))^2 \qquad d_{q.conc} := d_q(k_{conc}) = 1.052$$
$$d_{q.timber} := d_q(k_{timber}) = 1.115$$

$$d_\gamma := 1.00 \quad \text{for all } \phi \qquad d_{\gamma.conc} := d_\gamma$$
$$d_{\gamma.timber} := d_\gamma$$

Load Inclination Factors:

$Q := 10lbf$ — Total footing load (magnitude is irrelevant, only the ratio of P to V is necessary for evaluation of *m*)

$P := Q$ — Component of load that acts perpendicular to bottom of footing.

$V := 0lbf$ — Component of load that acts parallel to bottom of footing.

$A_{conc} := B_{conc} \cdot L_{conc} = 500\ ft^2$ — Area of footing beneath concrete wall

$A_{timber} := B_{timber} \cdot L_{timber} = 1074\ ft^2$ — Area of footing beneath timber wall

$$m_{conc} := \frac{2 + \frac{B_{conc}}{L_{conc}}}{1 + \frac{B_{conc}}{L_{conc}}} = 1.952$$

For load inclination transverse to axis of tunnel

$$m_{timber} := \frac{2 + \frac{B_{timber}}{L_{timber}}}{1 + \frac{B_{timber}}{L_{timber}}} = 1.992$$

For load inclination transverse to axis of tunnel

$$i_q(A, m) := \left(1 - \frac{V}{P + \frac{A \cdot c}{\tan(\phi)}}\right)^m$$

$i_{q.conc} := i_q(A_{conc}, m_{conc}) = 1$

$i_{q.timber} := i_q(A_{timber}, m_{timber}) = 1$

$$i_\gamma(A, m) := \left(1 - \frac{V}{P + \frac{A \cdot c}{\tan(\phi)}}\right)^{m+1}$$

$i_{\gamma.conc} := i_\gamma(A_{conc}, m_{conc}) = 1$

$i_{\gamma.timber} := i_\gamma(A_{timber}, m_{timber}) = 1$

$$i_c(i_q) := i_q - \left(\frac{1 - i_q}{N_c \cdot \tan(\phi)}\right)$$

$i_{c.conc} := i_c(i_{q.conc}) = 1$

$i_{c.timber} := i_c(i_{q.timber}) = 1$

Ground Inclination Factors:

Vesic's factors for accounting for inclined ground surface

$\beta = 0 \cdot deg$

$g_c := 1 - \frac{\beta}{147deg}$ $\quad g_c = 1$

$g_q := (1 - \tan(\beta))^2$ $\quad g_q = 1$

$g_\gamma := g_q$ $\quad g_\gamma = 1$

Base Inclination Factors:

Vesic's factors for inclined base of footing.

$\alpha = 0 \cdot deg$ Angle of inclination of base of footing.

$b_c := 1 - \frac{\alpha}{147deg}$ $\quad b_c = 1$

$b_q := \left(1 - \frac{\alpha \cdot \tan(\phi)}{57deg}\right)^2$ $\quad b_q = 1$

$b_\gamma := b_q$ $\quad b_\gamma = 1$

Estimate Ultimate and Allowable Bearing Capacity Using Vesic's Extended Bearing Capacity Equation:

$$q_{ult.conc} := c \cdot N_c \cdot s_{c.conc} \cdot d_{c.conc} \cdot i_{c.conc} \cdot b_c \cdot g_c \cdots + \sigma_{zD.conc} \cdot N_q \cdot s_{q.conc} \cdot d_{q.conc} \cdot i_{q.conc} \cdot b_q \cdot g_q \cdots + 0.5 \cdot \gamma_{moist} \cdot B_{conc} \cdot N_\gamma \cdot s_{\gamma.conc} \cdot d_{\gamma.conc} \cdot i_{\gamma.conc} \cdot b_\gamma \cdot g_\gamma$$

$q_{ult.conc} = 16579 \cdot psf$

$$q_{ult.timber} := c \cdot N_c \cdot s_{c.timber} \cdot d_{c.timber} \cdot i_{c.timber} \cdot b_c \cdot g_c \cdots + \sigma_{zD.timber} \cdot N_q \cdot s_{q.timber} \cdot d_{q.timber} \cdot i_{q.timber} \cdot b_q \cdot g_q \cdots + 0.5 \cdot \gamma_{moist} \cdot B_{timber} \cdot N_\gamma \cdot s_{\gamma.timber} \cdot d_{\gamma.timber} \cdot i_{\gamma.timber} \cdot b_\gamma \cdot g_\gamma$$

$q_{ult.timber} = 13088 \cdot psf$

$FS := 3$ Factor of safety for use in estimating allowable bearing pressures. Typical value consistent with standard of practice for strip footings. Higher factors of safety may be justified considering the poorly-defined subsurface conditions and the consequences of failure

$q_{allow.conc} := \frac{q_{ult.conc}}{FS} = 5526 \cdot psf$ Allowable Bearing Capacity for Concrete Wall Footing

$q_{allow.timber} := \frac{q_{ult.timber}}{FS} = 4363 \cdot psf$ Allowable Bearing Capacity for Timber Wall Footing

Appendix 4B

PUREX Tunnel 2 Engineering Evaluation
(CHPRC-03365, Revision 0)

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CHPRC-03365
Revision 0

PUREX Tunnel 2 Engineering Evaluation

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

ch2m

P.O. Box 1600
Richland, Washington 99352

CHPRC-03365
Revision 0

PUREX Tunnel 2 Engineering Evaluation

M. D. Hasty
CH2M HILL Plateau Remediation Company

Date Published
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Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

P.O. Box 1600
Richland, Washington 99352

APPROVED
By Lana Perry at 3:48 pm, Jun 27, 2017

Release Approval | Date

CHPRC-03365
Revision 0

Title: *PUREX TUNNEL 2 ENGINEERING EVALUATION*
Project Number 693839

Craig Barrett
Originator:
Craig Barrett, PE
Senior Structural Engineer, CH2M

Signature 6-27-17 Date

Mark Kacmarcik
Mark Kacmarcik. PE
Geotechnical Engineer, CH2M

Signature 6/27/2017 Date

Kent Soelberg
Peer Review:
Kent Soelberg, SE
Senior Structural Engineer, CH2M

Signature 6-27-2017 Date

	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

1. Purpose

This engineering evaluation of PUREX Tunnel 2 was conducted to:

- Provide a structural evaluation for PUREX Tunnel 2
- Assess if there is an immediate risk of failure in PUREX Tunnel 2

It will be submitted to the State of Washington Department of Ecology to fulfill Administrative Order Docket #14156, dated May 10, 2017, Corrective Action 1.

2. Introduction

On May 9, 2017, a portion of the PUREX Tunnel 1 wood timber roof structure was observed to have collapsed into the tunnel resulting in a hole approximately 19 ft wide by 17 ft long. The actual time of the collapse and cause of the failure has not been determined. Potential factors contributing to the collapse are speculated to include heavy rainfall on May 4 and 5, 2017 deterioration of tunnel wood timber structural support members due to prolonged exposure to high levels of radioactivity, and influence of low vibration sources near the site such as local thunderstorms or distant low-magnitude seismic activity. Due to the uncertainty of the condition and structural integrity of the remaining roof and wall timber supports, measures were taken to prevent additional roof loads or personnel from being placed over the top of Tunnel 1 and within the roof load zone of influence until permanent stabilization measures can be taken.

Construction of the PUREX Tunnel 2 addition was completed in 1964 involving placement of the cast-in-place tunnel spur between Tunnels 1 and 2 and installation of the 1,688 ft storage tunnel extension to the south. The Tunnel 2 consists of three sections, a water-fillable door, a storage area, and a ventilation shaft. The water-filled door is housed in a concrete structure and located at the north end of the storage area. The door serves as a barrier between the storage area and the railroad extension tunnel. The water-fillable door is 24.5 ft high, 22 ft wide, and 7 ft deep, constructed of 0.5 inch thick steel plate and hollow to permit filling with water for radiation shielding. The storage area of Tunnel 2 extends from the water-filled door south to the ventilation shaft. The tunnel is constructed in the shape of a Quonset hut with a series of transverse steel rib support beams on a 17 ft rolled radius (approximately 38 inches on-center spacing) that support 3/16 inch thick by 16 inch wide stamped corrugated steel plate roof panels that span between and bolt to steel rib supports. Interior and exterior surfaces of the roof system are coated with a bituminous material. Steel ribs are supported by a 21 inch minimum thick by 6 ft wide by continuous reinforced concrete wall thrust block foundation system. The steel roof structure was then further supported by a retrofit addition of a series of longitudinal steel wale beam wide flange supports that are supported by underhung anchor bolt connections embedded in 15 inch wide by 36 inch deep (minimum) reinforced arched concrete rib girders (approximately 16 ft on-center spacing). Concrete ribs are supported by additional 18 inch thick by 6 ft wide by 6.5 ft long reinforced concrete thrust blocks placed over the top of existing wall footings. A minimum depth of 8 ft of uncompacted soil fill was then placed over the tunnel storage area and the fill was contoured to provide slope stability. The nominal inside dimensions of the tunnel are 26 ft in height, 34 ft in width, and 1,688 ft in length with a downward slope of 0.1% grade from north to south. Due to the water-filled door clearance constraints, the usable storage area is 22 ft in height and 19 ft in width above the top of the rail which is the same as Tunnel 1. The floor consists of two railroad track rails supported by transverse 6 inch by 8 inch railroad ties at 2 ft spacing laid over a gravel bed. The spaces between ties are filled to the top of the ties with gravel ballast. The ventilation shaft is located at the south end of the tunnel. The shaft is approximately 5 ft by 5 ft in cross section and constructed of reinforced concrete. The ventilation shaft protrudes approximately 1 ft above grade and is capped with a single-stage high-efficiency particulate air filter, an exhaust fan, and a 20 ft tall stack. The ventilation system is not in operation. The tunnel is filled with 28 railcars containing radioactive process equipment.

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As denoted in CAC-964, *PUREX Equipment Disposal Tunnel Inspection Report*, dated March 17, 1964, portions of Tunnel 2 catastrophically collapsed on two separate occasions during backfilling operations performed at different locations. The events led to design modifications including addition of interior steel Wale beams underhung and supported by new exterior arched concrete rib girders and to changes in construction soil placement procedures to prevent uneven placement of soil fill along both sides of the tunnel during backfilling operations.

3. Design Input

Design input used in the structural evaluation consists of the following:

A. Tunnel No. 2 Drawings and Specifications
   - H-2-58191 (drawing), *Plot Plan*, 1962 Tunnel 2
   - H-2-58192 (drawing), *Plot Plan & Profile – Arch Liner*, 1962 Tunnel 2
   - H-2-58193 (drawing), *Architectural Plans*, 1962 Tunnel 2
   - H-2-58194 (drawing), *Structural Sections & Details*, 1962 Tunnel 2
   - H-2-58195 (drawing), *Structural Sections & Details*, 1962 Tunnel 2
   - H-2-58196 (drawing), *Roof Plan Structural Sections & Details*, 1962 Tunnel 2
   - H-2-58532 (drawing), *PUREX Tunnel Reinforcement Plan*, 1964 Tunnel 2 Modifications
   - H-2-58533 (drawing), *PUREX Tunnel Reinforcement Sections & Details*, 1964 Tunnel 2 Modifications
   - H-2-58731 (drawing), *Clearance Diagram for Tunnel Section*, 1964 Tunnel 2 Modifications
   - H-2-58738 (drawing), *Survey Controls and Data*, 1964 Tunnel 2 Modifications
   - HWS-8262, *Specification for PUREX Equipment Disposal*, dated October 5, 1962 (Tunnel 2), Project CCC-964
   - HW-4798-S, *Standard Specification for Placing Reinforced Concrete*, (revised Dec 20, 1962)
   - HW-4926-S, *Standard Specification for Welding Carbon Steels*, (revised July 10, 1968)

B. Structure Performance Category = PC-1, General Service in accordance with PRC-PRO-EN-097, *Engineering Design and Evaluation (Natural Phenomena Hazard)*, Rev2

C. Soil Design Parameters (see Appendix B):
   - Soil Density = 110 pcf (moist condition)
   - Lateral Earth Pressure (at-rest condition): $K_O = 0.50$ for horizontal ground surface conditions
   - Allowable Bearing Capacity: 3,000 psf (average soil strength using industry standard 3.0 factor of safety)

D. Ground Snow Load = 15 psf (PRC-PRO-EN-097)

E. Live Load: None Permitted (includes personnel and equipment)

F. Load and Resistance Factor Design (LRFD) Load Factors: 1.2 Dead (self-weight + vertical soil weight)
   1.6 Snow
   1.6 Lateral Earth Pressures

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G. Structural Steel Properties

- Structural Steel: ASTM A36, F_y = 36 ksi (includes WF beams, angles, and plates unless otherwise noted)
- Liner Plate: ASTM A283-58 Grade C (90 in. radius, 2 in. flanges, bolted end and side connections)
- Bolts: ASTM A36, F_y = 36 ksi minimum yield strength
  ASTM A325, F_y = 92 ksi minimum yield strength, F_t = 120 ksi minimum tensile strength

H. Concrete

- Steel Rib Concrete Wall Footings: 3,000 psi compressive strength at 28-days (per Note 1 on drawing H-2-58194)
- Retrofit Arched Concrete Rib Girder Supports (includes foundation): 4,000 psi compressive strength at 28-days (per General Note 1 on drawing H-2-58532)

I. Reinforcing: F_y = 40 ksi for ASTM A15-58T Intermediate Grade (per Specification HW-4798-S)

4. Methodology

Engineering evaluation of Tunnel 2 steel structure is based on 2012 International Building Code (IBC) design standards using LRFD methods when subjected to soil and snow loading conditions. The evaluation did not include the potential for degradation of structural steel supports and bolt and welded connections due to adverse effects from corrosion, material defects, and long-term exposure to high levels of radioactivity.

Structural evaluation of Tunnel 2 was performed on primary structural support elements based on a series of hand calculations used to estimate applied soil design loads and interaction between radial and longitudinal structural supports. Due to the overall complexity of Tunnel 2 including arched structural steel and retrofit concrete supports, soil fill configuration, variable soil loading, and sloped conditions at foundation supports, a complete three-dimensional finite element analysis addressing interaction between soil and structure would be required to determine actual structural member design loads and foundation support bearing pressures. Original design calculations were not available through the Document Control Management System (DMCS) for review or comparison with evaluation results.

The 2008 Light, Data, and Ranging (LIDAR) topographic survey data was utilized to provide an initial estimate of existing grade elevations associated with the Tunnel 2 structure. This information was compared to 1962 design drawing tunnel geometry to determine depth of soil fill and soil loading conditions used in the engineering evaluation. Field surveys of finish grade and tunnel structure elevations would be required to determine actual soil depth and soil loading conditions that are applied to the structure.

Based on information provided in RHO-RH-34-3, *Geologic and Seismic Investigation of the PUREX Building Site*, there are no known geotechnical investigation or design reports associated with the PUREX facility including Tunnel 2. Estimated geotechnical soil properties for undisturbed native soil and for soil fill placed over the tunnel used in this engineering evaluation were based on best available geotechnical information further described in Appendix B. Sampling and testing of existing soils at or near Tunnel 2 would be required to determine actual soil design properties of soil fill and native soils used in the construction of Tunnel 2.

5. Computations

Calculations are performed in U.S. customary units and are included in the attachments.

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6. Computer Software

None

7. Assumptions

Subsurface soil conditions are similar to those reported by others in the project vicinity. Topography of existing cover soil over Tunnel 2 is consistent with the 2008 LIDAR topographic survey and with Tunnel 2 design drawings listed in Section 12.

8. Results

Comparison of structural support member demand to capacity summarized by individual Design-to-Capacity Ratio (DCR) for each design check are as follows (DCR greater than 1.0 exceed design code requirements). For detailed calculations, see Appendix A.

A. Arched Steel Rib Beams (6I12.6, ASTM A36, spaced at ~ 37 inch on center, fabricated on ~ 17 ft rolled radius):

DCR	Design Check
0.55	Axial Compression
0.60	Bending
1.04	Combined Bending and Axial Compression
0.50	Shear

Note: red value(s) listed in table above indicate design force exceeds member structural design capacity

B. Arched Steel Rib Beam Splice (L4x6x3/8 angle with 3/8 inch gusset plate, typical top & bottom on each side of splice)

DCR	Design Check
0.14	Shear Yielding of Angle Leg
0.26	Shear Rupture of Angle Leg
0.38	Bolt Shear Yielding
0.21	Bolt Bearing Strength
1.09	Weld Connection

Note: red value(s) listed in table above indicate design force exceeds member structural design capacity

C. Steel Wale Beams (W10x25 @ W1, W12x31 @ W2-W4, and W12x27 @ W5; extend in tunnel longitudinal direction):

Design Check	W1 DCR	W2 DCR	W3 DCR	W4 DCR	W5 DCR
Shear	0.16	0.50	0.46	0.45	0.30
Bending Stress	0.51	1.12	1.04	1.01	0.77

Note: red value(s) listed in table above indicate design force exceeds member structural design capacity

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D. Wale Splice Connection (5/16 inch or 3/8 inch thick tab plate fully welded on one side of Wale beam web)

Design Check	W10x25 DCR	W12x27 DCR	W12x31 DCR
Weld	0.10	0.25	0.25
Bending	0.08	0.17	0.17
Shear Yielding	0.05	0.13	0.13
Shear Rupture	0.06	0.18	0.18

E. Arched Concrete Rib Girders (15 inch wide x 36 inch min concrete arch on ~ 19 ft radius spaced at ~ 15.75 ft o.c.)

DCR	Design Check
0.28	Axial Compression
0.20	Bending
0.58	Shear

F. Wale Underhung Support Bolted Connection (four 1.125 inch to 1.375 inch dia A36 bolts with 0.75 inch to 1.00 inch thick plate)

Design Check	W1 DCR	W2 DCR	W3 DCR	W4 DCR	W5 DCR
Bolts	0.12	0.34	0.32	0.34	0.22
Plate	0.05	0.15	0.14	0.15	0.08
Concrete Breakout	0.25	1.04	0.96	0.94	0.55

Note: red value(s) listed in table above indicate design force exceeds member structural design capacity

G. Concrete Rib Girder Thrust Block Support (18 inch thick x 6 ft x 6.5 ft reinforced concrete ftg)

DCR	Design Check
0.37	Punching Shear
0.60	Shear
0.72	Bending
1.03	Soil Bearing Capacity at Concrete Rib Girder Supports

Note: red value(s) listed above indicate design force exceeds member structural design capacity

ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

9. Conclusions

This structural evaluation of Tunnel 2 indicates that design loads on several structural support members exceed building code design capacities including arched steel rib supports, wide flange steel wale supports (members, splice connection, and failure sensitive underhung tension bolt connections), and foundation soil bearing pressures. Structural evaluation does not address further reduction in the structural capacity of members and connections due to adverse effects from corrosion, material defects, and increased stresses induced from documented unbalanced loading conditions applied to the structure during original construction backfill operations.

Based on overstressed conditions in structural support members and connections and uncertainty of additional unknown stresses induced during original construction, Tunnel 2 has a potential high risk of localized collapse. Foundation support conditions are further subject to increased risk of failure during moderate to strong seismic activity. Although removal of soil fill over the tunnel could result in reduced applied loads, the potential reduction in loads may not eliminate all overstressed conditions and adverse effects from extended deterioration (e.g. corrosion, radiation exposure, etc.) but could in turn result in initiating a localized collapse caused by construction activities. Stabilization of the tunnel is recommended to be implemented as soon as possible to minimize risk of failure. For safety purposes (e.g. avoid potential collapse, avoid high level radiation exposure, etc.), placement of personnel and equipment on top of the tunnel and within the roof load zone of influence is not recommended without further evaluation.

10. Risk of Future Failure

The Tunnel 2 arched steel structure including retrofit addition of cast-in-place arched concrete rib supports with underhung structural steel wale supports has been in service for more than 50 years which is beyond the typical design life for similar structures. The risk of future failure of the tunnel (partial or global collapse) is considered high based on identified design overstress conditions and problems encountered during original construction including lateral displacement/distortion, partial collapse of the structure, and failure of a number of welded and bolted steel connections during backfill operations. As a result, the existing Tunnel 2 structure presents a high potential collapse hazard until such time that physical evaluation of the structural members including bolted and welded connections can be performed.

11. References

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ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

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ASTM A283/A283M-13, 2013, *Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates,* ASTM International, West Conshohocken, Pennsylvania.

ASTM A325/A325M-10, 2010, *Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength,* ASTM International, West Conshohocken, Pennsylvania.

ASTM A15, 1958, *Standard Specification for Billet-Steel Bars for Concrete Reinforcing,* ASTM International, West Conshohocken, Pennsylvania.

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FLUOR Hanford LIDAR Digital Elevation Model(s) & Topographic Contour Maps, 2008, prepared by Aero-Metric, Seattle, Washington.

RHO-R-34-3, 1981, *Geologic and Seismic Investigation of the PUREX Building Site*, URS/John A. Blume & Associates, San Francisco, California.

ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Appendix A

Calculations

Scope: Following the partial roof collapse of Tunnel 1 at the PUREX facility at the Hanford Nuclear Reservation, CH2M was requested to perform an initial structural evaluation of Tunnel No. 2 to determine the overall structural capacity of the tunnel and soil bearing conditions when subjected to current design load conditions. Tunnel 2, which was designed and constructed in 1962-1963, consists of a continuous below-grade arched hangar-style steel structure enclosure used to support 8ft minimum soil cover over the tunnel for radiation shielding purposes. The tunnel was modified during construction in 1964-1965 with a series of retrofit arched cast-in-place concrete ribs using under-hung bolted structural steel supports to further support the original arched steel enclosure after a couple of localized failures occurred during construction backfill operations. The condition of existing structural support members including adverse effects from radiation exposure and corrosion are not known because of the soil back fill along exterior surfaces and inability to physically access the tunnel interior due to high levels of radioactive contamination from the materials stored within the tunnel. This evaluation does not include potential degradation effects from radiation or corrosion.

Codes/References:

- 2012 IBC
- ASCE 7-10
- ACI 318-11
- AISC 360-10 (14th edition LRFD method)
- AWS D1.1/2008

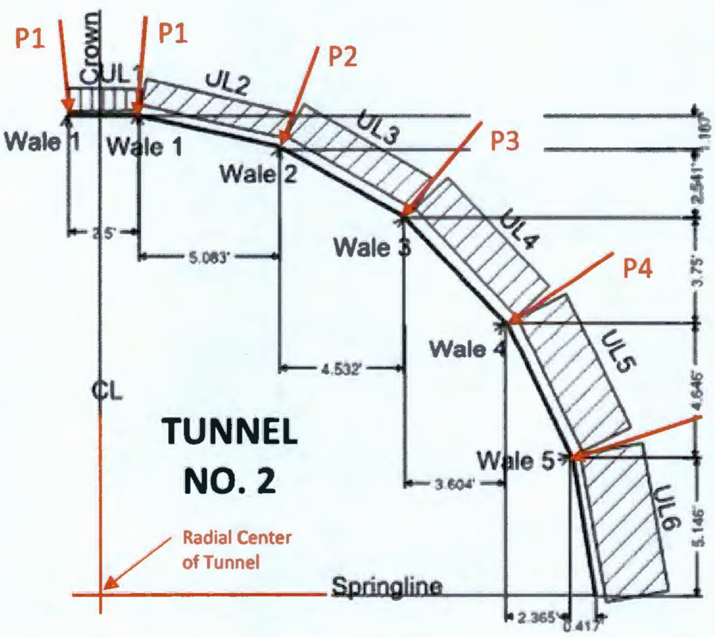
Design Parameters:

- Soil Fill Over Tunnel Roof: 8ft deep
- Soil Unit Weight: 110 pcf (moist in situ)
- Soil Lateral Earth Pressure: per Soil Design Load Parameters Calculations for at-rest pressures
- Ground Snow Load: 15psf
- Concrete Strength: 3,000psi @ 28 days for original continuous wall footings (per Note 1 on Dwg H-2-58194)
  4,000psi @ 28 days for retrofit designed concrete arched ribs and associated concrete thrust block foundations (per General Note 1 on Dwg H-2-58532)
- Reinforcing Bars: ASTM A15-52T, Grade 40 (intermediate grade)
- Bolts: A325-61T
- Tunnel No. 2: 1962 Design Drawings and 1964 Retrofit Repair Drawings
- Radiation Effects: Unknown, not included in evaluation
- Corrosion Effects: Unknown, not included in evaluation
- Tunnel Slope: 0.1% (downward from north to south)
- LRFD Load Factors:
  - Dead Load (DL): 1.2
  - Soil Weight (DL): 1.2
  - Snow Load (S): 1.6
  - Lateral Earth Pressure (H): 1.6

Controlling LRFD Load Combination = 1.2(DL) + 1.6(S) + 1.6(H)

Determine Loads Applied to Structural Support Elements

Unfactored design load pressures were determined in the Soil Design Parameter calculations. The diagram below shows overall tunnel geometry and general design loading conditions.



Structural Supports:

3.14ft o.c. Arched Steel Ribs (37 11/16" spacing)

15.73ft o.c. Arched Concrete Ribs (15'-8.75" spacing)

UL2 = average uniform design load pressure between Wale supports

P3 = design load pressure at Wale Support location

TUNNEL 2 - Geometry Summary

Support	Coordinates X*1 (ft)	Coordinates Y*2 (ft)	Load Segment	Location Start	Location End	Segment*3 Length (ft)	Wale Member	Tributary*4 Width (ft)
E Wale 1	(1.250)	17.753	-	-	-	-	-	-
Crown	-	17.753	UL1	E Wale 1	W Wale 1	2.500	-	-
W Wale 1	1.250	17.753	UL2	Wale 1	Wale 2	5.350	Wale 1	3.925
Wale 2	6.333	16.083	UL3	Wale 2	Wale 3	5.196	Wale 2	5.273
Wale 3	10.865	13.542	UL4	Wale 3	Wale 4	5.201	Wale 3	5.198
Wale 4	14.469	9.792	UL5	Wale 4	Wale 5	5.213	Wale 4	5.207
Wale 5	16.834	5.146	UL6	Wale 5	Springlilne	5.163	Wale 5	5.188
Springline	17.251	-	-	-	-	-	Base	-

FOOTNOTES:

(*1) distance from tunnel crown (at centerline)

(*2) distance from base of tunnel (at centerline)

(*3) load segment length based on coordinate locations = $[(X_2-X_1)2+(Y_2-Y_1)2]^{1/2}$

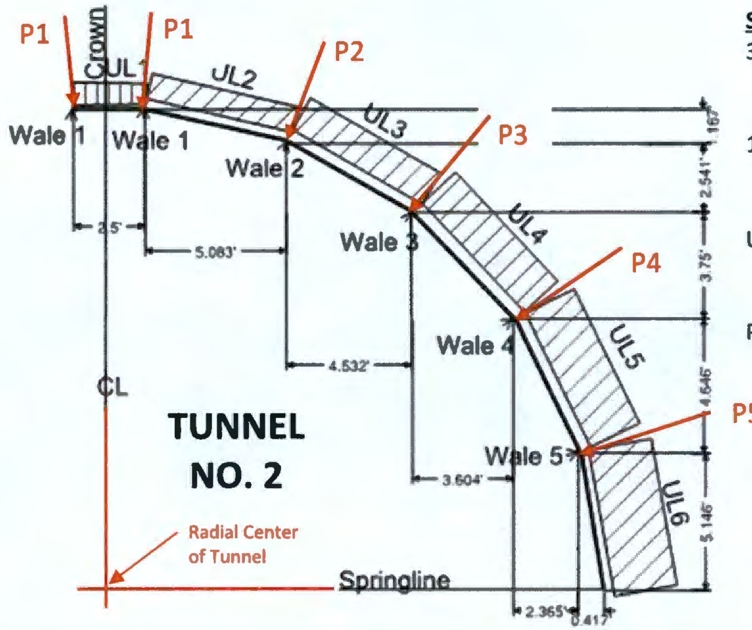
(*4) load segment tributary to Wale Support: Example Wale 2 = (UL2+UL3)/2 = (5.350+5.196)/2 = 5.273

TUNNEL NO. 2

SUMMARY	Normal Stress component of Vertical Effective Stress (psf)			Normal Stress component of Horizontal Lateral Earth Pressure (psf)			Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)			Total Normal Stress on Tunnel (psf)		
Point No.	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX
E. SPRINGLINE	0.0	0.0	0.0	601.8	711.28	892.0	7.5	7.5	7.5	609.3	718.8	899.5
E. WALE 5	479.8	547.4	605.9	413.5	503.58	647.3	11.9	11.9	11.9	905.3	1062.8	1265.1
E. WALE 4	650.2	769.5	854.2	264.7	334.50	431.1	14.8	14.8	14.8	929.7	1118.8	1300.0
E. WALE 3	713.3	865.6	948.2	159.8	206.80	256.1	16.5	16.5	16.5	889.6	1088.8	1194.6
E. WALE 2	853.0	923.2	986.6	162.8	176.15	188.2	16.7	16.7	16.7	1032.4	1116.1	1191.5
E. WALE 1	801.0	891.2	965.6	28.3	31.46	34.1	15.5	15.5	15.5	844.8	938.2	1015.2
CROWN	792.0	889.8	968.0	0.0	0.00	0.0	15.0	15.0	15.0	807.0	904.8	983.0
W. WALE 1	801.0	891.2	965.6	28.3	31.46	34.1	15.5	15.5	15.5	844.8	938.2	1015.2
W. WALE 2	811.9	888.4	966.1	154.9	169.51	184.3	16.7	16.7	16.7	983.5	1074.6	1167.1
W. WALE 3	748.1	833.2	948.2	175.4	208.24	243.6	16.5	16.5	16.5	967.0	1057.9	1200.7
W. WALE 4	682.1	756.1	847.8	280.8	344.21	403.0	14.8	14.8	14.8	980.6	1115.1	1246.1
W. WALE 5	500.8	547.2	602.4	424.6	527.75	622.5	11.9	11.9	11.9	937.3	1086.8	1194.8
W. SPRINGLINE	0.0	0.0	0.0	613.9	746.62	882.4	7.5	7.5	7.5	621.4	754.1	889.9

NOTES:

1. For details of soil geometry and design load development summarized in this table, see Appendix B Soil Design Parameters
2. Highlighted values represent controlling design load used in this Tunnel 2 structural evaluation.



Structural Supports:

3.14ft o.c. — Arched Steel Ribs (37 11/16" spacing)

15.73ft o.c. — Arched Concrete Ribs (15'-8.75" spacing)

UL2 = average uniform design load pressure between Wale supports

P3 = design load pressure at Wale Support location

	Unfactored Normal Applied Loads*1			Unfactored Uniform Load Segments*2						Unfactored Normal Applied Loads*3							Factored Normal Applied Loads*6				
										Steel Rib Supports (6I12.5)*4				LRFD Design Load Factors*5			Steel Rib Supports (6I12.5)*4				
Location	Vert Soil Component (psf)	Horiz Soil Component (psf)	(Vert+Horiz) Snow (psf)	LOAD SEGMENT	Segment Length (ft)	Vert Soil Component (psf)	Horiz Soil Component (psf)	(Vert+Horiz) Snow (psf)	Total Load (psf)	Trib Width (ft)	Vert Soil (klf)	Horiz Soil (klf)	Snow (klf)	Vert Soil Load	Horiz Soil Load	Snow	Trib Width (ft)	Vert Soil (klf)	Horiz Soil (klf)	Snow (klf)	Total (klf)
Crown	968.0	0.0	15.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0
Wale 1	965.6	34.1	15.5	UL1	2.500	968.0	0.0	15.0	983.0	3.146	3.05	0.00	0.05	1.2	1.6	1.6	3.146	3.65	0.00	0.08	3.73
Wale 2	986.6	188.2	16.7	UL2	5.350	976.1	111.2	16.1	1103.4	3.146	3.07	0.35	0.05	1.2	1.6	1.6	3.146	3.68	0.56	0.08	4.33
Wale 3	948.2	256.1	16.5	UL3	5.196	967.4	222.2	16.6	1206.2	3.146	3.04	0.70	0.05	1.2	1.6	1.6	3.146	3.65	1.12	0.08	4.85
Wale 4	854.2	431.1	14.8	UL4	5.201	901.2	343.6	15.7	1260.5	3.146	2.84	1.08	0.05	1.2	1.6	1.6	3.146	3.40	1.73	0.08	5.21
Wale 5	605.9	647.3	11.9	UL5	5.213	730.1	539.2	13.4	1282.6	3.146	2.30	1.70	0.04	1.2	1.6	1.6	3.146	2.76	2.71	0.07	5.54
Springline	0.0	892.0	7.5	UL6	5.163	303.0	769.7	9.7	1082.3	3.146	0.95	2.42	0.03	1.2	1.6	1.6	3.146	1.14	3.87	0.05	5.07

FOOTNOTES:

*1 Values listed represent maximum service load design pressures acting radially inward toward center of arched tunnel base (see Soil Design Parameter Calcs).

*2 Average uniform design load pressure between Wale support locations: Example UL2 = (Wale 2 + Wale 1)/2 = (986.6 + 965.6)/2 = 976.1 psf; UL1 = Crown = 968.0 psf; UL6 = (Springline + Wale 5)/2 = (0.0 + 605.9)/2 = 303.0 psf

*3 Unfactored service load pressure applied at Steel Rib Supports: Example UL1 (vert soil) = 968 psf * 3.146 ft = 3.05 klf

*4 Tributary width based on steel rib spacing of 37.75 inches = 3.146 ft

*5 LRFD design load factors per 2012 IBC.

*6 LRFD factored uniform design loads applied to Steel Rib support members.

STEEL RIB BEAMS

Per the existing drawings, all steel rib beams are A36, 6I12.5, spaced at 3.14ft (Tributary Width), spanning 5.2ft max between wale beams.

Section Index and Nominal Size	District Rolled	Weight per Foot	Area of Section	Depth of Beam	Width of Flange	Aver. Flange Thickness	Web Thickness	Axis 1-1			Axis 2-2		
								I	S	r	I	S	r
		Lbs.	In.²	In.	In.	In.	In.	In.⁴	In.³	In.	In.⁴	In.³	In.
6" I													
★ B 14	P.C.B.G.S.	17.25	5.02	6	3.565	.359	.465	26.0	8.7	2.28	2.3	1.3	0.68
6 x 3⅜	P.C.B.G.S.	12.5	3.61		3.330	.359	.230	21.8	7.3	2.46	1.8	1.1	0.72
R=.33													

Properties are similar to **S6x12.5, which are:**

$I_{XX} = 22 \cdot in^4$ $S_{XX} = 7.34 \cdot in^3$ $Z_{XX} = 8.45 \cdot in^3$ $r_{XX} = 2.45 \cdot in$

WALE BEAMS

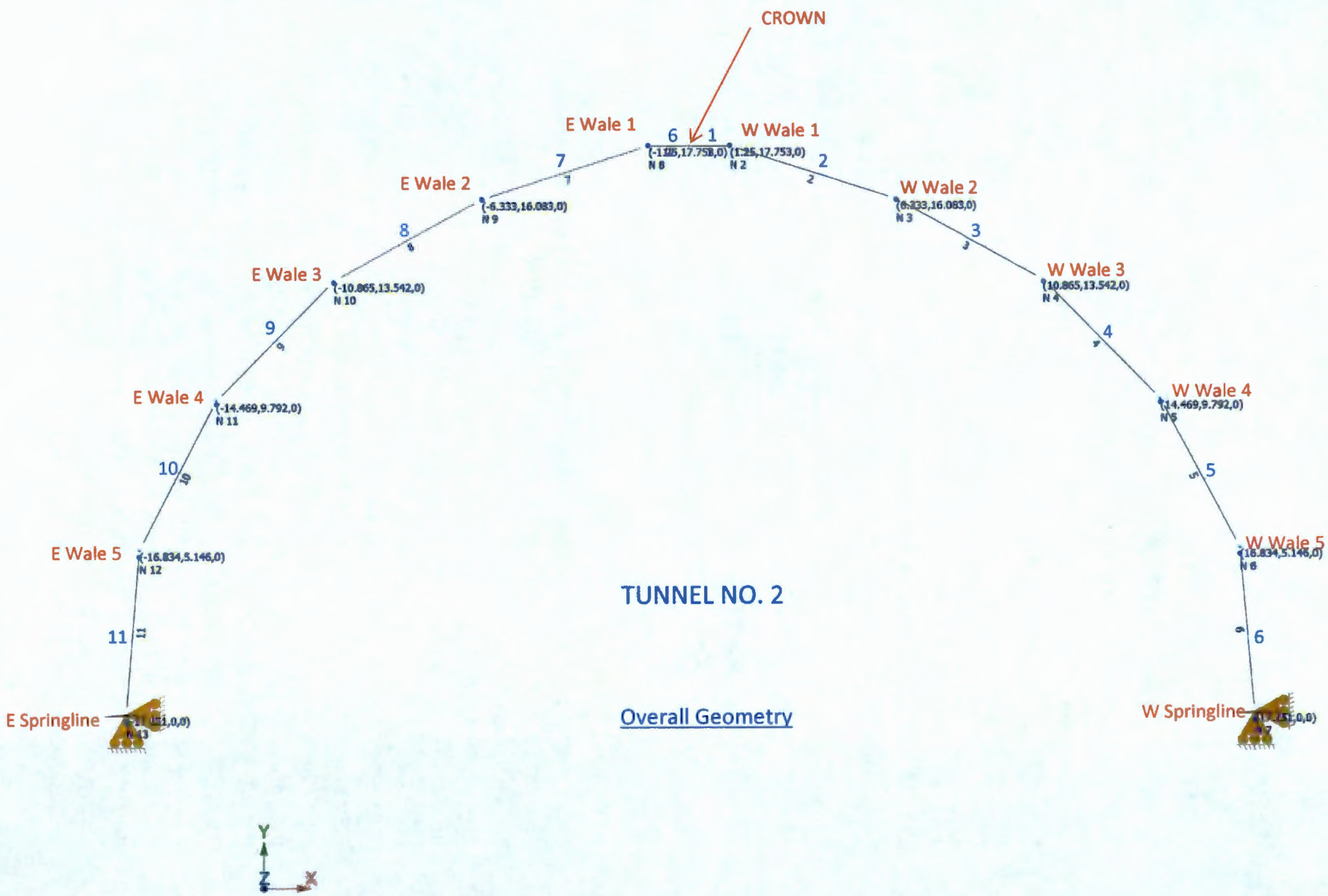
Per the existing drawings (see excerpt below), there are 5 Wale Beams (each side of tunnel). They span 15.73ft between concrete ribs and are spaced at 5.2ft. They are spliced at eavery other support, creating a propped cantilever system. The beams are specified as 12WF31, 12WF27, and 10WF25.

Section Index and Nominal Size	Weight per Foot	Area of Section	Depth of Section	Flange		Web Thickness	Axis 1-1			Axis 2-2		
				Width	Thickness		I	S	r	I	S	r
	Lbs.	In.²	In.	In.	In.	In.	In.⁴	In.³	In.	In.⁴	In.³	In.
12" WF CB 121 12 x 6½ R=.37	36	10.59	12.24	6.565	.540	.305	280.8	45.9	5.15	23.7	7.2	1.50
	31	9.12	12.09	6.525	.465	.265	238.4	39.4	5.11	19.8	6.1	1.47
	27	7.97	11.96	6.500	.400	.240	204.1	34.1	5.06	16.6	5.1	1.44
10" WF CB 101 10 x 5¾ R=.32	29	8.53	10.22	5.799	.500	.289	157.3	30.8	4.29	15.2	5.2	1.34
	25	7.35	10.08	5.762	.430	.252	133.2	26.4	4.26	12.7	4.4	1.31
	21	6.19	9.90	5.750	.340	.240	106.3	21.5	4.14	9.7	3.4	1.25

The 12WFs are very similar to W12x30, W12x26, while the properties of the 10WF25 fall between a W10x22 and a W10x26. A W10x22 will be used in the analysis, with the understanding that there is additional 13% +/- capacity in the actual existing beam.

ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Arched Steel Rib Beam Analysis

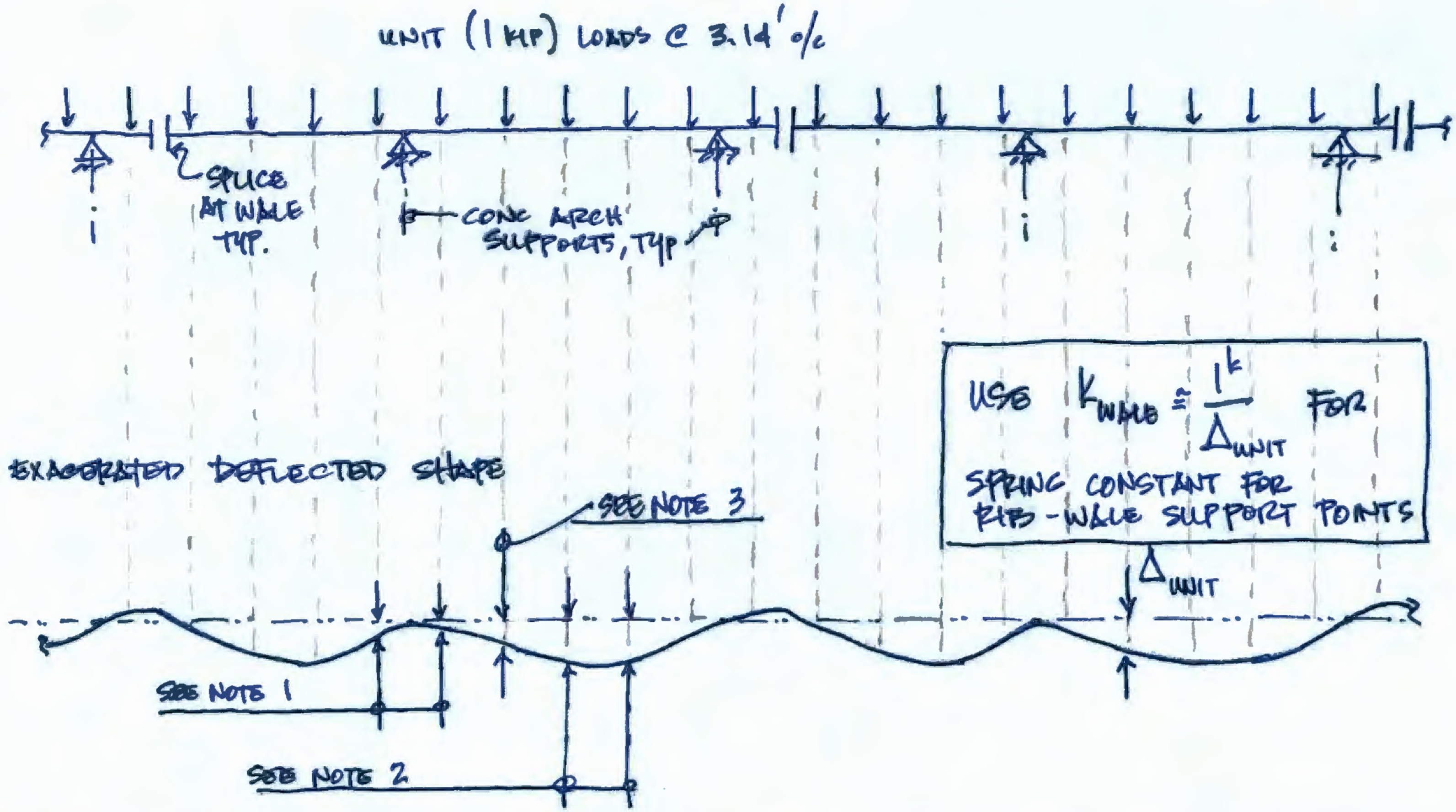

CROWN
E Wale 1
W Wale 1
E Wale 2
W Wale 2
E Wale 3
W Wale 3
E Wale 4
W Wale 4
E Wale 5
W Wale 5
E Springline
W Springline
(-6.333,16.083,0)
(6.333,16.083,0)
(-10.865,13.542,0)
(10.865,13.542,0)
(-14.469,9.792,0)
(14.469,9.792,0)
(-16.834,5.146,0)
(16.834,5.146,0)
(1.25,17.753,0)
N 2
N 3
N 4
N 5
N 6
N 8
N 9
N 10
N 11
N 12
N 13
TUNNEL NO. 2
Overall Geometry
Y
Z
X

STEEL RIB - WALE INTERACTION

THE ORIGINAL STEEL RIBS FORMING THE "QUONSET" SHAPE ARE SUPPORTED INTERNALLY BY LONGITUDINAL WALE BEAMS, WHICH SPAN TO CONCRETE ARCHES INSTALLED EVERY FIFTH RIB. THE INTERACTION OF THE RIBS AND WALES IS BASED ON THEIR RELATIVE STIFFNESS.

AN APPROXIMATION OF THE STIFFNESS OF THE WALES IS MADE BY CALCULATING THE DEFLECTED SHAPE OF THE WALE UNDER A SERIES OF UNIT LOADS (1 KIP) SPACED TO MATCH THE STEEL RIB LAYOUT. THE WALE IS PINNED TO EACH CONCRETE ARCH, AND THE PROPPED-CANTILEVER CONFIGURATION IS TAKEN INTO ACCOUNT. SEE THE ATTACHED SKETCH.

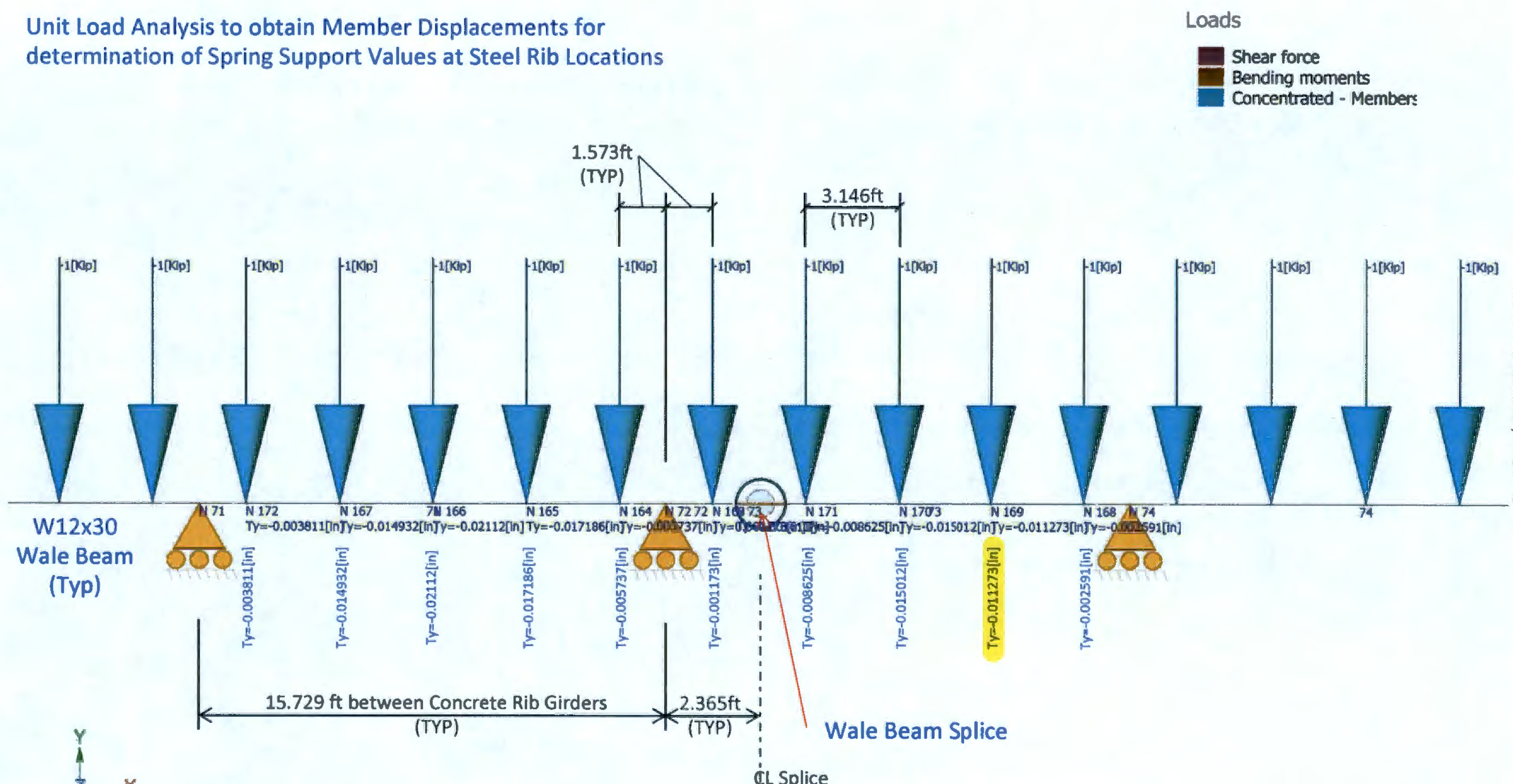
NOTE:
This structural behavior of the arched steel ribs/wale beams/arched concrete rib girder system is a function of the relative stiffnesses of the components at their respective points of interaction (attachments). The current structural evaluation is based on a two-dimensional (2-D) analysis using an approximation of one such point of interaction – the relative stiffness of wale beam at the steel rib/wale beam attachment located approximately at the third point of the wale span between arched concrete rib girders. Additional analysis would be required to more accurately account for the variable relative stiffness of the wale beam member along its full length. Arched steel rib supports located near concrete rib girders would see stiffer support from the wale beam than those located between concrete rib girders which means more of the applied load would be carried by the wale beam than by that steel rib in arching action at that location. A more rigorous three-dimensional (3-D) analysis of the tunnel structure would be required to account for this complex 2-way behavior interaction in order to more accurately determine distribution of design loads and forces to each member.



NOTES

1. THE RIBS CLOSEST TO THE CONCRETE ARCH WILL RECIEVE THE STIFFEST SUPPORT FROM THE WALE, SINCE THE WALE CANNOT DEFLECT AS MUCH NEAR THE CONCRETE ARCH.
2. THE RIBS LOCATED NEAR THE WALE MIDSPAN WILL RECIEVE THE LEAST SUPPORT FROM THE WALE, CONSEQUENTLY THE STRESSES IN THESE RIBS ESTABLISH A RELATIVE UPPER BOUND FOR THE PURPOSES OF THIS ANALYSIS.
3. THE RIBS AT ROUGHLY THIRD POINTS OF THE WALE SPAN CAN BE TAKEN AS AN AVERAGE CONDITION. AN ARCH MODELED WITH SPRING SUPPORTS WILL PROVIDE REACTION VALUES FOR WALE, WALE SUPPORT ANCHORAGE, AND CONCRETE ARCH ANALYSIS

Unit Load Analysis to obtain Member Displacements for determination of Spring Support Values at Steel Rib Locations



P = kΔ   where P = 1.0 kip and Δ = 0.011273" (representative design displacement)

W12x30 Wale Beam Spring Support Constant = 1.00 k / 0.011273 in =88.7 k/in

Tunnel 2

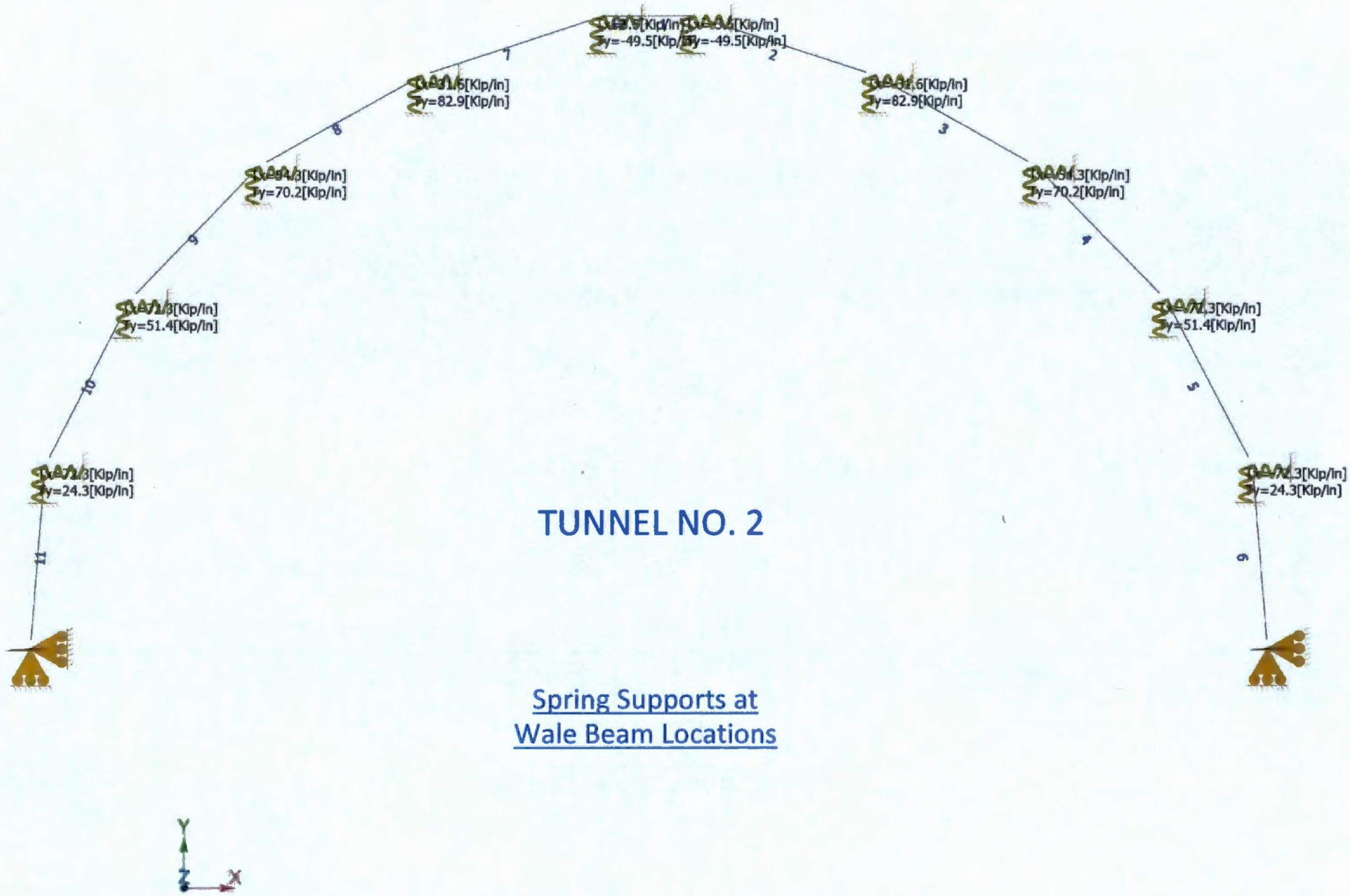
Arched Steel Rib Spring Supports

Location	X (ft)	Y (ft)	R (ft)	Actual		Analysis Basis		Deflect	Wale	Nominal Support Stiffness			Adjusted Support Stiffness		
				Wale Section	I_{xx} (in^4)	Member Section	I_{xxi} (in^4)	Adjust Factor	I.D.	R_o [*1] (k/in)	R_{ox} (k/in)	R_{oy} (k/in)	R_{tot} [*2] (k/in)	R_x (k/in)	R_y (k/in)
Crown	-	17.750	17.750	-	-	-	-	-	-	-	-	-	-	-	-
Wale 1	1.250	17.708	17.752	W10x25	133.2	W12x30	238.0	0.56	**P1**	88.7	6.2	88.5	49.7	3.5	49.5
Wale 2	6.333	16.583	17.752	W12x31	238.4	W12x30	238.0	1.00	**P2**	88.7	31.6	82.9	88.7	31.6	82.9
Wale 3	10.865	14.042	17.754	W12x31	238.4	W12x30	238.0	1.00	**P3**	88.7	54.3	70.2	88.7	54.3	70.2
Wale 4	14.469	10.292	17.756	W12x31	238.4	W12x30	238.0	1.00	**P4**	88.7	72.3	51.4	88.7	72.3	51.4
Wale 5	16.833	5.646	17.755	W12x27	204.1	W12x30	238.0	0.86	**P5**	88.7	84.1	28.2	76.3	72.3	24.3
Springline	17.750	-	17.750	-	-	-	-	-	-	-	-	-	-	-	-

Equivalency: $(R_{tot} / R) = (R_x / X_i) = (R_y / Y_i)$ $R_x = (R_{tot} / R) * X$ $R_y = (R_{tot} / R) * Y$

NOTES:

1. R_o = determined based on 0.011273-inch design deflection for continuous longitudinal W12x30 Wale beam
2. $R_{tot} = R_o$ * (adjustment factor); Wale 1: R_{tot} = (88.7k/in)*(0.56) = 49.7 k/in
3. Example (Wale 4): R_{ox} = ([88.7k/in]/17.756ft) * 14.469ft = 72.3 k/in R_x = ([88.7k/in]/17.756ft) * 14.469ft = 72.3 k/in
R_{oy} = ([88.7k/in]/17.756ft) * 10.292ft = 51.4 k/in R_y = ([88.7k/in]/17.756ft) * 10.292ft = 51.4 k/in


TUNNEL NO. 2
Spring Supports at
Wale Beam Locations
y=-49.5[Kip/in]
y=82.9[Kip/in]
y=70.2[Kip/in]
y=51.4[Kip/in]
y=24.3[Kip/in]
Y
X
Z

Geometry data

GLOSSARY

Cb22, Cb33	: Moment gradient coefficients
Cm22, Cm33	: Coefficients applied to bending term in interaction formula
d0	: Tapered member section depth at J end of member
DJX	: Rigid end offset distance measured from J node in axis X
DJY	: Rigid end offset distance measured from J node in axis Y
DJZ	: Rigid end offset distance measured from J node in axis Z
DKX	: Rigid end offset distance measured from K node in axis X
DKY	: Rigid end offset distance measured from K node in axis Y
DKZ	: Rigid end offset distance measured from K node in axis Z
dL	: Tapered member section depth at K end of member
Ig factor	: Inertia reduction factor (Effective Inertia/Gross Inertia) for reinforced concrete members
K22	: Effective length factor about axis 2
K33	: Effective length factor about axis 3
L22	: Member length for calculation of axial capacity
L33	: Member length for calculation of axial capacity
LB pos	: Lateral unbraced length of the compression flange in the positive side of local axis 2
LB neg	: Lateral unbraced length of the compression flange in the negative side of local axis 2
RX	: Rotation about X
RY	: Rotation about Y
RZ	: Rotation about Z
TO	: 1 = Tension only member 0 = Normal member
TX	: Translation in X
TY	: Translation in Y
TZ	: Translation in Z

Nodes

Node	X [ft]	Y [ft]	Z [ft]	Rigid Floor
1	0.00	17.753	0.00	0
2	1.25	17.753	0.00	0
3	6.333	16.083	0.00	0
4	10.865	13.542	0.00	0
5	14.469	9.792	0.00	0
6	16.834	5.146	0.00	0
7	17.251	0.00	0.00	0
8	-1.25	17.753	0.00	0
9	-6.333	16.083	0.00	0
10	-10.865	13.542	0.00	0
11	-14.469	9.792	0.00	0
12	-16.834	5.146	0.00	0
13	-17.251	0.00	0.00	0

Restraints

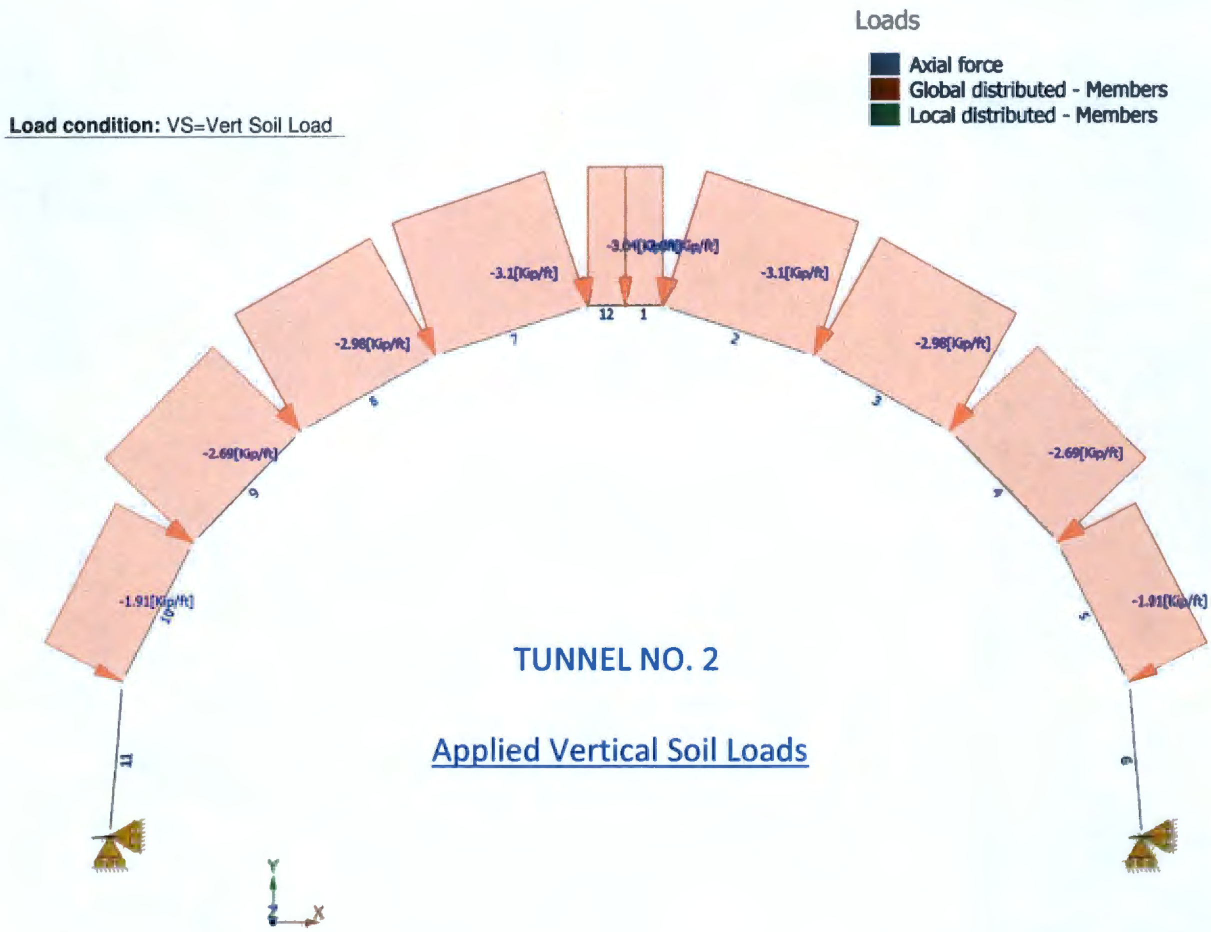
Node	TX	TY	TZ	RX	RY	RZ
7	1	1	1	0	0	0
13	1	1	1	0	0	0

Springs

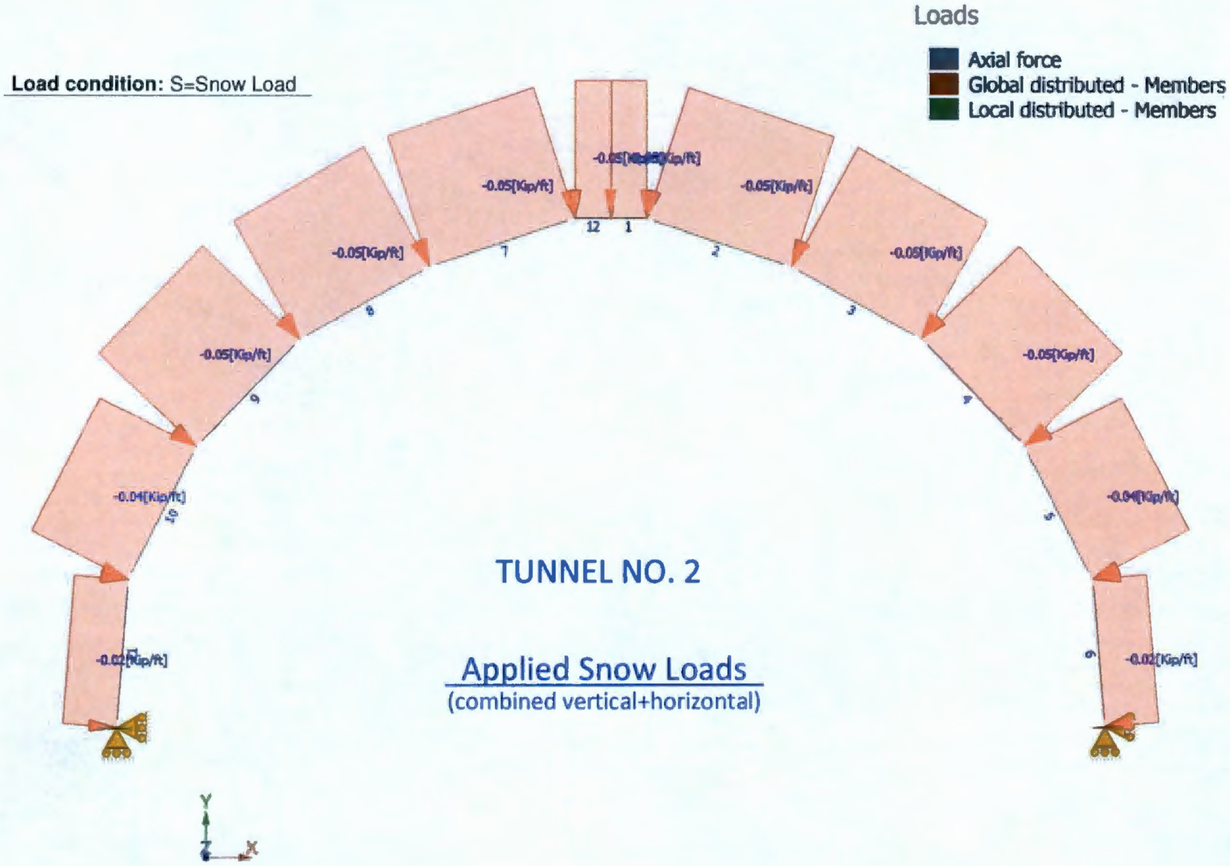
Node	TX [Kip/in]	TY [Kip/in]	TZ [Kip/in]	RX [Kip*ft/rad]	RY [Kip*ft/rad]	RZ [Kip*ft/rad]
2	-3.50	-49.50	0.00	0.00	0.00	0.00
3	-31.60	82.90	0.00	0.00	0.00	0.00
4	-54.30	70.20	0.00	0.00	0.00	0.00
5	-72.30	51.40	0.00	0.00	0.00	0.00
6	-72.30	24.30	0.00	0.00	0.00	0.00
8	3.50	-49.50	0.00	0.00	0.00	0.00
9	31.60	82.90	0.00	0.00	0.00	0.00
10	54.30	70.20	0.00	0.00	0.00	0.00
11	72.30	51.40	0.00	0.00	0.00	0.00
12	72.30	24.30	0.00	0.00	0.00	0.00

Members

Member	NJ	NK	Description	Section	Material	d0 [in]	dL [in]	Ig factor
1	1	2	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
2	2	3	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
3	3	4	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
4	4	5	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
5	5	6	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
6	6	7	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
7	8	9	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
8	9	10	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
9	10	11	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
10	11	12	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
11	12	13	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00
12	1	8	Arched Steel Rib	S 6X12.5	A36	0.00	0.00	0.00


Loads
Axial force
Global distributed - Members
Local distributed - Members
Load condition: VS=Vert Soil Load
-3.1[Kip/ft]
-2.98[Kip/ft]
-2.69[Kip/ft]
-1.91[Kip/ft]
TUNNEL NO. 2
Applied Vertical Soil Loads


Load condition: HS=Horiz Soil Load
-0.59[Kip/ft]
-0.81[Kip/ft]
-1.36[Kip/ft]
-2.04[Kip/ft]
-2.81[Kip/ft]
TUNNEL NO. 2
Applied Lateral Earth Pressure Loads


Loads
Axial force
Global distributed - Members
Local distributed - Members
Load condition: S=Snow Load
-0.05[Kip/ft]
-0.04[Kip/ft]
-0.02[Kip/ft]
TUNNEL NO. 2
Applied Snow Loads
(combined vertical+horizontal)

Load data

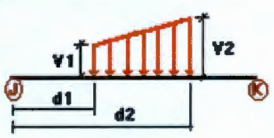
GLOSSARY

Comb : Indicates if load condition is a load combination

Load conditions

Condition	Description	Comb.	Category
DL	Dead Load	No	DL
VS	Vert Soil Load	No	EARTH
HS	Horiz Soil Load	No	EARTH
S	Snow Load	No	SNOW
S1	DL+VS+HS+S	Yes	
C1	1.2DL+1.2VS+1.6HS+1.6S	Yes	

Distributed force on members



Condition	Member	Dir1	Val1 [Kip/ft]	Val2 [Kip/ft]	Dist1 [ft]	%	Dist2 [ft]	%
VS	1	2	-3.04	0.00	0.00	No	0.00	No
	2	2	-3.10	0.00	0.00	No	0.00	No
	3	2	-2.98	0.00	0.00	No	0.00	No
	4	2	-2.69	0.00	0.00	No	0.00	No
	5	2	-1.91	0.00	0.00	No	0.00	No
	6	2	0.00	0.00	0.00	No	0.00	No
	7	2	-3.10	0.00	0.00	No	0.00	No
	8	2	-2.98	0.00	0.00	No	0.00	No
	9	2	-2.69	0.00	0.00	No	0.00	No
	10	2	-1.91	0.00	0.00	No	0.00	No
	11	2	0.00	0.00	0.00	No	0.00	No
	12	2	-3.04	0.00	0.00	No	0.00	No
HS	1	2	-0.11	0.00	0.00	No	0.00	No
	2	2	-0.59	0.00	0.00	No	0.00	No
	3	2	-0.81	0.00	0.00	No	0.00	No
	4	2	-1.36	0.00	0.00	No	0.00	No
	5	2	-2.04	0.00	0.00	No	0.00	No
	6	2	-2.81	0.00	0.00	No	0.00	No
	7	2	-0.59	0.00	0.00	No	0.00	No
	8	2	-0.81	0.00	0.00	No	0.00	No
	9	2	-1.36	0.00	0.00	No	0.00	No
	10	2	-2.04	0.00	0.00	No	0.00	No
	11	2	-2.81	0.00	0.00	No	0.00	No
	12	2	-0.11	0.00	0.00	No	0.00	No
S	1	2	-0.05	0.00	0.00	No	0.00	No
	2	2	-0.05	0.00	0.00	No	0.00	No
	3	2	-0.05	0.00	0.00	No	0.00	No

4	2	-0.05	0.00	0.00	No	0.00	No
5	2	-0.04	0.00	0.00	No	0.00	No
6	2	-0.02	0.00	0.00	No	0.00	No
7	2	-0.05	0.00	0.00	No	0.00	No
8	2	-0.05	0.00	0.00	No	0.00	No
9	2	-0.05	0.00	0.00	No	0.00	No
10	2	-0.04	0.00	0.00	No	0.00	No
11	2	-0.02	0.00	0.00	No	0.00	No
12	2	-0.05	0.00	0.00	No	0.00	No

Self weight multipliers for load conditions

		Self weight multiplier			
Condition	**Description**	**Comb.**	**MultX**	**MultY**	**MultZ**
DL	Dead Load	No	0.00	-1.00	0.00
VS	Vert Soil Load	No	0.00	0.00	0.00
HS	Horiz Soil Load	No	0.00	0.00	0.00
S	Snow Load	No	0.00	0.00	0.00
S1	DL+VS+HS+S	Yes	0.00	0.00	0.00
C1	1.2DL+1.2VS+1.6HS+1.6S	Yes	0.00	0.00	0.00

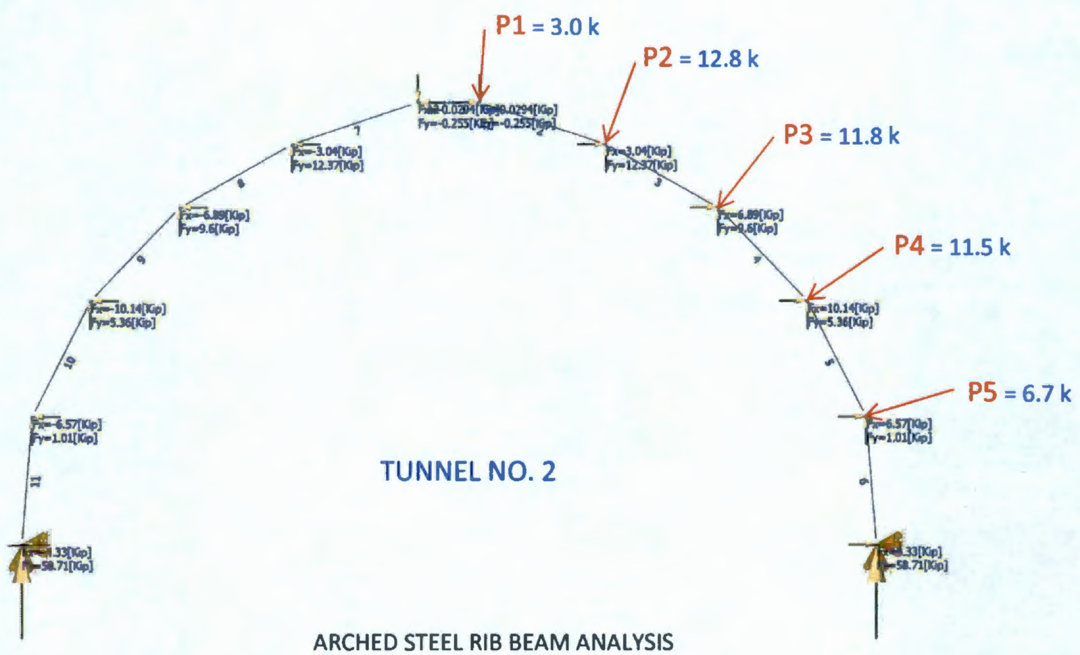
Earthquake (Dynamic analysis only)

Condition	a/g	Ang. [Deg]	Damp. [%]
DL	0.00	0.00	0.00
VS	0.00	0.00	0.00
HS	0.00	0.00	0.00
S	0.00	0.00	0.00
S1	0.00	0.00	0.00
C1	0.00	0.00	0.00

Load condition: C1=1.2DL+1.2VS+1.6HS+1.6S

Px = Spring Support Reaction at Wale Support Location (radial direction)
= Load Applied to Wale Beam Supports

Example: $P3 = [(F_x^2)+(F_y^2)]^{0.5} = [(6.89k)^2+(9.6k)^2]^{0.5} = 11.8\ k$



ARCHED STEEL RIB BEAM ANALYSIS

SPRING SUPPORT REACTIONS

LRFD FACTORED LOADS
1.2(DL) + 1.6(S) + 1.6(H)

Steel Code Check

Report: Comprehensive

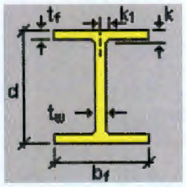
Members: Hot-rolled
Design code: AISC 360-2010 LRFD

Member	:	**1 (Arched Steel Rib)**
Design status	:	**OK**

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	**Unit**	**Major axis**	**Minor axis**
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	1.00

Distance between member lateral bracing points

Length (Lb) [ft] Top	Bottom
1.25	1.25

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
1.25	1.00	1.25	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	:	0.00		
Capacity	:	118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	:	0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	:	0.50		
Capacity	:	118.35 [Kip]	Reference	: Sec. E1
Demand	:	59.49 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	118.35	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	1.25	
Effective slenderness ($(KL/r)_{33}$)	--	6.12	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	7646.40	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	35.93	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	131.50	Eq. E3-1

Compression in the minor axis 22

Ratio	: 0.51		
Capacity	: 116.49 [Kip]	Reference	: Sec. E4
Demand	: 59.49 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	116.49	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	1.25	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	845.07	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	845.07	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	35.36	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	129.43	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	: 0.55			
Capacity	: 22.82 [Kip*ft]	Reference	: Sec. F1	
Demand	: -12.54 [Kip*ft]	Ctrl Eq.	: C1 at 100.00%	

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1

Bending about minor axis, M22

Ratio	: 0.00		
Capacity	: 4.67 [Kip*ft]	Reference	: Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	: 0.00		
Capacity	: 46.46 [Kip]		
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	:	0.16			
Capacity	:	30.02 [Kip]	Reference	:	Sec. G2.1(a)
Demand	:	-4.90 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✔

Combined flexure and axial compression

Ratio	:	0.99			
Ctrl Eq.	:	C1 at 100.00%	Reference	:	Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	0.99	Eq. H1-1a
In-plane required flexural strength (M_{r33})	[Kip*ft]	-12.54	
In-plane available flexural strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (P_r)	[Kip]	59.49	
In-plane available axial compressive strength (P_c)	[Kip]	118.35	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.86	Eq. H1-2
Out-of-plane required flexural strength (M_{r33})	[Kip*ft]	-12.54	
Out-of-plane available flexural-torsional strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (P_r)	[Kip]	59.49	
Out-of-plane available axial compressive strength (P_{co})	[Kip]	116.49	Sec. E4

Combined flexure and axial tension

Ratio	:	0.55			
Ctrl Eq.	:	C1 at 100.00%	Reference	:	Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-12.54	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (P_r)	[Kip]	0.00	
Available axial tensile strength (P_c)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	:	N/A			
Ctrl Eq.	:	--	Reference	:	

Combined flexure and axial tension about local axis

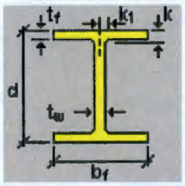
Ratio	:	N/A			
Ctrl Eq.	:	--	Reference	:	

Member : **2 (Arched Steel Rib)**
Design status : **OK**

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	5.35

Distance between member lateral bracing points

Length (Lb) [ft] Top	Bottom
5.35	5.35

Laterally unbraced length

Length [ft] Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Effective length factor Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
5.35	1.00	5.35	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.51		
Capacity	: 114.38 [Kip]	Reference	: Sec. E1
Demand	: 58.18 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	114.38	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	5.35	
Effective slenderness ($(KL/r)_{33}$)	--	26.19	Eq. E3-4
Elastic critical buckling stress (Fe_{33})	[Kip/in2]	417.37	Eq. E3-4
Reduction factor for slender unstiffened elements (Qs_{33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Qa_{33})	--	1.00	

Full reduction factor for slender elements (Q33)	--	1.00	Sec. E7
Critical stress for flexural buckling (Fcr33)	[Kip/in2]	34.72	Eq. E3-2
Nominal flexural buckling strength (Pn33)	[Kip]	127.09	Eq. E3-1

Compression in the minor axis 22

Ratio	: 0.55			
Capacity	: 104.86 [Kip]	Reference	: Sec. E4
Demand	: 58.18 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕPn22)	[Kip]	116.77	Sec. E1
Effective length factor (K22)	--	1.00	
Unbraced length (L22)	[ft]	1.00	
Effective slenderness ((KL/r)22)	--	17.11	Eq. E3-4
Elastic critical buckling stress (Fe22)	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Qs22)	--	1.00	
Effective area of the cross section based on the effective width (Aeff22)	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Qa22)	--	1.00	
Full reduction factor for slender elements (Q22)	--	1.00	Sec. E7
Critical stress for flexural buckling (Fcr22)	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (Pn22)	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕPn11)	[Kip]	104.86	Sec. E4
Effective length factor (K11)	--	1.00	
Unbraced length (L11)	[ft]	5.35	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (Fe11)	[Kip/in2]	122.47	Eq. E4-4
Elastic torsional buckling stress (Fez)	[Kip/in2]	122.47	Eq. E4-9
Reduction factor for slender unstiffened elements (Qs11)	--	1.00	
Effective area of the cross section based on the effective width (Aeff11)	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Qa11)	--	1.00	
Full reduction factor for slender elements (Q11)	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (Fcr11)	[Kip/in2]	31.83	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (Pn11)	[Kip]	116.51	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	: 0.55		
Capacity	: 22.82 [Kip*ft]	Reference	: Sec. F1
Demand	: -12.54 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕMn)	[Kip*ft]	22.82	Sec. F1

Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	2.92	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	0.83	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (L_r	[ft]	14.47	Eq. F2-6
Lateral-torsional buckling modification factor (C_b)	--	2.06	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	167.38	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	25.35	Eq. F2-2

Bending about minor axis, M22

Ratio	:	0.00			
Capacity	:	4.67 [Kip*ft]	Reference	:	Sec. F1
Demand	:	0.00 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	:	0.00			
Capacity	:	46.46 [Kip]			
Demand	:	0.00 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	:	0.46			
Capacity	:	30.02 [Kip]	Reference	:	Sec. G2.1(a)
Demand	:	13.68 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✔

Combined flexure and axial compression

Ratio	:	1.00		
Ctrl Eq.	:	C1 at 0.00%	Reference	: Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	1.00	Eq. H1-1a
In-plane required flexural strength (Mr33)	[Kip*ft]	-12.54	
In-plane available flexural strength (Mc33)	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (Pr)	[Kip]	58.16	
In-plane available axial compressive strength (Pc)	[Kip]	114.38	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.75	Eq. H1-2
Out-of-plane required flexural strength (Mr33)	[Kip*ft]	-12.54	
Out-of-plane available flexural-torsional strength (Mc33)	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (Pr)	[Kip]	58.16	
Out-of-plane available axial compressive strength (Pco)	[Kip]	104.86	Sec. E4

Combined flexure and axial tension

Ratio	:	0.55		
Ctrl Eq.	:	C1 at 0.00%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (Mr33)	[Kip*ft]	-12.54	
Available flexural strength about strong axis (Mc33)	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (Mr22)	[Kip*ft]	0.00	
Available flexural strength about weak axis (Mc22)	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (Pr)	[Kip]	0.00	
Available axial tensile strength (Pc)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Combined flexure and axial tension about local axis

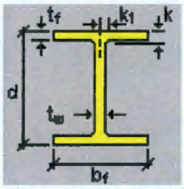
Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Member : 3 (Arched Steel Rib)
Design status : OK

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	5.20

Distance between member lateral bracing points

Length (Lb) [ft] Top	Bottom
5.20	5.20

Laterally unbraced length

Length [ft] Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Effective length factor Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
5.20	1.00	5.20	1.0	1.0	1.0

Additional assumptions	
Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.49		
Capacity	: 114.61 [Kip]	Reference	: Sec. E1
Demand	: 56.00 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	114.61	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	5.20	
Effective slenderness ($(KL/r)_{33}$)	--	25.43	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	442.57	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	34.79	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	127.35	Eq. E3-1

Compression in the minor axis 22

Ratio	:	0.53			
Capacity	:	105.12 [Kip]	Reference	:	Sec. E4
Demand	:	56.00 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	105.12	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	5.20	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	124.99	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	124.99	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	31.91	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	116.80	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	:	0.55			
Capacity	:	22.82 [Kip*ft]	Reference	:	Sec. F1
Demand	:	-12.58 [Kip*ft]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	2.92	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	0.83	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (Lr	[ft]	14.47	Eq. F2-6

Lateral-torsional buckling modification factor (C_b)	--	2.13	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	180.41	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	25.35	Eq. F2-2

Bending about minor axis, M22

Ratio	: 0.00			
Capacity	: 4.67 [Kip*ft]	Reference	:	Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	: 0.00			
Capacity	: 46.46 [Kip]			
Demand	: 0.00 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.46			
Capacity	: 30.02 [Kip]	Reference	:	Sec. G2.1(a)
Demand	: -13.89 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✔

Combined flexure and axial compression

Ratio	: 0.98		
Ctrl Eq.	: C1 at 100.00%	Reference	: Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	0.98	Eq. H1-1a
In-plane required flexural strength (Mr33)	[Kip*ft]	-12.58	
In-plane available flexural strength (Mc33)	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (Pr)	[Kip]	56.00	
In-plane available axial compressive strength (Pc)	[Kip]	114.61	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.72	Eq. H1-2
Out-of-plane required flexural strength (Mr33)	[Kip*ft]	-12.58	
Out-of-plane available flexural-torsional strength (Mc33)	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (Pr)	[Kip]	56.00	
Out-of-plane available axial compressive strength (Pco)	[Kip]	105.12	Sec. E4

Combined flexure and axial tension

Ratio	: 0.55		
Ctrl Eq.	: C1 at 100.00%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (Mr33)	[Kip*ft]	-12.58	
Available flexural strength about strong axis (Mc33)	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (Mr22)	[Kip*ft]	0.00	
Available flexural strength about weak axis (Mc22)	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (Pr)	[Kip]	0.00	
Available axial tensile strength (Pc)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	: N/A		
Ctrl Eq.	: --	Reference	:

Combined flexure and axial tension about local axis

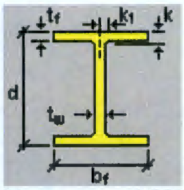
Ratio	: N/A		
Ctrl Eq.	: --	Reference	:

Member : 4 (Arched Steel Rib)
Design status : OK

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	5.20

Distance between member lateral bracing points

Length (Lb) [ft] Top	Bottom
5.20	5.20

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
5.20	1.00	5.20	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.48		
Capacity	: 114.61 [Kip]	Reference	: Sec. E1
Demand	: 55.53 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	114.61	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	5.20	
Effective slenderness ($(KL/r)_{33}$)	--	25.46	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	441.66	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	34.79	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	127.34	Eq. E3-1

Compression in the minor axis 22

Ratio	: 0.53			
Capacity	: 105.11 [Kip]		Reference	: Sec. E4
Demand	: 55.53 [Kip]		Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	105.11	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	5.20	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	124.90	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	124.90	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	31.91	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	116.79	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	: 0.55			
Capacity	: 22.82 [Kip*ft]		Reference	: Sec. F1
Demand	: -12.58 [Kip*ft]		Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	2.92	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	0.83	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (L_r	[ft]	14.47	Eq. F2-6

Lateral-torsional buckling modification factor (C_b)	--	2.22	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	187.83	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	25.35	Eq. F2-2

Bending about minor axis, M22

Ratio	:	0.00		
Capacity	:	4.67 [Kip*ft]	Reference	: Sec. F1
Demand	:	0.00 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	:	0.00		
Capacity	:	46.46 [Kip]		
Demand	:	0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (Aw)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	:	0.49		
Capacity	:	30.02 [Kip]	Reference	: Sec. G2.1(a)
Demand	:	14.56 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (Aw)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✔

Combined flexure and axial compression

Ratio	:	0.97		
Ctrl Eq.	:	C1 at 0.00%	Reference	: Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	0.97	Eq. H1-1a
In-plane required flexural strength (M_{r33})	[Kip*ft]	-12.58	
In-plane available flexural strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (P_r)	[Kip]	55.48	
In-plane available axial compressive strength (P_c)	[Kip]	114.61	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.71	Eq. H1-2
Out-of-plane required flexural strength (M_{r33})	[Kip*ft]	-12.58	
Out-of-plane available flexural-torsional strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (P_r)	[Kip]	55.48	
Out-of-plane available axial compressive strength (P_{co})	[Kip]	105.11	Sec. E4

Combined flexure and axial tension

Ratio	:	0.55		
Ctrl Eq.	:	C1 at 0.00%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-12.58	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (P_r)	[Kip]	0.00	
Available axial tensile strength (P_c)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Combined flexure and axial tension about local axis

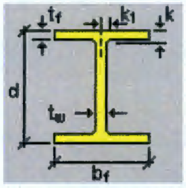
Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Member : 5 (Arched Steel Rib)
Design status : N.G.

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	5.21

Distance between member lateral bracing points

Length (Lb) [ft] Top	Bottom
5.21	5.21

Laterally unbraced length

Length [ft] Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Effective length factor Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
5.21	1.00	5.21	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.50		
Capacity	: 114.59 [Kip]	Reference	: Sec. E1
Demand	: 57.10 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	114.59	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	5.21	
Effective slenderness ($(KL/r)_{33}$)	--	25.52	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	439.59	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	34.79	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	127.32	Eq. E3-1

Compression in the minor axis 22

Ratio	:	0.54			
Capacity	:	105.09 [Kip]	Reference	:	Sec. E4
Demand	:	57.10 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	105.09	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	5.21	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	124.69	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	124.69	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	31.90	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	116.76	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	:	0.60			
Capacity	:	22.82 [Kip*ft]	Reference	:	Sec. F1
Demand	:	-13.61 [Kip*ft]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	2.92	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	0.83	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (L_r	[ft]	14.47	Eq. F2-6

Lateral-torsional buckling modification factor (C_b)	--	2.34	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	197.15	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	25.35	Eq. F2-2

Bending about minor axis, M22

Ratio	: 0.00			
Capacity	: 4.67 [Kip*ft]	Reference	:	Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	: 0.00			
Capacity	: 46.46 [Kip]			
Demand	: 0.00 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.50			
Capacity	: 30.02 [Kip]	Reference	:	Sec. G2.1(a)
Demand	: -15.14 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✘

Combined flexure and axial compression

Ratio	: 1.03		
Ctrl Eq.	: C1 at 100.00%	Reference	: Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	1.03	Eq. H1-1a
In-plane required flexural strength (Mr33)	[Kip*ft]	-13.61	
In-plane available flexural strength (Mc33)	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (Pr)	[Kip]	57.10	
In-plane available axial compressive strength (Pc)	[Kip]	114.59	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.73	Eq. H1-2
Out-of-plane required flexural strength (Mr33)	[Kip*ft]	-13.61	
Out-of-plane available flexural-torsional strength (Mc33)	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (Pr)	[Kip]	57.10	
Out-of-plane available axial compressive strength (Pco)	[Kip]	105.09	Sec. E4

Combined flexure and axial tension

Ratio	: 0.60		
Ctrl Eq.	: C1 at 100.00%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (Mr33)	[Kip*ft]	-13.61	
Available flexural strength about strong axis (Mc33)	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (Mr22)	[Kip*ft]	0.00	
Available flexural strength about weak axis (Mc22)	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (Pr)	[Kip]	0.00	
Available axial tensile strength (Pc)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	: N/A		
Ctrl Eq.	: --	Reference	:

Combined flexure and axial tension about local axis

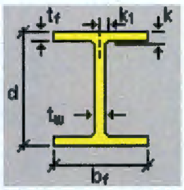
Ratio	: N/A		
Ctrl Eq.	: --	Reference	:

Member : 6 (Arched Steel Rib)
Design status : N.G.

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	5.16

Distance between member lateral bracing points

Length (Lb) [ft]	
Top	Bottom
5.16	5.16

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
5.16	1.00	5.16	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.51		
Capacity	: 114.66 [Kip]	Reference	: Sec. E1
Demand	: 58.17 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	114.66	Sec. E1
Effective length factor (K33)	--	1.00	
Unbraced length (L33)	[ft]	5.16	
Effective slenderness ((KL/r)33)	--	25.27	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	448.22	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q33)	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	34.81	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	127.40	Eq. E3-1

Compression in the minor axis 22

Ratio	:	0.55			
Capacity	:	105.17 [Kip]	Reference	:	Sec. E4
Demand	:	58.17 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	105.17	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	5.16	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	125.55	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	125.55	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	31.93	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	116.86	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	:	0.60			
Capacity	:	22.82 [Kip*ft]	Reference	:	Sec. F1
Demand	:	-13.61 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	2.92	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	0.83	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (L_r	[ft]	14.47	Eq. F2-6

Lateral-torsional buckling modification factor (C_b)	--	1.81	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	154.25	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	25.35	Eq. F2-2

Bending about minor axis, M22

Ratio	:	0.00		
Capacity	:	4.67 [Kip*ft]	Reference	: Sec. F1
Demand	:	0.00 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	:	0.00		
Capacity	:	46.46 [Kip]		
Demand	:	0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	:	0.48		
Capacity	:	30.02 [Kip]	Reference	: Sec. G2.1(a)
Demand	:	14.33 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✘

Combined flexure and axial compression

Ratio	:	1.04		
Ctrl Eq.	:	C1 at 0.00%	Reference	: Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	1.04	Eq. H1-1a
In-plane required flexural strength (Mr33)	[Kip*ft]	-13.61	
In-plane available flexural strength (Mc33)	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (Pr)	[Kip]	58.10	
In-plane available axial compressive strength (Pc)	[Kip]	114.66	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.79	Eq. H1-2
Out-of-plane required flexural strength (Mr33)	[Kip*ft]	-13.61	
Out-of-plane available flexural-torsional strength (Mc33)	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (Pr)	[Kip]	58.10	
Out-of-plane available axial compressive strength (Pco)	[Kip]	105.17	Sec. E4

Combined flexure and axial tension

Ratio	:	0.60		
Ctrl Eq.	:	C1 at 0.00%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (Mr33)	[Kip*ft]	-13.61	
Available flexural strength about strong axis (Mc33)	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (Mr22)	[Kip*ft]	0.00	
Available flexural strength about weak axis (Mc22)	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (Pr)	[Kip]	0.00	
Available axial tensile strength (Pc)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Combined flexure and axial tension about local axis

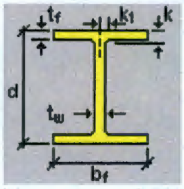
Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Member : 7 (Arched Steel Rib)
Design status : OK

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	5.35

Distance between member lateral bracing points

Length (Lb) [ft]	
Top	Bottom
5.35	5.35

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
5.35	1.00	5.35	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	:	0.00		
Capacity	:	118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	:	0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	:	0.51		
Capacity	:	114.38 [Kip]	Reference	: Sec. E1
Demand	:	58.18 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	114.38	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	5.35	
Effective slenderness ($(KL/r)_{33}$)	--	26.19	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	417.37	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	34.72	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	127.09	Eq. E3-1

Compression in the minor axis 22

Ratio	:	0.55			
Capacity	:	104.86 [Kip]	Reference	:	Sec. E4
Demand	:	58.18 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	104.86	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	5.35	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	122.47	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	122.47	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	31.83	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	116.51	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	:	0.55			
Capacity	:	22.82 [Kip*ft]	Reference	:	Sec. F1
Demand	:	-12.54 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	2.92	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	0.83	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (Lr	[ft]	14.47	Eq. F2-6

Lateral-torsional buckling modification factor (C_b)	--	2.06	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	167.38	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	25.35	Eq. F2-2

Bending about minor axis, M22

Ratio	: 0.00			
Capacity	: 4.67 [Kip*ft]	Reference	:	Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	**Unit**	**Value**	**Reference**
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	: 0.00			
Capacity	: 46.46 [Kip]			
Demand	: 0.00 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	**Unit**	**Value**	**Reference**
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.46			
Capacity	: 30.02 [Kip]	Reference	:	Sec. G2.1(a)
Demand	: 13.68 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	**Unit**	**Value**	**Reference**
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✔

Combined flexure and axial compression

Ratio	:	1.00			
Ctrl Eq.	:	C1 at 0.00%	Reference	:	Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	1.00	Eq. H1-1a
In-plane required flexural strength (M_{r33})	[Kip*ft]	-12.54	
In-plane available flexural strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (P_r)	[Kip]	58.16	
In-plane available axial compressive strength (P_c)	[Kip]	114.38	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.75	Eq. H1-2
Out-of-plane required flexural strength (M_{r33})	[Kip*ft]	-12.54	
Out-of-plane available flexural-torsional strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (P_r)	[Kip]	58.16	
Out-of-plane available axial compressive strength (P_{co})	[Kip]	104.86	Sec. E4

Combined flexure and axial tension

Ratio	:	0.55			
Ctrl Eq.	:	C1 at 0.00%	Reference	:	Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-12.54	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (P_r)	[Kip]	0.00	
Available axial tensile strength (P_c)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	:	N/A			
Ctrl Eq.	:	--	Reference	:	

Combined flexure and axial tension about local axis

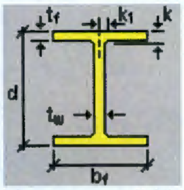
Ratio	:	N/A			
Ctrl Eq.	:	--	Reference	:	

Member : 8 (Arched Steel Rib)
Design status : OK

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

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Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	5.20

Distance between member lateral bracing points

Length (Lb) [ft] Top	Bottom
5.20	5.20

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
5.20	1.00	5.20	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.49		
Capacity	: 114.61 [Kip]	Reference	: Sec. E1
Demand	: 56.00 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	114.61	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	5.20	
Effective slenderness ($(KL/r)_{33}$)	--	25.43	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	442.57	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	34.79	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	127.35	Eq. E3-1

Compression in the minor axis 22

Ratio	:	0.53			
Capacity	:	105.12 [Kip]	Reference	:	Sec. E4
Demand	:	56.00 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	105.12	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	5.20	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	124.99	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	124.99	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	31.91	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	116.80	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	:	0.55			
Capacity	:	22.82 [Kip*ft]	Reference	:	Sec. F1
Demand	:	-12.58 [Kip*ft]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	2.92	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	0.83	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (L_r	[ft]	14.47	Eq. F2-6

Lateral-torsional buckling modification factor (C_b)	--	2.13	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	180.41	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	25.35	Eq. F2-2

Bending about minor axis, M22

Ratio	:	0.00		
Capacity	:	4.67 [Kip*ft]	Reference	: Sec. F1
Demand	:	0.00 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	:	0.00		
Capacity	:	46.46 [Kip]		
Demand	:	0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	:	0.46		
Capacity	:	30.02 [Kip]	Reference	: Sec. G2.1(a)
Demand	:	-13.89 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✔

Combined flexure and axial compression

Ratio	:	0.98			
Ctrl Eq.	:	C1 at 100.00%	Reference	:	Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	0.98	Eq. H1-1a
In-plane required flexural strength (M_{r33})	[Kip*ft]	-12.58	
In-plane available flexural strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (P_r)	[Kip]	56.00	
In-plane available axial compressive strength (P_c)	[Kip]	114.61	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.72	Eq. H1-2
Out-of-plane required flexural strength (M_{r33})	[Kip*ft]	-12.58	
Out-of-plane available flexural-torsional strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (P_r)	[Kip]	56.00	
Out-of-plane available axial compressive strength (P_{co})	[Kip]	105.12	Sec. E4

Combined flexure and axial tension

Ratio	:	0.55			
Ctrl Eq.	:	C1 at 100.00%	Reference	:	Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-12.58	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (P_r)	[Kip]	0.00	
Available axial tensile strength (P_c)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	:	N/A			
Ctrl Eq.	:	--	Reference	:	

Combined flexure and axial tension about local axis

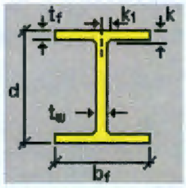
Ratio	:	N/A			
Ctrl Eq.	:	--	Reference	:	

Member : 9 (Arched Steel Rib)
Design status : OK

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

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Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	5.20

Distance between member lateral bracing points

Length (Lb) [ft] Top	Bottom
5.20	5.20

Laterally unbraced length

Length [ft] Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Effective length factor Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
5.20	1.00	5.20	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00			
Capacity	: 118.58 [Kip]	Reference	:	Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.48			
Capacity	: 114.61 [Kip]	Reference	:	Sec. E1
Demand	: 55.53 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	114.61	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	5.20	
Effective slenderness ($(KL/r)_{33}$)	--	25.46	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	441.66	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	34.79	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	127.34	Eq. E3-1

Compression in the minor axis 22

Ratio	:	0.53			
Capacity	:	105.11 [Kip]	Reference	:	Sec. E4
Demand	:	55.53 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	105.11	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	5.20	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	124.90	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	124.90	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	31.91	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	116.79	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	:	0.55			
Capacity	:	22.82 [Kip*ft]	Reference	:	Sec. F1
Demand	:	-12.58 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	2.92	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	0.83	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (Lr	[ft]	14.47	Eq. F2-6

Lateral-torsional buckling modification factor (C_b)	--	2.22	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	187.83	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	25.35	Eq. F2-2

Bending about minor axis, M22

Ratio	: 0.00			
Capacity	: 4.67 [Kip*ft]	Reference	:	Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	: 0.00			
Capacity	: 46.46 [Kip]			
Demand	: 0.00 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.49			
Capacity	: 30.02 [Kip]	Reference	:	Sec. G2.1(a)
Demand	: 14.56 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✔

Combined flexure and axial compression

Ratio	: 0.97		
Ctrl Eq.	: C1 at 0.00%	Reference	: Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	0.97	Eq. H1-1a
In-plane required flexural strength (M_{r33})	[Kip*ft]	-12.58	
In-plane available flexural strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (P_r)	[Kip]	55.48	
In-plane available axial compressive strength (P_c)	[Kip]	114.61	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.71	Eq. H1-2
Out-of-plane required flexural strength (M_{r33})	[Kip*ft]	-12.58	
Out-of-plane available flexural-torsional strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (P_r)	[Kip]	55.48	
Out-of-plane available axial compressive strength (P_{co})	[Kip]	105.11	Sec. E4

Combined flexure and axial tension

Ratio	: 0.55		
Ctrl Eq.	: C1 at 0.00%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-12.58	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (P_r)	[Kip]	0.00	
Available axial tensile strength (P_c)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	: N/A		
Ctrl Eq.	: --	Reference	:

Combined flexure and axial tension about local axis

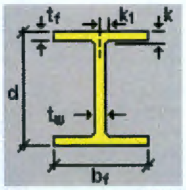
Ratio	: N/A		
Ctrl Eq.	: --	Reference	:

Member : 10 (Arched Steel Rib)
Design status : N.G.

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

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Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	5.21

Distance between member lateral bracing points

Length (Lb) [ft]	
Top	Bottom
5.21	5.21

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
5.21	1.00	5.21	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.50		
Capacity	: 114.59 [Kip]	Reference	: Sec. E1
Demand	: 57.10 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	114.59	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	5.21	
Effective slenderness ($(KL/r)_{33}$)	--	25.52	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	439.59	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	34.79	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	127.32	Eq. E3-1

Compression in the minor axis 22

Ratio	:	0.54			
Capacity	:	105.09 [Kip]	Reference	:	Sec. E4
Demand	:	57.10 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	105.09	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	5.21	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	124.69	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	124.69	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	31.90	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	116.76	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	:	0.60			
Capacity	:	22.82 [Kip*ft]	Reference	:	Sec. F1
Demand	:	-13.61 [Kip*ft]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	2.92	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	0.83	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (Lr	[ft]	14.47	Eq. F2-6

Lateral-torsional buckling modification factor (C_b)	--	2.34	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	197.15	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	25.35	Eq. F2-2

Bending about minor axis, M22

Ratio	: 0.00			
Capacity	: 4.67 [Kip*ft]	Reference	:	Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	: 0.00			
Capacity	: 46.46 [Kip]			
Demand	: 0.00 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.50			
Capacity	: 30.02 [Kip]	Reference	:	Sec. G2.1(a)
Demand	: -15.14 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✘

Combined flexure and axial compression

Ratio	:	1.03		
Ctrl Eq.	:	C1 at 100.00%	Reference	: Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	1.03	Eq. H1-1a
In-plane required flexural strength (M_{r33})	[Kip*ft]	-13.61	
In-plane available flexural strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (P_r)	[Kip]	57.10	
In-plane available axial compressive strength (P_c)	[Kip]	114.59	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.73	Eq. H1-2
Out-of-plane required flexural strength (M_{r33})	[Kip*ft]	-13.61	
Out-of-plane available flexural-torsional strength (M_{c33})	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (P_r)	[Kip]	57.10	
Out-of-plane available axial compressive strength (P_{co})	[Kip]	105.09	Sec. E4

Combined flexure and axial tension

Ratio	:	0.60		
Ctrl Eq.	:	C1 at 100.00%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-13.61	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (P_r)	[Kip]	0.00	
Available axial tensile strength (P_c)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Combined flexure and axial tension about local axis

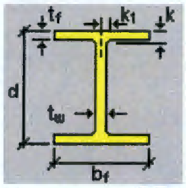
Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Member : 11 (Arched Steel Rib)
Design status : N.G.

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	5.16

Distance between member lateral bracing points

Length (Lb) [ft]	
Top	Bottom
5.16	5.16

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
5.16	1.00	5.16	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.51		
Capacity	: 114.66 [Kip]	Reference	: Sec. E1
Demand	: 58.17 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	114.66	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	5.16	
Effective slenderness ($(KL/r)_{33}$)	--	25.27	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	448.22	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	34.81	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	127.40	Eq. E3-1

Compression in the minor axis 22

Ratio	: 0.55			
Capacity	: 105.17 [Kip]	Reference	: Sec. E4
Demand	: 58.17 [Kip]	Ctrl Eq.	: C1 at 100.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	105.17	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	5.16	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	125.55	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	125.55	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	31.93	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	116.86	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	: 0.60		
Capacity	: 22.82 [Kip*ft]	Reference	: Sec. F1
Demand	: -13.61 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	2.92	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	0.83	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (L_r)	[ft]	14.47	Eq. F2-6

Lateral-torsional buckling modification factor (C_b)	--	1.81	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	154.25	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	25.35	Eq. F2-2

Bending about minor axis, M22

Ratio	: 0.00			
Capacity	: 4.67 [Kip*ft]	Reference	:	Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	: 0.00			
Capacity	: 46.46 [Kip]			
Demand	: 0.00 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.48			
Capacity	: 30.02 [Kip]	Reference	:	Sec. G2.1(a)
Demand	: 14.33 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✘

Combined flexure and axial compression

Ratio	:	1.04		
Ctrl Eq.	:	C1 at 0.00%	Reference	: Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	1.04	Eq. H1-1a
In-plane required flexural strength (Mr33)	[Kip*ft]	-13.61	
In-plane available flexural strength (Mc33)	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (Pr)	[Kip]	58.10	
In-plane available axial compressive strength (Pc)	[Kip]	114.66	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.79	Eq. H1-2
Out-of-plane required flexural strength (Mr33)	[Kip*ft]	-13.61	
Out-of-plane available flexural-torsional strength (Mc33)	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (Pr)	[Kip]	58.10	
Out-of-plane available axial compressive strength (Pco)	[Kip]	105.17	Sec. E4

Combined flexure and axial tension

Ratio	:	0.60		
Ctrl Eq.	:	C1 at 0.00%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (Mr33)	[Kip*ft]	-13.61	
Available flexural strength about strong axis (Mc33)	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (Mr22)	[Kip*ft]	0.00	
Available flexural strength about weak axis (Mc22)	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (Pr)	[Kip]	0.00	
Available axial tensile strength (Pc)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Combined flexure and axial tension about local axis

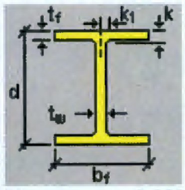
Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Member : 12 (Arched Steel Rib)
Design status : OK

Section information

Section name: S 6X12.5 **(US)**

Dimensions



bf	=	3.330	[in]	Width
d	=	6.000	[in]	Depth
k	=	0.813	[in]	Distance k
k1	=	0.813	[in]	Distance k1
tf	=	0.359	[in]	Flange thickness
tw	=	0.232	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	3.660	
Moment of Inertia (local axes) (I)	[in4]	22.000	1.800
Moment of Inertia (principal axes) (I')	[in4]	22.000	1.800
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	2.452	0.701
Radius of gyration (principal axes) (r')	[in]	2.452	0.701
Saint-Venant torsion constant. (J)	[in4]	0.167	
Section warping constant. (Cw)	[in6]	14.300	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	7.340	1.080
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	7.340	1.080
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	7.340	1.080
Plastic section modulus (local axis) (Z)	[in3]	8.450	1.860
Plastic section modulus (principal axis) (Z')	[in3]	8.450	1.860
Polar radius of gyration. (ro)	[in]	2.550	
Area for shear (Aw)	[in2]	2.390	1.390
Torsional constant. (C)	[in3]	0.352	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	1.00

Distance between member lateral bracing points

Length (Lb) [ft] Top	Bottom
1.25	1.25

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
1.25	1.00	1.25	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 118.58 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	118.58	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	131.76	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.50		
Capacity	: 118.35 [Kip]	Reference	: Sec. E1
Demand	: 59.49 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	118.35	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	1.25	
Effective slenderness ($(KL/r)_{33}$)	--	6.12	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	7646.40	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	35.93	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	131.50	Eq. E3-1

Compression in the minor axis 22

Ratio	:	0.51			
Capacity	:	116.49 [Kip]	Reference	:	Sec. E4
Demand	:	59.49 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	**Unit**	**Value**	**Reference**
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	4.64	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	18.85	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	116.77	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	1.00	
Effective slenderness ($(KL/r)_{22}$)	--	17.11	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	977.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	35.45	Eq. E3-2
Nominal flexural buckling strength (P_{n22})	[Kip]	129.74	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	116.49	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	1.25	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	845.07	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	845.07	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	3.66	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	35.36	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	129.43	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	:	0.55			
Capacity	:	22.82 [Kip*ft]	Reference	:	Sec. F1
Demand	:	-12.54 [Kip*ft]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	**Unit**	**Value**	**Reference**
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.82	Sec. F1
Yielding (M_n)	[Kip*ft]	25.35	Eq. F2-1

Bending about minor axis, M22

Ratio	:	0.00			
Capacity	:	4.67 [Kip*ft]	Reference	:	Sec. F1
Demand	:	0.00 [Kip*ft]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	4.64	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	18.85	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	4.67	Sec. F1
Yielding (M_n)	[Kip*ft]	5.18	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	:	0.00			
Capacity	:	46.46 [Kip]			
Demand	:	0.00 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	46.46	
Web slenderness (λ_w)	--	4.64	Sec. G2
Shear area (A_w)	[in2]	2.39	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	51.62	Eq. G2-1

Shear in minor axis 22

Ratio	:	0.16			
Capacity	:	30.02 [Kip]	Reference	:	Sec. G2.1(a)
Demand	:	-4.90 [Kip]	Ctrl Eq.	:	C1 at 100.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	30.02	Sec. G2.1(a)
Web slenderness (λ_w)	--	18.85	Sec. G2
Shear area (A_w)	[in2]	1.39	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	30.02	Eq. G2-1

COMBINED ACTIONS DESIGN ✔

Combined flexure and axial compression

Ratio	:	0.99			
Ctrl Eq.	:	C1 at 100.00%	Reference	:	Eq. H1-1a

Intermediate results	Unit	Value	Reference
Interaction for doubly symmetric members for in-plane bending	--	0.99	Eq. H1-1a
In-plane required flexural strength (Mr33)	[Kip*ft]	-12.54	
In-plane available flexural strength (Mc33)	[Kip*ft]	22.82	Sec. F1
In-plane required axial compressive strength (Pr)	[Kip]	59.49	
In-plane available axial compressive strength (Pc)	[Kip]	118.35	Sec. E1
Interaction for doubly symmetric members for out-of-plane bending	--	0.86	Eq. H1-2
Out-of-plane required flexural strength (Mr33)	[Kip*ft]	-12.54	
Out-of-plane available flexural-torsional strength (Mc33)	[Kip*ft]	22.82	Sec. F1
Out-of-plane required axial compressive strength (Pr)	[Kip]	59.49	
Out-of-plane available axial compressive strength (Pco)	[Kip]	116.49	Sec. E4

Combined flexure and axial tension

Ratio	:	0.55		
Ctrl Eq.	:	C1 at 100.00%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (Mr33)	[Kip*ft]	-12.54	
Available flexural strength about strong axis (Mc33)	[Kip*ft]	22.82	Sec. F1
Required flexural strength about weak axis (Mr22)	[Kip*ft]	0.00	
Available flexural strength about weak axis (Mc22)	[Kip*ft]	4.67	Sec. F1
Required axial tensile strength (Pr)	[Kip]	0.00	
Available axial tensile strength (Pc)	[Kip]	118.58	Eq. Sec. D2

Combined flexure and axial compression about local axis

Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

Combined flexure and axial tension about local axis

Ratio	:	N/A		
Ctrl Eq.	:	--	Reference	:

ch2m:	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Arched Steel Rib Beam Splice Analysis

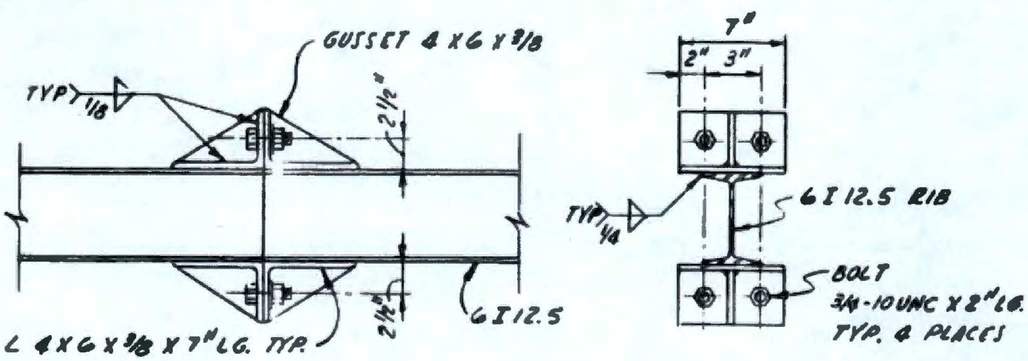
I6 Rib Splice

Demands (from Steel Rib Beam Analysis at Members 2 or 7)

Maximum Shear	$V_u := 13.68\text{kip}$
Maximum Moment	$M_u := 12.54\text{kip}\cdot\text{ft}$
Maximum Compression	$P_u := 58.18\text{kip}$

Material Properties

Nominal Steel Yield Stress	$F_{yl} := 36\text{ksi}$
Minimum Steel Ultimate Stress	$F_{ul} := 58\text{ksi}$
Weld Strength	$F_{EXX} := 60\text{ksi}$



DETAIL 5
SCALE 1 1/2" = 1'-0"

Bolt Properties

Bolt Diameter $d_b := \frac{3}{4}\text{in}$ Number of Bolts $n_b := 4$

Hole Diameter $h_b := d_b + \frac{1}{16}\text{in} = \frac{13}{16}\cdot\text{in}$

Angle Dimensions

Angle thickness $t_L := \frac{3}{8}\text{in}$ Angle Width $w_L := 7\text{in}$

OS Leg Length $l_{OS} := 4\text{in}$

Horiz. Leg Length $l_{HZ} := 6\text{in}$

# of sixteenths of weld $D_{weld} := 4$

Shear Yielding of OS Angle Leg

Resistance Factor for Shear Yielding $\phi_{sy} := 1.00$

Gross Area of OS Angle Leg $A_{gv} := t_L \cdot w_L = 2.625 \cdot in^2$

Shear Yield Strength of Angle OS Leg $\phi Rn_{sy} := \phi_{sy} \cdot F_{yl} \cdot A_{gv} = 94.5 \cdot kip$

$$SYDCR := \frac{V_u}{\phi Rn_{sy}} = 0.14$$

Shear Rupture of OS Angle Leg

Resistance Factor for Shear Rupture $\phi_{sr} := 0.75$

Net Area of OS Angle Leg $A_{nv} := t_L \cdot (w_L - 2 \cdot h_b) = 2.016 \cdot in^2$

Shear Rupture Strength OS Angle Leg $\phi Rn_{sr} := \phi_{sr} \cdot 0.60 \cdot F_{ul} \cdot A_{nv} = 52.608 \cdot kip$

$$SRDCR := \frac{V_u}{\phi Rn_{sr}} = 0.26$$

Shear Yield on Bolts

Bolt Shear Strength $\phi r_n := 8.97kip$ *(AISC Table 7-1 for A307 Bolts*

Bolt group shear strength $\phi r_{ng} := n_b \cdot \phi r_n = 35.88 \cdot kip$

$$SYbDCR := \frac{V_u}{\phi r_{ng}} = 0.38$$

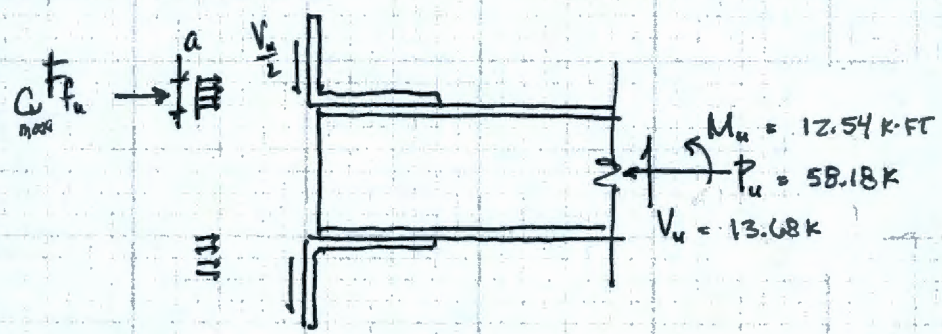
Bearing Strength of Bolts

Bolt Bearing Strength $\phi r_{nb} := 44.0 \frac{kip}{in}$ *(AISC Table 7-5,std hole, 1-1/4" min edge distance)*

Bolt Group Bearing Strength $\phi r_{nbg} := \phi r_{nb} \cdot t_L \cdot n_b = 66 \cdot kip$

$$BrgDCR := \frac{V_u}{\phi r_{nbg}} = 0.21$$

weld check at rib splice angles



note: flexural demand is low enough that the bolts in the splice will never see net tension

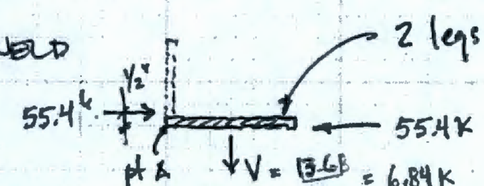
$$C_{u(max)} = \frac{58.18}{2} + \frac{12.54\ \text{k}\cdot 12}{(6" - 0.28")} = \text{Flange force } F_{fu} = 55.4^k$$

$$\text{bearing area req'd} = \frac{55.4\text{k}}{.9(36\text{ ksi})} = 1.7\ \text{in}^2$$

for effective bearing width = bf of I-section = 3"

$$a = \frac{2}{3} = \frac{2}{3}"\quad \text{say } 1"$$

CHECK WELD



at critical pt A:

$$f'_x = \frac{55.4}{2(5.5)} = 5.04\ \text{k/in} \qquad f'_y = \frac{6.84\text{K}}{2(5.5)} = 0.62\ \text{k/in}$$

$$f''_x = 0 \qquad f''_y = \frac{55.4 \times \frac{1}{2}"}{2\left(\frac{5.5^2}{6}\right)} = 2.75\ \text{k/in}$$

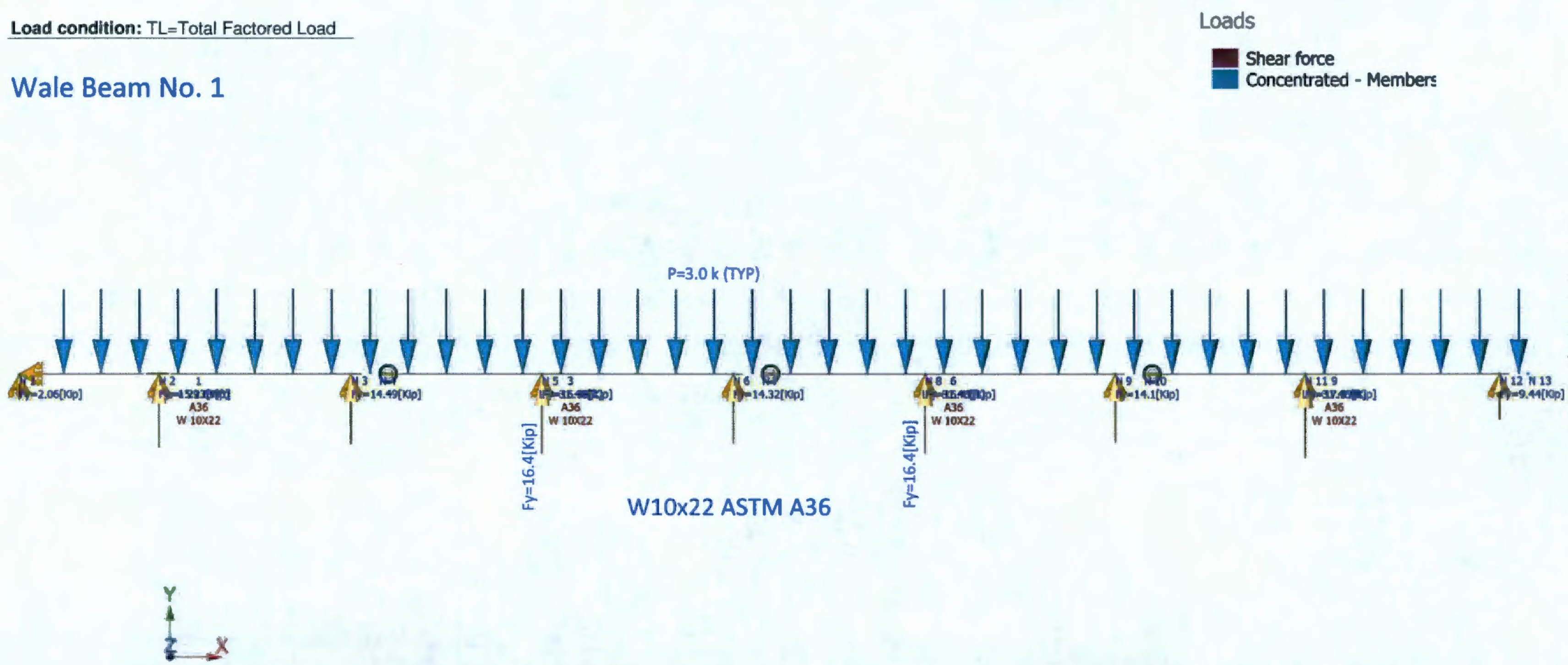
$$R_u = \left[(5.04)^2 + (0.62 + 2.75)^2\right]^{1/2}$$

$$= 6.06^k/"$$

for E70xx electrodes, 1/4" FILLET → $\phi R_n = 5.57^k/"$ DCR = 1.09

ch2m:	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Steel Wale Beam Support Analysis

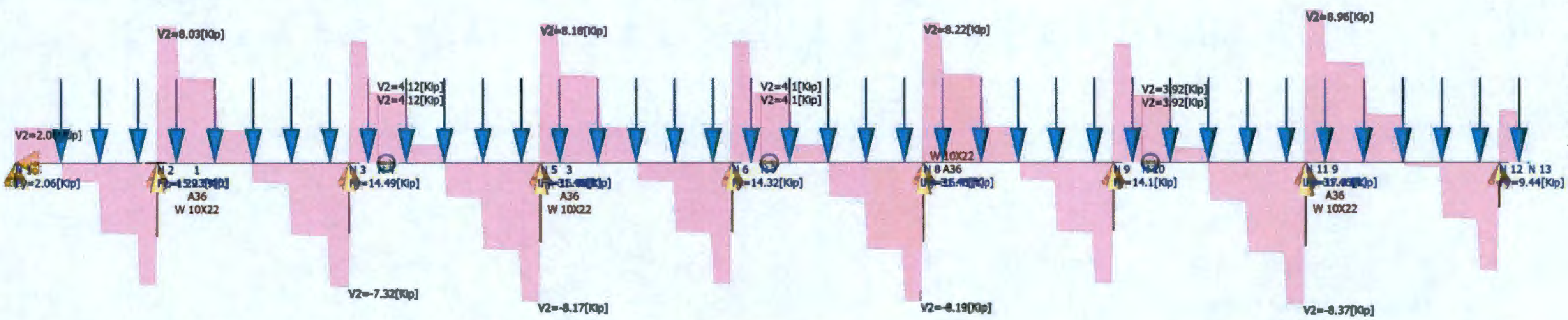

Load condition: TL=Total Factored Load
Wale Beam No. 1
Loads
Shear force
Concentrated - Members
P=3.0 k (TYP)
Fy=2.06[Kip]
Fy=14.49[Kip]
Fy=14.32[Kip]
Fy=14.1[Kip]
Fy=9.44[Kip]
Fy=16.4[Kip]
Fy=16.4[Kip]
A36
W 10X22
W10x22 ASTM A36
Y
Z
X

Load condition: TL=Total Factored Load

Internal forces / Loads

- Shear force
- Concentrated - Members

Wale Beam No. 1



W10x22 ASTM A36

MEMBER SHEAR DIAGRAM RESULTS

Wale Beam No. 1

Steel Code Check

Report: Comprehensive

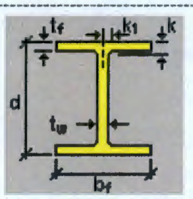
Members: Hot-rolled
Design code: AISC 360-2010 LRFD

Member	:	**6 (Wale 1)**
Design status	:	**OK**

Section information

Section name: W 10X22 **(US)**

Dimensions



bf	=	5.750	[in]	Width
d	=	10.200	[in]	Depth
k	=	0.660	[in]	Distance k
k1	=	0.625	[in]	Distance k1
tf	=	0.360	[in]	Flange thickness
tw	=	0.240	[in]	Web thickness

Properties

Section properties	**Unit**	**Major axis**	**Minor axis**
Gross area of the section. (Ag)	[in2]	6.490	
Moment of Inertia (local axes) (I)	[in4]	118.000	11.400
Moment of Inertia (principal axes) (I')	[in4]	118.000	11.400
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	4.264	1.325
Radius of gyration (principal axes) (r')	[in]	4.264	1.325
Saint-Venant torsion constant. (J)	[in4]	0.239	
Section warping constant. (Cw)	[in6]	275.000	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	23.200	3.970
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	23.200	3.970
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	23.200	3.970
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	23.200	3.970
Plastic section modulus (local axis) (Z)	[in3]	26.000	6.100
Plastic section modulus (principal axis) (Z')	[in3]	26.000	6.100
Polar radius of gyration. (ro)	[in]	4.465	
Area for shear (Aw)	[in2]	4.140	2.450
Torsional constant. (C)	[in3]	0.623	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	31.46

Distance between member lateral bracing points

Length (Lb) [ft] Top	Bottom
31.46	31.46

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
31.46	31.46	31.46	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 210.28 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	210.28	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	233.64	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.00		
Capacity	: 139.19 [Kip]	Reference	: Sec. E1
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	7.99	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	37.00	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	139.19	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	31.46	
Effective slenderness ($(KL/r)_{33}$)	--	88.53	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	36.52	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	6.49	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	23.83	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	154.65	Eq. E3-1

Compression in the minor axis 22

Ratio	: 0.00		
Capacity	: 18.07 [Kip]	Reference	: Sec. E1
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	7.99	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	37.00	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	18.07	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	31.46	
Effective slenderness ($(KL/r)_{22}$)	--	284.83	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	3.53	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	6.49	Eq. E3-3
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	3.09	Eq. E3-3
Nominal flexural buckling strength (P_{n22})	[Kip]	20.08	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	116.52	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	31.46	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	25.52	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	25.52	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	6.49	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	19.95	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	129.47	Eq. E4-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	: 0.51		
Capacity	: 40.25 [Kip*ft]	Reference	: Sec. F1
Demand	: -20.55 [Kip*ft]	Ctrl Eq.	: C1 at 41.67%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	7.99	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	37.00	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	70.20	Sec. F1
Yielding (M_n)	[Kip*ft]	78.00	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	40.25	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	5.52	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	1.55	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (L_r	[ft]	17.28	Eq. F2-6
Lateral-torsional buckling modification factor (C_b)	--	1.98	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	23.13	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	44.73	Eq. F2-3

Bending about minor axis, M22

Ratio	: 0.00		
Capacity	: 16.47 [Kip*ft]	Reference	: Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	7.99	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	37.00	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	16.47	Sec. F1
Yielding (M_n)	[Kip*ft]	18.30	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	: 0.00		
Capacity	: 80.48 [Kip]		
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	80.48	
Web slenderness (λ_w)	--	7.99	Sec. G2
Shear area (A_w)	[in2]	4.14	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	89.42	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.16		
Capacity	: 52.92 [Kip]	Reference	: Sec. G2.1(a)
Demand	: 8.21 [Kip]	Ctrl Eq.	: C1 at 43.75%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	52.92	Sec. G2.1(a)
Web slenderness (λ_w)	--	37.00	Sec. G2
Shear area (A_w)	[in2]	2.45	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	52.92	Eq. G2-1

COMBINED ACTIONS DESIGN ✔

Combined flexure and axial compression

Ratio	: 0.51		
Ctrl Eq.	: C1 at 41.67%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Interaction of flexure and axial force	--	0.51	Eq. H1-1b
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-20.55	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	40.25	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	16.47	Sec. F1
Required axial compressive strength (P_r)	[Kip]	0.00	
Available axial compressive strength (P_c)	[Kip]	18.07	Sec. E1

Combined flexure and axial tension

Ratio	: 0.51		
Ctrl Eq.	: C1 at 41.67%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-20.55	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	40.25	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	16.47	Sec. F1
Required axial tensile strength (P_r)	[Kip]	0.00	
Available axial tensile strength (P_c)	[Kip]	210.28	Eq. Sec. D2

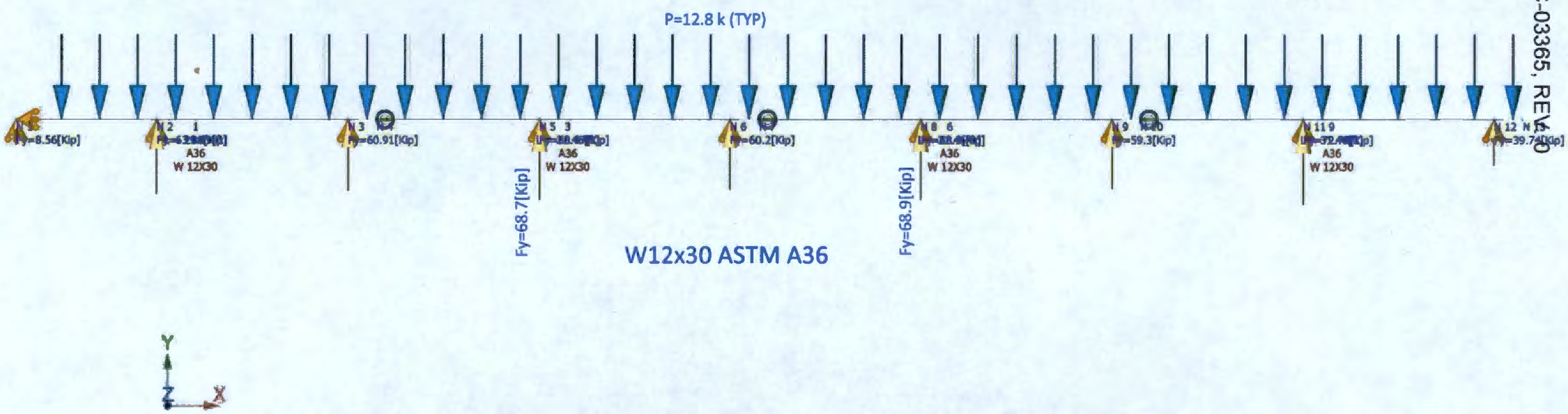
Load condition: TL=Total Factored Load

Wale Beam No. 2

Loads

Shear force

Concentrated - Members

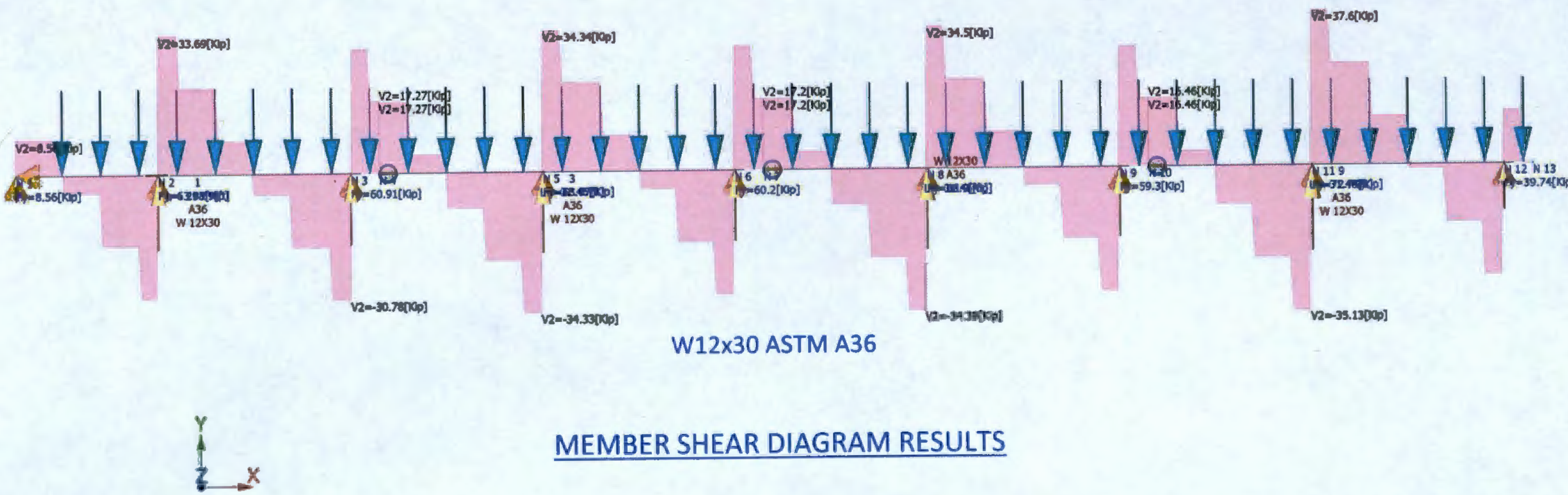


Load condition: TL=Total Factored Load

Wale Beam No. 2

Internal forces / Loads

- Shear force
- Concentrated - Members



W12x30 ASTM A36

MEMBER SHEAR DIAGRAM RESULTS

Wale Beam No. 2

Steel Code Check

Report: Comprehensive

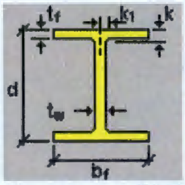
Members: Hot-rolled
Design code: AISC 360-2010 LRFD

Member	:	**6 (Wale 2)**
Design status	:	**N.G.**

Section information

Section name: W 12X30 **(US)**

Dimensions



bf	=	6.520	[in]	Width
d	=	12.300	[in]	Depth
k	=	0.740	[in]	Distance k
k1	=	0.750	[in]	Distance k1
tf	=	0.440	[in]	Flange thickness
tw	=	0.260	[in]	Web thickness

Properties

Section properties	**Unit**	**Major axis**	**Minor axis**
Gross area of the section. (Ag)	[in2]	8.790	
Moment of Inertia (local axes) (I)	[in4]	238.000	20.300
Moment of Inertia (principal axes) (I')	[in4]	238.000	20.300
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	5.203	1.520
Radius of gyration (principal axes) (r')	[in]	5.203	1.520
Saint-Venant torsion constant. (J)	[in4]	0.457	
Section warping constant. (Cw)	[in6]	720.000	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	38.600	6.240
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	38.600	6.240
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	38.600	6.240
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	38.600	6.240
Plastic section modulus (local axis) (Z)	[in3]	43.100	9.560
Plastic section modulus (principal axis) (Z')	[in3]	43.100	9.560
Polar radius of gyration. (ro)	[in]	5.421	
Area for shear (Aw)	[in2]	5.740	3.200
Torsional constant. (C)	[in3]	0.999	

Material : A36

Properties	**Unit**	**Value**
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	**Unit**	**Value**
Length for tension slenderness ratio (L)	[ft]	31.46

Distance between member lateral bracing points

Length (Lb) [ft]	
Top	Bottom
31.46	31.46

Laterally unbraced length

	Length [ft]			Effective length factor	
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
31.46	31.46	31.46	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00			
Capacity	: 284.80 [Kip]		Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]		Ctrl Eq.	: C1 at 0.00%

Intermediate results	**Unit**	**Value**	**Reference**
Factored axial tension capacity(ϕP_n)	[Kip]	284.80	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	316.44	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.00			
Capacity	: 215.88 [Kip]		Reference	: Sec. E1
Demand	: 0.00 [Kip]		Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	7.41	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	41.62	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	215.88	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	31.46	
Effective slenderness ($(KL/r)_{33}$)	--	72.55	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	54.38	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	8.79	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	27.29	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	239.86	Eq. E3-1

Compression in the minor axis 22

Ratio	: 0.00		
Capacity	: 32.18 [Kip]	Reference	: Sec. E1
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	7.41	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	41.62	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	32.18	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	31.46	
Effective slenderness ($(KL/r)_{22}$)	--	248.40	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	4.64	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	8.79	Eq. E3-3
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	4.07	Eq. E3-3
Nominal flexural buckling strength (P_{n22})	[Kip]	35.76	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	159.39	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	31.46	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	25.96	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	25.96	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	8.79	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	20.15	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	177.10	Eq. E4-1

FLEXURAL DESIGN ✗

Bending about major axis, M33

Ratio	: 1.12		
Capacity	: 76.69 [Kip*ft]	Reference	: Sec. F1
Demand	: -86.08 [Kip*ft]	Ctrl Eq.	: C1 at 41.67%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	7.41	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	41.62	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	116.37	Sec. F1
Yielding (M_n)	[Kip*ft]	129.30	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	76.69	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	6.33	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	1.77	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (L_r	[ft]	19.49	Eq. F2-6
Lateral-torsional buckling modification factor (C_b)	--	1.98	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	26.49	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	85.21	Eq. F2-3

Bending about minor axis, M22

Ratio	: 0.00		
Capacity	: 25.81 [Kip*ft]	Reference	: Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	7.41	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	41.62	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	25.81	Sec. F1
Yielding (M_n)	[Kip*ft]	28.68	Eq. F6-1

DESIGN FOR SHEAR ✓

Shear in major axis 33

Ratio	: 0.00		
Capacity	: 111.59 [Kip]		
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	111.59	
Web slenderness (λ_w)	--	7.41	Sec. G2
Shear area (Aw)	[in2]	5.74	
Web buckling coefficient (kv)	--	1.20	Sec. G7
Web buckling coefficient (Cv)	--	1.00	Eq. G2-3
Nominal shear strength (Vn)	[Kip]	123.98	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.50		
Capacity	: 69.12 [Kip]	Reference	: Sec. G2.1(a)
Demand	: 34.49 [Kip]	Ctrl Eq.	: C1 at 43.75%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	69.12	Sec. G2.1(a)
Web slenderness (λ_w)	--	41.62	Sec. G2
Shear area (Aw)	[in2]	3.20	
Web buckling coefficient (Cv)	--	1.00	Eq. G2-2
Nominal shear strength (Vn)	[Kip]	69.12	Eq. G2-1

COMBINED ACTIONS DESIGN ✖

Combined flexure and axial compression

Ratio	: 1.12		
Ctrl Eq.	: C1 at 41.67%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Interaction of flexure and axial force	--	1.12	Eq. H1-1b
Required flexural strength about strong axis (Mr33)	[Kip*ft]	-86.08	
Available flexural strength about strong axis (Mc33)	[Kip*ft]	76.69	Sec. F1
Required flexural strength about weak axis (Mr22)	[Kip*ft]	0.00	
Available flexural strength about weak axis (Mc22)	[Kip*ft]	25.81	Sec. F1
Required axial compressive strength (Pr)	[Kip]	0.00	
Available axial compressive strength (Pc)	[Kip]	32.18	Sec. E1

Combined flexure and axial tension

Ratio	: 1.12		
Ctrl Eq.	: C1 at 41.67%	Reference	: Eq. H1-1b

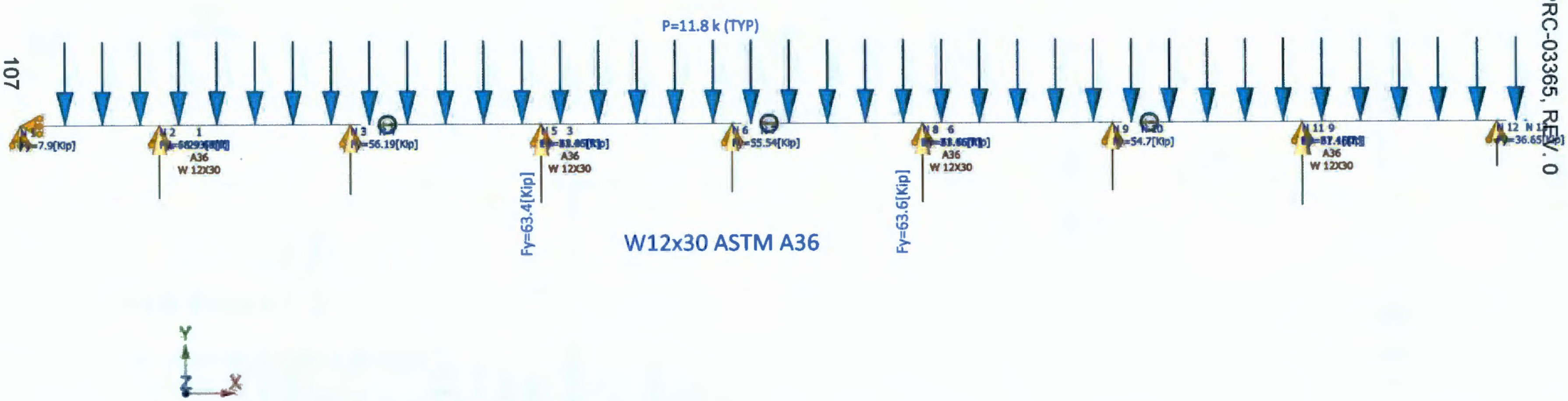
Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (Mr33)	[Kip*ft]	-86.08	
Available flexural strength about strong axis (Mc33)	[Kip*ft]	76.69	Sec. F1
Required flexural strength about weak axis (Mr22)	[Kip*ft]	0.00	
Available flexural strength about weak axis (Mc22)	[Kip*ft]	25.81	Sec. F1
Required axial tensile strength (Pr)	[Kip]	0.00	
Available axial tensile strength (Pc)	[Kip]	284.80	Eq. Sec. D2

Load condition: TL=Total Factored Load

Wale Beam No. 3

Loads

Shear force
Concentrated - Members



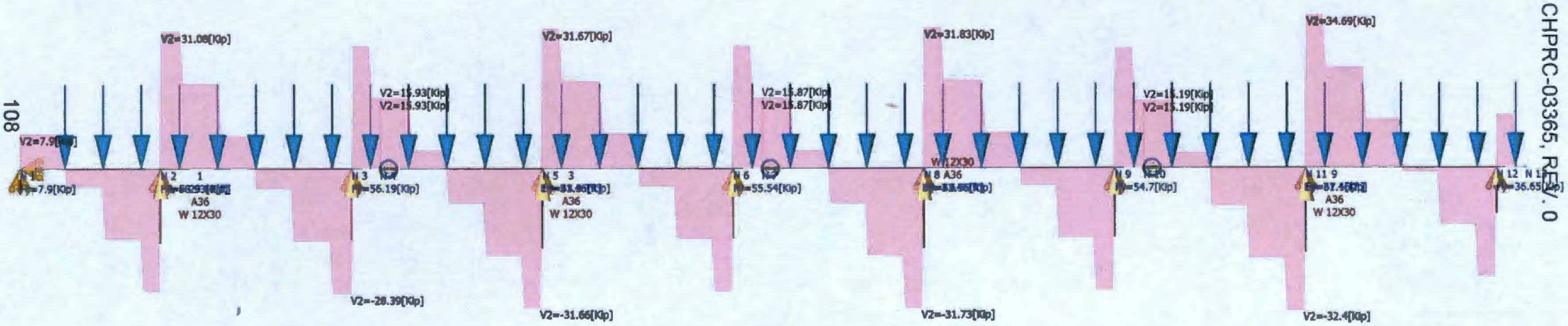
Load condition: TL=Total Factored Load

Wale Beam No. 3

Internal forces / Loads

Shear force

Concentrated - Members



W12x30 ASTM A36

MEMBER SHEAR DIAGRAM RESULTS

Wale Beam No. 3

Steel Code Check

Report: Comprehensive

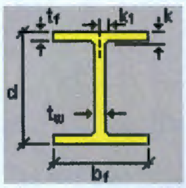
Members: Hot-rolled
Design code: AISC 360-2010 LRFD

Member	:	**6 (Wale 3)**
Design status	:	**N.G.**

Section information

Section name: W 12X30 **(US)**

Dimensions



bf	=	6.520	[in]	Width
d	=	12.300	[in]	Depth
k	=	0.740	[in]	Distance k
k1	=	0.750	[in]	Distance k1
tf	=	0.440	[in]	Flange thickness
tw	=	0.260	[in]	Web thickness

Properties

Section properties	**Unit**	**Major axis**	**Minor axis**
Gross area of the section. (Ag)	[in2]	8.790	
Moment of Inertia (local axes) (I)	[in4]	238.000	20.300
Moment of Inertia (principal axes) (I')	[in4]	238.000	20.300
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	5.203	1.520
Radius of gyration (principal axes) (r')	[in]	5.203	1.520
Saint-Venant torsion constant. (J)	[in4]	0.457	
Section warping constant. (Cw)	[in6]	720.000	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	38.600	6.240
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	38.600	6.240
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	38.600	6.240
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	38.600	6.240
Plastic section modulus (local axis) (Z)	[in3]	43.100	9.560
Plastic section modulus (principal axis) (Z')	[in3]	43.100	9.560
Polar radius of gyration. (ro)	[in]	5.421	
Area for shear (Aw)	[in2]	5.740	3.200
Torsional constant. (C)	[in3]	0.999	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

)ESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	31.46

Distance between member lateral bracing points

Length (Lb) [ft] Top	Bottom
31.46	31.46

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
31.46	31.46	31.46	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

)ESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 284.80 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	284.80	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	316.44	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.00		
Capacity	: 215.88 [Kip]	Reference	: Sec. E1
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	7.41	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	41.62	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	215.88	Sec. E1
Effective length factor (K_{33})	--	1.00	
Unbraced length (L_{33})	[ft]	31.46	
Effective slenderness ($(KL/r)_{33}$)	--	72.55	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	54.38	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	8.79	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q_{33})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	27.29	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	239.86	Eq. E3-1

Compression in the minor axis 22

Ratio	: 0.00		
Capacity	: 32.18 [Kip]	Reference	: Sec. E1
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	7.41	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	41.62	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	32.18	Sec. E1
Effective length factor (K_{22})	--	1.00	
Unbraced length (L_{22})	[ft]	31.46	
Effective slenderness ($(KL/r)_{22}$)	--	248.40	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	4.64	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	8.79	Eq. E3-3
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q_{22})	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	4.07	Eq. E3-3
Nominal flexural buckling strength (P_{n22})	[Kip]	35.76	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	159.39	Sec. E4
Effective length factor (K_{11})	--	1.00	
Unbraced length (L_{11})	[ft]	31.46	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	25.96	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	25.96	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	8.79	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q_{11})	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	20.15	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	177.10	Eq. E4-1

FLEXURAL DESIGN ✗

Bending about major axis, M33

Ratio	: 1.04		
Capacity	: 76.69 [Kip*ft]	Reference	: Sec. F1
Demand	: -79.41 [Kip*ft]	Ctrl Eq.	: C1 at 41.67%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	7.41	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	41.62	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	116.37	Sec. F1
Yielding (M_n)	[Kip*ft]	129.30	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	76.69	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	6.33	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	1.77	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (Lr	[ft]	19.49	Eq. F2-6
Lateral-torsional buckling modification factor (C_b)	--	1.98	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	26.49	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	85.21	Eq. F2-3

Bending about minor axis, M22

Ratio	: 0.00		
Capacity	: 25.81 [Kip*ft]	Reference	: Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	7.41	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	41.62	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	25.81	Sec. F1
Yielding (M_n)	[Kip*ft]	28.68	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	: 0.00		
Capacity	: 111.59 [Kip]		
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	111.59	
Web slenderness (λ_w)	--	7.41	Sec. G2
Shear area (A_w)	[in2]	5.74	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	123.98	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.46		
Capacity	: 69.12 [Kip]	Reference	: Sec. G2.1(a)
Demand	: 31.82 [Kip]	Ctrl Eq.	: C1 at 43.75%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	69.12	Sec. G2.1(a)
Web slenderness (λ_w)	--	41.62	Sec. G2
Shear area.(A_w)	[in2]	3.20	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	69.12	Eq. G2-1

COMBINED ACTIONS DESIGN ✖

Combined flexure and axial compression

Ratio	: 1.04		
Ctrl Eq.	: C1 at 41.67%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Interaction of flexure and axial force	--	1.04	Eq. H1-1b
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-79.41	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	76.69	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	25.81	Sec. F1
Required axial compressive strength (P_r)	[Kip]	0.00	
Available axial compressive strength (P_c)	[Kip]	32.18	Sec. E1

Combined flexure and axial tension

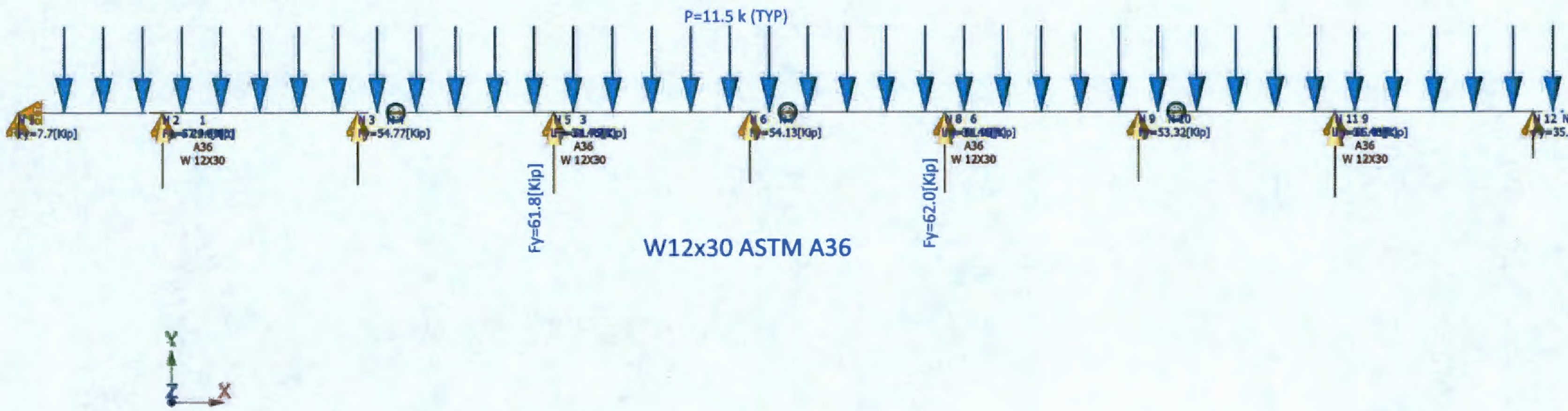
Ratio	: 1.04		
Ctrl Eq.	: C1 at 41.67%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-79.41	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	76.69	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	25.81	Sec. F1
Required axial tensile strength (P_r)	[Kip]	0.00	
Available axial tensile strength (P_c)	[Kip]	284.80	Eq. Sec. D2

Load condition: TL=Total Factored Load

Wale Beam No. 4

Loads
Shear force
Concentrated - Members

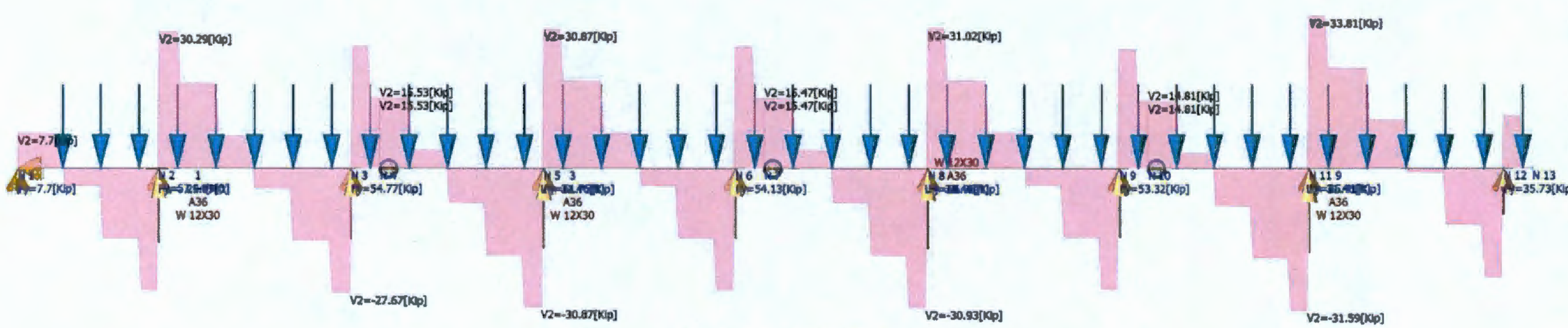


Load condition: TL=Total Factored Load

Internal forces / Loads

- Shear force
- Concentrated - Members

Wale Beam No. 4



W12x30 ASTM A36

MEMBER SHEAR DIAGRAM RESULTS

Wale Beam No. 4

Steel Code Check

Report: Comprehensive

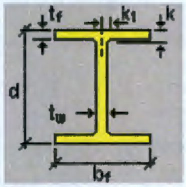
Members: Hot-rolled
Design code: AISC 360-2010 LRFD

Member	:	**6 (Wale 4)**
Design status	:	**N.G.**

Section information

Section name: W 12X30 **(US)**

Dimensions



bf	=	6.520	[in]	Width
d	=	12.300	[in]	Depth
k	=	0.740	[in]	Distance k
k1	=	0.750	[in]	Distance k1
tf	=	0.440	[in]	Flange thickness
tw	=	0.260	[in]	Web thickness

Properties

Section properties	**Unit**	**Major axis**	**Minor axis**
Gross area of the section. (Ag)	[in2]	8.790	
Moment of Inertia (local axes) (I)	[in4]	238.000	20.300
Moment of Inertia (principal axes) (I')	[in4]	238.000	20.300
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	5.203	1.520
Radius of gyration (principal axes) (r')	[in]	5.203	1.520
Saint-Venant torsion constant. (J)	[in4]	0.457	
Section warping constant. (Cw)	[in6]	720.000	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	38.600	6.240
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	38.600	6.240
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	38.600	6.240
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	38.600	6.240
Plastic section modulus (local axis) (Z)	[in3]	43.100	9.560
Plastic section modulus (principal axis) (Z')	[in3]	43.100	9.560
Polar radius of gyration. (ro)	[in]	5.421	
Area for shear (Aw)	[in2]	5.740	3.200
Torsional constant. (C)	[in3]	0.999	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	31.46

Distance between member lateral bracing points

Length (Lb) [ft]	
Top	Bottom
31.46	31.46

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
31.46	31.46	31.46	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 284.80 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	284.80	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	316.44	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.00		
Capacity	: 215.88 [Kip]	Reference	: Sec. E1
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	7.41	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	41.62	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	215.88	Sec. E1
Effective length factor (K33)	--	1.00	
Unbraced length (L33)	[ft]	31.46	
Effective slenderness ((KL/r)33)	--	72.55	Eq. E3-4
Elastic critical buckling stress (F_{e33})	[Kip/in2]	54.38	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s33})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff33})	[in2]	8.79	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a33})	--	1.00	
Full reduction factor for slender elements (Q33)	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr33})	[Kip/in2]	27.29	Eq. E3-2
Nominal flexural buckling strength (P_{n33})	[Kip]	239.86	Eq. E3-1

Compression in the minor axis 22

Ratio	:	0.00			
Capacity	:	32.18 [Kip]	Reference	:	Sec. E1
Demand	:	0.00 [Kip]	Ctrl Eq.	:	C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	7.41	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Non slender	
Stiffened element slenderness (λ)	--	41.62	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	32.18	Sec. E1
Effective length factor (K22)	--	1.00	
Unbraced length (L22)	[ft]	31.46	
Effective slenderness ((KL/r)22)	--	248.40	Eq. E3-4
Elastic critical buckling stress (F_{e22})	[Kip/in2]	4.64	Eq. E3-4
Reduction factor for slender unstiffened elements (Q_{s22})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff22})	[in2]	8.79	Eq. E3-3
Reduction factor for slender stiffened elements (Q_{a22})	--	1.00	
Full reduction factor for slender elements (Q22)	--	1.00	Sec. E7
Critical stress for flexural buckling (F_{cr22})	[Kip/in2]	4.07	Eq. E3-3
Nominal flexural buckling strength (P_{n22})	[Kip]	35.76	Eq. E3-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	159.39	Sec. E4
Effective length factor (K11)	--	1.00	
Unbraced length (L11)	[ft]	31.46	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (F_{e11})	[Kip/in2]	25.96	Eq. E4-4
Elastic torsional buckling stress (F_{ez})	[Kip/in2]	25.96	Eq. E4-9
Reduction factor for slender unstiffened elements (Q_{s11})	--	1.00	
Effective area of the cross section based on the effective width (A_{eff11})	[in2]	8.79	Eq. E3-2
Reduction factor for slender stiffened elements (Q_{a11})	--	1.00	
Full reduction factor for slender elements (Q11)	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (F_{cr11})	[Kip/in2]	20.15	Eq. E3-2
Nominal torsional or flexural-torsional buckling strength (P_{n11})	[Kip]	177.10	Eq. E4-1

FLEXURAL DESIGN ✗

Bending about major axis, M33

Ratio	: 1.01		
Capacity	: 76.69 [Kip*ft]	Reference	: Sec. F1
Demand	: -77.40 [Kip*ft]	Ctrl Eq.	: C1 at 41.67%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	7.41	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	41.62	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	116.37	Sec. F1
Yielding (M_n)	[Kip*ft]	129.30	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	76.69	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	6.33	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	1.77	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (L_r	[ft]	19.49	Eq. F2-6
Lateral-torsional buckling modification factor (C_b)	--	1.98	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	26.49	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	85.21	Eq. F2-3

Bending about minor axis, M22

Ratio	: 0.00		
Capacity	: 25.81 [Kip*ft]	Reference	: Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	7.41	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	41.62	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	25.81	Sec. F1
Yielding (M_n)	[Kip*ft]	28.68	Eq. F6-1

DESIGN FOR SHEAR ✓

Shear in major axis 33

Ratio	: 0.00		
Capacity	: 111.59 [Kip]		
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	111.59	
Web slenderness (λ_w)	--	7.41	Sec. G2
Shear area (A_w)	[in2]	5.74	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	123.98	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.45		
Capacity	: 69.12 [Kip]	Reference	: Sec. G2.1(a)
Demand	: 31.01 [Kip]	Ctrl Eq.	: C1 at 43.75%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	69.12	Sec. G2.1(a)
Web slenderness (λ_w)	--	41.62	Sec. G2
Shear area (A_w)	[in2]	3.20	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	69.12	Eq. G2-1

COMBINED ACTIONS DESIGN ✖

Combined flexure and axial compression

Ratio	: 1.01		
Ctrl Eq.	: C1 at 41.67%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Interaction of flexure and axial force	--	1.01	Eq. H1-1b
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-77.40	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	76.69	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	25.81	Sec. F1
Required axial compressive strength (P_r)	[Kip]	0.00	
Available axial compressive strength (P_c)	[Kip]	32.18	Sec. E1

Combined flexure and axial tension

Ratio	: 1.01		
Ctrl Eq.	: C1 at 41.67%	Reference	: Eq. H1-1b

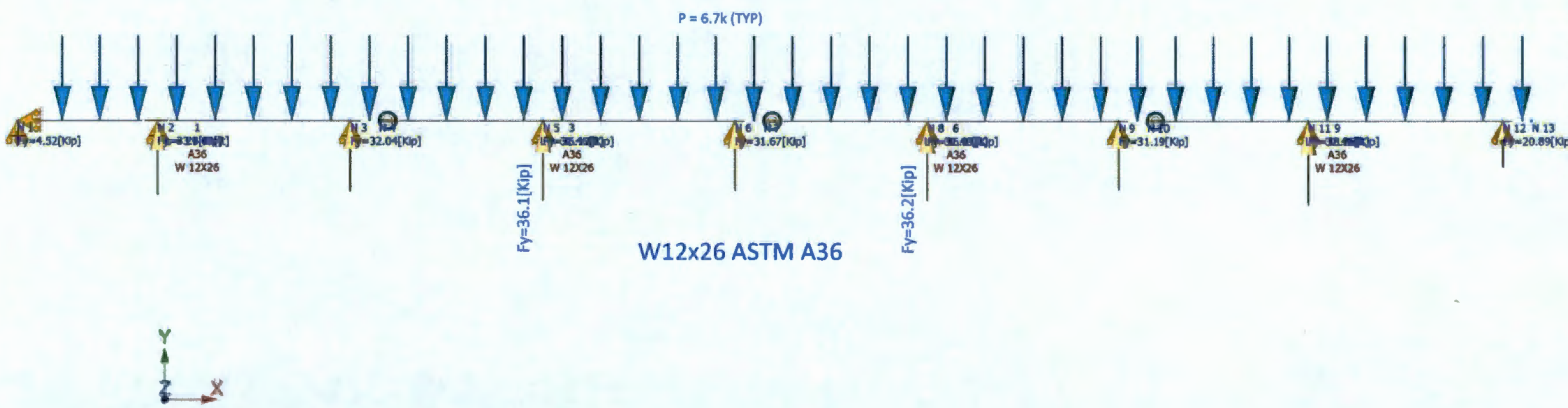
Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-77.40	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	76.69	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	25.81	Sec. F1
Required axial tensile strength (P_r)	[Kip]	0.00	
Available axial tensile strength (P_c)	[Kip]	284.80	Eq. Sec. D2

Load condition: TL=Total Factored Load

Wale Beam No. 5

Loads

Shear force
Concentrated - Members



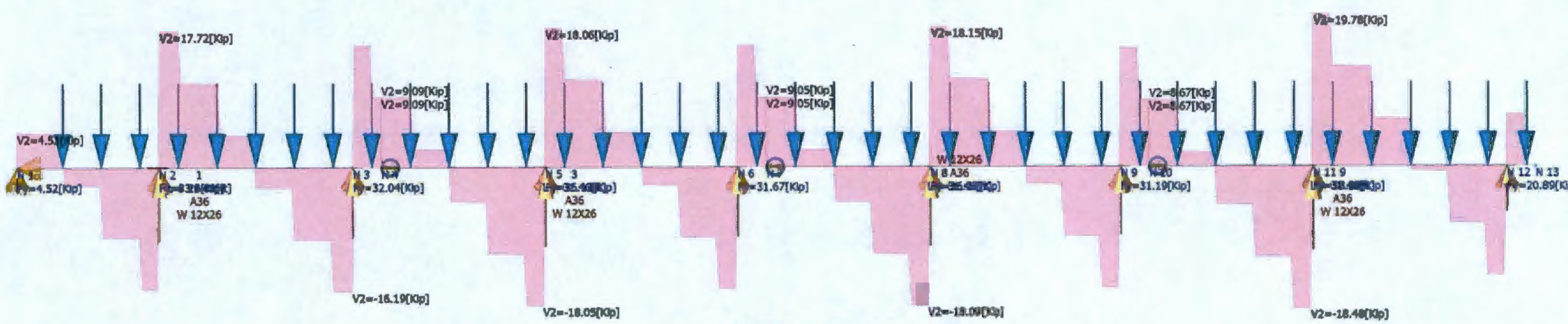
W12x26 ASTM A36

Load condition: TL=Total Factored Load

Wale Beam No. 5

Internal forces / Loads

- Shear force
- Concentrated - Members



W12x26 ASTM A36

MEMBER SHEAR DIAGRAM RESULTS

Wale Beam No. 5

Steel Code Check

Report: Comprehensive

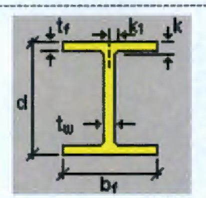
Members: Hot-rolled
Design code: AISC 360-2010 LRFD

Member	:	**6 (Wale 5)**
Design status	:	**OK**

Section information

Section name: W 12X26 **(US)**

Dimensions



bf	=	6.490	[in]	Width
d	=	12.200	[in]	Depth
k	=	0.680	[in]	Distance k
k1	=	0.750	[in]	Distance k1
tf	=	0.380	[in]	Flange thickness
tw	=	0.230	[in]	Web thickness

Properties

Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	7.650	
Moment of Inertia (local axes) (I)	[in4]	204.000	17.300
Moment of Inertia (principal axes) (I')	[in4]	204.000	17.300
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	5.164	1.504
Radius of gyration (principal axes) (r')	[in]	5.164	1.504
Saint-Venant torsion constant. (J)	[in4]	0.300	
Section warping constant. (Cw)	[in6]	607.000	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	33.400	5.340
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	33.400	5.340
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	33.400	5.340
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	33.400	5.340
Plastic section modulus (local axis) (Z)	[in3]	37.200	8.170
Plastic section modulus (principal axis) (Z')	[in3]	37.200	8.170
Polar radius of gyration. (ro)	[in]	5.378	
Area for shear (Aw)	[in2]	4.930	2.810
Torsional constant. (C)	[in3]	0.751	

Material : A36

Properties	Unit	Value
Yield stress (Fy):	[Kip/in2]	36.00
Tensile strength (Fu):	[Kip/in2]	58.00
Elasticity Modulus (E):	[Kip/in2]	29000.00
Shear modulus for steel (G):	[Kip/in2]	11507.94

DESIGN CRITERIA

Description	Unit	Value
Length for tension slenderness ratio (L)	[ft]	31.46

Distance between member lateral bracing points

Length (Lb) [ft]	
Top	Bottom
31.46	31.46

Laterally unbraced length

Length [ft]			Effective length factor		
Major axis(L33)	Minor axis(L22)	Torsional axis(Lt)	Major axis(K33)	Minor axis(K22)	Torsional axis(Kt)
31.46	31.46	31.46	1.0	1.0	1.0

Additional assumptions

Continuous lateral torsional restraint	No
Tension field action	No
Continuous flexural torsional restraint	No
Effective length factor value type	None
Major axis frame type	Sway
Minor axis frame type	Sway

DESIGN CHECKS

AXIAL TENSION DESIGN ✔

Axial tension

Ratio	: 0.00		
Capacity	: 247.86 [Kip]	Reference	: Eq. Sec. D2
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored axial tension capacity(ϕP_n)	[Kip]	247.86	Eq. Sec. D2
Nominal axial tension capacity (P_n)	[Kip]	275.40	Eq. D2-1

AXIAL COMPRESSION DESIGN ✔

Compression in the major axis 33

Ratio	: 0.00		
Capacity	: 187.08 [Kip]	Reference	: Sec. E1
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	8.54	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Slender	
Stiffened element slenderness (λ)	--	47.13	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n33})	[Kip]	187.08	Sec. E1
Effective length factor (K33)	--	1.00	
Unbraced length (L33)	[ft]	31.46	
Effective slenderness ((KL/r)33)	--	73.10	Eq. E3-4
Elastic critical buckling stress (Fe33)	[Kip/in2]	53.56	Eq. E3-4
Reduction factor for slender unstiffened elements (Qs33)	--	1.00	
Effective area of the cross section based on the effective width (Aeff33)	[in2]	7.65	Eq. E7-2
Reduction factor for slender stiffened elements (Qa33)	--	1.00	Eq. E7-16
Full reduction factor for slender elements (Q33)	--	1.00	Sec. E7
Critical stress for flexural buckling (Fcr33)	[Kip/in2]	27.17	Eq. E7-2
Nominal flexural buckling strength (Pn33)	[Kip]	207.87	Eq. E7-1

Compression in the minor axis 22

Ratio	: 0.00		
Capacity	: 27.43 [Kip]	Reference	: Sec. E1
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Non slender	
Unstiffened element slenderness (λ)	--	8.54	
Unstiffened element limiting slenderness (λ_r)	--	15.89	
Stiffened element classification	--	Slender	
Stiffened element slenderness (λ)	--	47.13	
Stiffened element limiting slenderness (λ_r)	--	42.29	
Factored flexural buckling strength(ϕP_{n22})	[Kip]	27.43	Sec. E1
Effective length factor (K22)	--	1.00	
Unbraced length (L22)	[ft]	31.46	
Effective slenderness ((KL/r)22)	--	251.03	Eq. E3-4
Elastic critical buckling stress (Fe22)	[Kip/in2]	4.54	Eq. E3-4
Reduction factor for slender unstiffened elements (Qs22)	--	1.00	
Effective area of the cross section based on the effective width (Aeff22)	[in2]	7.65	Eq. E7-3
Reduction factor for slender stiffened elements (Qa22)	--	1.00	Eq. E7-16
Full reduction factor for slender elements (Q22)	--	1.00	Sec. E7
Critical stress for flexural buckling (Fcr22)	[Kip/in2]	3.98	Eq. E7-3
Nominal flexural buckling strength (Pn22)	[Kip]	30.47	Eq. E7-1
Factored torsional or flexural-torsional buckling strength(ϕP_{n11})	[Kip]	121.40	Sec. E4
Effective length factor (K11)	--	1.00	
Unbraced length (L11)	[ft]	31.46	
Flexural constant (H)	--	1.00	Eq. E4-10
Torsional or flexural-torsional elastic buckling stress (Fe11)	[Kip/in2]	21.11	Eq. E4-4
Elastic torsional buckling stress (Fez)	[Kip/in2]	21.11	Eq. E4-9
Reduction factor for slender unstiffened elements (Qs11)	--	1.00	
Effective area of the cross section based on the effective width (Aeff11)	[in2]	7.65	Eq. E7-2
Reduction factor for slender stiffened elements (Qa11)	--	1.00	Eq. E7-16
Full reduction factor for slender elements (Q11)	--	1.00	Sec. E7
Critical stress for torsional or flexural-torsional buckling (Fcr11)	[Kip/in2]	17.63	Eq. E7-2
Nominal torsional or flexural-torsional buckling strength (Pn11)	[Kip]	134.89	Eq. E7-1

FLEXURAL DESIGN ✔

Bending about major axis, M33

Ratio	: 0.77		
Capacity	: 59.09 [Kip*ft]	Reference	: Sec. F1
Demand	: -45.28 [Kip*ft]	Ctrl Eq.	: C1 at 41.67%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	8.54	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	47.13	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	100.44	Sec. F1
Yielding (M_n)	[Kip*ft]	111.60	Eq. F2-1
Factored lateral-torsional buckling strength(ϕM_n)	[Kip*ft]	59.09	Sec. F1
Limiting laterally unbraced length for yielding (L_p)	[ft]	6.26	Eq. F2-5
Effective radius of gyration used in the determination of Lr (r_{ts})	[in]	1.75	Eq. F2-7
Lateral-torsional factor (c)	--	1.00	Eq. F2-8a
Limiting laterally unbraced length for inelastic lateral-torsional buckling (L_r	[ft]	18.37	Eq. F2-6
Lateral-torsional buckling modification factor (C_b)	--	1.98	Eq. F1-1
Critical stress (F_{cr})	[Kip/in2]	23.59	Eq. F2-4
Lateral-torsional buckling (M_n)	[Kip*ft]	65.65	Eq. F2-3

Bending about minor axis, M22

Ratio	: 0.00		
Capacity	: 22.06 [Kip*ft]	Reference	: Sec. F1
Demand	: 0.00 [Kip*ft]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Section classification			
Unstiffened element classification	--	Compact	
Unstiffened element slenderness (λ)	--	8.54	
Limiting slenderness for noncompact unstiffened element (λ_r)	--	28.38	
Limiting slenderness for compact unstiffened element (λ_p)	--	10.79	
Stiffened element classification	--	Compact	
Stiffened element slenderness (λ)	--	47.13	
Limiting slenderness for noncompact stiffened element (λ_r)	--	161.78	
Limiting slenderness for compact stiffened element (λ_p)	--	106.72	
Factored yielding strength(ϕM_n)	[Kip*ft]	22.06	Sec. F1
Yielding (M_n)	[Kip*ft]	24.51	Eq. F6-1

DESIGN FOR SHEAR ✔

Shear in major axis 33

Ratio	: 0.00		
Capacity	: 95.84 [Kip]		
Demand	: 0.00 [Kip]	Ctrl Eq.	: C1 at 0.00%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	95.84	
Web slenderness (λ_w)	--	8.54	Sec. G2
Shear area (A_w)	[in2]	4.93	
Web buckling coefficient (k_v)	--	1.20	Sec. G7
Web buckling coefficient (C_v)	--	1.00	Eq. G2-3
Nominal shear strength (V_n)	[Kip]	106.49	Eq. G2-1

Shear in minor axis 22

Ratio	: 0.30		
Capacity	: 60.70 [Kip]	Reference	: Sec. G2.1(a)
Demand	: 18.14 [Kip]	Ctrl Eq.	: C1 at 43.75%

Intermediate results	Unit	Value	Reference
Factored shear capacity(ϕV_n)	[Kip]	60.70	Sec. G2.1(a)
Web slenderness (λ_w)	--	47.13	Sec. G2
Shear area (A_w)	[in2]	2.81	
Web buckling coefficient (C_v)	--	1.00	Eq. G2-2
Nominal shear strength (V_n)	[Kip]	60.70	Eq. G2-1

COMBINED ACTIONS DESIGN ✔

Combined flexure and axial compression

Ratio	: 0.77		
Ctrl Eq.	: C1 at 41.67%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Interaction of flexure and axial force	--	0.77	Eq. H1-1b
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-45.28	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	59.09	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	22.06	Sec. F1
Required axial compressive strength (P_r)	[Kip]	0.00	
Available axial compressive strength (P_c)	[Kip]	27.43	Sec. E1

Combined flexure and axial tension

Ratio	: 0.77		
Ctrl Eq.	: C1 at 41.67%	Reference	: Eq. H1-1b

Intermediate results	Unit	Value	Reference
Required flexural strength about strong axis (M_{r33})	[Kip*ft]	-45.28	
Available flexural strength about strong axis (M_{c33})	[Kip*ft]	59.09	Sec. F1
Required flexural strength about weak axis (M_{r22})	[Kip*ft]	0.00	
Available flexural strength about weak axis (M_{c22})	[Kip*ft]	22.06	Sec. F1
Required axial tensile strength (P_r)	[Kip]	0.00	
Available axial tensile strength (P_c)	[Kip]	247.86	Eq. Sec. D2

ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Steel Wale Beam Splice Connection Analysis

Wale Splice Connection

Demands (from Member Analysis)

Maximum Shear Wale #1 $R_{u10} := 4.1kip$

Maximum Shear Wales 2, 3, 4, 5 $R_{u12} := 17.2kip$

(Vu12 = 17.2k, 15.9k, 15.5k, 9.1k at Wale Beams 2, 3, 4, and 5)

Material Properties

Nominal Steel Yield Stress $F_{yp} := 36ksi$

Minimum Steel Ultimate Stress $F_{up} := 58ksi$

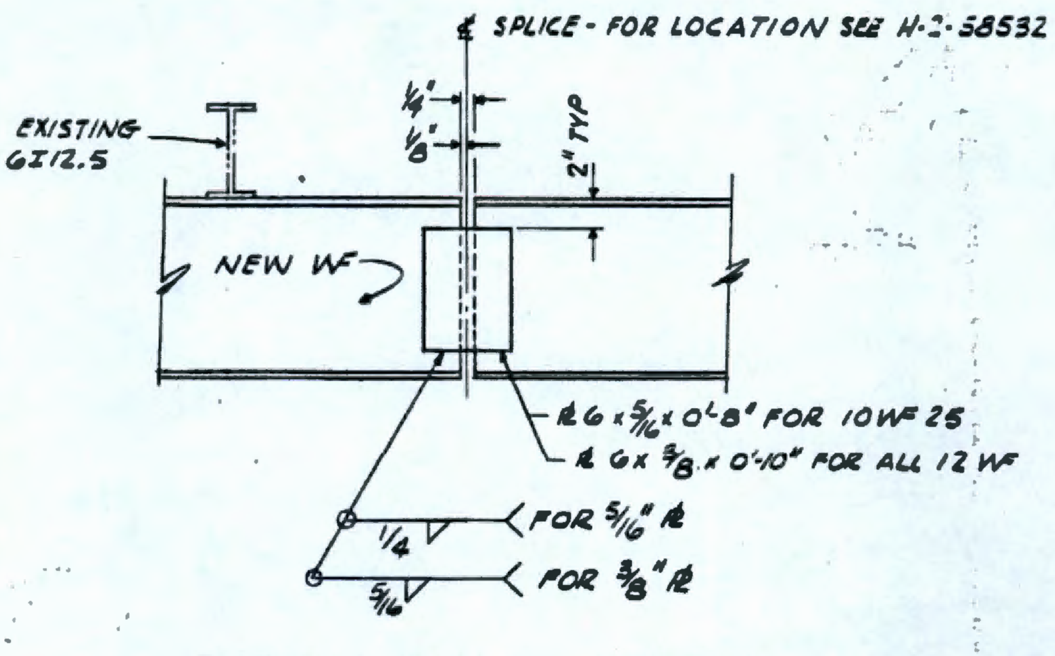
Weld Strength $F_{EXX} := 60ksi$

Member Properties

Wale #1 (W10x25) *(use W10x22)* $t_{w25} := 0.24in$

Wales #2, 3, & 4 (W12x31) *(use W12x30)* $t_{w31} := 0.25in$

Wale #5 (W12x27) *(use W12x26)* $t_{w27} := 0.23in$



TYPICAL WALE SPLICE

Splice Plate Dimensions

W10 Plate

thickness	$t_{p10} := \frac{5}{16}in$	Weld Thickness (# sixteenths)	$t_{weld10} := 4$
width	$w_{p10} := 6in$		
length	$l_{p10} := 8in$		

W12 Plate

thickness	$t_{p12} := \frac{3}{8}in$	Weld Thickness (# sixteenths)	$t_{weld12} := 5$
width	$w_{p12} := 6in$		
length	$l_{p12} := 10in$		

WALE SPLICE CHECK

$k_{WF10} = .36$

$k_{WF12} = .29$

$a_{10} = \frac{6 - 2(.075)}{\ell_{10}} = 5.85/8 = 0.73$

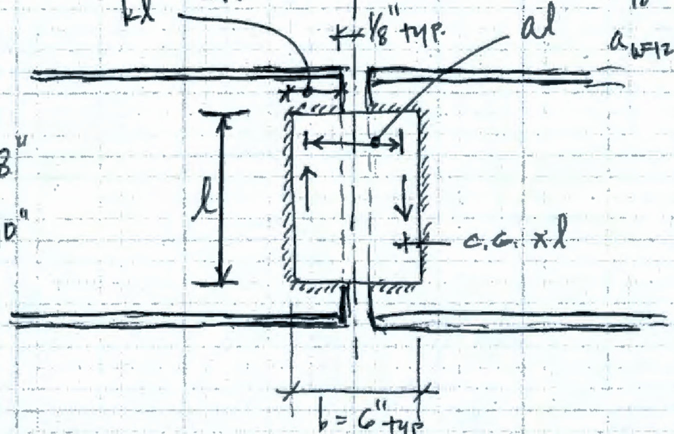
$a_{WF12} = 6 - 2(.052) = 5.9/10 = 0.59$

$\ell_{WF10} = 8''$

$\ell_{WF12} = 10''$

$x_{WF10} = .075$

$x_{WF12} = .052$



From AISC Table 8-8 (Angle = 0°)

$R_n = \phi C C_1 D \ell$ $\quad C_1 = 1.0$ for E70xx electrodes

$\phi = 0.75$ LRFD $\quad D_{WF10} = 4$

$D_{WF12} = 5$

for WF10 $a = 0.73$ $k = 0.36$ interpolate $\Rightarrow C_{WF10} = 1.77$

$\phi R_{n(WF10)} = 0.75 \times 1.77 \times 1.0 \times 4 \times 8 = \underline{42.5\,k}$

for $R_{u\,WF10} = 4.1k$ $\quad DCR_{WF10} = 0.10$

for WF12 $a = 0.59$ $k = 0.29$ interpolate $\Rightarrow C_{WF12} = 1.87$

$\phi R_{n(WF12)} = 0.75 \times 1.87 \times 1.0 \times 5 \times 10 \Rightarrow \underline{70.3^k}$

for $R_{u\,WF12} = 17.2k$ $\quad DCR_{WF12} = 0.25$

Flexural Yielding of Splice Plate

Resistance Factor for Flexural Yielding $\phi_f := 0.90$

Flexural Demands

W10 Splice Plate

$$M_{u10} := R_{u10} \cdot \frac{w_{p10}}{2} = 12.3 \cdot kip \cdot in$$

W12 Splice Plate

$$M_{u12} := R_{u12} \cdot \frac{w_{p12}}{2} = 51.6 \cdot kip \cdot in$$

Splice Plate Capacity

W10 Splice Plate

$$Z_{10} := \frac{t_{p10} \cdot l_{p10}^2}{4} = 5 \cdot in^3$$

$$\phi M_{nf10} := \phi_f \cdot F_{yp} \cdot Z_{10} = 162 \cdot kip \cdot in$$

$$FlexDCR_{10} := \frac{M_{u10}}{\phi M_{nf10}} = 0.08$$

W12 Splice Plate

$$Z_{12} := \frac{t_{p12} \cdot l_{p12}^2}{4} = 9.375 \cdot in^3$$

$$\phi M_{nf12} := \phi_f \cdot F_{yp} \cdot Z_{12} = 303.75 \cdot kip \cdot in$$

$$FlexDCR_{12} := \frac{M_{u12}}{\phi M_{nf12}} = 0.17$$

Shear Yielding of Splice Plate

Resistance Factor for Shear Yielding $\phi_{sy} := 1.00$

W10 Splice Plate

$$A_{gv10} := t_{p10} \cdot l_{p10} = 2.5 \cdot in^2$$

$$\phi Rn_{sy10} := \phi_{sy} \cdot F_{yp} \cdot A_{gv10} = 90 \cdot kip$$

$$SYDCR_{10} := \frac{R_{u10}}{\phi Rn_{sy10}} = 0.05$$

W12 Splice Plate

$$A_{gv12} := t_{p12} \cdot l_{p12} = 3.75 \cdot in^2$$

$$\phi Rn_{sy12} := \phi_{sy} \cdot F_{yp} \cdot A_{gv12} = 135 \cdot kip$$

$$SYDCR_{12} := \frac{R_{u12}}{\phi Rn_{sy12}} = 0.13$$

Shear Rupture of Splice Plate

Resistance Factor for Shear Rupture $\phi_{sr} := 0.75$

W10 Splice Plate

$$\phi Rn_{sr10} := \phi_{sr} \cdot 0.60 \cdot F_{up} \cdot A_{gv10} = 65.25 \cdot kip$$

$$SRDCR_{10} := \frac{R_{u10}}{\phi Rn_{sr10}} = 0.06$$

W12 Splice Plate

$$\phi Rn_{sr12} := \phi_{sr} \cdot 0.60 F_{up} \cdot A_{gv12} = 97.9 \cdot kip$$

$$SRDCR_{12} := \frac{R_{u12}}{\phi Rn_{sr12}} = 0.18$$

ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Arched Concrete Rib Girder Analysis

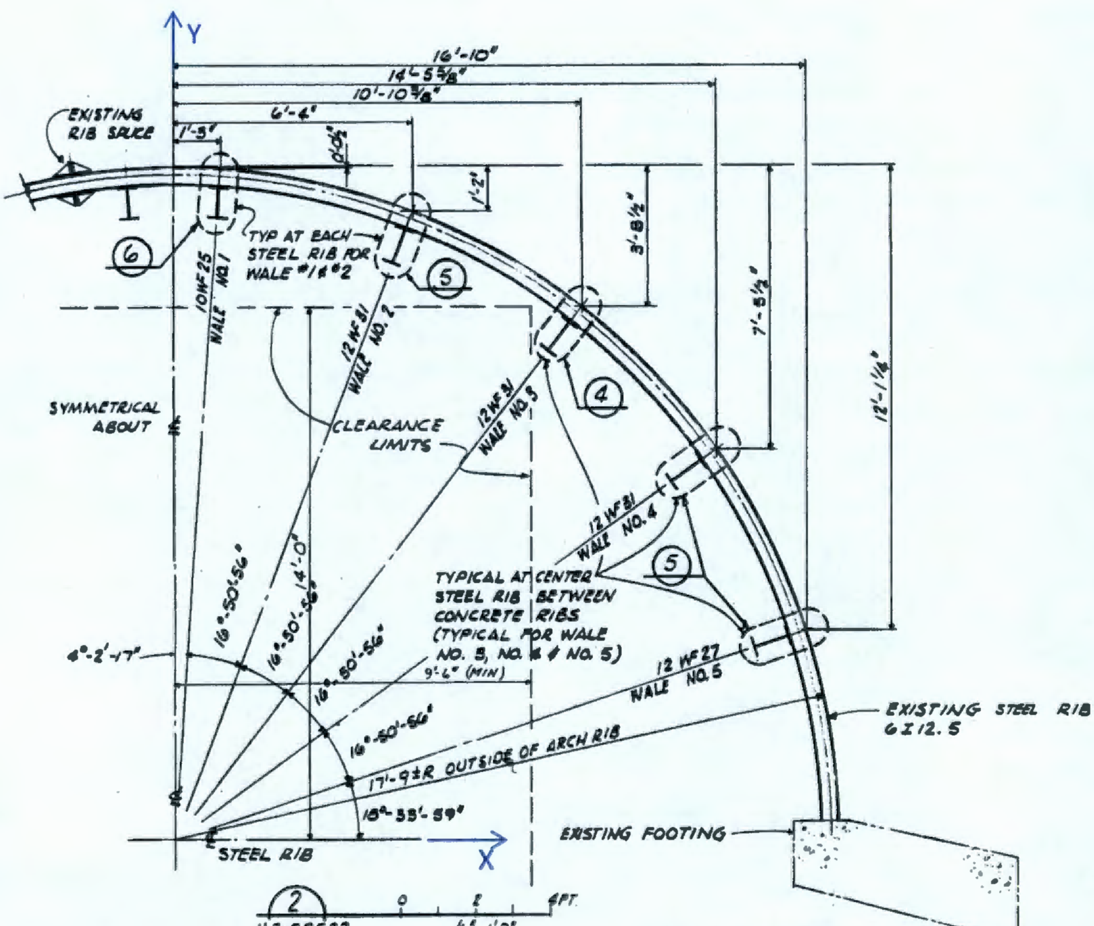
Tunnel 2

Concrete Rib Girder Design Load Components

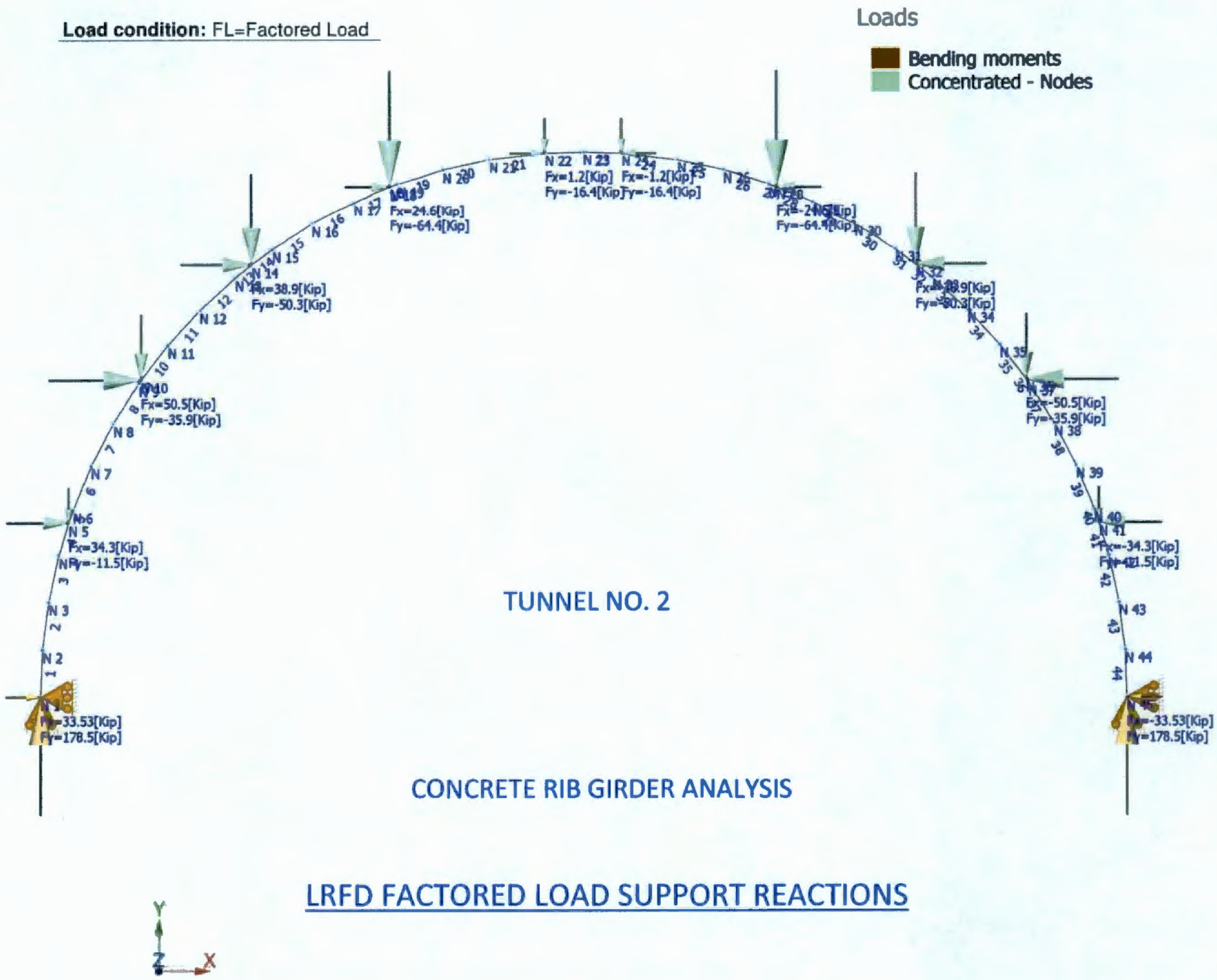
Location	X (ft)	Y (ft)	R (ft)	Wale I.D.	Wale Load (LRFD) $P_{u(tot)}$ *1 (k)	P_{ux} (k)	P_{uy} (k)
Crown	-	17.750	17.750	-	-	-	-
Wale 1	1.250	17.708	17.752	P1	16.4	1.2	16.4
Wale 2	6.333	16.583	17.752	P2	68.9	24.6	64.4
Wale 3	10.865	14.042	17.754	P3	63.6	38.9	50.3
Wale 4	14.469	10.292	17.756	P4	62.0	50.5	35.9
Wale 5	16.833	5.646	17.755	P5	36.2	34.3	11.5
Springline	17.750	-	17.750				

Equivalency: $(P_{u(tot)} / R) = (P_{ux} / X_i) = (P_{uy} / Y_i)$

Example: Wale 4: P_{ux} = (62.0k / 17.756ft) * 14.469ft = 50.5k
P_{uy} = (62.0k / 17.756ft) * 10.292ft = 35.9k



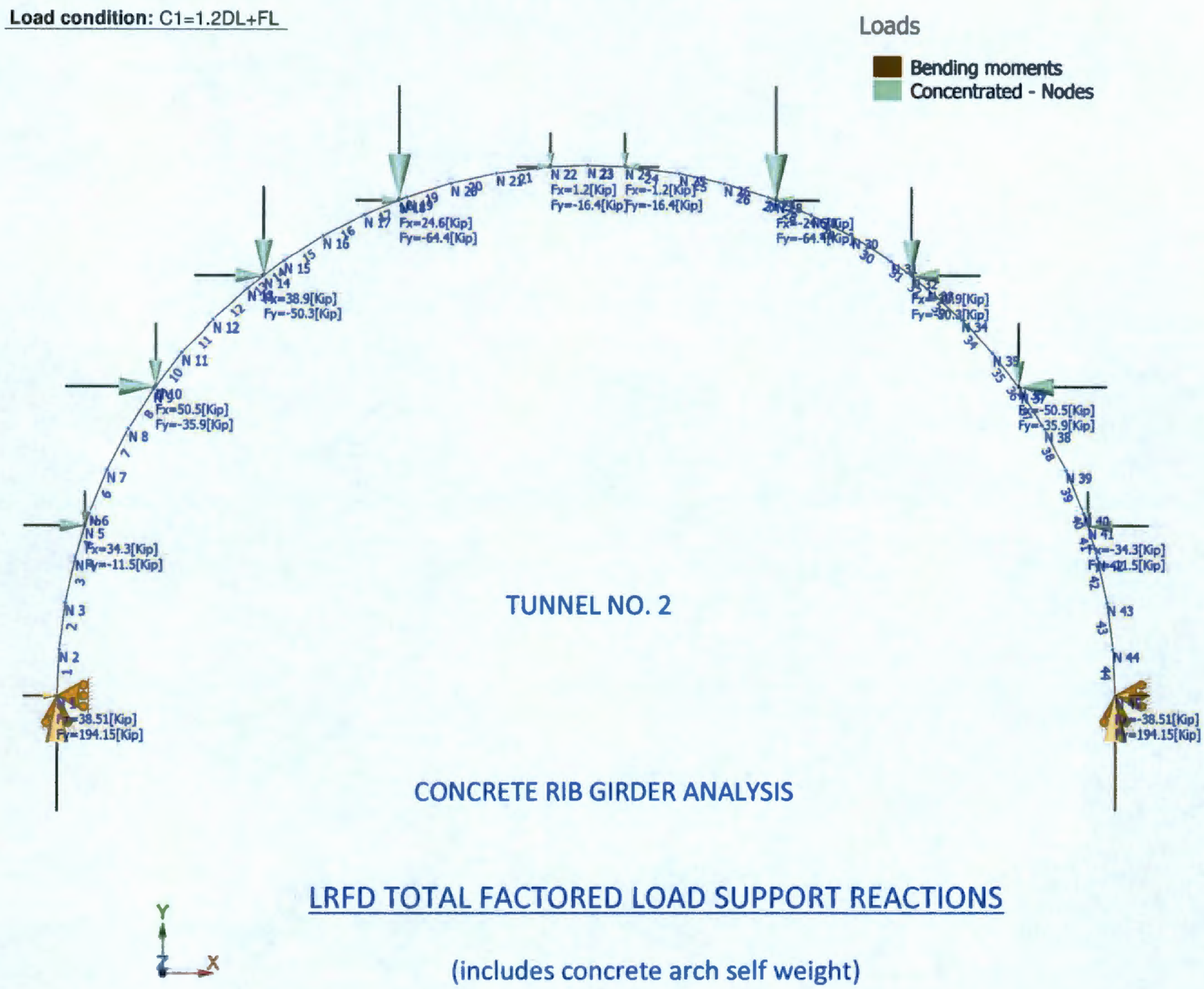
DWG H-2-58583



TUNNEL NO. 2

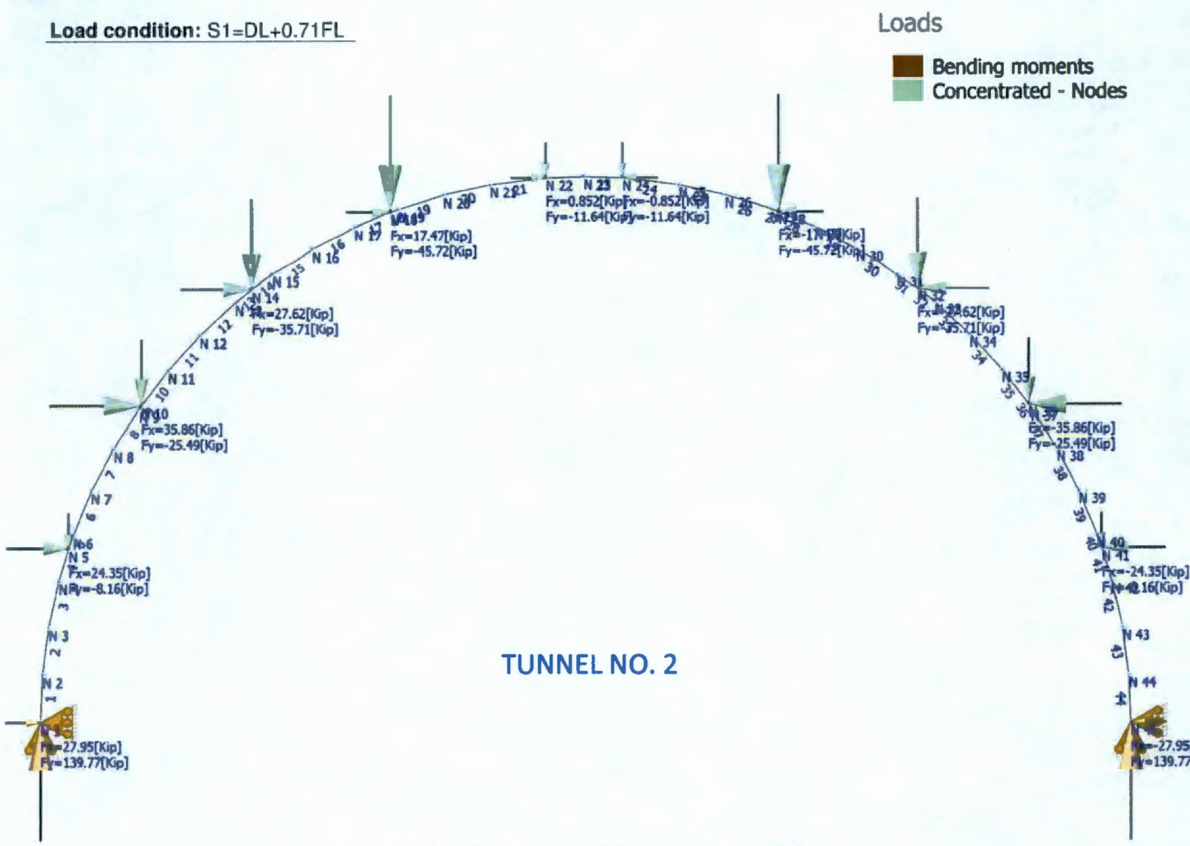
CONCRETE RIB GIRDER ANALYSIS

LRFD FACTORED LOAD SUPPORT REACTIONS



LRFD TOTAL FACTORED LOAD SUPPORT REACTIONS

(includes concrete arch self weight)



CONCRETE RIB GIRDER ANALYSIS

ASD SERVICE LOAD SUPPORT REACTIONS

ARCHED CONCRETE RIB GIRDER

Geometry data

GLOSSARY

Cb22, Cb33	: Moment gradient coefficients
Cm22, Cm33	: Coefficients applied to bending term in interaction formula
d0	: Tapered member section depth at J end of member
DJX	: Rigid end offset distance measured from J node in axis X
DJY	: Rigid end offset distance measured from J node in axis Y
DJZ	: Rigid end offset distance measured from J node in axis Z
DKX	: Rigid end offset distance measured from K node in axis X
DKY	: Rigid end offset distance measured from K node in axis Y
DKZ	: Rigid end offset distance measured from K node in axis Z
dL	: Tapered member section depth at K end of member
Ig factor	: Inertia reduction factor (Effective Inertia/Gross Inertia) for reinforced concrete members
K22	: Effective length factor about axis 2
K33	: Effective length factor about axis 3
L22	: Member length for calculation of axial capacity
L33	: Member length for calculation of axial capacity
LB pos	: Lateral unbraced length of the compression flange in the positive side of local axis 2
LB neg	: Lateral unbraced length of the compression flange in the negative side of local axis 2
RX	: Rotation about X
RY	: Rotation about Y
RZ	: Rotation about Z
TO	: 1 = Tension only member 0 = Normal member
TX	: Translation in X
TY	: Translation in Y
TZ	: Translation in Z

Nodes

Node	X [ft]	Y [ft]	Z [ft]	Rigid Floor
1	-19.00	0.00	0.00	0
2	-18.9277	1.656	0.00	0
3	-18.7113	3.2993	0.00	0
4	-18.3526	4.9176	0.00	0
5	-18.0112	6.0497	0.00	0
6	-17.8542	6.4984	0.00	0
7	-17.2198	8.0297	0.00	0
8	-16.4545	9.50	0.00	0
9	-15.5639	10.898	0.00	0
10	-15.4845	11.0105	0.00	0
11	-14.5548	12.213	0.00	0
12	-13.435	13.435	0.00	0
13	-12.213	14.5548	0.00	0
14	-11.6284	15.026	0.00	0
15	-10.898	15.5639	0.00	0
16	-9.50	16.4545	0.00	0
17	-8.0297	17.2198	0.00	0
18	-6.774	17.7514	0.00	0
19	-6.4984	17.8542	0.00	0
20	-4.9176	18.3526	0.00	0
21	-3.2993	18.7113	0.00	0
22	-1.338	18.9528	0.00	0
23	0.00	19.00	0.00	0
24	1.338	18.9528	0.00	0
25	3.2993	18.7113	0.00	0
26	4.9176	18.3526	0.00	0

27	6.4984	17.8542	0.00	0
28	6.774	17.7514	0.00	0
29	8.0297	17.2198	0.00	0
30	9.50	16.4545	0.00	0
31	10.898	15.5639	0.00	0
32	11.6284	15.026	0.00	0
33	12.213	14.5548	0.00	0
34	13.435	13.435	0.00	0
35	14.5548	12.213	0.00	0
36	15.4845	11.0105	0.00	0
37	15.5639	10.898	0.00	0
38	16.4545	9.50	0.00	0
39	17.2198	8.0297	0.00	0
40	17.8542	6.4984	0.00	0
41	18.0112	6.0497	0.00	0
42	18.3526	4.9176	0.00	0
43	18.7113	3.2993	0.00	0
44	18.9277	1.656	0.00	0
45	19.00	0.00	0.00	0

Restraints

Node	TX	TY	TZ	RX	RY	RZ
1	1	1	0	0	0	0
45	1	1	0	0	0	0

Members

Member	NJ	NK	Description	Section	Material	d0 [in]	dL [in]	Ig factor
1	1	2	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
2	2	3	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
3	3	4	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
4	4	5	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
5	5	6	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
6	6	7	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
7	7	8	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
8	8	9	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
9	9	10	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
10	10	11	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
11	11	12	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
12	12	13	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
13	13	14	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
14	14	15	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
15	15	16	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
16	16	17	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
17	17	18	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
18	18	19	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
19	19	20	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
20	20	21	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
21	21	22	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
22	22	23	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
23	23	24	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
24	24	25	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
25	25	26	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00

26	26	27	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
27	27	28	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
28	28	29	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
29	29	30	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
30	30	31	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
31	31	32	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
32	32	33	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
33	33	34	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
34	34	35	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
35	35	36	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
36	36	37	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
37	37	38	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
38	38	39	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
39	39	40	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
40	40	41	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
41	41	42	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
42	42	43	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
43	43	44	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00
44	44	45	Conc Rib Girder	RcBeam 14x30in	C 4-40	0.00	0.00	0.00

ARCHED CONCRETE RIB GIRDER

Load data

GLOSSARY

Comb : Indicates if load condition is a load combination

Load conditions

Condition	Description	Comb.	Category
DL	Dead	No	DL
FL	Factored Load	No	DL
S1	DL+0.71FL	Yes	
C1	1.2DL+FL	Yes	

Load on nodes

Condition	Node	FX [Kip]	FY [Kip]	FZ [Kip]	MX [Kip*ft]	MY [Kip*ft]	MZ [Kip*ft]
FL	5	34.30	-11.50	0.00	0.00	0.00	0.00
	10	50.50	-35.90	0.00	0.00	0.00	0.00
	14	38.90	-50.30	0.00	0.00	0.00	0.00
	18	24.60	-64.40	0.00	0.00	0.00	0.00
	22	1.20	-16.40	0.00	0.00	0.00	0.00
	24	-1.20	-16.40	0.00	0.00	0.00	0.00
	28	-24.60	-64.40	0.00	0.00	0.00	0.00
	32	-38.90	-50.30	0.00	0.00	0.00	0.00
	36	-50.50	-35.90	0.00	0.00	0.00	0.00
	41	-34.30	-11.50	0.00	0.00	0.00	0.00

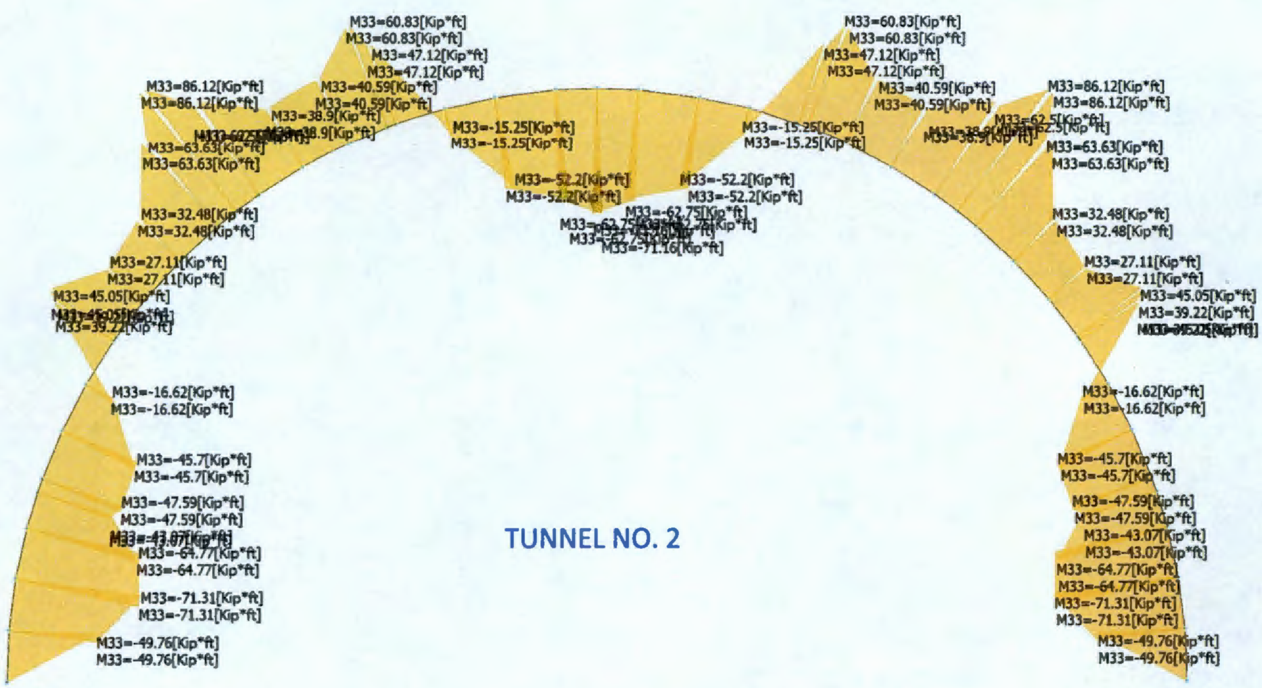
Self weight multipliers for load conditions

Condition	Description	Self weight multiplier			
		Comb.	MultX	MultY	MultZ
DL	Dead	No	0.00	-1.00	0.00
FL	Factored Load	No	0.00	0.00	0.00
S1	DL+0.71FL	Yes	0.00	0.00	0.00
C1	1.2DL+FL	Yes	0.00	0.00	0.00

Internal forces

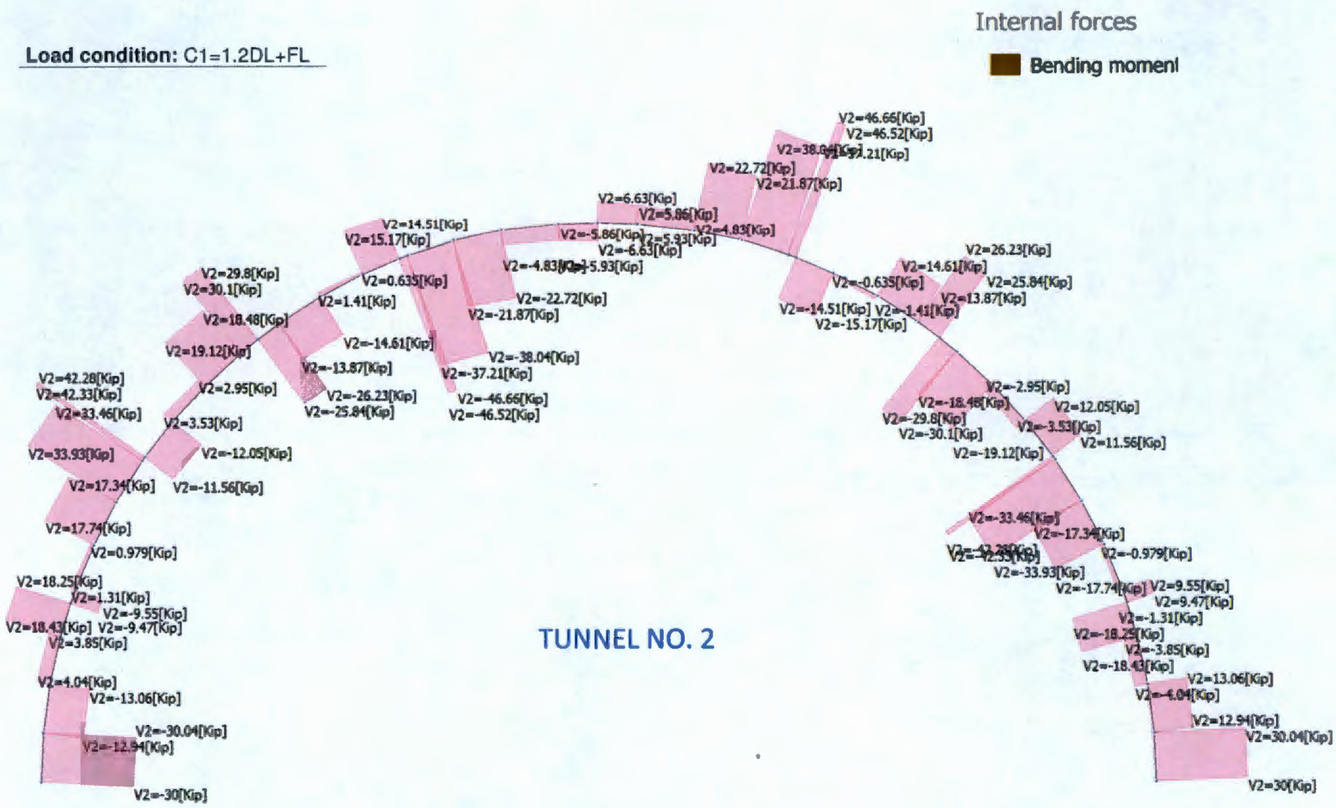
Bending moment

Load condition: C1=1.2DL+FL



CONCRETE RIB GIRDER ANALYSIS

MEMBER BENDING MOMENT DESIGN FORCES



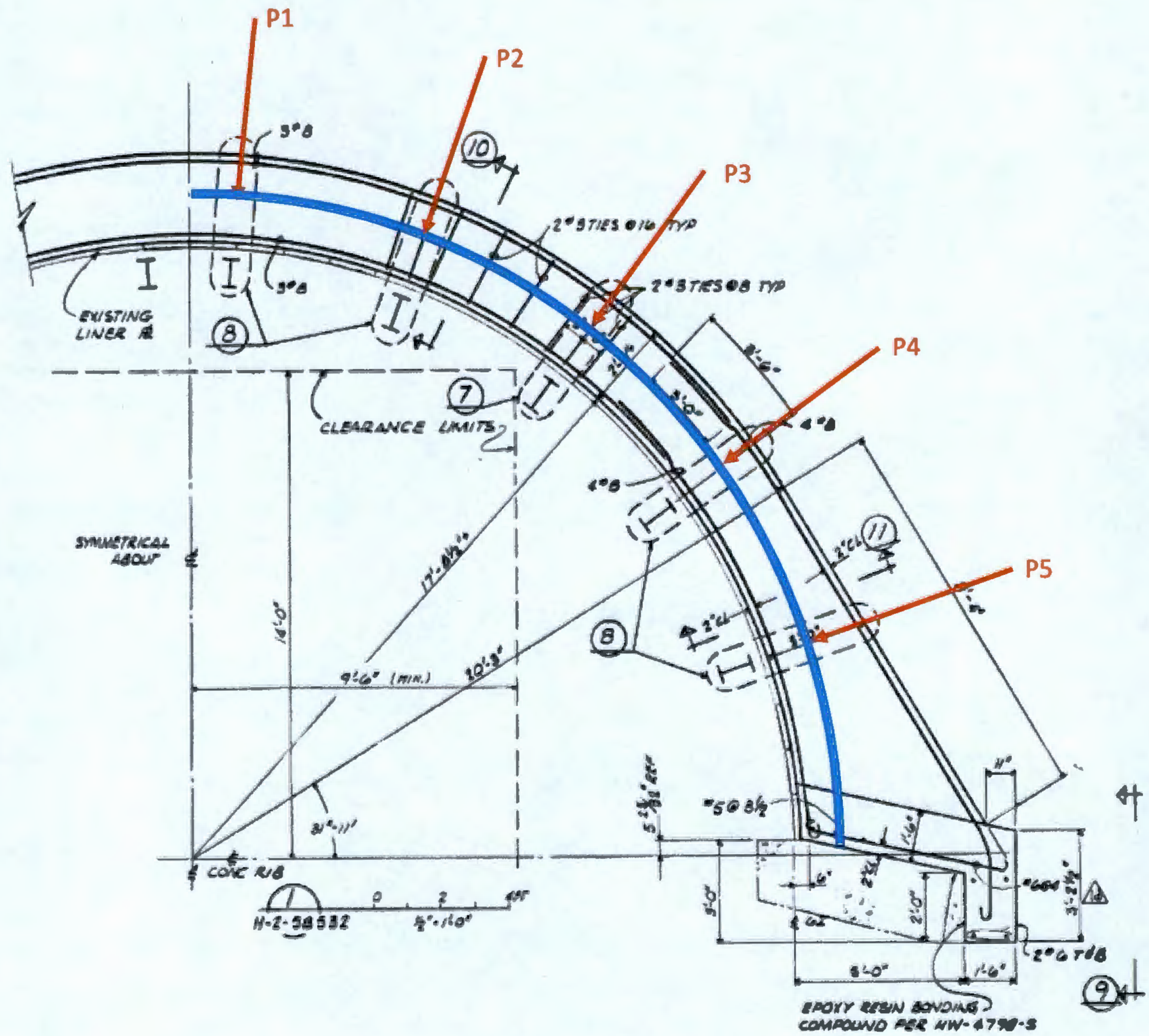
CONCRETE RIB GIRDER ANALYSIS

MEMBER SHEAR DESIGN FORCES

ARCHED CONCRETE RIB GIRDER LOAD DIAGRAM:

Concentrated loads applied to the concrete arch have been developed in the Wale Support analysis. These loads are applied at anchorage points as noted on the design drawings.

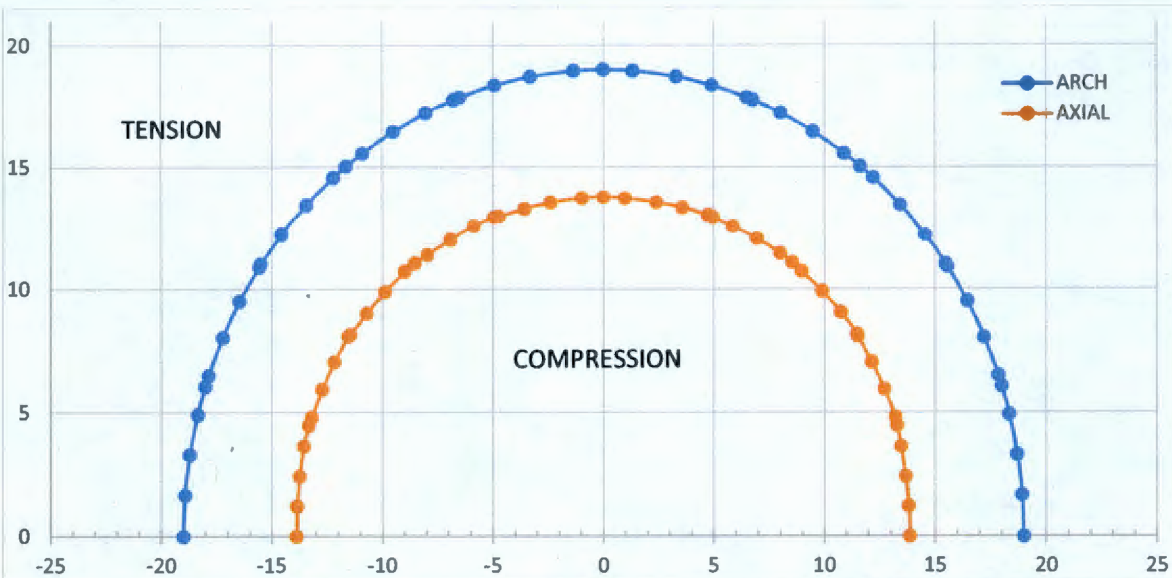
P1	=	16.4	kips
P2	=	68.9	kips
P3	=	63.6	kips
P4	=	62.0	kips
P5	=	36.2	kips



ARCHED CONCRETE RIB GIRDER ANALYSIS RESULTS:

AXIAL DEMANDS

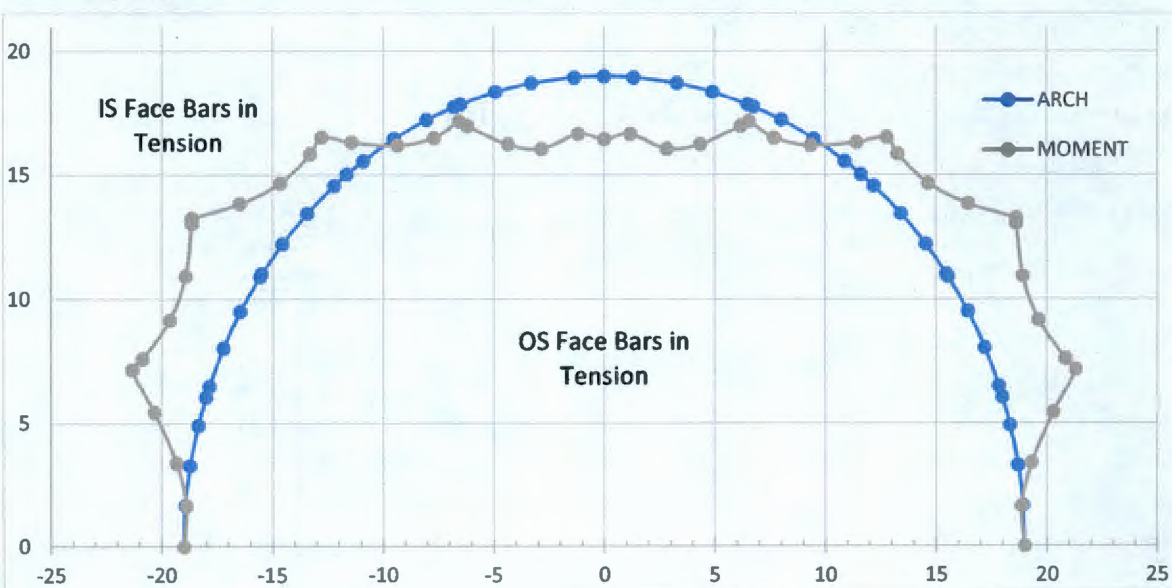
Note: Graph provided for demonstration of variance of values (not to be scaled).



MAXIMUM	-	196.7 kips	(Compression)	=	P_U
MINIMUM	-	182.0 kips	(Compression)		

BENDING DEMANDS

Note: Graph provided for demonstration of variance of values (not to be scaled).

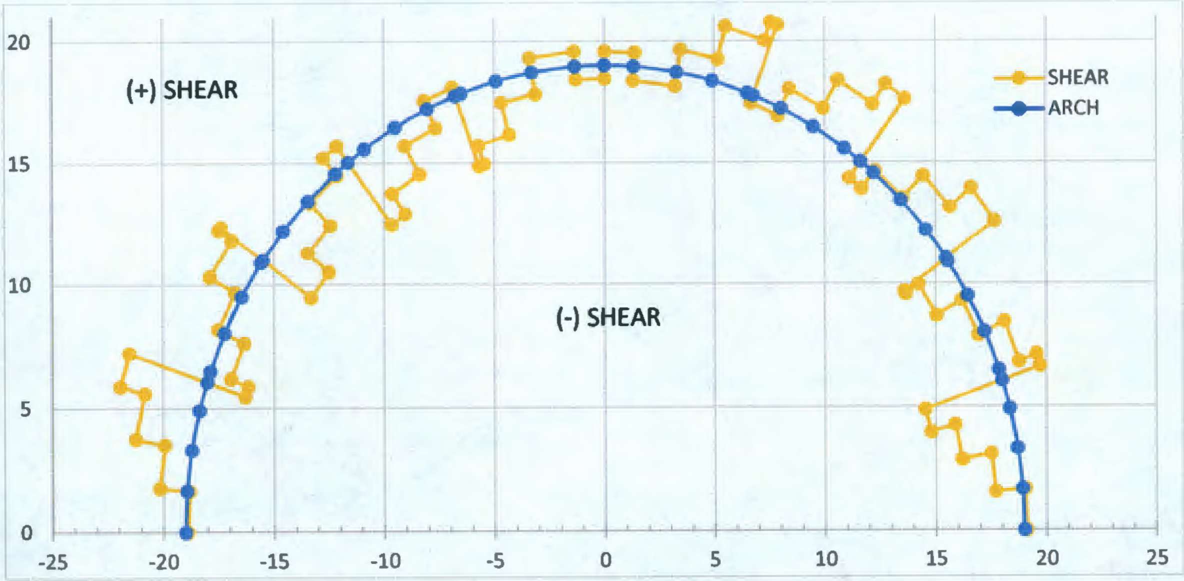


MAXIMUM - 86.1 ft-kips (OS Face Bars in Tension) = M_U

MINIMUM - 71.3 ft-kips (IS Face Bars in Tension)

SHEAR DEMANDS

Note: Graph provided for demonstration of variance of values. It is not to be scaled.

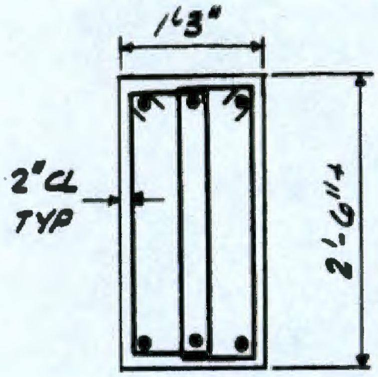


MAXIMUM - 46.7 kips (Absolute Value) = V_U

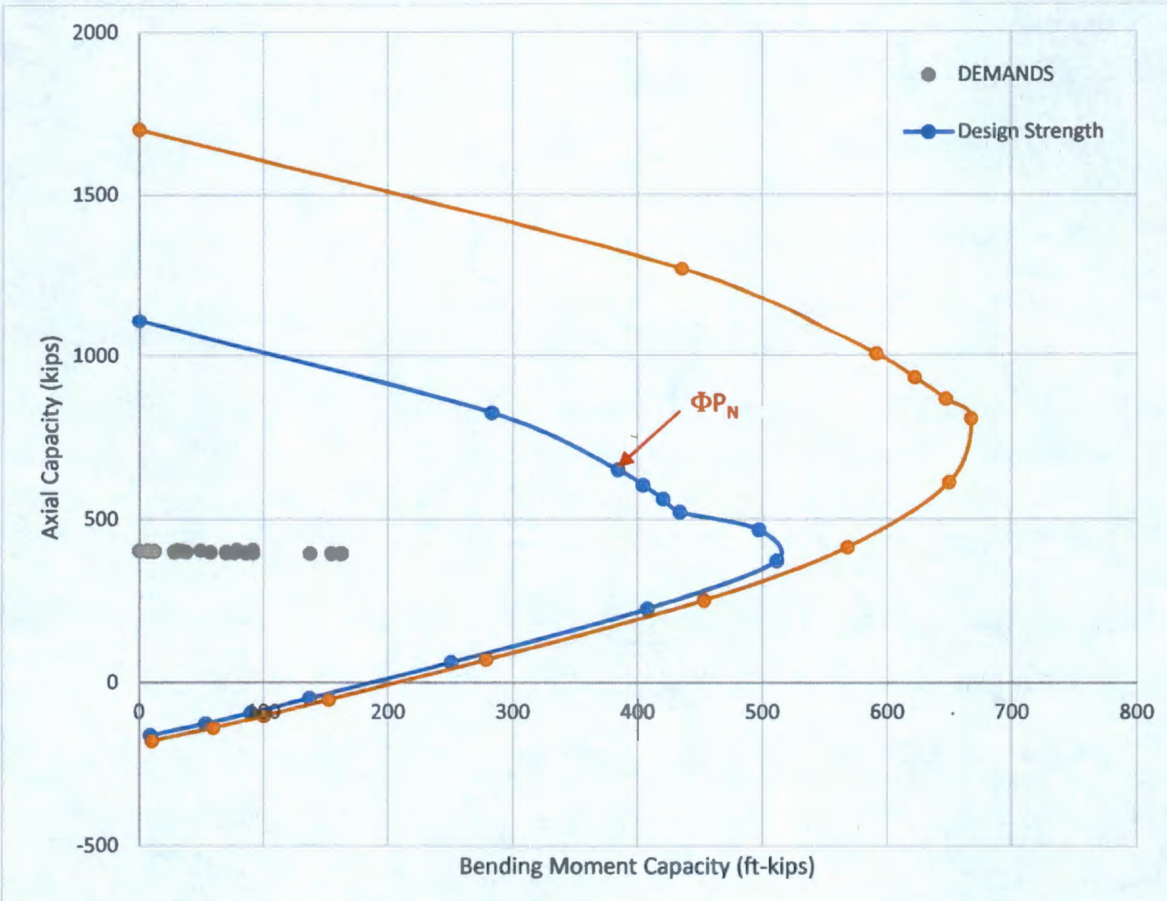
ARCHED CONCRETE RIB GIRDER CAPACITIES:

DESIGN SECTION PROPERTIES:

Concrete Compressive Strength	f'c	=	4000 psi
Steel Reinforcement Yield Strength	fy	=	40,000 psi
O/S Face Reinforcement	(3) - #8 Bars		
I/S Face Reinforcement	(3) - #8 Bars		
Stirrups	(2) - #3 Closed Loops		



AXIAL & BENDING INTERACTION CAPACITY CALCULATIONS:



Sample Calculation for data point on Interaction Curve (Balanced Condition):

Concrete Compressive Strength	$f_c := 4ksi$
Beam Width	$b := 15in$
Total Beam Depth	$h := 30in$
Clear Cover to Tension Reinforcing	$C_c := 2in$
Reinforcing Yield Strength	$f_y := 40ksi$
Steel Modulus of Elasticity	$E_s := 29000ksi$

$P_U / \Phi P_N = 196.7 / 523.6 = 0.38$

Quantity of Tension Rebar	$n_{t.rebar} := 3$	
Size of Tension Rebar	#8	
Diameter of Tension Rebar	$d_{t.rebar} := 1.0in$	
Area of Tension Reinforcing	$A_s := n_{t.rebar} \cdot \frac{\pi \cdot d_{t.rebar}^2}{4}$	$A_s = 2.356\,in^2$
Quantity of Compression Rebar	$n_{c.rebar} := 3$	
Size of Compression Rebar	#8	
Diameter of Compression Rebar	$d_{c.rebar} := 1.0in$	
Area of Compression Reinforcing	$A'_s := n_{c.rebar} \cdot \frac{\pi \cdot d_{c.rebar}^2}{4}$	$A'_s = 2.356\,in^2$
Quantity of Effective Stirrup Legs	$n_{stirrup} := 4$	
Size of Stirrups	#3	
Diameter of Stirrups	$d_{stirrup} := 0.375in$	
Area of Stirrup Leg	$A_{stirrup} := \frac{\pi \cdot d_{stirrup}^2}{4}$	$A_{stirrup} = 0.11\,in^2$
Total Stirrup Area	$A_v := n_{stirrup} \cdot A_{stirrup}$	$A_v = 0.442\,in^2$
Depth to Tension Reinforcing	$d := h - C_c - d_{stirrup} - \frac{d_{t.rebar}}{2}$	$d = 27.125\,in$
Depth to Compression Reinforcing	$d' := (C_c + d_{stirrup}) + \frac{d_{t.rebar}}{2}$	$d' = 2.875\,in$
Steel Yeilding Strain	$\varepsilon_y := \frac{f_y}{E_s}$	$\varepsilon_y = 0.00138$
Assumed Tensile Steel Strain	$\varepsilon_s := \varepsilon_y$	$\varepsilon_s = 0.00138$
Depth to Neutral Axis	$c_{NA} := 0.003 \cdot \frac{d}{\varepsilon_s + 0.003}$	$c_{NA} = 18.582\,in$

$M_U / \Phi M_N = 86.1 / 433.7 = 0.20$

FLEXURE BENDING CALCULATION

Compression Block Factor

$$\beta_1 := \begin{cases} 0.85 & \text{if } f'_c \le 4000psi \\ 0.65 & \text{if } f'_c \ge 8000psi \\ \left(\left(1.05 - 0.05 \cdot \frac{f'_c}{1000 \cdot psi}\right)\right) & \text{otherwise} \end{cases} \qquad \beta_1 = 0.85$$

Depth of Rectangular Stress Block

$$a := \beta_1 \cdot c_{NA} \qquad a = 15.794\,in$$

Compressive Force Due to Concrete

$$C_{conc} := 0.85 \cdot f'_c \cdot b \cdot a \qquad C_{conc} = 805.516\,kip$$

Compressive Steel Strain

$$\varepsilon'_s := 0.003 \cdot \frac{(c_{NA} - d')}{c_{NA}} \qquad \varepsilon'_s = 0.00254$$

Axial Force Due to A's

$$C_s := A'_s \cdot E_s \cdot \min(\varepsilon'_s, \varepsilon_y) \qquad C_s = 94.248\,kip$$

Tension Force Due to As

$$T_s := A_s \cdot E_s \cdot \min(\varepsilon_s, \varepsilon_y) \qquad T_s = 94.248\,kip$$

Nominal Axial Strength

$$P_n := C_{conc} + C_s - T_s \qquad P_n = 805.516\,kip$$

Nominal Flexural Strength

$$M_n := C_{conc} \cdot \left(\frac{h}{2} - \frac{a}{2}\right) + C_s \cdot \left(\frac{h}{2} - d'\right) + T_s \cdot \left(d - \frac{h}{2}\right)$$

$$M_n = 667.243\,ft \cdot kip$$

Strength Reduction Factor

$$\phi_d := \min\left[0.65 + 0.25 \cdot \frac{(\varepsilon_s - \varepsilon_y)}{0.005 - \varepsilon_y}, 0.9\right]$$

$$\phi_d = 0.65$$

Design Axial Strength

$$\phi P_n := \phi_d \cdot P_n \qquad \phi P_n = 523.586\,kip$$

Design Flexural Strength

$$\phi M_n := \phi_d \cdot M_n \qquad \phi M_n = 433.708\,ft \cdot kip$$

SHEAR CAPACITY CALCULATION:

Input Data

Reinforcing Yield Strength	$f_y := 40ksi$
Concrete Compressive Strength	$f_c := 4ksi$
Beam Width	$b := 15in$
Depth to Tension Reinforcing	$d := 27.125in$
Total Beam Depth	$h := 30in$
Total Stirrup Area	$A_v := 0.441in^2$
Tie/Stirrup Spacing	$s_{stirrup} := 16in$
Compressive Demand on Section	$N_u := 470kip$

Calculations

Gross Area of Section $A_g := b \cdot h$ $A_g = 450in^2$

$\phi_v := 0.75$

$$V_c := 2 \cdot \left(1 + \frac{N_u}{2000 \cdot A_g \cdot psi}\right)\sqrt{\frac{f_c}{psi}} \cdot psi \cdot b \cdot d \qquad V_c = 78.3 \cdot kip \qquad \textit{[EQN 11-4]}$$

$$V_s := \frac{f_y \cdot d \cdot A_v}{s_{stirrup}} \qquad V_s = 29.9 \cdot kip \qquad \textit{[EQN 11-15]}$$

$$V_{s\_max} := 8 \cdot \sqrt{\frac{f_c}{psi}} \cdot psi \cdot b \cdot d \qquad V_{s\_max} = 205.9 \cdot kip \qquad \textit{[§ 11.4.7.9]}$$

$$\phi V_n := \phi_v \cdot (V_c + \min(V_s, V_{s\_max})) \qquad \phi V_n = 81.2 \cdot kip \qquad \textit{[EQN 11-2]}$$

$V_U / \Phi V_N = 46.7 / 81.2 = 0.58$

ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Wale Underhung Support Bolted Connection

Concrete Arch to Wale Connection

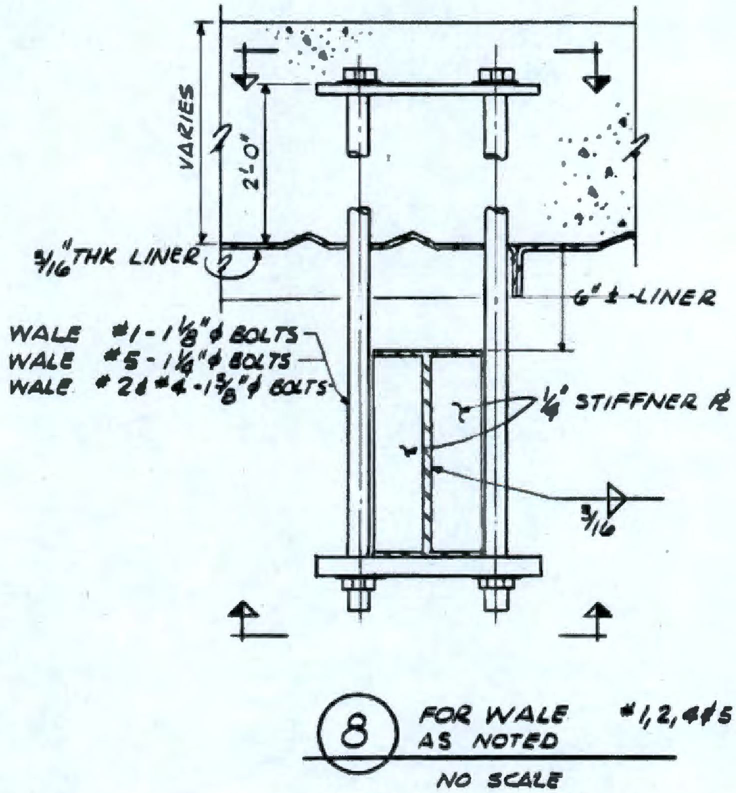


Figure: Wale 1, 2, 4, & 5 to Concrete Arch Connection

Loading (from Wale Beam analysis - maximum factored support reaction)

Wale #1 (W10x25) $P_{W1} := 16.4kip$

Wale #2 (W12x31) $P_{W2} := 68.9kip$

Wale #3 (W12x31) $P_{W3} := 63.6kip$

Wale #4 (W12x31) $P_{W4} := 62.0kip$

Wale #5 (W12x27) $P_{W5} := 36.2kip$

Bolt Properties

Bolt and Plate Type ASTM := A36 *(Drawing H-2-58532)*

Bolt Tensile Strength $F_{nt} := 45ksi$

Bolt Shear Strength $F_{nv} := 27ksi$

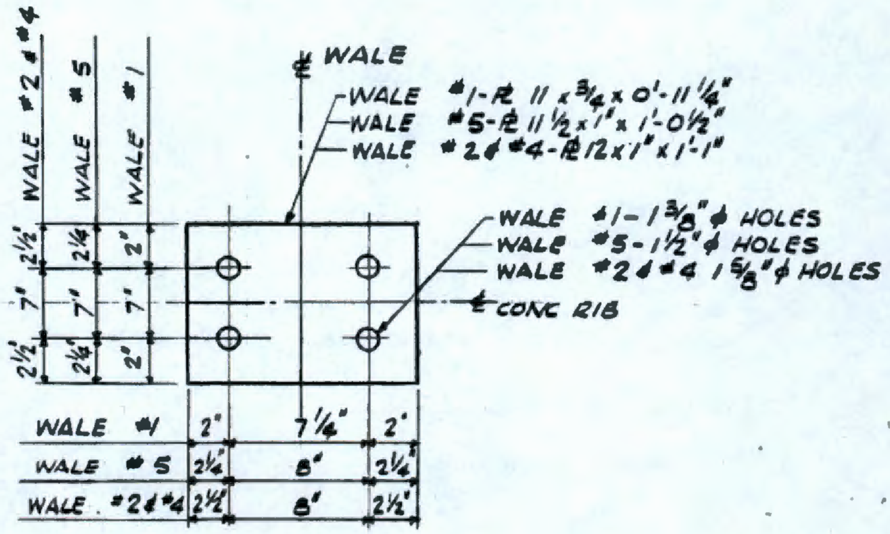


Figure: Wale 1, 2, 4, & 5 Plates

Member Properties

Wale 1 Bolt Properties at Concrete Arch

Wale 1 Bolt Diameter $dbc_{W1} := 1.125in$

Wale 1 Bolt Area $Abc_{W1} := \pi \cdot \left(\frac{dbc_{W1}}{2}\right)^2 = 0.994 \cdot in^2$

Wale 1 Plate Properties at Concrete Arch

Plate Minimum Yield Stress $Fy_p := 36ksi$

Plate Tensile Stress $Fu_p := 58ksi$

Wale 1 Arch Plate Thickness $tc_{W1} := 0.75in$

Wale 1 Arch Plate Depth $dc_{W1} := 11in$

Wale 1 Arch Plate Width $wc_{W1} := 11.25in$

Wale 1 Bolt Hole Diameter $hole_{W1} := dbc_{W1} + \frac{1}{4}in = 1.375 \cdot in$

Wale 2 & 4 Bolt Properties at Concrete Arch

Wale 2 Bolt Diameter $dbc_{W2\_4} := 1.375in$

Wale 2 Bolt Area $Abc_{W2\_4} := \pi \cdot \left(\frac{dbc_{W2\_4}}{2}\right)^2 = 1.485 \cdot in^2$

Wale 2 & 4 Plate Properties at Concrete Arch

Wale 2 & 4 Arch Plate Thickness $tc_{W2\_4} := 1in$

Wale 2 & 4 Arch Plate Depth $dc_{W2\_4} := 12in$

Wale 2 & 4 Arch Plate Width $wc_{W2\_4} := 13in$

Wale 2 & 4 Bolt Hole Diameter $hole_{W2\_4} := dbc_{W2\_4} + \frac{1}{4}in = 1.625 \cdot in$

Wale 5 Bolt Properties at Concrete Arch

Wale 5 Bolt Diameter $dbc_{W5} := 1.25in$

Wale 5 Bolt Area $Abc_{W5} := \pi \cdot \left(\frac{dbc_{W5}}{2}\right)^2 = 1.227 \cdot in^2$

Wale 5 Plate Properties at Concrete Arch

Wale 5 Arch Plate Thickness $tc_{W5} := 1.0in$

Wale 5 Arch Plate Depth $dc_{W5} := 11.5in$

Wale 5 Arch Plate Width $wc_{W5} := 12.5in$

Wale 5 Bolt Hole Diameter $hole_{W5} := dbc_{W5} + \frac{1}{4}in = 1.5 \cdot in$

Bolt Tensile Strength

Tension Resistance Factor $\phi_t := 0.75$

Wale 1 Arch Bolt Tensile Strength $\phi Rnb_{W1} := \phi_t \cdot F_{nt} \cdot Abc_{W1} = 33.55 \cdot kip$

Wale 2 & 4 Arch Bolt Tensile Strength $\phi Rnb_{W2\_4} := \phi_t \cdot F_{nt} \cdot Abc_{W2\_4} = 50.12 \cdot kip$

Wale 5 Arch Bolt Tensile Strength $\phi Rnb_{W5} := \phi_t \cdot F_{nt} \cdot Abc_{W5} = 41.42 \cdot kip$

Plate Capacity

Resistance Factor for shear yielding $\phi_{sy} := 1.0$

Resistance Factor for shear rupture $\phi_{sr} := 0.75$

Wale 1

Wale 1 Plate Gross Area $Agv_{W1} := 2dc_{W1} \cdot tc_{W1} = 16.5 \cdot in^2$

Wale 1 Plate Net Area $Ant_{W1} := 2(dc_{W1} - 2 \cdot hole_{W1}) \cdot tc_{W1} = 12.375 \cdot in^2$

Wale 1 Plate shear yield capacity $\phi Rny_{W1} := \phi_{sy} \cdot 0.6Fy_p \cdot Agv_{W1} = 356.4 \cdot kip$

Wale 1 Plate shear rupture capacity $\phi Rnu_{W1} := \phi_{sr} \cdot 0.6Fu_p \cdot Ant_{W1} = 322.99 \cdot kip$

Wale 1 Plate Shear Capacity $\phi Rns_{W1} := \min(\phi Rny_{W1}, \phi Rnu_{W1}) = 322.99 \cdot kip$

Wale 2 & 4

Wale 2 & 4 Plate Gross Area $Agv_{W2\_4} := 2dc_{W2\_4} \cdot tc_{W2\_4} = 24 \cdot in^2$

Wale 2 & 4 Plate Net Area $Ant_{W2\_4} := 2(dc_{W2\_4} - 2 \cdot hole_{W2\_4}) \cdot tc_{W2\_4} = 17.5 \cdot in^2$

Wale 2 & 4 Plate shear yield capacity $\phi Rny_{W2\_4} := \phi_{sy} \cdot 0.6Fy_p \cdot Agv_{W2\_4} = 518.4 \cdot kip$

Wale 2 & 4 Plate shear rupture capacity $\phi Rnu_{W2\_4} := \phi_{sr} \cdot 0.6Fu_p \cdot Ant_{W2\_4} = 456.75 \cdot kip$

Wale 2 & 4 Plate Shear Capacity $\phi Rns_{W2\_4} := \min(\phi Rny_{W2\_4}, \phi Rnu_{W2\_4}) = 456.75 \cdot kip$

Wale 5

Wale 5 Plate Gross Area $Agv_{W5} := 2dc_{W5} \cdot tc_{W5} = 23 \cdot in^2$

Wale 5 Plate Net Area $Ant_{W5} := 2(dc_{W5} - 2 \cdot hole_{W5}) \cdot tc_{W5} = 17 \cdot in^2$

Wale 5 Plate shear yield capacity $\phi Rny_{W5} := \phi_{sy} \cdot 0.6Fy_p \cdot Agv_{W5} = 496.8 \cdot kip$

Wale 5 Plate shear rupture capacity $\phi Rnu_{W5} := \phi_{sr} \cdot 0.6Fu_p \cdot Ant_{W5} = 443.7 \cdot kip$

Wale 5 Plate Shear Capacity $\phi Rns_{W5} := \min(\phi Rny_{W5}, \phi Rnu_{W5}) = 443.7 \cdot kip$

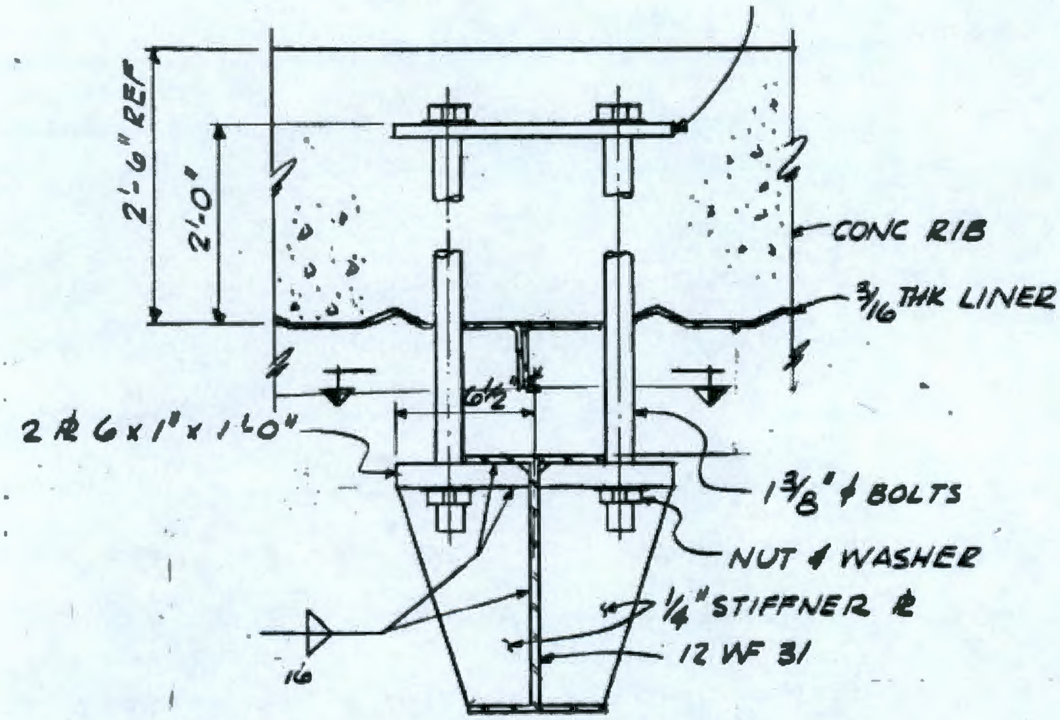


Figure: Wale 3 to Concrete Arch Connection

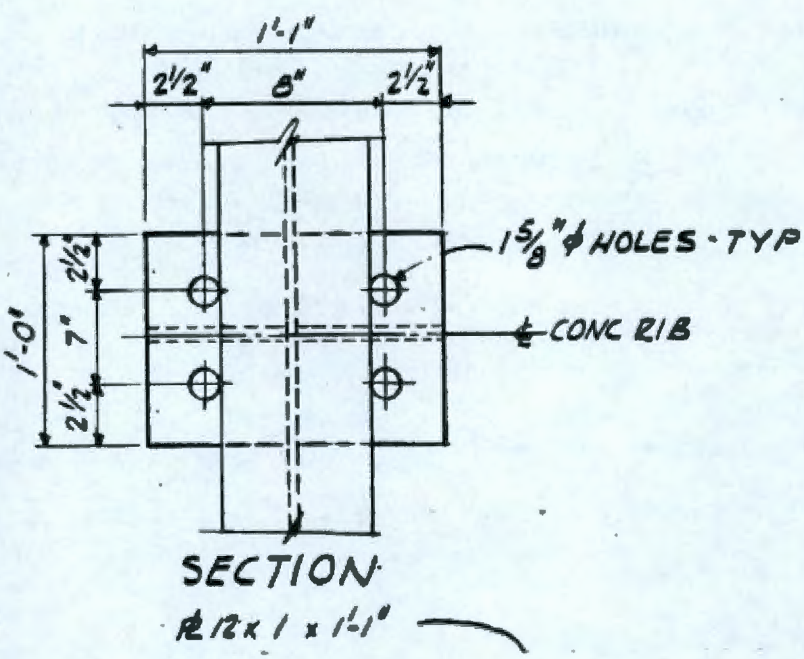


Figure: Wale 3 Plate

Member Properties

Concrete Arch to Wale 3

Wale 3 Bolt Properties at Concrete Arch

Wale 3 Bolt Diameter $dbc_{W3} := 1.375in$

Wale 3 Bolt Area $Abc_{W3} := \pi \cdot \left(\frac{dbc_{W3}}{2}\right)^2 = 1.485 \cdot in^2$

Wale 3 Plate Properties at Concrete Arch

Plate Minimum Yield Stress $Fy_p = 36 \cdot ksi$

Plate Tensile Stress $Fu_p = 58 \cdot ksi$

Wale 3 Arch Plate Thickness $tc_{W3} := 1.0in$

Wale 3 Arch Plate Depth $dc_{W3} := 12in$

Wale 3 Arch Plate Width $wc_{W3} := 6in$

Wale 3 Bolt Hole Diameter $hole_{W3} := dbc_{W3} + \frac{1}{4}in = 1.625 \cdot in$

Bolt Tensile Strength

Tension Resistance Factor $\phi_t = 0.75$

Wale 3 Arch Bolt Tensile Strength $\phi Rnb_{W3} := \phi_t \cdot F_{nt} \cdot Abc_{W3} = 50.115 \cdot kip$

Plate Capacity

Resistance Factor for shear yielding $\phi_{sy} = 1.0$

Resistance Factor for shear rupture $\phi_{sr} = 0.75$

Wale 3 Plate Gross Area $Agv_{W3} := 2dc_{W3} \cdot tc_{W3} = 24 \cdot in^2$

Wale 3 Plate Net Area $Ant_{W3} := 2\left(dc_{W3} - 2 \cdot hole_{W3}\right) \cdot tc_{W3} = 17.5 \cdot in^2$

Wale 3 Plate shear yield capacity $\phi Rny_{W3} := \phi_{sy} \cdot 0.6Fy_p \cdot Agv_{W3} = 518.4 \cdot kip$

Wale 3 Plate shear rupture capacity $\phi Rnu_{W3} := \phi_{sr} \cdot 0.6Fu_p \cdot Ant_{W3} = 456.75 \cdot kip$

Wale 3 Plate Shear Capacity $\phi Rns_{W3} := \min\left(\phi Rny_{W3}, \phi Rnu_{W3}\right) = 456.75 \cdot kip$

Demand / Capacity Ratios Recall Reactions at Arch Connections

Wale #1 (W10x25)	$P_{W1} = 16.4 \cdot kip$	Wale #4 (W12x31)	$P_{W4} = 62 \cdot kip$
Wale #2 (W12x31)	$P_{W2} = 68.9 \cdot kip$	Wale #5 (W12x27)	$P_{W5} = 36.2 \cdot kip$
Wale #3 (W12x31)	$P_{W3} = 63.6 \cdot kip$		

Controlling 2 & 4 Wale Reaction $P_{W2\_4} := \max(P_{W2}, P_{W4}) = 68.9 \cdot kip$

Arch Bolt DCR

Wale 1 Arch Bolt DCR $DCRb_{W1} := \dfrac{P_{W1}}{4 \cdot \phi Rnb_{W1}} = 0.12$

Wale 2 & 4 Arch Bolt DCR $DCRb_{W2\_4} := \dfrac{P_{W2\_4}}{4 \cdot \phi Rnb_{W2\_4}} = 0.34$

Wale 3 Arch Bolt DCR $DCRb_{W3} := \dfrac{P_{W3}}{4 \cdot \phi Rnb_{W3}} = 0.32$

Wale 5 Arch Bolt DCR $DCRb_{W5} := \dfrac{P_{W5}}{4 \cdot \phi Rnb_{W5}} = 0.22$

Arch Plate DCR

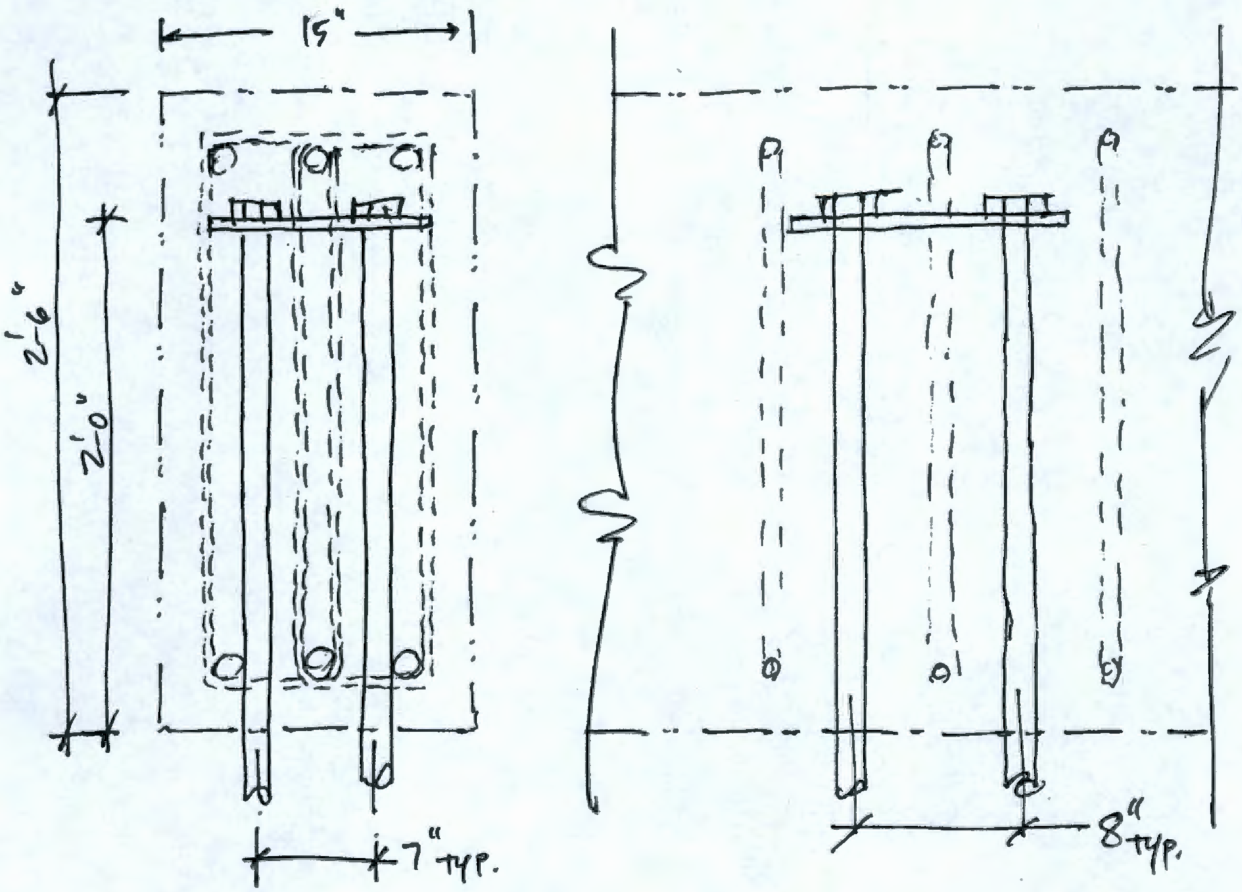
Wale 1 Arch Plate DCR $DCRp_{W1} := \dfrac{P_{W1}}{\phi Rns_{W1}} = 0.05$

Wale 2 & 4 Arch Plate DCR $DCRp_{W2\_4} := \dfrac{P_{W2\_4}}{\phi Rns_{W2\_4}} = 0.15$

Wale 3 Arch Plate DCR $DCRp_{W3} := \dfrac{P_{W3}}{\phi Rns_{W3}} = 0.14$

Wale 5 Arch Plate DCR $DCRp_{W5} := \dfrac{P_{W5}}{\phi Rns_{W5}} = 0.08$

WALE ANCHORAGE TO CONC ARCH



ACI 318 APPENDIX D CHECKS for TENSION:

D.4.1

a) steel strength in tension (D.5.1)

b) conc. breakout strength (D.5.2) see attached

c) pull-out strength in tension (D.5.3) does not govern by insp.

d) conc side-face blow-out (D.5.4) see attached

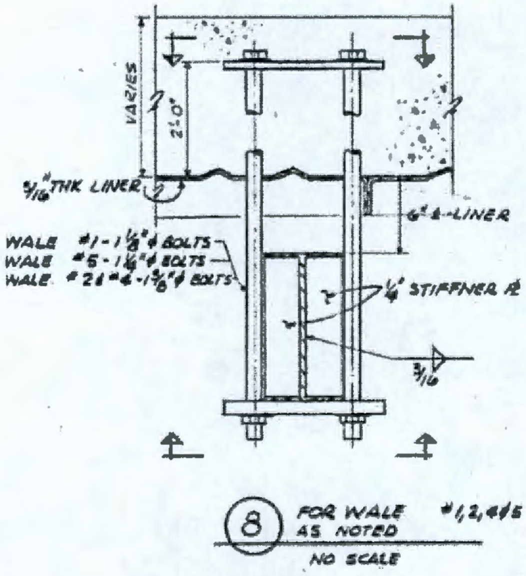


Figure: Wale 1, 2, 4, & 5 to Concrete Arch Connection

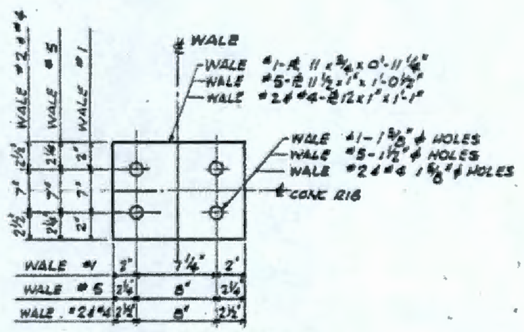


Figure: Wale 1, 2, 4, & 5 Plates

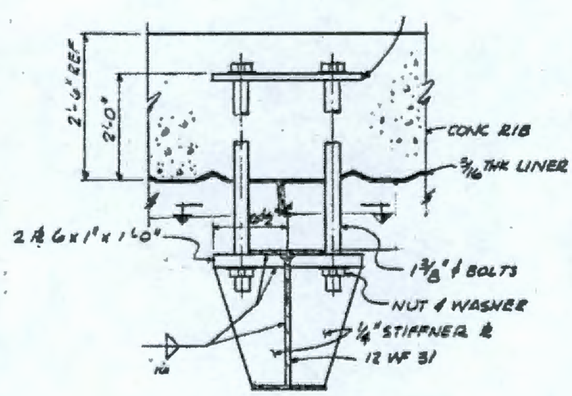


Figure: Wale 3 to Concrete Arch Connection

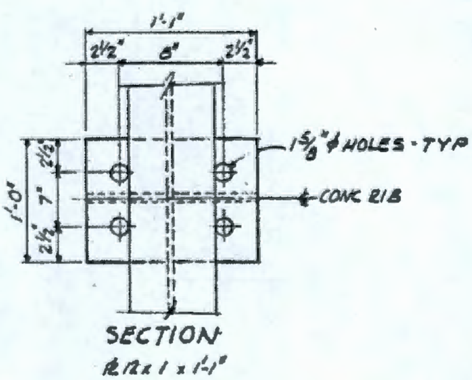


Figure: Wale 3 Plate

$f'_c = 4000$ psi

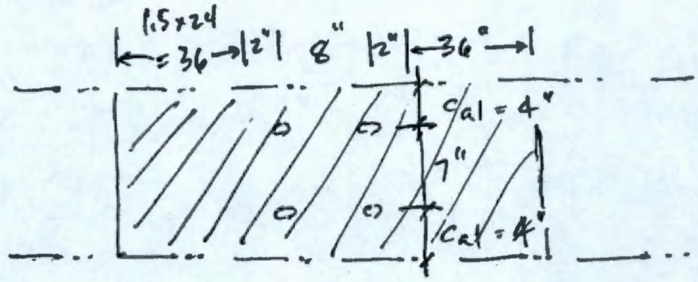
ACI 318 APPENDIX D

SECTION D.5.2 - Concrete Breakout Strength, Tension

D.5.2: for group of anchors:

(D-4) $N_{cbg} \leq \frac{A_{NC}}{A_{NCO}} * \psi_{ec,N} * \psi_{ed,N} * \psi_{c,N} * \psi_{cp,N} * N_b$

where $A_{NC} = 84 \times 15$
$= 1260$



(D-5) $A_{NCO} = 9(h_{ef})^2 = 9(24)^2 = 5184$

(D-6) $N_b = k_c \lambda_a \sqrt{f'_c} (h_{ef})^{1.5} = 24 * 1.0 * \frac{\sqrt{4000}}{1000} * (24)^{1.5} = 178.5^k$

(D-8) $\psi_{ec,N} = 1.0$ (no eccentricity)

(D-10) $\psi_{ed,N} = 0.7 + 0.3\left[\frac{c_{a,min}}{1.5 h_{ef}}\right]$

$= 0.7 + .3\left[\frac{4}{1.5(24)}\right] = 0.733$

$\psi_{c,N} = 1.25$ for cast-in place

$\psi_{cp,N} = 1.0$

$N_{cbg} = \frac{1260}{5184} * 1.0 * .733 * 1.25 * 1.0 * 178.5^k = 39.8^k$

$\phi N_{cbg} = .75(39.8) = 29.8^k$

D5.2.9 for anchor reinforcement developed per Chpt 12 on both sides of the breakout surface use design strength of reinforcement

$A_s = 20 * .11 * = 2.20$
(# of legs) (#3 bars)

$\phi N_N = .75 * 2.20 * 40 = 66^k$ ← governs.

Brk DCR $_{wave\ 1}$ = $\frac{16.4\ k}{66.0\ k}$ = 0.25

Brk DCR $_{wave\ 2}$ = $\frac{68.9\ k}{66.0\ k}$ = 1.04 > 1.0 EXCEEDS DESIGN CODE LIMITS

Brk DCR $_{wave\ 3}$ = $\frac{63.6\ k}{66.0\ k}$ = 0.96

Brk DCR $_{wave\ 4}$ = $\frac{62.0\ k}{66.0\ k}$ = 0.94

Brk DCR $_{wave\ 5}$ = $\frac{36.2\ k}{66.0\ k}$ = 0.55

ACI 318 APPENDIX D
SECTION D.5.4 - SIDE-FACE BLOWOUT

D.5.4.2 : deep embedment close to an edge? YES.

$h_{ef} > 2.5 c_{a1}$ where $c_{a1} = 4"$

$h_{ef} = 24" > 2.5(4) = 10"$

$s = 8"$

$N_{sbg} = \left(1 + \frac{s}{6 c_{a1}}\right) N_{sb}$

N_{sb} (from Eq D-16)
$= \left(160\, c_{a1} \sqrt{A_{brg}}\right)(\lambda_a)\sqrt{f'_c}$
$= 160 * 4 * \sqrt{4" \times 4"}\,(1.0)\sqrt{4000}$
↑ EFFECT OF ANCHOR PL, ASSUMED
$= 161.9^k$

$N_{sbg} = \left(1 + \frac{8}{6(4)}\right)(161.9) = 215.9^k$ for 2 rods

ϕ for side-face blow-out, with Condition A (ties act as supplemental reinforcement) = 0.75

TOTAL CAPACITY SIDE-FACE BLOW-OUT $= 2 * (.75)(215.9) = 323.8^k$ FOR ALL WALE ANCHORAGES.
↑ 2 sets of 2 "edge" anchors.

(DOES NOT GOVERN)

ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Concrete Rib Girder Thrust Block Foundation

Concrete Rib Girder Thrust Block Support

Reactions from Arched Concrete Rib Girder onto Foundation

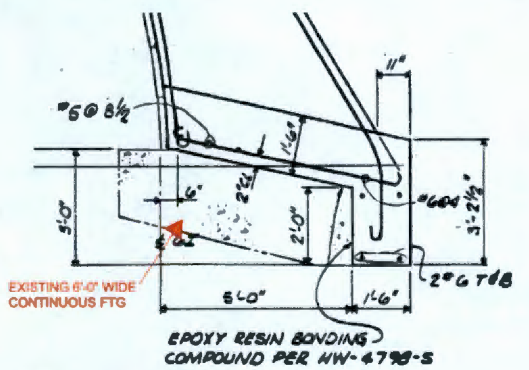
Maximum factored reactions from analysis of concrete arch:

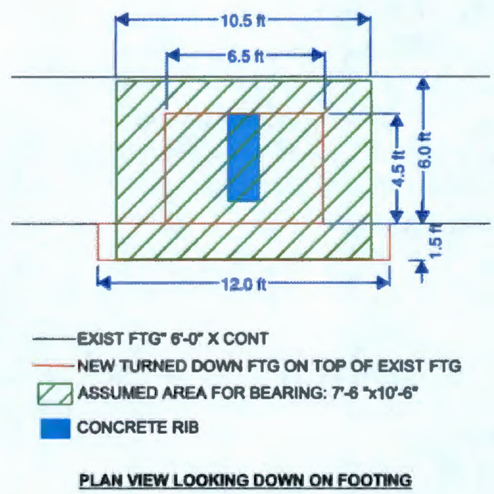
$P_{u(vert)}$ = 194.2 k (max factored vertical support reaction) $P_{(vert)}$ = 139.8 k (service load reaction)

$H_{u(lat)}$ = 38.5 k (max factored horizontal support reaction) $H_{(lat)}$ = 28.0 k (service load reaction)

Foundation Analysis

The new footing which supports the concrete rib was placed on top of the existing continuous footing for the steel hangar structure and turned down.





Sliding:

Passive pressure γ_{pass} = 300 pcf

Depth to surface from thrust block d = 12 ft

Length of turn down L = 12 ft

Height of turn down d_{stem} = 3.21 ft

qallow = 3,000 psf (allowable soil bearing capacity)

Calculate the resisting force on the vertical surface of the thrust block:

$H_{res} = \gamma_{pass} \times d \times L \times d_{stem}$ = 139 kips

$FS_{sliding} = H_{res}/H_{lat}$ = 139 k / 28.0 k = 4.96 $DCR_{sliding} = H_{lat} / H_{res}$ = 0.20

Bearing:

Dimensions for Bearing Calculation:

B_{brg} = 7.5 ft

L_{brg} = 10.5 ft

Bearing pressure is equal to the un-factored reaction due to the arch plus the weight of the soil over the footing:

$q = [(P_{vert})+(110pcf \times d \times B_{brg} \times L_{brg})]/(B_{brg} \times L_{brg})$ = (139.8+104.0) / (7.5*10.5) = 243.8 / 78.8 = 3,100 psf

DCR_{brg} = q / qallow = 3100 / 3000 = 1.03

Shear:

Check punching shear on the new footing:

Column Dimensions:

b_{col} = 1.25 ft

d_{col} = 5.583 ft

$\beta_{col} = d_{col}/ b_{col} =$ 4.47

$Vu = P_{vert} =$ 194.2 kips

ϕ_{shear} = 0.75

d_{new_ftg} = 16.5in

$bo = 2\times(d_{col}+ d_{new\_ftg})+2\times(b_{col}+ d_{new\_ftg})$ = 230 in

$\phi Vc_{punch} = \phi_{shear} \times(2+(4/\beta_{col}))\times 1psi\times\sqrt{(4000)}\times bo\times d_{new\_ftg}$ = 521 kips

$Vu / \phi Vc_{punch}$ = 194.2k / 521k = 0.37 **OK**

By Inspection, the punching shear on the existing footing is okay because bo and d for the existing footing are larger.

Check beam shear on the new footing:

Critical Length for 1 ft section at face of column:

$L_{crit} = (1/2)\times(6.5ft- b_{col})$ = 2.63 ft

$Vu_{\_beam\_new} = 1.4\times q\times 1ft\times L_{crit}$ = 11.4 kips

$\phi Vc_{beam\_new} = \phi_{shear} \times 2\times 1psi\times\sqrt{(4000)}\times 12in\times d_{new\_ftg}$ = 19 kips

$Vu_{\_beam\_new} / \phi Vc_{beam\_new}$ = 11.4 k / 19 k = 0.60 **OK**

Check reinforcement in the new footing:

$Mu_{\_beam\_new} = 1.4\times q\times 1ft\times L_{crit}\times L_{crit}/2$ = 15.0 kip-ft per ft

Fy = 40ksi

ϕ_b = 0.9

$As_{new} = 0.44in^2$ per ft

$a_{new} = (Fy\times As_{new})/ (0.85\times 4ksi\times 12in)$ = 0.43 in

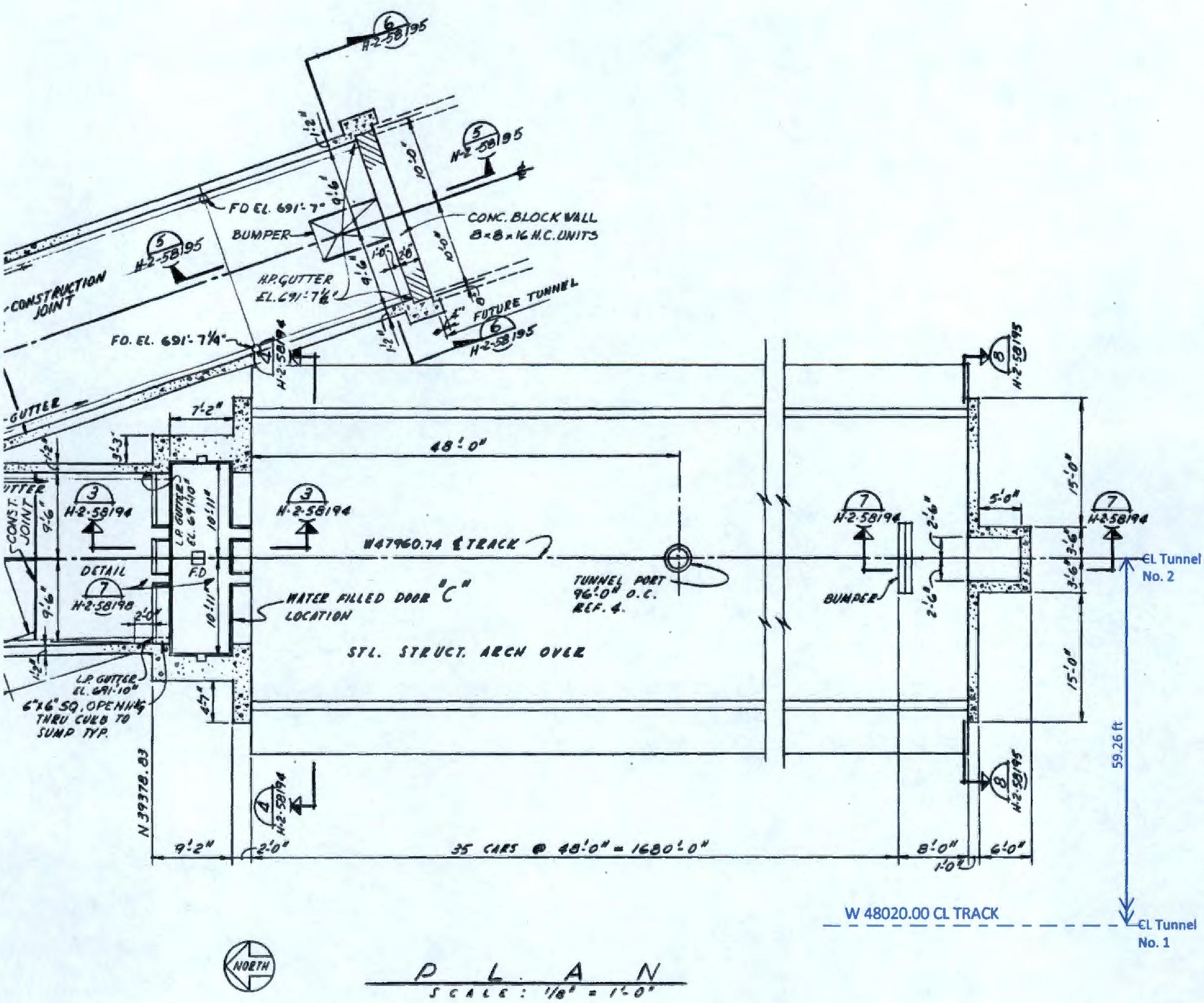
$\phi Mn_{new} = \phi_b\times Fy\times As_{new}\times(d_{new\_ftg}-(a_{new}/2))$ = 21 kip-ft per ft

$Mu_{\_beam\_new}/\phi Mn_{new}$ = 15.0 k-ft / 21.0 k-ft = 0.72 **OK**

By Inspection, the beam shear and moment on the existing footing is okay: "d" for the existing footing is larger and the idealized critical length is shorter.

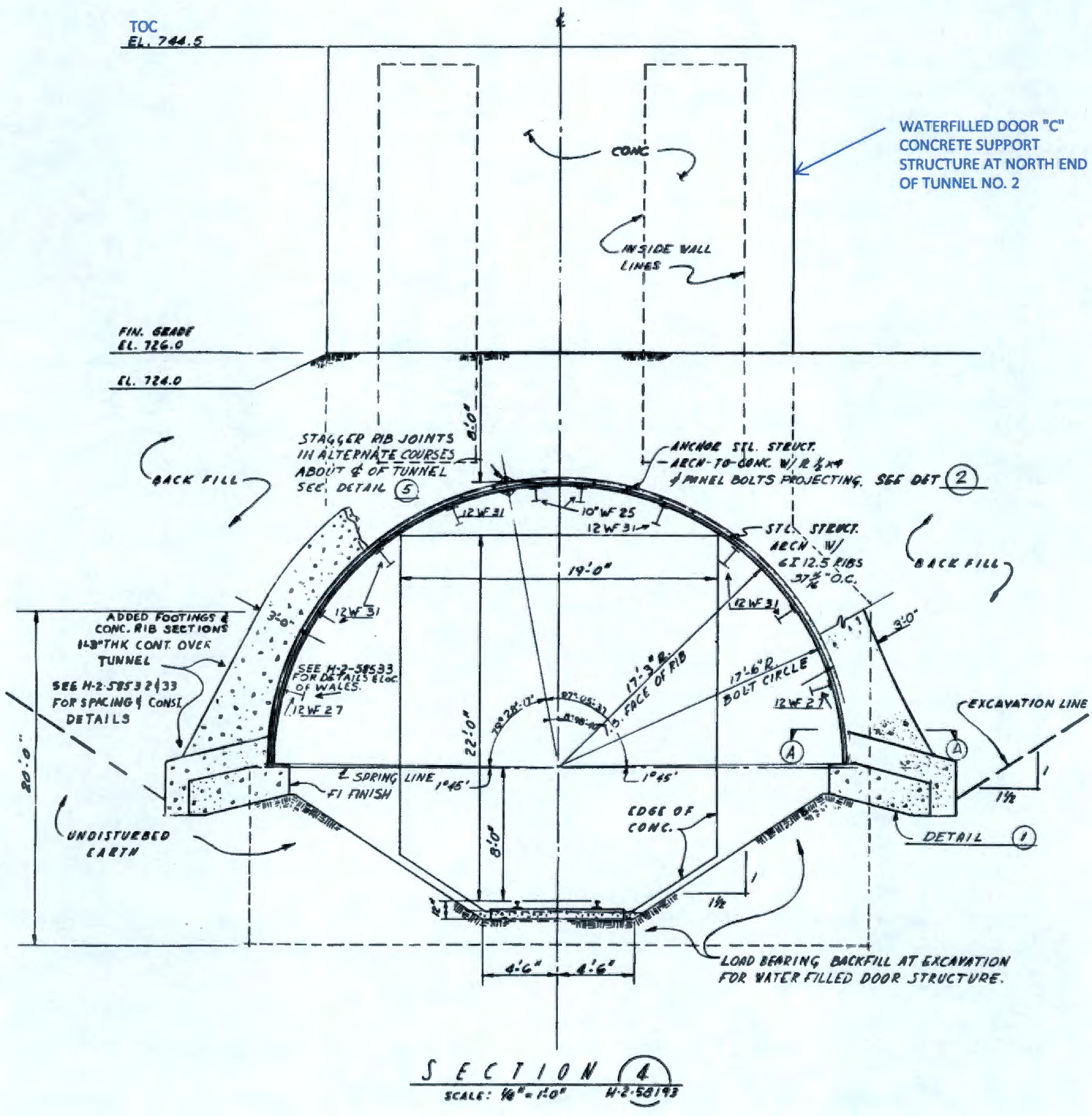
ch2m:	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

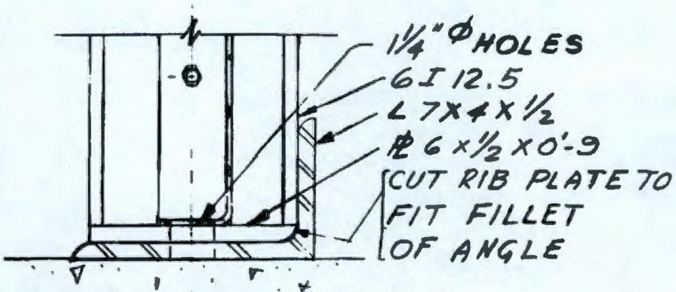
Original Design Drawings



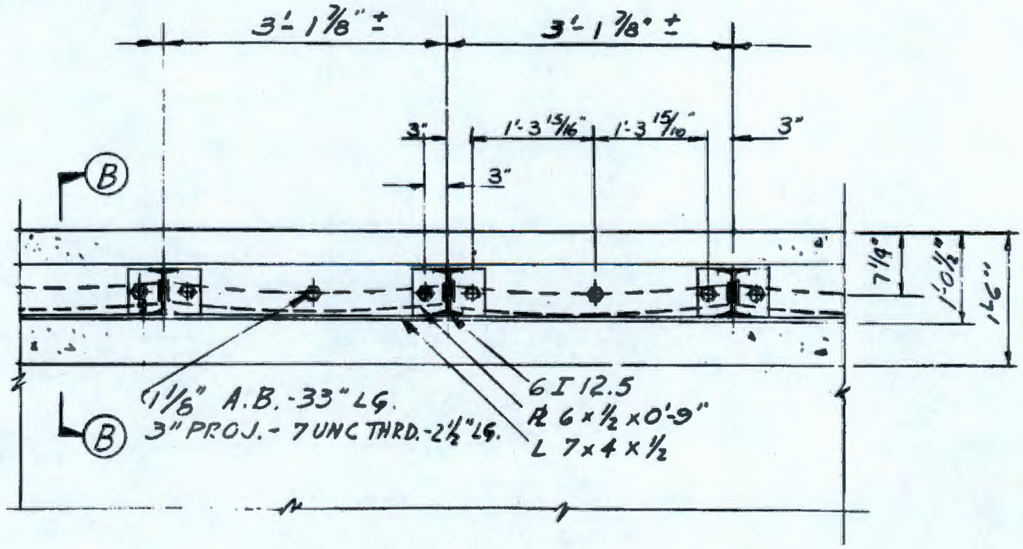
PLAN
SCALE: 1/8" = 1'-0"

1962 DWG H-2-58193

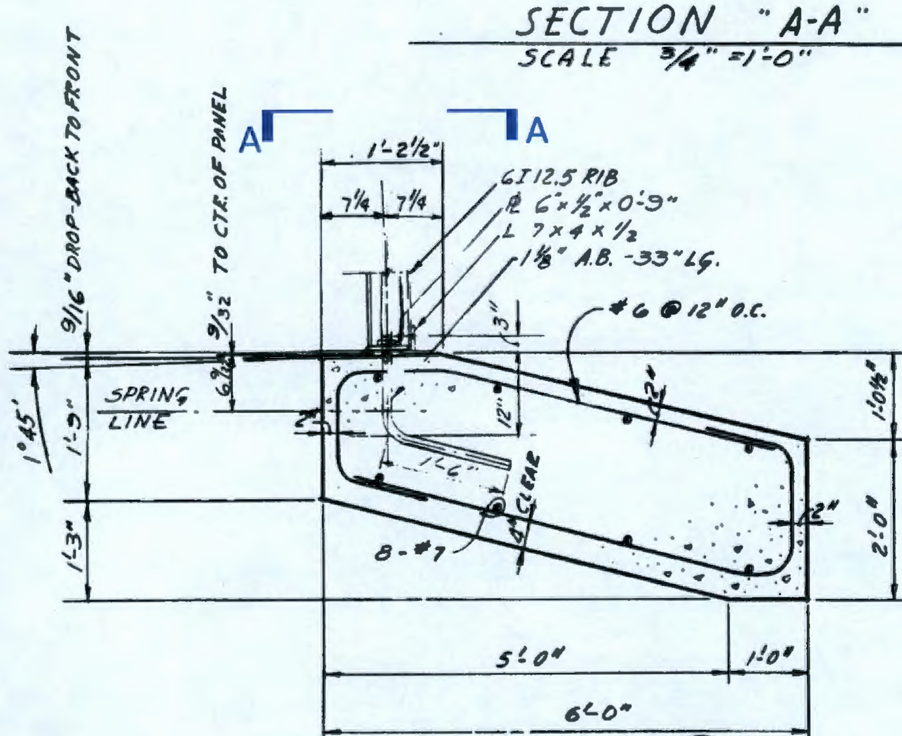

TOC
EL. 744.5
WATERFILLED DOOR "C" CONCRETE SUPPORT STRUCTURE AT NORTH END OF TUNNEL NO. 2
CONC
INSIDE WALL LINES
FIN. GRADE EL. 726.0
EL. 724.0
STAGGER RIB JOINTS IN ALTERNATE COURSES ABOUT ¢ OF TUNNEL SEE DETAIL 5
ANCHOR STL. STRUCT. ARCH-TO-CONC. W/ R ½ x4 ¢ PANEL BOLTS PROJECTING. SEE DET 2
BACK FILL
STL. STRUCT. ARCH W/ 6 I 12.5 RIBS 37½" O.C.
19'-0"
ADDED FOOTINGS & CONC. RIB SECTIONS
1'-3" THK CONT. OVER TUNNEL
SEE H-2-58532 & 33 FOR SPACING & CONST. DETAILS
SEE H-2-58533 FOR DETAILS & LOC. OF WALES.
17'-3" R. FACE OF RIB
17'-6" R. BOLT CIRCLE
EXCAVATION LINE
SPRING LINE
FI FINISH
EDGE OF CONC.
DETAIL 1
UNDISTURBED EARTH
LOAD BEARING BACKFILL AT EXCAVATION FOR WATER FILLED DOOR STRUCTURE.
SECTION 4
SCALE: ⅛" = 1'-0"
H-2-58193
1962 DWG H-2-58194



SECTION "B-B"
SCALE 3"=1'-0"

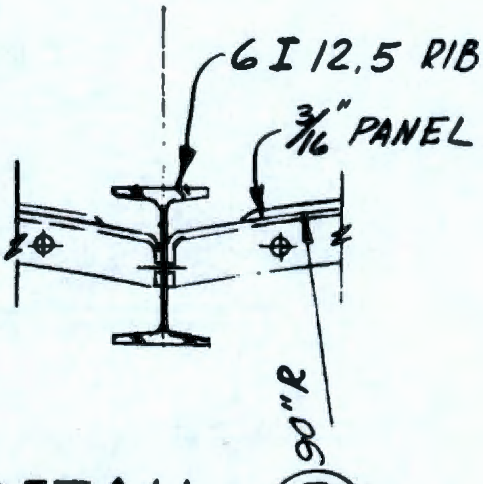


SECTION "A-A"
SCALE ¾"=1'-0"



DETAIL (1)
SCALE: ¾"=1'-0"

1962 DWG H-2-58194



DETAIL 3
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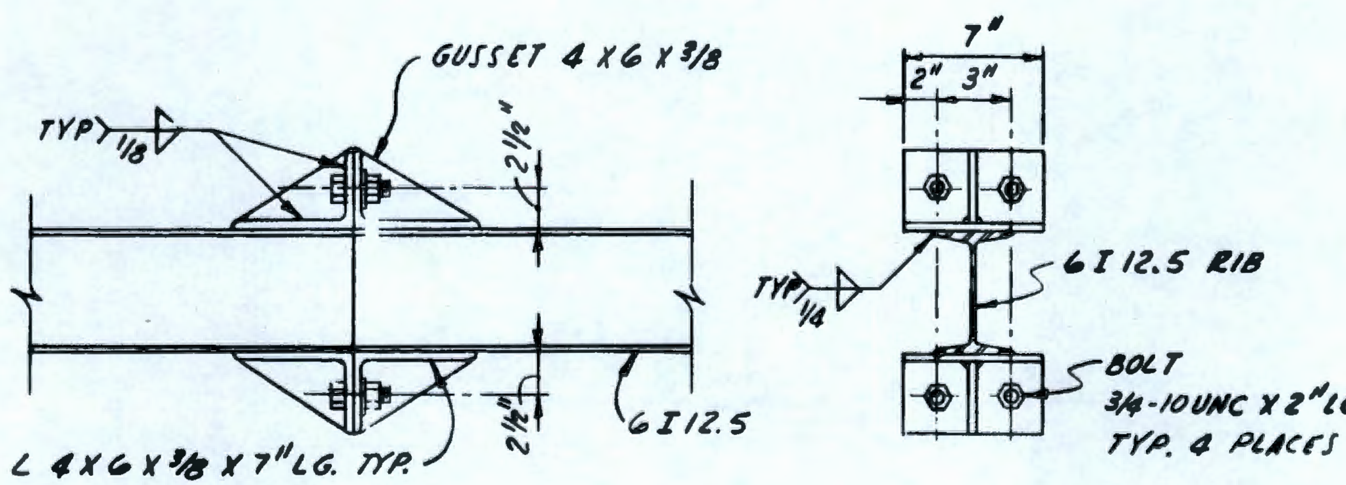
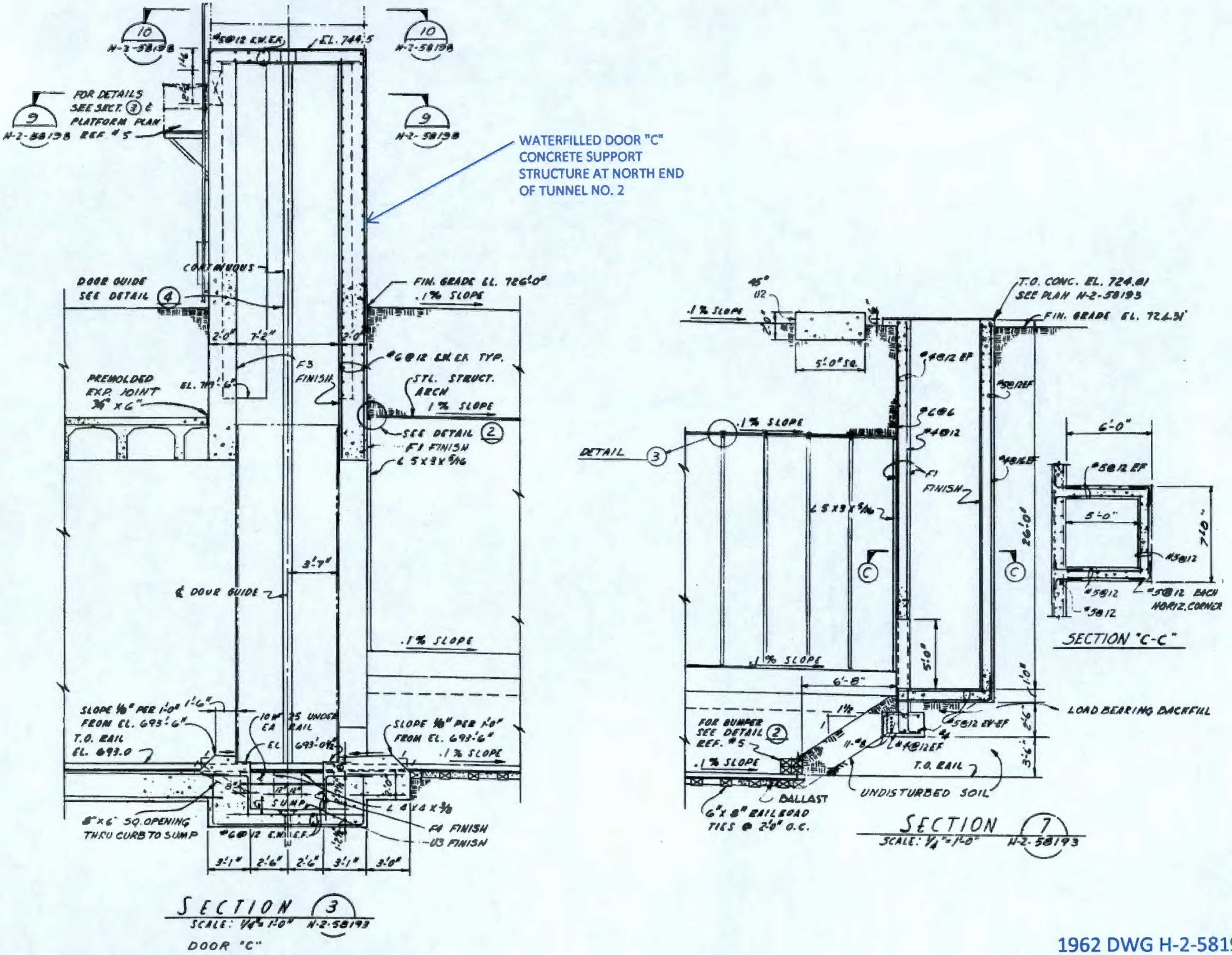


DETAIL 5
SCALE 1½" = 1'-0"

1962 DWG H-2-58194



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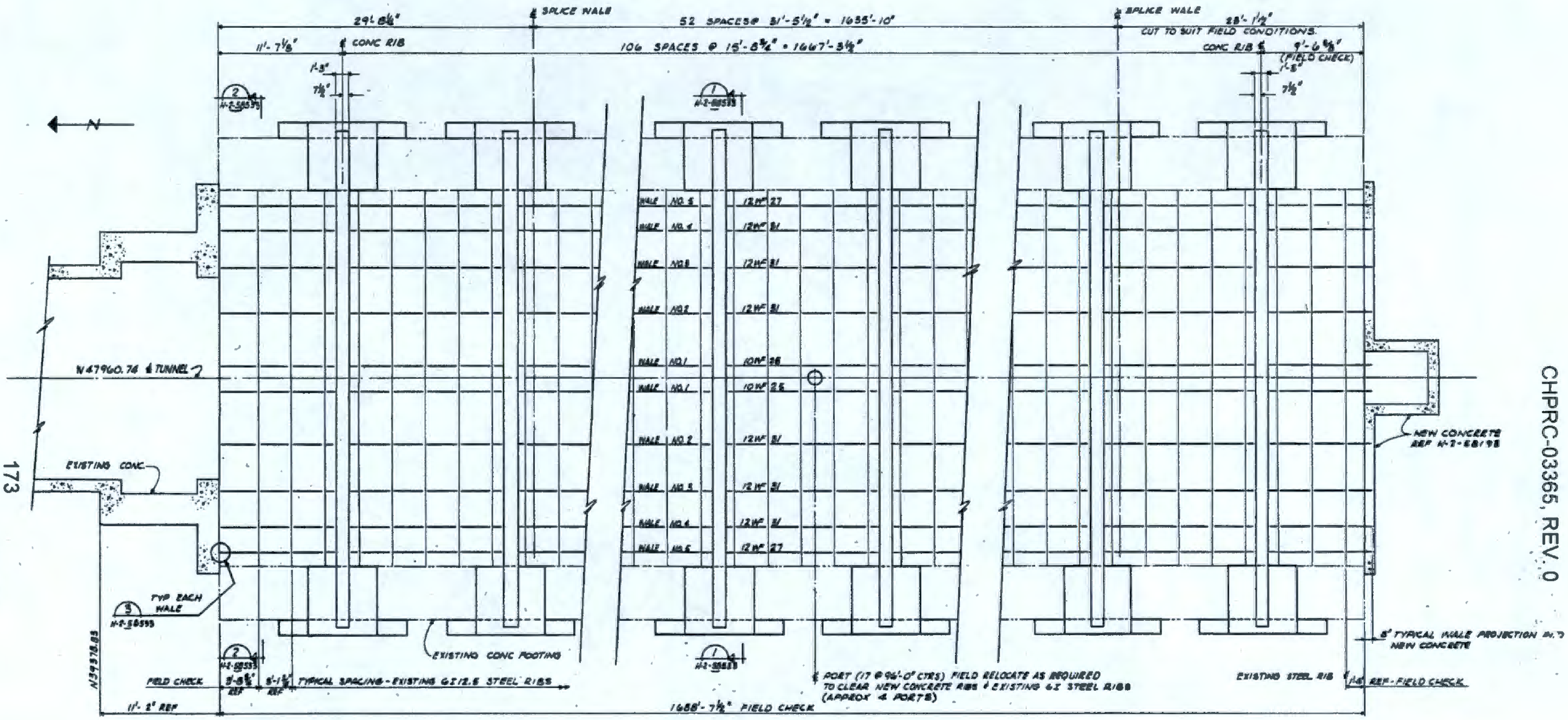


PLAN

0 4 8FT
¼" = 1'-0"

INTERNAL STEEL WALE LIST				
WALE NO.	SIZE	QTY	LENGTH	SPLICE ℄
1	10WF25 10WF25 10WF25	2 104 2	29'-8⅛" 31'-5¼" 23'-9⅜" *	106-6x⅜x0'-8"
2	12WF31 12WF31 12WF31	2 104 2	29'-8⅛" 31'-5¼" 23'-9⅜" *	106-6x⅜x0'-10"
3	12WF31 12WF31 12WF31	2 104 2	29'-8⅛" 31'-5¼" 23'-9⅜" *	106-6x⅜x0'-10"
4	12WF31 12WF31 12WF31	2 104 2	29'-8⅛" 31'-5¼" 23'-9⅜" *	106-6x⅜x0'-10"
5	12WF27 12WF27 12WF27	2 104 2	29'-8⅛" 31'-5¼" 23'-9⅜" *	106-6x⅜x0'-10"

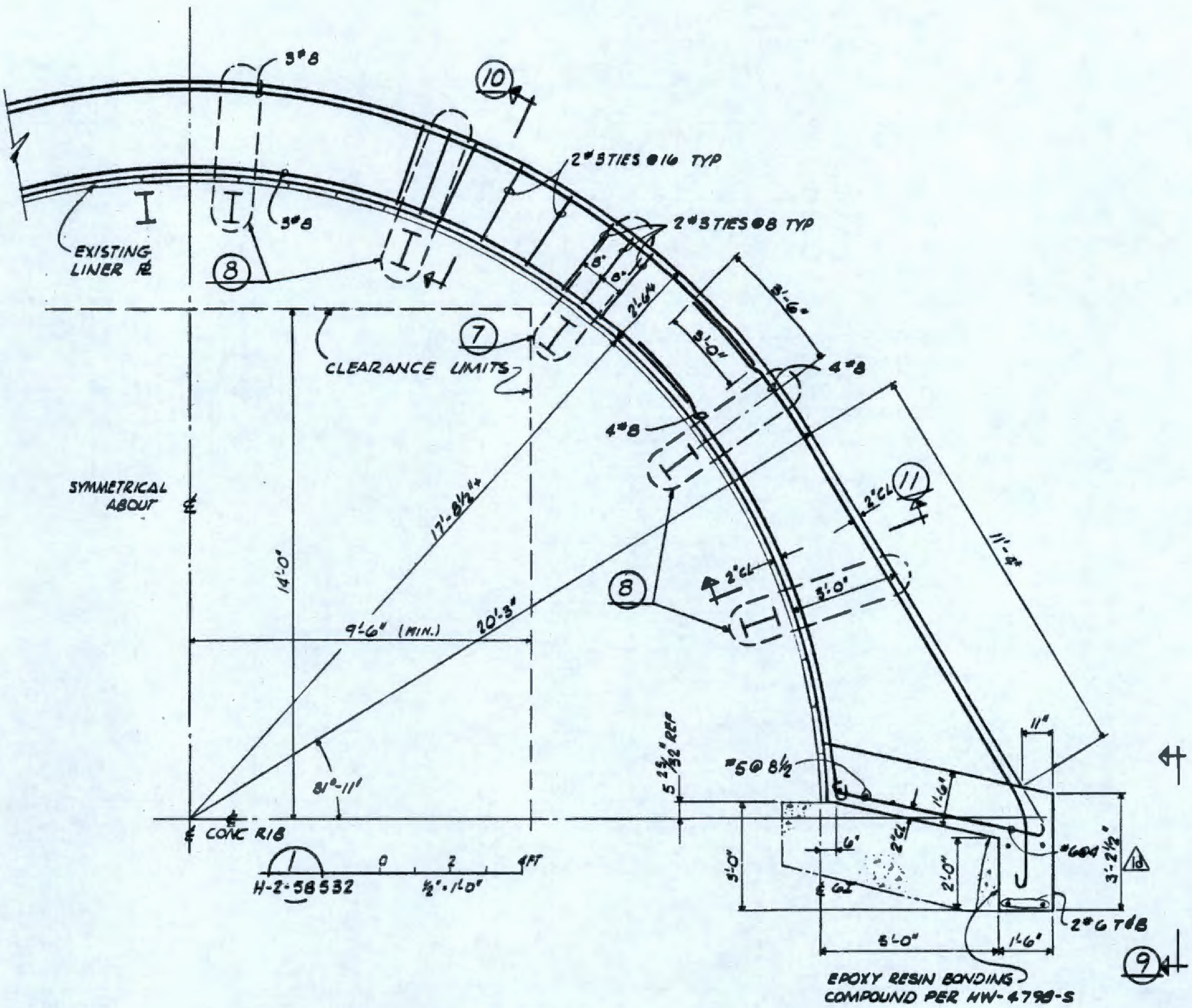
* CUT TO SUIT FIELD CONDITIONS

GENERAL NOTES

1. CONCRETE TO DEVELOP A COMPRESSIVE STRENGTH OF 4,000 # PSI PRIOR TO ANY BACKFILL LOADING
2. REINFORCING STEEL TO BE ASTM-A-432.
3. STRUCTURAL STEEL, PLATES & BOLTS TO BE ASTM-A-36.
4. HW-4798-S STANDARD SPECIFICATION FOR PLACING REINFORCED CONCRETE.
6. HW-4926-S STANDARD SPECIFICATION FOR WELDING CARBON STEELS.
7. PAINTING: ALL EXPOSED STEEL SHALL RECEIVE A 20 MIL DRY THICKNESS COATING COMPOUND, BITUMINOUS, SOLVENT COAL TAR BASE CONFORMING TO MIL SPEC MIL-C-18480 (DOCKS) (AM.1) (KOPPERS BITUMASTIC #50)

⚠ 8. SLOPES ON INTERIOR OF TUNNEL SECTION SHALL BE MAINTAINED DURING CONSTRUCTION.

1964 DWG H-2-58532



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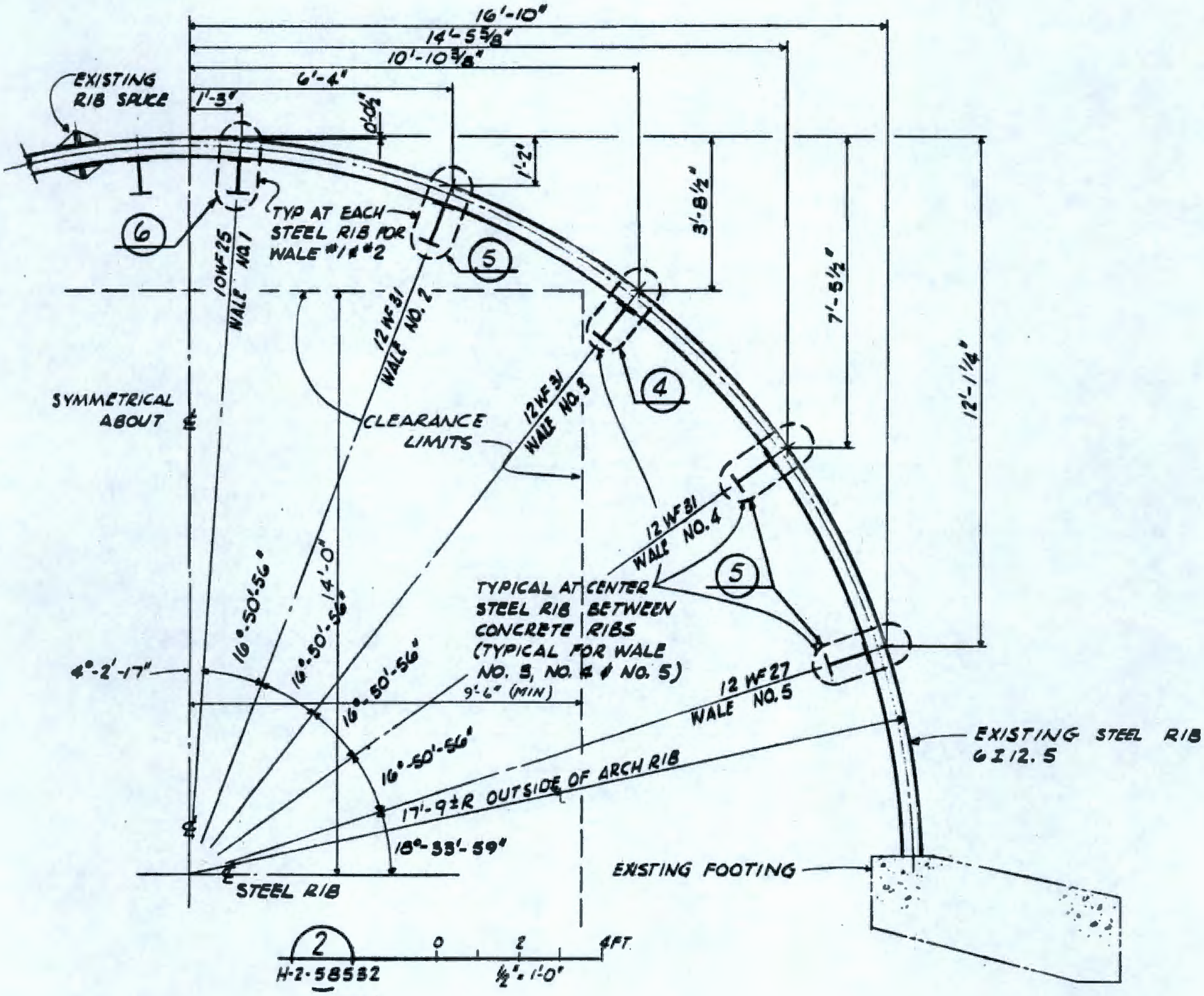

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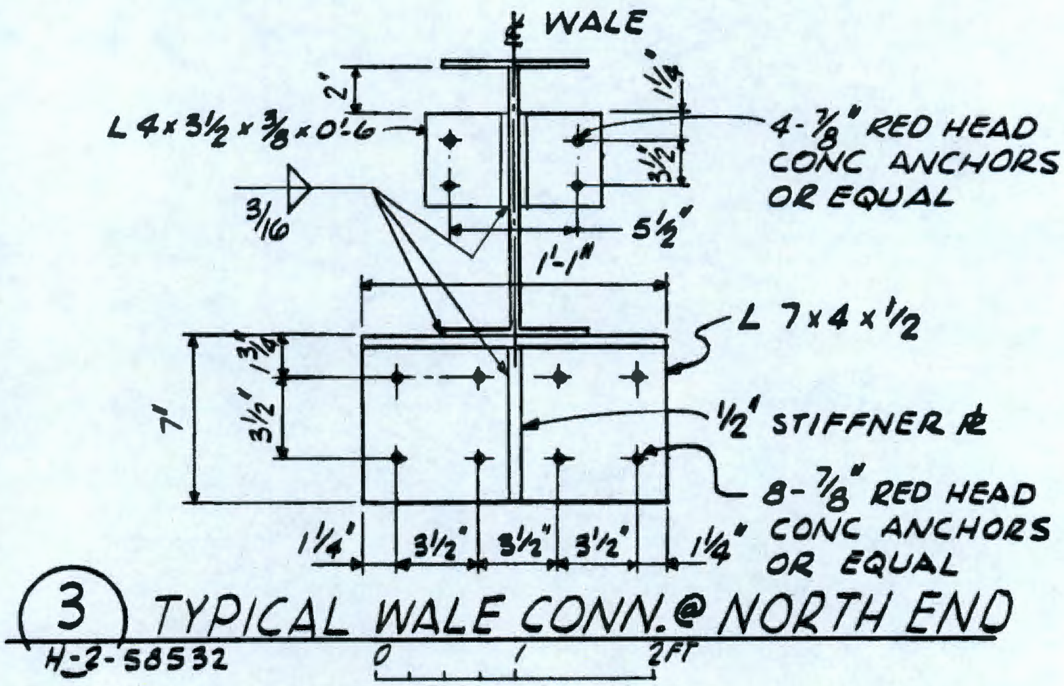

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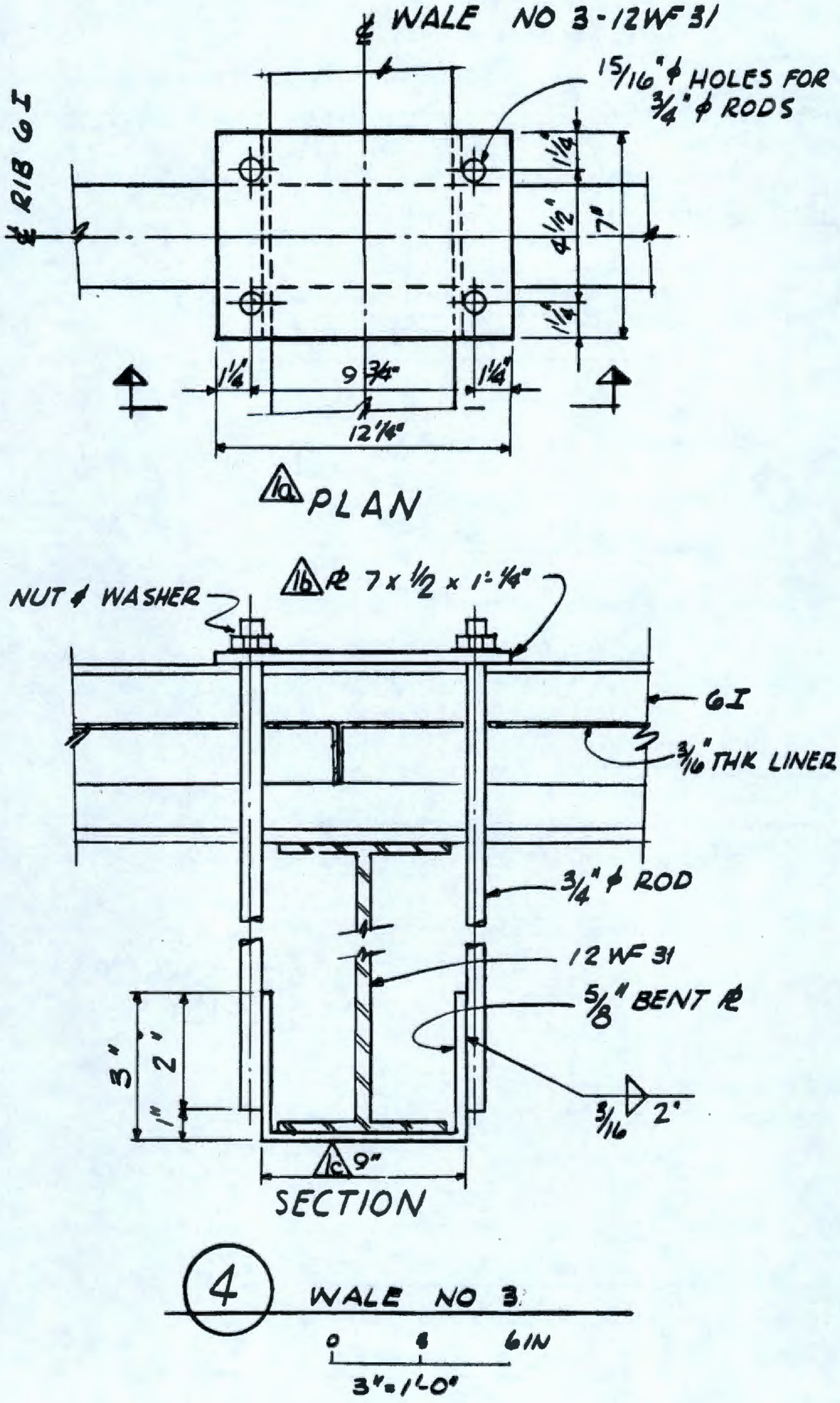

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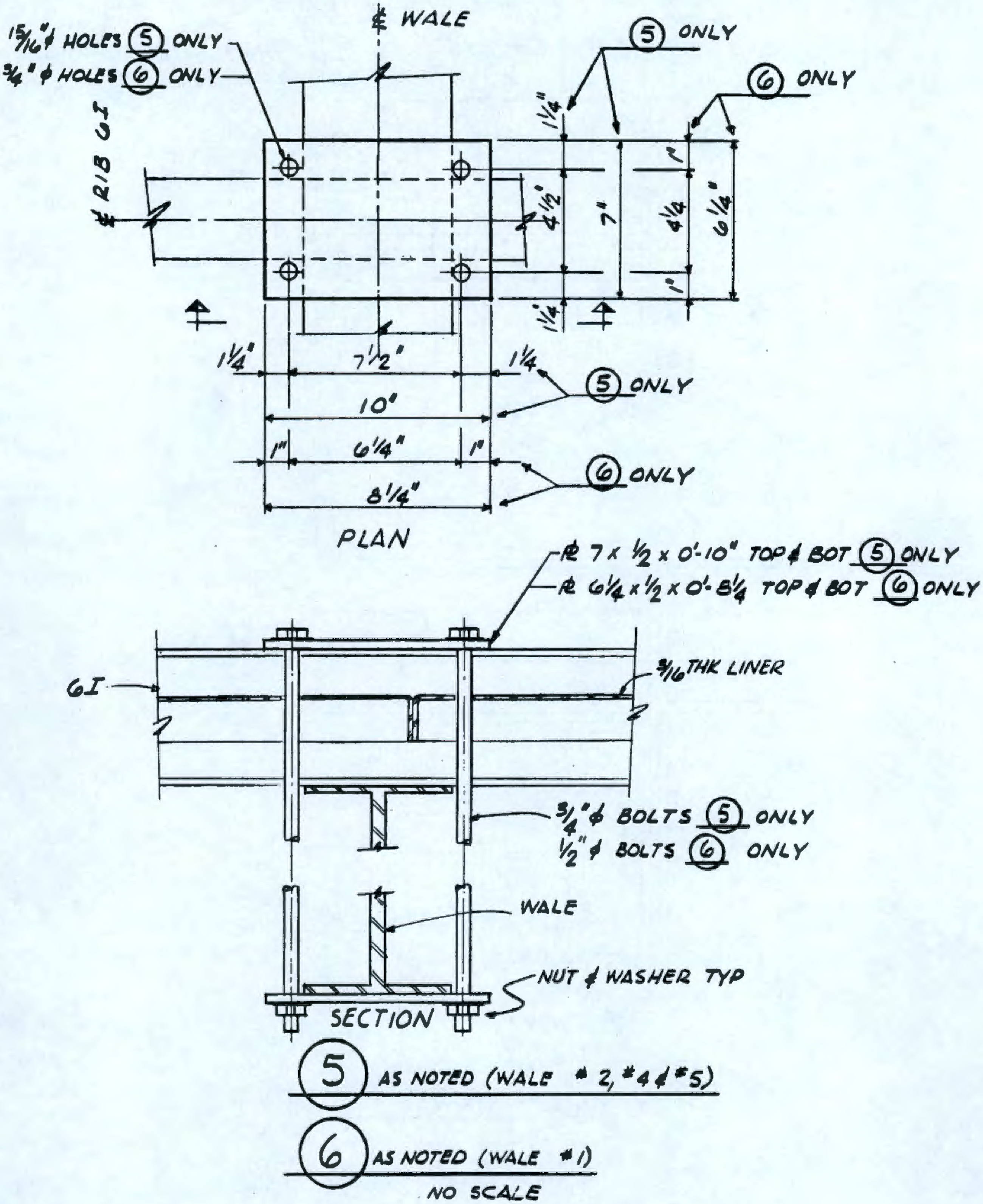

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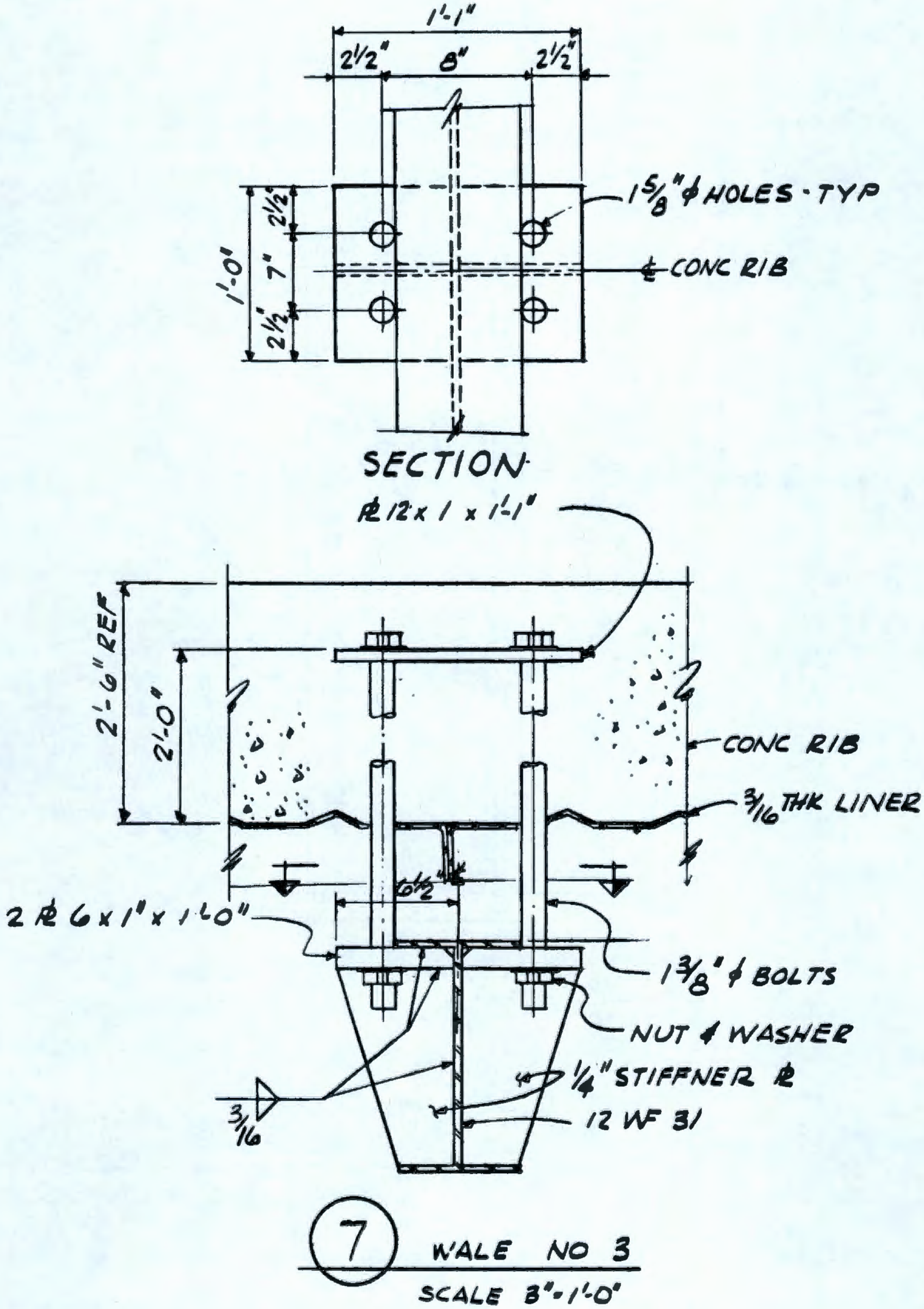

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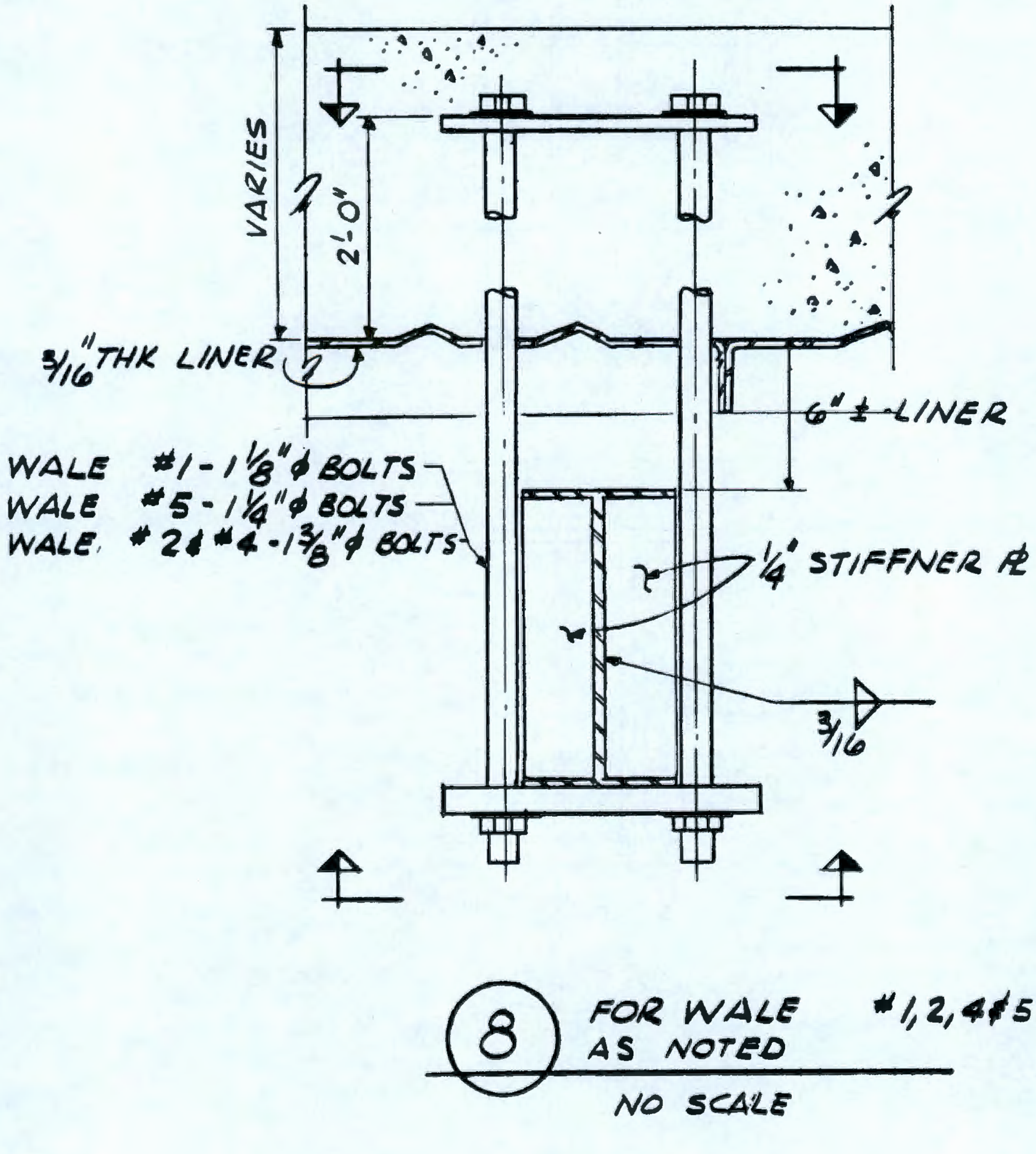

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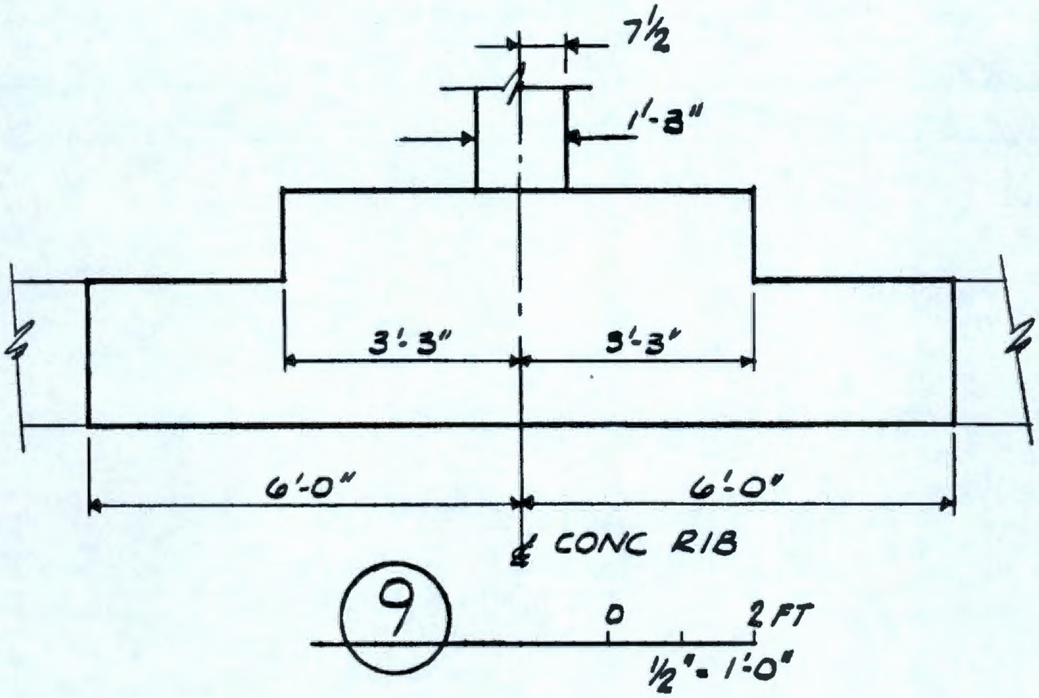

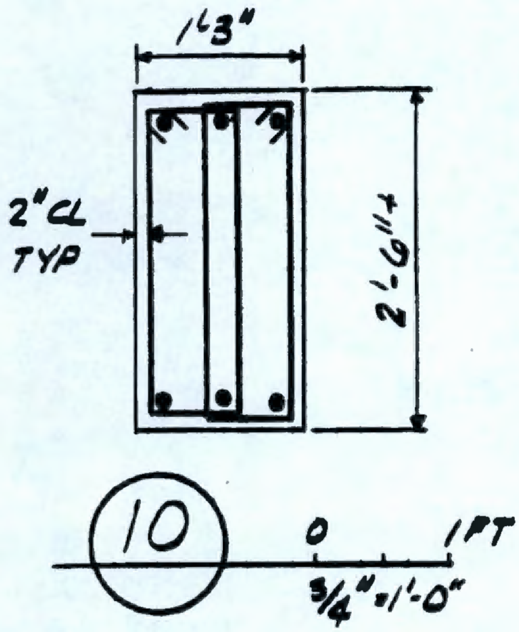

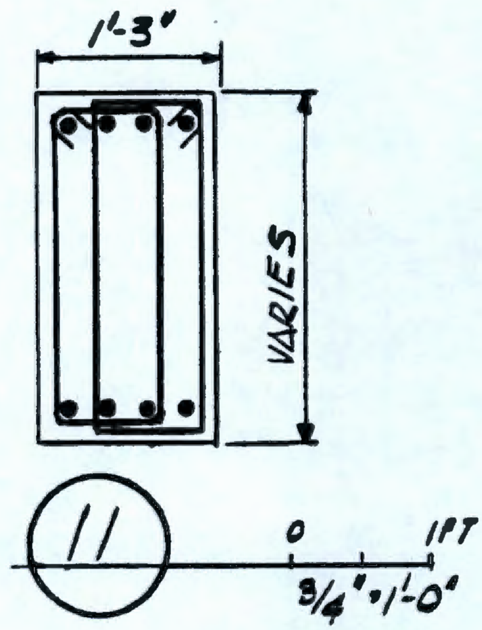

1964 DWG H-2-58533

ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Appendix B

Soil Design Parameters

Geotechnical Soil Design Parameters for Engineering Evaluation of PUREX Tunnel 2

PREPARED FOR:	Pete Hopkins/CH2M
COPY TO:	Craig Barrett/CH2M
	Mark Hasty/PRC
PREPARED BY:	Mark Kacmarcik/CH2M
DATE:	June 14, 2017
PROJECT NUMBER:	693839.BS
REVISION NO.:	0
REVIEWED BY:	Nason McCullough/CH2M

Introduction

Geotechnical soil design parameters are presented herein for use in preliminary structural evaluation of PUREX Failed Equipment Storage Tunnel No. 2, Facility 218-E-15 (hereinafter described as Tunnel 2). Structure-specific geotechnical data is not available for this Tunnel. This memorandum describes the methodologies employed to estimate tunnel soil geometry, geotechnical engineering properties of soils, earth pressures on the outer skin of the tunnel, and bearing capacity of footings. A brief discussion of considerations for soil structure interaction (SSI) analysis is also provided in the event that more-refined analysis methodologies are warranted as a next-step beyond the methods described herein.

Limitations

At the time of issue of this report, site-specific geotechnical data was not available for use in the evaluation of Tunnel 2. Available geotechnical data generally consists of historical photographs, regional geologic studies, or site-specific studies for other facilities in the project vicinity. All evaluations and recommendations provided herein are derived from interpretation of data reported by others. As such, errors or misrepresentation of site information by others would affect our recommendations. In the event that additional geotechnical data is made available, or subsurface investigation programs are performed, analysis results should be updated accordingly.

Geotechnical Properties of Cover Soil

Geotechnical properties of Tunnel 2 cover soils were estimated for use in evaluation of soil loading on the outer skin of the structure. At this time, there is no known geotechnical investigation data which has characterized the Tunnel 2 cover soil, and original design calculations for the tunnel are not available.

Soil properties were estimated considering review of as-built drawings, construction specifications, construction photographs, previous geotechnical investigation results in the vicinity of Tunnel 2, regional geologic studies, and other investigations performed by others. From construction photos, it is interpreted that the cover soil was not placed in lifts and compacted as specified, but was placed loosely with a dragline and bulldozer (Exhibit 1). These placement methods were documented to have caused two failures during original construction of Tunnel 2, prior to re-design to incorporate cast-in-place structural concrete arch supports.

Exhibit 1 – Cover soil placement operations at Tunnel 2; note loose placement of fill over concrete-reinforced Tunnel with a dragline

The recommended cover soil properties for Tunnel 2 are as follows:

- Unified Soil Classification System (USCS) classification: Silty Sand with Gravel (SM)
- Moist unit weight, γ_m = 110 pcf (Expected range: 105 to 115 pcf)
- Internal friction angle, ϕ' = 30 degrees
- Cohesion, c' = 0 psf

The selection of soil parameters for the cover soils is complicated due to the lack of clear documentation of material properties or fill placement methods. Variability in the dry density of the soil and the in-situ moisture content are expected to contribute to corresponding variations moist unit weight of the overlying soil. The soil unit weight may change seasonally in response to seasonal weather patterns, variations in with depth and location are likely. Discussion of the selection of these parameters is included in Attachment A.

Cover Soil Geometry

The geometry of the Tunnel 2 cover soil was evaluated by comparing the existing site topography to the as-built geometry of the tunnel. Light, Data, and Ranging (LIDAR) topographic survey data was collected in 2008 for the Central Plateau of the Hanford site by Aero-Metric, Inc. of Seattle, Washington. Examples of this topography are shown in Exhibits 2 and 3.

The collected data for the Central Plateau is arranged in 343 tiles arranged across the site. Tiles 153, 154, 177, and 178 provide coverage of PUREX Storage Tunnel 1 and Tunnel 2 and were provided to CHPRC by MSA of Richland, Washington for use in the analysis. The LIDAR survey data in the provided tiles consisted of a "bare earth" digital elevation model (DEM) processed by Aero-Metric to remove projections from the ground surface such as structures and vegetation as well as a "first return" DEM which includes all data points regardless of impacted surface.

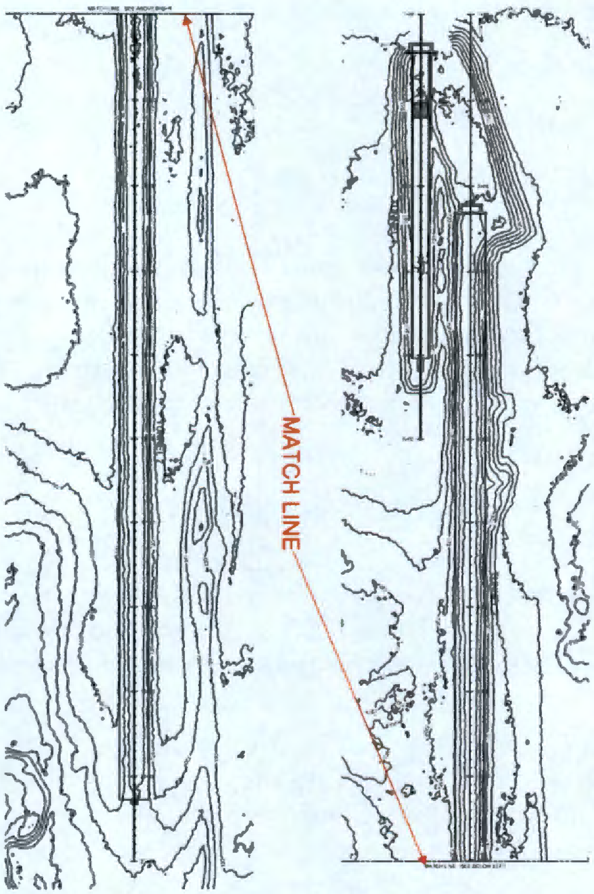

Exhibit 2 – Example view showing of LIDAR topography and as-built geometry of Tunnel 2. North is (refer to Attachment B)

The horizontal coordinate system for the LIDAR data is State Plane, NAD83, Washington South Zone, meters. The vertical elevation system was NAVD88, meters. The LIDAR data was converted from the original coordinate system to match the 200E survey datum using survey monument data for brass-cap Monument 2E-41. This conversion allows direct comparison of topographic survey data to the as-built plan and elevation of the Tunnel 2 structure. The results of the LIDAR analysis, including site topography, tunnel profile, tunnel cross sections, and conversion factors between datums are included in Attachment B.

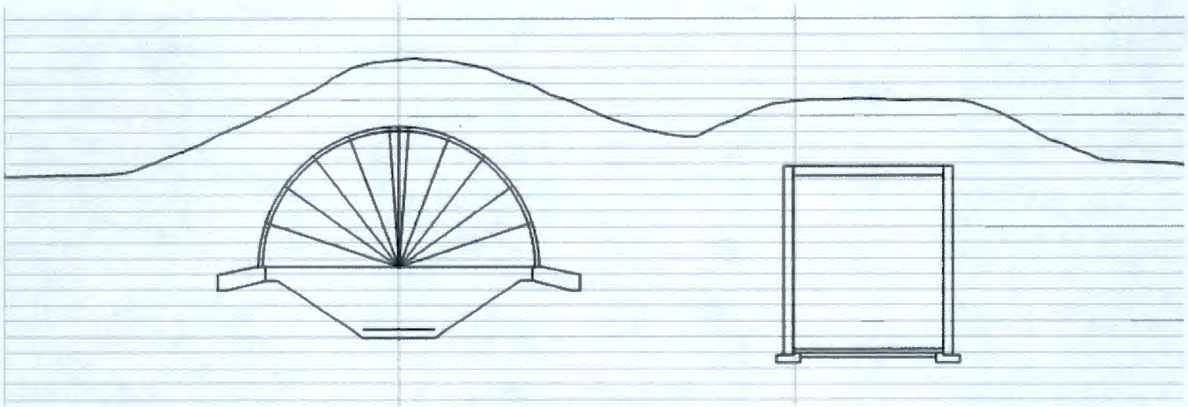

Exhibit 3 – Cross Section at STA 4+00, looking south, showing geometry of Tunnel 1 (right), Tunnel 2 (left), and Tunnel Cover Soil Topography

At this time, no known recent survey data is available to confirm the horizontal or vertical position of the tunnel or cover soil. The most recent LIDAR data was collected in 2008, and at the time of this analysis was greater than 9 years old. It is possible that changes in the ground surface may have occurred since the data was collected. The geometry of Tunnel 2 was reproduced from horizontal and vertical coordinates shown on the 1962 as-built drawings (refer to specific drawings noted in the References sections). Plan, profile, and cross sections of Tunnel 2 were then generated for evaluation of cover soil geometry as shown in Attachment B. Considering the age of the data, it is emphasized that the elevations and locations developed for this study are approximate.

To investigate the accuracy of the tunnel and cover soil geometries, "first return" LIDAR elevation data for the exposed portions of the Tunnel 1 and Tunnel 2 water-filled door structures was compared to the as-built design elevations of the structures reported in 1955 and 1962, respectively. First-return elevation data was found to generally be within 0.3 feet of the as-built elevation of the water-filled door structures. To our knowledge, the elevation of the water-filled door structures have not been recently surveyed to confirm the as-built elevations; some movement of these structures over time is possible.

The LIDAR elevation data is expected to be the best-available topographic data for the site. The agreement between the LIDAR data and the as-built water-filled door elevations supports the use of these two data sources in development of preliminary evaluations of earth pressures on the tunnel with reasonable accuracy. If improved topography or tunnel geometry data becomes available, the cover soil geometry should be re-evaluated and incorporated in revised earth pressure calculations.

Earth Pressures

Earth pressures were estimated for the Tunnel 2 structure at wales 1 thru 5 on both sides (east and west) of the structure as well as the tunnel crown and springline (see Exhibit 4). Earth loads were estimated using the 2008 LIDAR cover soil topography, the as-built tunnel geometry, and the estimated geotechnical properties of the cover soils. Estimation earth pressures was performed considering the combined influence of vertical overburden pressure, horizontal at-rest lateral earth pressure, and both the horizontal and vertical components of snow load (15 psf). These loads were resolved into their normal and shear components, and the normal stresses acting orthogonal to the tunnel structure were provided to the structural engineer. Cross sections were evaluated every 100 feet along the tunnel length as a means of considering the variation in cover soil geometry.

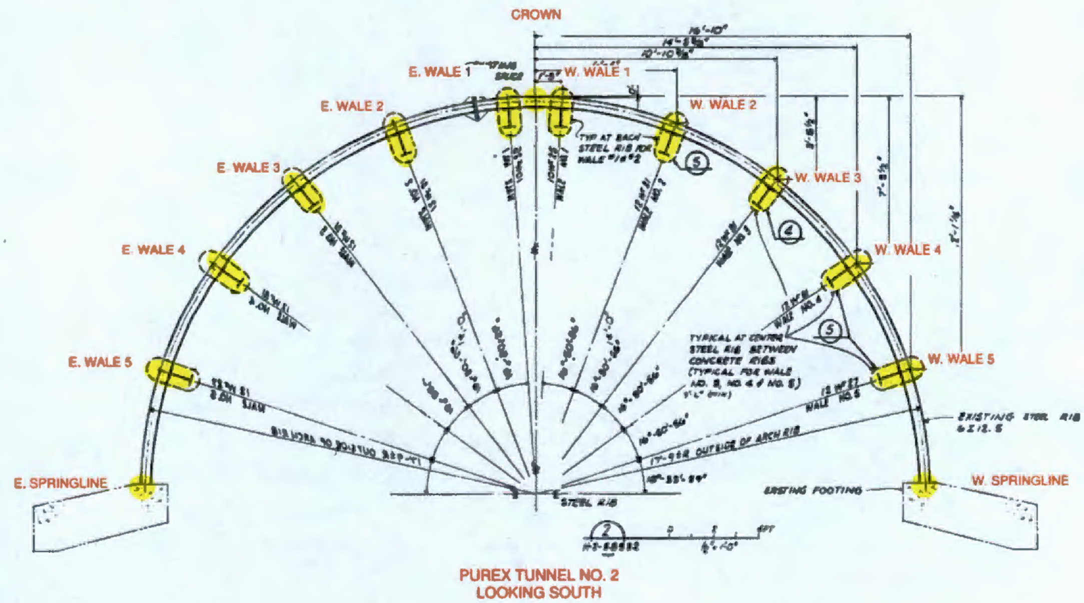

Exhibit 4 – Schematic representation of Tunnel 2 Geometry. Earth pressures are provided at each wale, the crown, and the springlines of the structure.

Normal Stresses due to Vertical Overburden Soil Height

Normal stress due to the vertical overburden soil over the tunnel wales were estimated by taking scaled measurements of the cover soil height over the tunnel roof. Measurements were taken each location shown in Exhibit 4. The soil height was multiplied by the estimated moist unit weight of the cover soil to determine the vertical effective stress, then multiplied by the cosine of the angle between the vertical stress and the wale position. Shear stresses were also calculated but not incorporated into the analysis. An example free-body diagram showing the forces applied to the tunnel wales is included in Exhibit 5.

Normal Stresses on Tunnel due to Lateral Earth Pressures

Normal stress due to the at-rest lateral earth pressures on the tunnel were estimated by taking the vertical effective stresses estimated at each wale location and multiplying by the adjusted at-rest lateral earth pressure coefficient. Adjustments were made to the lateral earth pressure coefficient for wales 3, 4, 5, and the springline to account for the sloping ground surface. The slope was measured as the approximate average slope of the tunnel cover soil as represented by the LIDAR cross sections. At-rest lateral earth pressure coefficients for wales 1, 2, and the tunnel crown were not adjusted, as the overlying ground surface above these locations is generally horizontal. The lateral earth pressures at each location on the tunnel surface were then multiplied by the sine of the angle between the vertical stress and the wale position. Shear stresses were also calculated but not incorporated into the analysis. An example free-body diagram showing the forces applied to the tunnel wales is included in Exhibit 5.

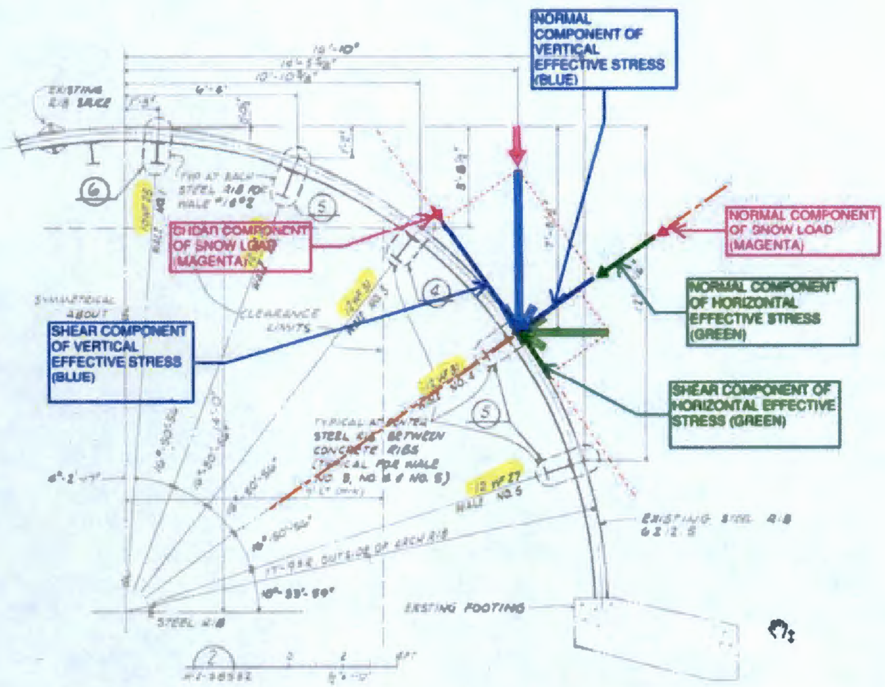

Exhibit 5 – Example of Normal Stresses and Shear Stresses resulting from vertical effective stress (blue), horizontal at-rest lateral earth pressures (green), and snow loading (magenta) at Wale No. 4. (not to scale)

Normal Stresses on Tunnel due to Snow Loading

Normal stresses due to the snow load (15 psf) were estimated assuming a uniform wide-area distribution of the snow load and a corresponding uniform stress increase across the tunnel. Snow loading was converted to the normal stress component of the corresponding vertical effective stress and increase in horizontal at-rest lateral earth pressure using similar constructions as described above. An example free-body diagram showing the forces applied to the tunnel wales is included in Exhibit 5.

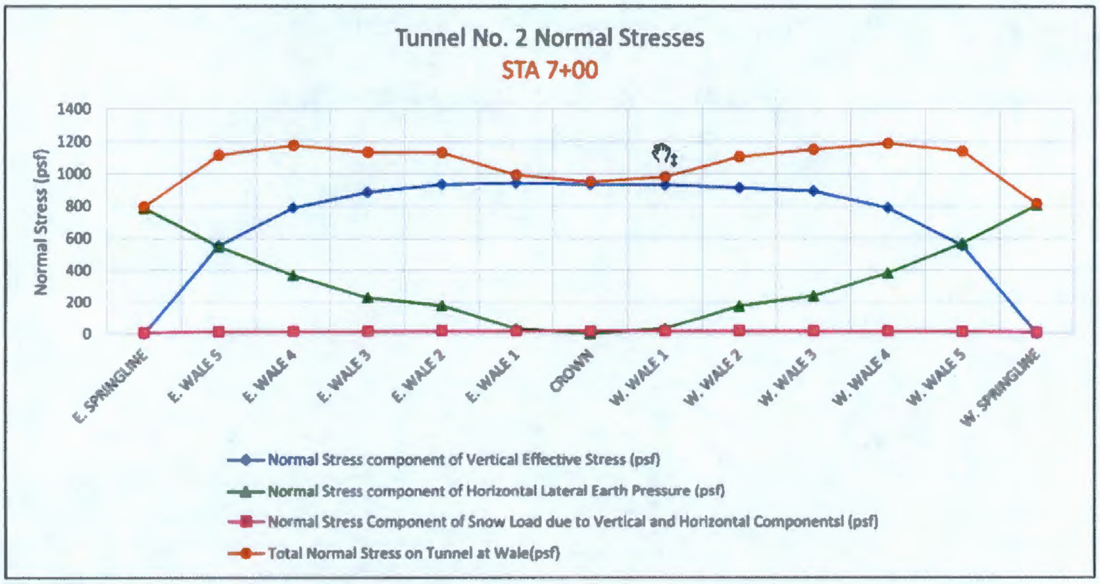

Exhibit 6 – Example showing estimated normal stresses contributions of Vertical Effective Stress, Horizontal lateral earth pressure, and snow loading on tunnel perimeter.

The lateral earth pressure component of the normal stresses on the tunnel were estimated assuming at-rest lateral earth pressures act against the structure relative to the vertical effective stress at the wale locations, and that the wale locations beneath the cover soil side slopes (Wales 3, 4, 5, and the springline) were adjusted to account for the influence of sloping ground

The at-rest lateral earth pressure coefficient was estimated using the material properties described herein and adjusted to account for sloping ground surface.

At-rest Earth Pressure Coefficient, $K_O = 1 - \sin(\phi')$

Adjusted At-Rest Earth Pressure Coefficient, $K_{Oi} = K_O \cdot (1 + \sin(i))$

where:

ϕ' is the drained internal friction angle of the soil

i is the slope of the ground surface in degrees

The slope of the ground surface measured as the average slope of the ground surface on the side slopes of the cover soil. The adjusted lateral earth pressure coefficient was multiplied by the estimated vertical effective stress at the wale location to obtain a lateral earth pressure. Detailed earth pressure calculations are included in format in Attachment C. Exhibit 6 shows an example plot of the relative distribution of stresses on the tunnel perimeter, along with the combined total stress. Exhibit 7 shows the interpreted soil heights at each wale.

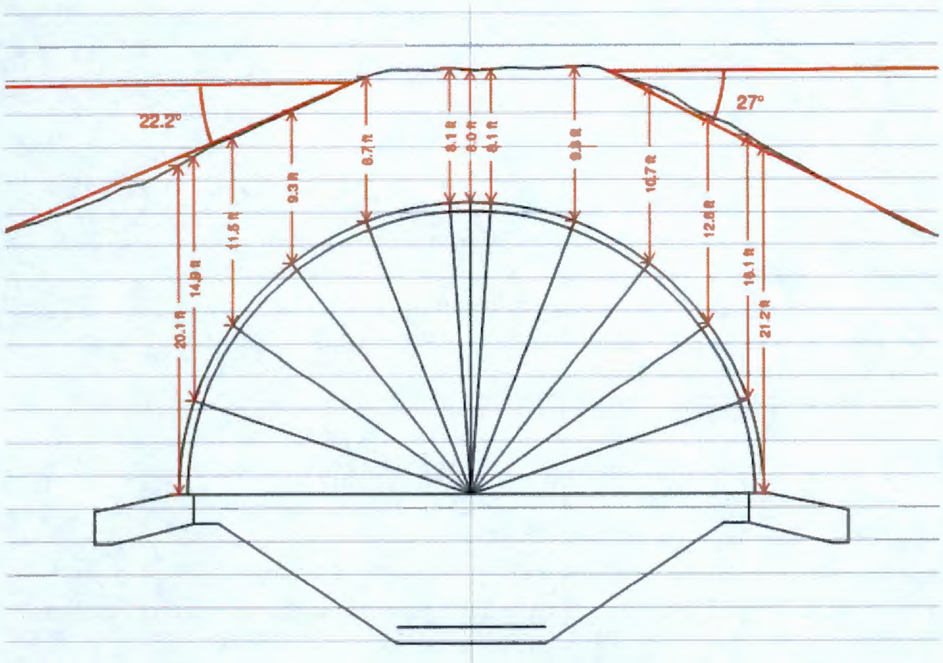

Exhibit 7 – Example showing typical interpretation of cover soil geometry over tunnel perimeter.

Footing Bearing Capacity

The ultimate bearing capacity of the Tunnel 2 footings was estimated using the SLIDE version 7.022 two-dimensional limit equilibrium analysis program (Rocscience, 2017) to evaluate the complex footing and soil geometry within Tunnel 2. SLIDE was first calibrated using manual calculations for a simplified geometry using Vesic's extended bearing capacity equation, then the calibrated approach was applied to the as-built tunnel geometry.

Footing Geometry

The footing geometry was simplified to represent a single equivalent strip footing with a width approximately equal to the average width of the existing footings. The geometry of the footings is shown in Exhibits 8, 9, and 10. The footings were modeled considering the as-built footing shape, which includes an approximate 10 degree footing inclination angle.

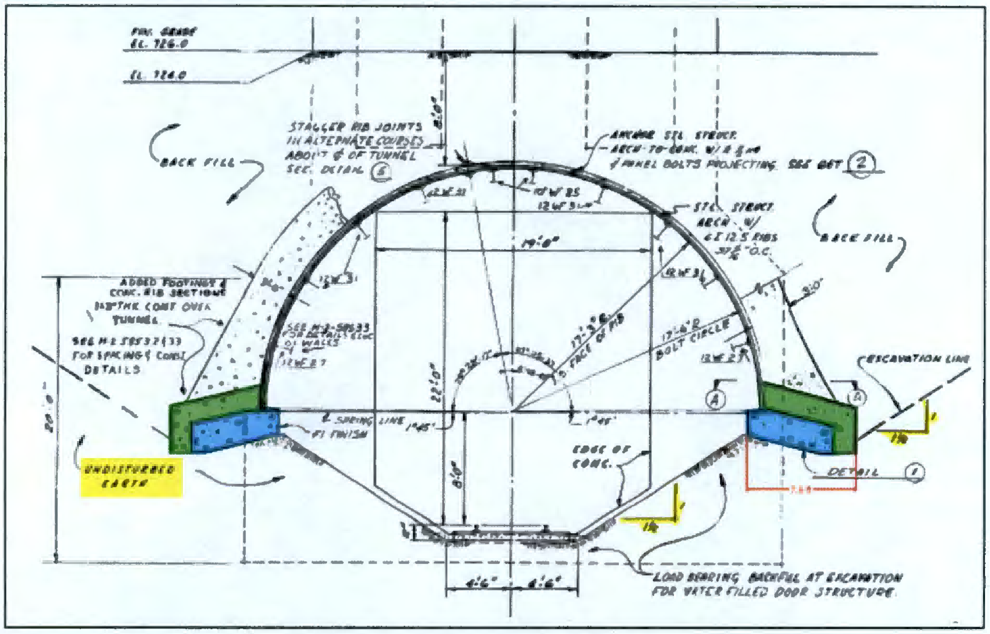

Exhibit 8 – Cross-sectional view of Tunnel 2 as-built footing geometry

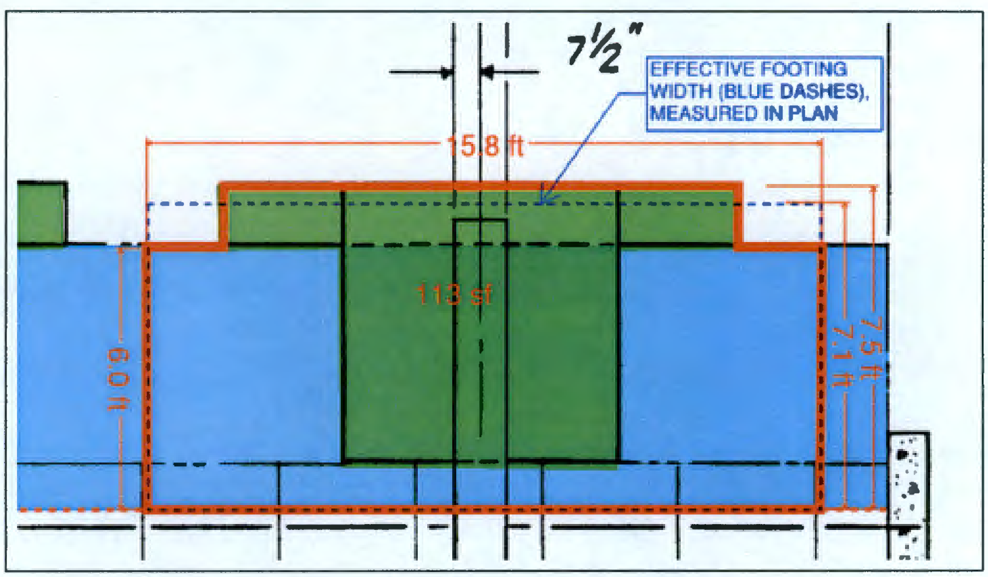

Exhibit 9 – Plan view of typical strip footing showing evaluation of effective footing width

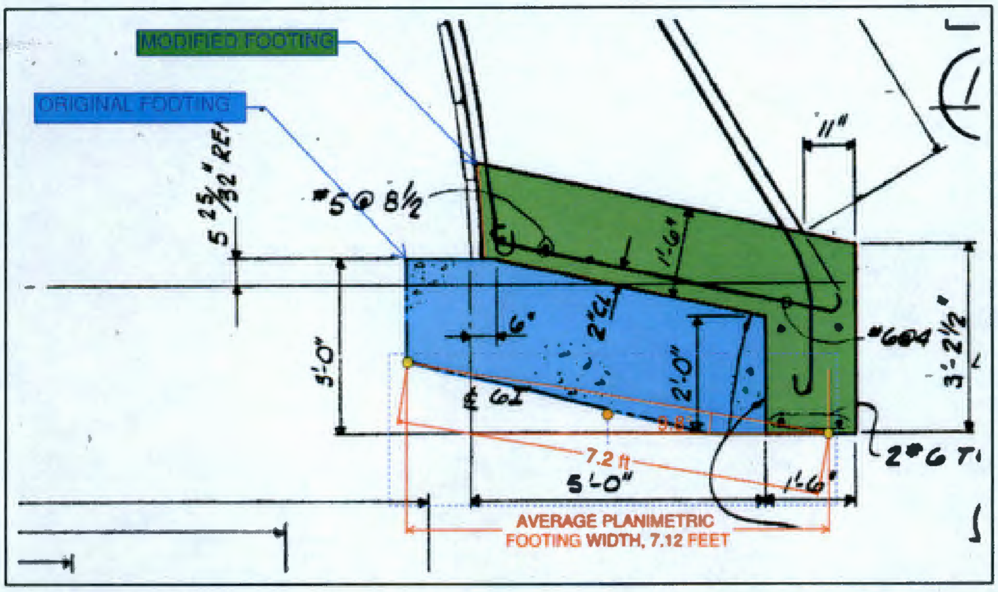

Exhibit 10 – Cross-sectional detail showing application of equivalent footing width

Slope Geometry

The slope geometry shown in the as-built drawings and confirmed by construction photographs indicates that the tunnel was constructed with 1.5:1 (Horizontal:Vertical) slopes. These slopes were modeled in SLIDE along with the equivalent footing geometry to investigate the relationship between footing load and bearing capacity, represented as a factor of safety against bearing capacity failure. The footing geometry modeled in SLIDE is presented in Exhibit 11.

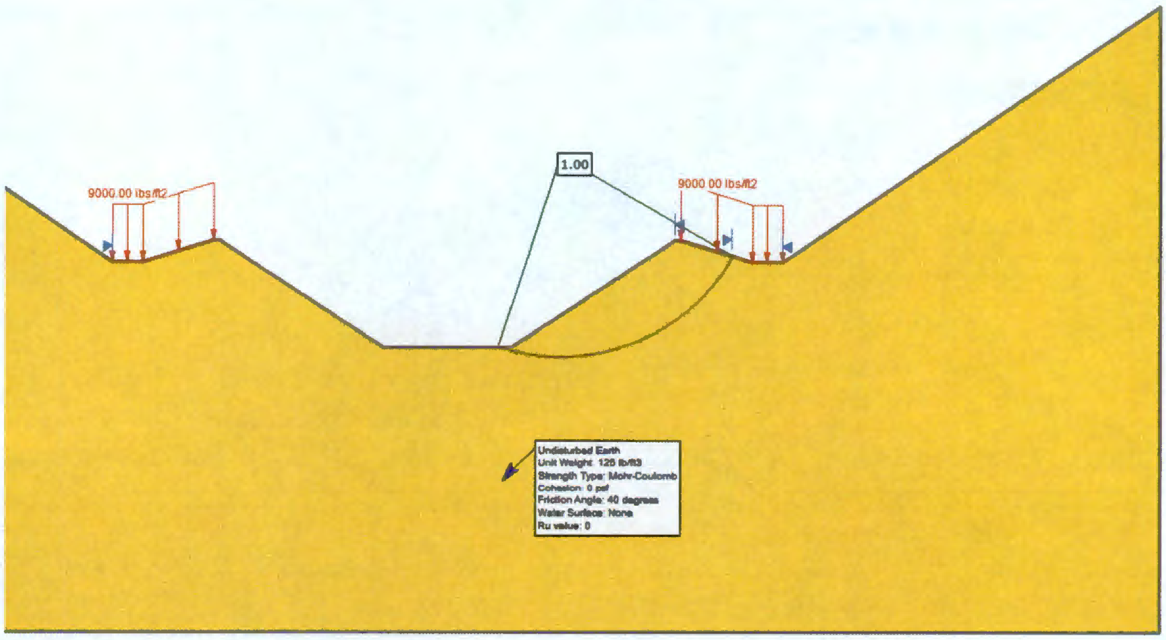

Exhibit 11 – Footing geometry evaluated in SLIDE to evaluate footing bearing capacity for in-situ geometry

In-situ Bearing Pressure

Bearing pressures on the existing footings were scaled from cross sections cut through Tunnel 2 and showing the LIDAR topography. Tributary areas were identified and multiplied by the unit weight of the cover soil, then divided by the footing width to obtain an approximate average bearing pressure. A snow load was applied considering uniform application of a 15 psf snow loading over the tributary area over the footings. An example of the in-situ bearing pressure estimation geometry is shown in Exhibit 12.

These values were estimated for 6 cross-sections through Tunnel 2 and soil pressures were estimated for both the east and west footings, totaling 12 evaluations of footing bearing pressure along the tunnel length. The resulting bearing pressures were estimated to vary from approximately 4,600 psf to 5,600 psf with an average of approximately 5,100 psf.

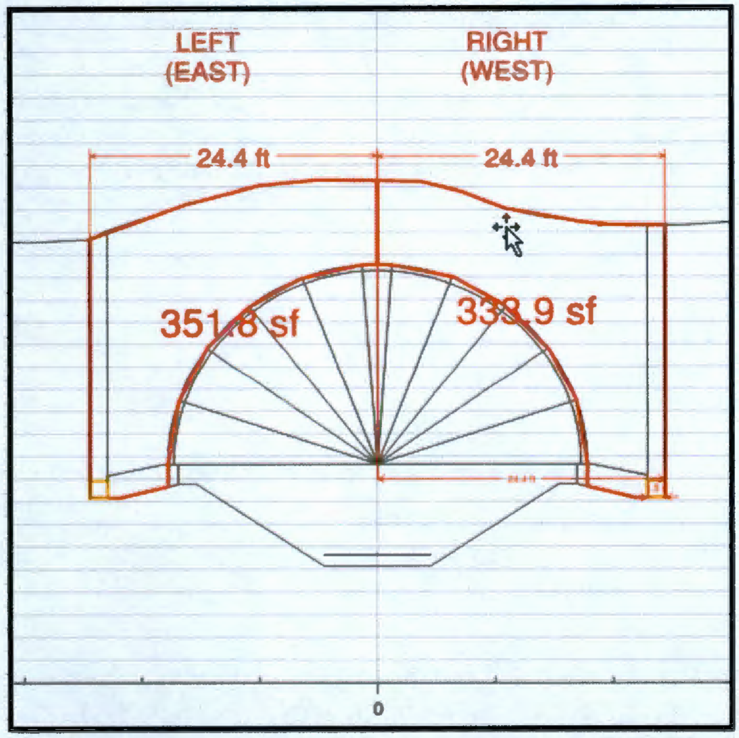

Exhibit 12 – Example showing evaluation of geometry for estimation of in-situ bearing pressures on Tunnel 2 footings

Bearing Capacity Estimation

The Tunnel 2 footing subgrade was assumed to be relatively undisturbed native material as identified on the as-built drawings and visible in construction photographs. The strength of the foundation material is not well understood, and there is no known facility-specific geotechnical data available at this time.

Shannon and Wilson (2015) reported that the Hanford Formation, which underlies PUREX and other locations on the Hanford Plateau, has the following properties:

- Moist unit weight, γ_m: 120 to 130 pcf
- Internal friction angle, ϕ' = 38 to 54 degrees
- Cohesion, c' = 0 psf

Dames and Moore (1984) in their evaluation of subsurface conditions for the proposed Process Facility Modification Project, located approximately 0.25 miles west of Tunnel 2, provided the following recommendations for site soils which are expected to be similar to those at Tunnel 2:

- Moist unit weight, γ_m: 110 pcf
- Internal friction angle, ϕ' = 34 degrees
- Cohesion, c' = 0 psf

Groundwater is not expected at the Tunnel 2 location, and was noted to be greater than 300 feet deep below the project site by URS/Blume (1981).

The range of internal friction angle values provided by these sources spans 20 degrees and complicates the evaluation of ultimate bearing capacity for the tunnel footings. Considering a lower bound range of soil strength for the Tunnel 2 footing subgrade of 34 to 45 degrees, a range of plausible ultimate bearing pressures can be developed for comparison to the estimated footing bearing pressures discussed above.

The following soil strengths were used in evaluation of bearing capacity of the equivalent footing width at Tunnel 2:

- Drained shear strength, lower bound: ϕ' = 34 deg, c'=0psf
- Drained shear strength, average: ϕ' = 40 deg, c'=0 psf
- Drained shear strength, upper bound: ϕ' = 45 deg, c'=0 psf

The corresponding ultimate bearing capacity values were determined in SLIDE as follows:

- Ultimate bearing capacity, lower bound, q_{ult} = 3,000 psf
- Ultimate bearing capacity, average, q_{ult} = 9,000 psf
- Ultimate bearing capacity, upper bound q_{ult} = 2,4,000 psf

The standard of practice for conventional geotechnical design is to incorporate a factor of safety of 3.0 into the development of allowable bearing capacities. Larger factors of safety could be justified considering the uncertainty in subsurface conditions and the consequences of failure.

- Allowable bearing capacity, lower bound, q_{allow} = 1,000 psf
- Allowable bearing capacity, average, q_{allow} = 3,000 psf
- Allowable bearing capacity, upper bound, q_{allow} = 8,000 psf
- Factor of Safety = 3.0

Comparison of in-situ foundation bearing pressures to the range of allowable bearing capacity values is inconclusive with regard to the adequacy of the footings to provide long term support of the Tunnel 2 structure and cover soils. Results for lower bound soil strengths indicate bearing capacity failure of the foundation; upper bound strengths indicate acceptable foundation performance. Average strengths do not result in failure of the foundation, but have factors of safety less than the standard of practice for foundation design.

Considering that Tunnel 2 has been in place for over 50 years and has not shown evidence of loss of foundation support, it can be reasonably assumed that the structure foundations have a factor of safety greater than about 1.1. The standard of practice for geotechnical design of footings is to incorporate a factor of safety of 3.0 when proportioning footings. At this time, it cannot be definitively concluded that the Tunnel 2 footings have factors of safety in conformance with the standard of practice. Additional investigation to characterize in-situ materials could provide valuable clarification of material strength and more-accurate assessment of footing bearing capacity. Such subsurface investigation techniques as pressuremeter testing would be effective tools for confirming the geotechnical properties of the foundation soils. Soil bearing capacity calculations are included in Attachment D.

Evaluation of Global Stability of Tunnel 2 Footings

The global stability of Tunnel 2 footings was evaluated in SLIDE (Exhibit 13). This analysis evaluated the possibility of failure of the soil mass from the existing ground surface outside the tunnel, to the tunnel invert. This was conservatively analyzed assuming no overlying cover soil, and only the adding bearing pressure of the tunnel strip footings. The minimum factor of safety for this analysis was found to be greater than 1.5, which is acceptable. Global stability failure is not expected to influence the Tunnel 2 footings.

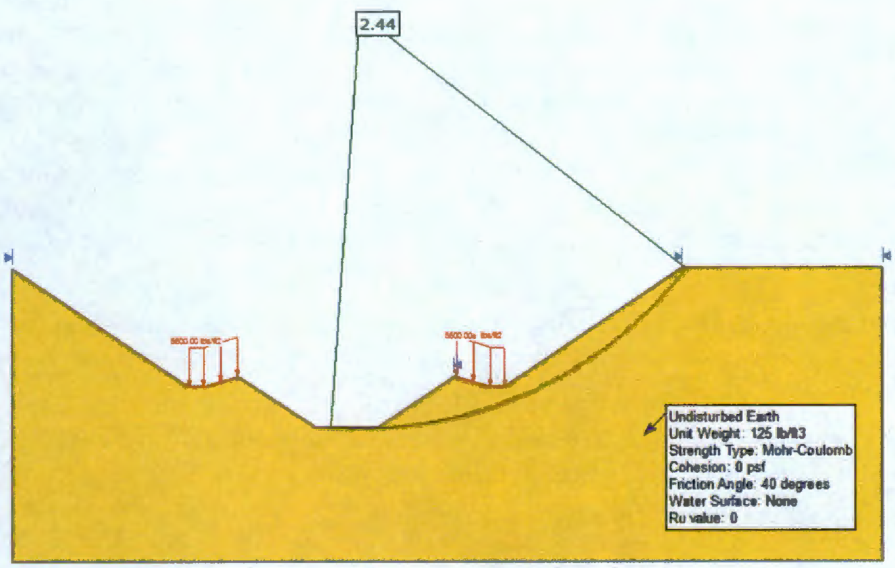

Exhibit 13 – Global stability of Tunnel 2 foundation, critical factor of safety of 2.4 shown.

Soil-Structure Interaction Analysis Considerations

Soil pressures were developed for Tunnel 2 using classical soil mechanics methodology adapted to the complex tunnel geometry. Soil pressures were estimated assuming a moist unit weight of loose placed cover soil of 105 to 115 pcf, an internal friction angle of 30 degrees, and zero cohesion. For each wale, soil pressures were estimated considering the relative contributions of the vertical height of cover soil, the corresponding at-rest lateral earth pressure adjusted for sloping ground, and the contribution of a

15 psf design snow load. Unfactored soil pressures were presented to the structural engineer as forces acting normal to the tunnel shell at each wale for incorporation into LRFD structural analysis.

Classically derived soil pressures are reasonable for a preliminary evaluation of soil stresses on the structure to investigate the expected stresses of structural elements; however, these classical methods are limited by the complex geometry of Tunnel 2 and the uncertainty in the geotechnical properties of the soils. These methods do not capture the strain or performance of the soil or structure. While classical methods are well-suited for engineering evaluation of conventional structures, the improved understanding of structure performance may be developed provided through more rigorous analysis methodologies which account for the complex geometry and Soil-Structure Interaction (SSI) considerations appropriate for the tunnel.

If performed, SSI analyses must be compared against clear performance criteria (e.g. design life, stress limits, strain limits, etc.) to be used effectively. The SSI analyses would include interface elements to capture the normal and shear behavior between the soil and structure and include the performance of the structure and the foundation. The SSI analyses would provide an improved understanding of failure modes, deformations, and to bound the influence of variation in geotechnical engineering parameters and geometry of native foundation soils and fill cover soils. However, these analyses will still be limited by the quality of the existing site information, including the soil properties and the existing condition of the structure.

The Tunnel 2 geometry is well suited for analysis using two-dimensional finite element analysis methods, such as those employed in two commonly used SSI programs, FLAC (Fast Lagrangian Analysis of Continua) or PLAXIS.

Further refinement of the advanced analyses can be realized through collection of field data to define cover soils and native foundation soils, as the analysis results are only as good as the data used in the analyses. Tunnel 2 cover soils can be sampled and evaluated in the laboratory to estimate strength, unit weight, and modulus properties; and if possible in-situ testing such as pressuremeter and/or flat-blade dilatometer testing. Native foundation soils can be evaluated using in-situ field methods such as pressuremeter testing, flat-blade dilatometer testing, or other methods. Such field investigation methods must be carefully planned to manage site constraints.

References

CHPRC-03241 Revision 0. PUREX Burial Tunnels, dated March 2017, prepared for the U.S. Department of Energy Assistant Secretary of Environmental Management, prepared by M. A. Maloof CH2M HILL Plateau Remediation Company.

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ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Attachment A

Cover Soil Parameters

Geotechnical Properties of Tunnel 2 Cover Soil

PREPARED FOR:	Project File
COPY TO:	Craig Barrett/CH2M
	Pete Hopkins/CH2M
	Mark Hasty/CH2M
PREPARED BY:	Mark Kacmarcik/CH2M
CHECKED BY:	Youssef Bougataya/CH2M
DATE:	June 24, 2017
PROJECT NUMBER:	693839.BS.02
REVISION NO.:	0

This memorandum documents the selection of geotechnical properties for the Tunnel 2 Cover soils for use in structural evaluation of Tunnel 2. Specifically, this memorandum summarizes the available information and provides recommended strength and unit weight values.

Review of Available Subsurface Information

There is very limited geotechnical information available for Tunnel 2. Collection of site-specific geotechnical data was beyond the scope of this evaluation. Recommendations provided herein are derived from interpretation of geotechnical data reported by others. Much of the available data is fragmentary or otherwise developed for other purposes. No responsibility can be taken for errors or misrepresentation of site information by others.

Construction Drawings (1962)

Original construction drawings are available for Tunnel 2. The drawings include limited information on the cover soils. The drawings indicate that the cover soil was to be placed 8'-0" thick over the tunnel crown as shown in Exhibit 1.

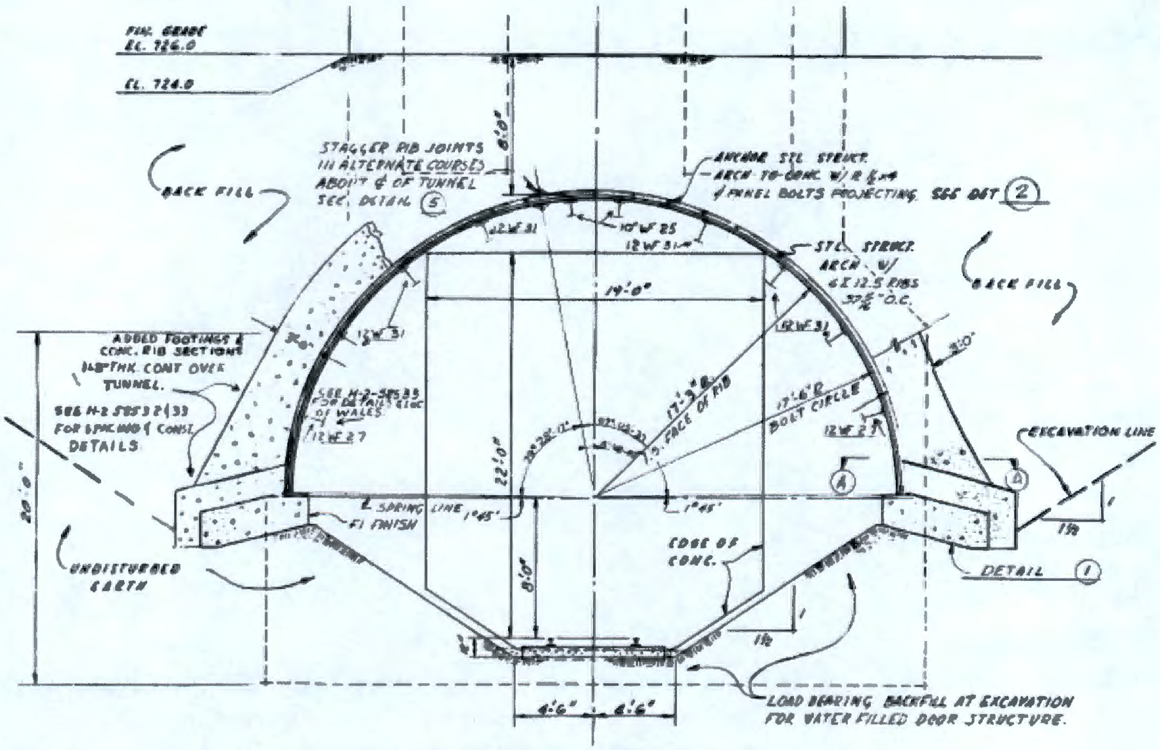

Exhibit 1 – Design Cross section of Tunnel 2 showing proposed finish grade relative to tunnel structure and configuration of "Undisturbed Earth" forming the lower interior of the tunnel

Construction Specifications (1962)

Original construction specifications for Tunnel 2 were available for review. Excerpts from these specifications are included as Exhibits 2a and 2b. Considering the available construction photos (discussed hereinafter), it is not known to what extent these specifications were enforced during in construction of the tunnel. The following are noted from review of the backfill specifications:

1. Frozen fill materials were not to be used
2. Materials were to be screened to remove particles larger than 8 inches; large particles were not discernable in construction photos.
3. Fill materials were to be free from vegetable matter or trash. Tumbleweeds are visible in tunnel excavations prior to backfilling, it is unclear whether these materials were removed prior to fill placement.
4. Trash is not allowed in spaces to be backfilled.
5. Structural backfill shall be placed in layers to not exceed 24 inches loose measurement and thoroughly compacted. Compaction by loaded scrapers and/or tractors will be considered.

Construction photos suggest that this material was not placed in horizontal lifts as specified, but rather was placed in mass using a combination of bulldozers and cranes with dragline buckets.

6. Care shall be exercised during backfilling to prevent excessive loads on walls and to insure balanced loading on opposite walls. It is documented that the original Tunnel 2 structure collapsed, in part, due to unbalanced loading during fill placement.
7. Compaction methods were not specified, except as to prohibit sluicing or flooding. It is unclear if the cover soils were compacted.

7. BACKFILL, METAL TUNNEL, RIBBED ARCH DESIGN

Backfill and embankment around the ribbed arch design tunnel shall conform to Sections 6b except stone size within two feet of tunnel section shall be 3" minus.

8. BACKFILL, METAL TUNNEL, ELIPTICAL DESIGN

Backfill for the eliptical design tunnel shall conform to the following:

a. Zone 1 backfill shall consist of 3/4" minus material and shall be compacted by vibration to a density conforming to the following:

When tested in the field in accordance with AASHO (American Association of State Highway Officials) Designation T-147-49 "Field Determination of Density of Soil in Place," each layer of compacted embankment shall have a density not less than the following: (All equipment and labor for performing the tests shall be provided by the Contractor.)

(1) For clayey and silty materials - 90% of the "maximum density" as determined in accordance with AASHO Designation: T-99-49 "Standard Method of Test for the Compaction and Density of Soils." The moisture content of the material shall be uniform throughout the layer and shall be such that the specified density can be obtained. In no case shall the mosture content vary more than 3 percentage points above or below the optimum moisture content as determined by AASHO Designation T-99-49.

-2- HWS-8262

Exhibit 2a – Backfill specifications for Tunnel 2

WORKMANSHIP (Cont'd)

(2) For cohesionless free-draining material - such as sands and gravels, [illegible]% relative density as determined by the Standard U. S. Bureau of Reclamation relative density tests for cohesionless free-draining soils. The relative density of cohesionless free-draining soil, expressed as a percentage, is defined as its state of compactness with respect to the loosest and most compact states at which it can be placed by laboratory procedures. The relative density will be based on the following formula, wherein the maximum density is the highest unit weight of the soil, minimum density is the lowest unit weight of the soil and in-place density is the unit weight of the soil in place. Tests for moisture content are made on the materials and unit weights are expressed in terms of oven-dry weights.

$$\text{Relative density} = \frac{\text{max. den. x(in-place den. - min. den.)}}{\text{in-place den. x(max. den. - min. den.)}} \times 100$$

The particular test to be used, depending on the type of soil, shall be as determined by the Commission.

b. Zone 2 backfill shall consist of 3" minus material and shall be brought up evenly on each side of the structure in 12" lifts and shall conform to the compaction specified in Section 8a of this division.

c. Zone 3 backfill and embankment shall conform to Sections 6b, c, d and e of this Division, except that material shall be 3" minus within 2' of the tunnel.

d. Load bearing backfill shall be compacted by vibration.

Exhibit 2b – Backfill specifications for Tunnel 2 (continued)

Design Documentation

At this time, no design documentation, design calculations, design reports, or related materials are known to exist.

Construction Photographs (various)

Tunnel 2 construction photographs documented in CH2M (2017) were reviewed. Particularly relevant photos are included herein as Exhibits 3 through 7. The following observations were made from review of the photos:

- Tunnel 2 was constructed without concrete ribs and failed upon backfilling. Following the failure, the tunnel was redesigned in 1964 and retrofitted with concrete ribs.
- Tunnel excavation geometry (i.e. trench) does not appear to allow adequate access for compaction of backfill soils in lifts against tunnel walls.
- Material appears to have been placed loosely using a crane and dragline bucket.
- Backfill material generally appears to be fine or sandy in nature, there is no evidence of cobbles, gravels, or coarse materials.

Exhibit 3 – Original construction of Tunnel 2. Note excavation geometry and steep slopes adjacent to tunnel walls

Exhibit 4 – Original construction photo of Tunnel 2.

Exhibit 5 – Tunnel 2 construction. Note concrete ribs and narrow, difficult geometry for soil backfilling.

Exhibit 6 – Alternate view of Tunnel 2 construction with concrete ribs.

Exhibit 7 – Placement of loose fill over tunnel with crane-mounted dragline bucket. Note loose placement of soil and absence of compaction equipment. Individual on top of placed fill likely assisting with survey to confirm fill height over crown.

Studies by Others

1.0 Report of Soils Investigation for Proposed Process Facility Modification Project (1984)

Dames & Moore (1984) submitted a soil investigation report for a proposed Process Facility Modification at the PUREX plant site. Four boreholes were advanced for the facility and geotechnical design parameters were developed. The facility was never constructed. URS (1981) noted that no known direct subsurface investigations were performed for the design or construction of the PUREX facility. As such, the Dames & Moore (1984) investigation is thought to represent the best available subsurface information in the vicinity of the PUREX Storage Tunnels. It is assumed that subsurface conditions at the PUREX Storage Tunnels are similar to those encountered by Dames & Moore (1984).

The following notes were made from this report:

1. 4 boreholes were advanced for this study. Boreholes were located approximately 1230 to 1350 feet west of PUREX Tunnel 1. The locations of these boreholes are presented in Exhibit 8, and the borehole logs are presented in Exhibits 9 and 10. Borehole were advanced with rotary hollow-stem auger methods and sampled using Dames & Moore proprietary U-type sampler.

   B-1, Total depth = 54.5 feet

   B-2, Total depth = 19.5 feet

   B-3, Total depth = 59.5 feet

   B-4, Total depth = 19.5 feet

2. Field classifications and laboratory testing were performed on selected samples to support evaluating shear strength, moisture content, density, grain-size distributions, resistivity, and pH.

3. The following geotechnical engineering parameters were recommended for use in design of the proposed facility:

   Angle of Internal Friction, ϕ = 34 degrees

   Cohesion, c' = 0 psf

   Mass Density, γ = 110 pcf

   Poisson's ratio, μ = 0.25

   Coefficient of Active Earth Pressure, Ka = 0.28

   Coefficient of At-Rest Earth Pressure, Ko = 0.44

   Coefficient of Passive Earth Pressure, Kp = 3.5

4. Lateral earth pressures:

   Active Equivalent Fluid Unit Weight = 30 pcf

   At-Rest Equivalent Fluid Unit Weight = 50 pcf

   *At-Rest Pressure for relatively rigid structures (psf) = 26*H (where H is the height of the wall in feet)*

   Passive Equivalent Fluid Unit Weight = 250 pcf (includes FS=1.5)

5. General Soil Description:

   The near-surface soils generally consist of a thin fill layer of gravelly sand (SW) to sandy gravel (GW). This fill was probably placed at the time that the subject area was *temporarily used during construction of the nearby PUREX plant. Under this fill and down to depths ranging from 3.5 to 6 to 7 feet, all borings encountered a layer of loose silty fine sand (SM) containing variable amounts of coarser sand and fine gravel with depth. In each of the shallow borings (B-2 and B-4), about 4 to 5 feet of medium dense to dense fine to coarse sands with occasional gravel (SW) were encountered below the silty fine sand (SM); however, this well-graded sandy material was not encountered in either of the deeper borings (B-1 and B-3).*

Below a depth ranging from 3.5 to approximately 6 to 7 feet, all borings encountered medium dense to dense poorly graded sands (SP). These soils generally appear to grade back and forth between the limits of a fine to medium sand with a trace of silt to a medium to coarse sand with variable amounts of fine gravel. ... It is believed that this strata of poorly graded sand with varying amounts of silt and fine gravel can be assumed to extend under the entire project site to depths in excess of 60 feet. This assumption is based on our field engineer's inspection of a 64-foot-deep excavation to elevation 622 that exists approximately 2300 feet to the northeast of the subject area. This tank farm excavation was made in soils consisting of interbedded sands and gravelly sands overlying poorly graded sands that are similar to those encountered in our exploratory borings.

No groundwater was encountered in any of the four borings. Based on previous geologic and seismic investigations at the PUREX building site, it is believed that the water table is at a depth of approximately 300 feet beneath the subject area.

6. Applicability to PUREX Tunnel Evaluation

Although the boreholes are located nearly 0.25 miles west of the PUREX storage tunnels, Dames & Moore noted that similar materials were observed in a tank farm excavation nearly 2300 feet northeast of the boreholes and surmised that conditions could be expected to be relatively similar between this area, which approximately includes the PUREX storage tunnels.

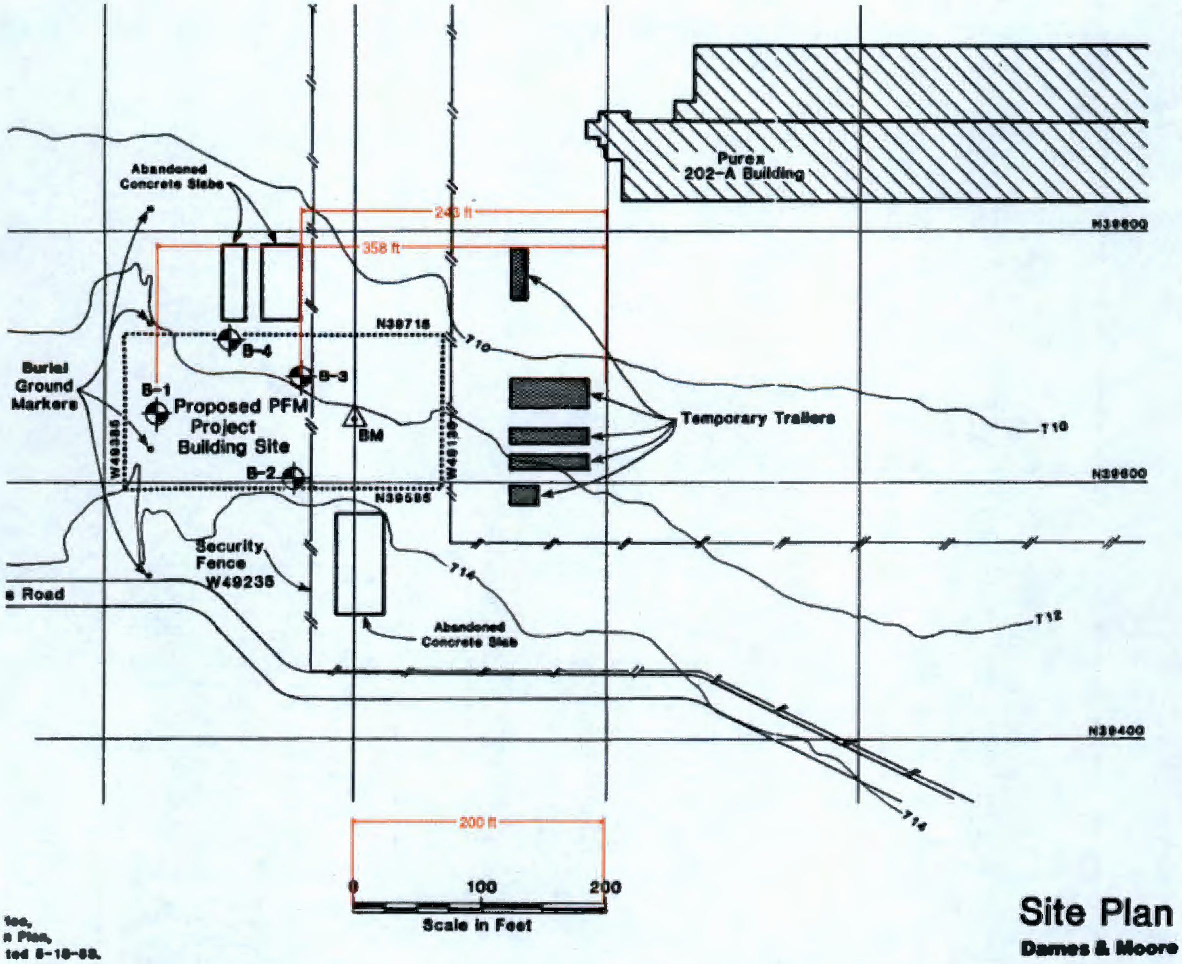

Exhibit 8 – Dames & Moore Site Plan Showing Borehole Locations relative to PUREX Facility. PUREX storage tunnels are not shown in this view.

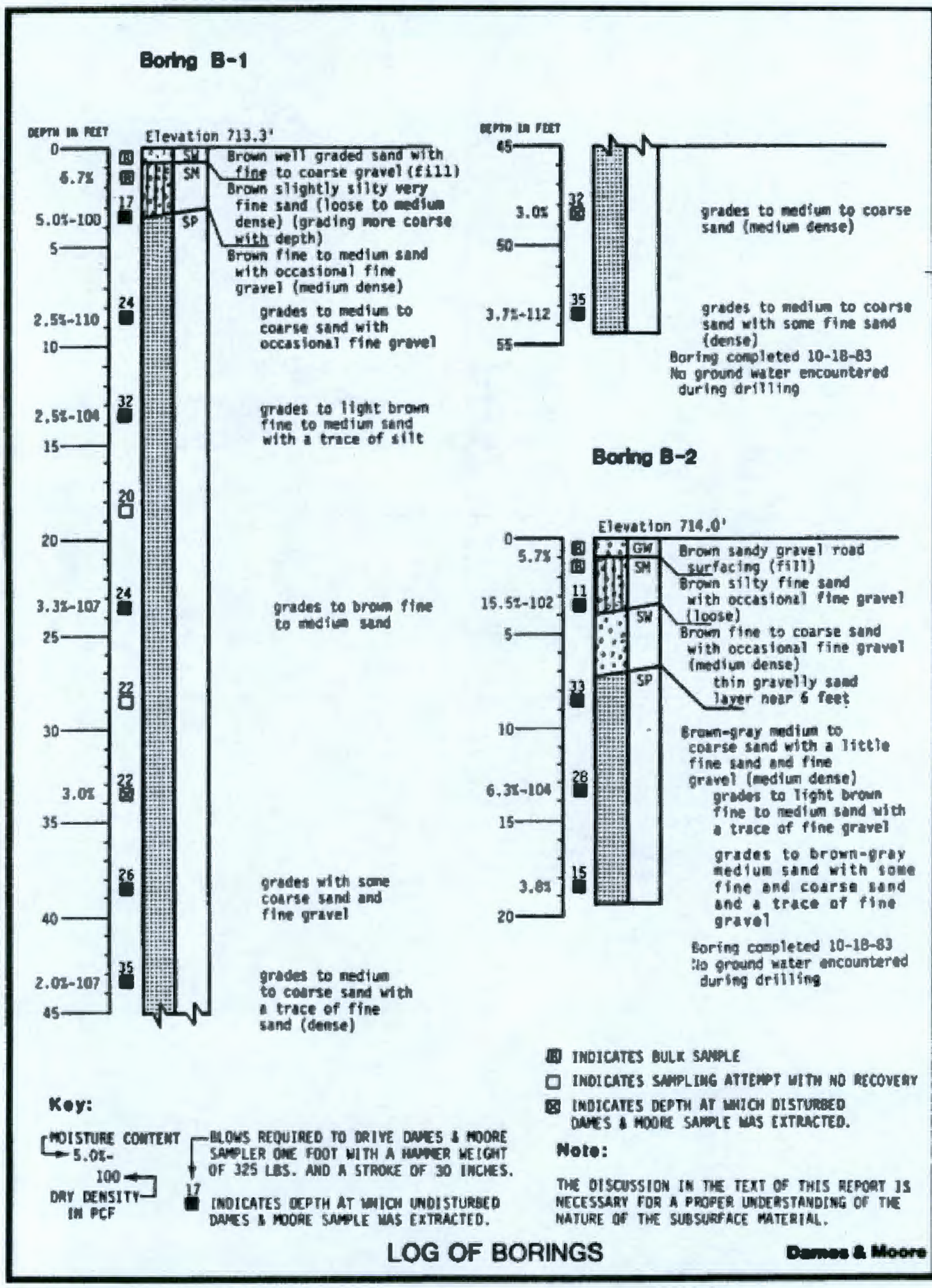

Exhibit 9 – Log of Borings B-1 and B-2

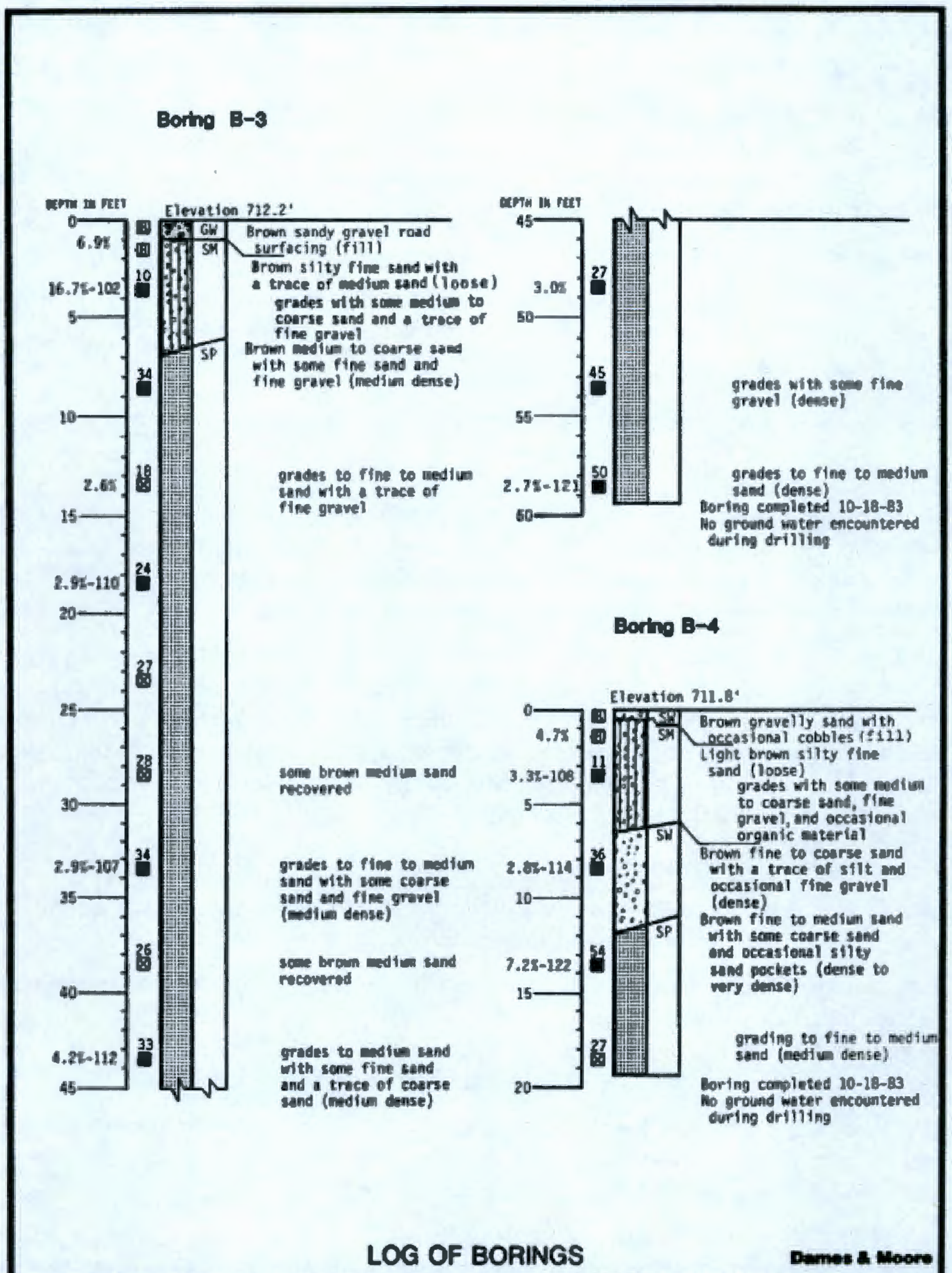

Exhibit 10 – Log of Borings B-3 and B-4

2.0 Geologic and Seismic Investigation of the PUREX Building Site (URS, 1981)

URS (1981) prepared a discussion of the regional geology setting the PUREX facility. This information provides a relevant geologic context for comparison to available geotechnical data, primarily for purposes of confirming expected extents and continuity of site materials. Cross sections of the expected site geology, prepared by URS, are presented in Exhibits 11 and 12.

The project site is underlain by three major geologic units:

1. *The Pasco (glaciofluvial) gravels and associated sediments of the late Pleistocene age at the ground surface* [also known as the Hanford Formation]
2. *Pleistocene-age Ringold formation*
3. *Basaltic lavas and intercalated sediments of the Columbia River basalt group.*

The Pasco basin was formed by downwarping and downfaulting of the basalt flows that underlie the basin. The basin then became the site of deposition of Pliocene sediments of the Ringold Formation and Pleistocene glaciofluvial deposits. The ground surface of the Pasco basin is now largely covered by windblown sand.

Deposition of the Ringold Formation ceased in late Pliocene time, one to two million years ago. Later, ice sheets of the Pleistocene glacial stages advanced from the north but stopped before reaching the Pasco basin. At the close of glaciation, while the ice sheets were retreating, great quantities of water were suddenly released. These huge floods scoured vast areas of basalt terrain in northeastern Washington, swept across the Hanford Reservation area, and crossed the Horse Heaven Hills anticline at Wallula Gap.

...

Locally, within the Pasco Basin, zones of medium-dense to loose sands and gravels, probably resulting from rapid accumulation during glacial floods, are encountered.

The Pasco Gravels are compact, though uncemented, deposits of late Pleistocene and early Recent times. They were laid down by glacial meltwaters and glacial lake floodwaters between about 100,000 and 10,000 years ago. Evidence suggests that in some places the sediments were buried by perhaps an additional 200 feet of gravel that was later swept away.

The Pasco Gravels occur at the surface, or under a thin cover of loessal materials. The water table is controlled by the Columbia River elevation. The Ringold formation occurs near the river level. The [Pasco] gravels, therefore, are typically unsaturated.

Within the 200-East area, where PUREX Building 202-A is located, the uppermost sands and silts were largely reworked during construction activities []. Although the soils beneath the PUREX building have been explored using seismic refraction, other direct exploration methods, such as drilling and sampling, have not been employed.

The water table is at a depth of about 300 feet beneath the plant; there is no liquefaction hazard.

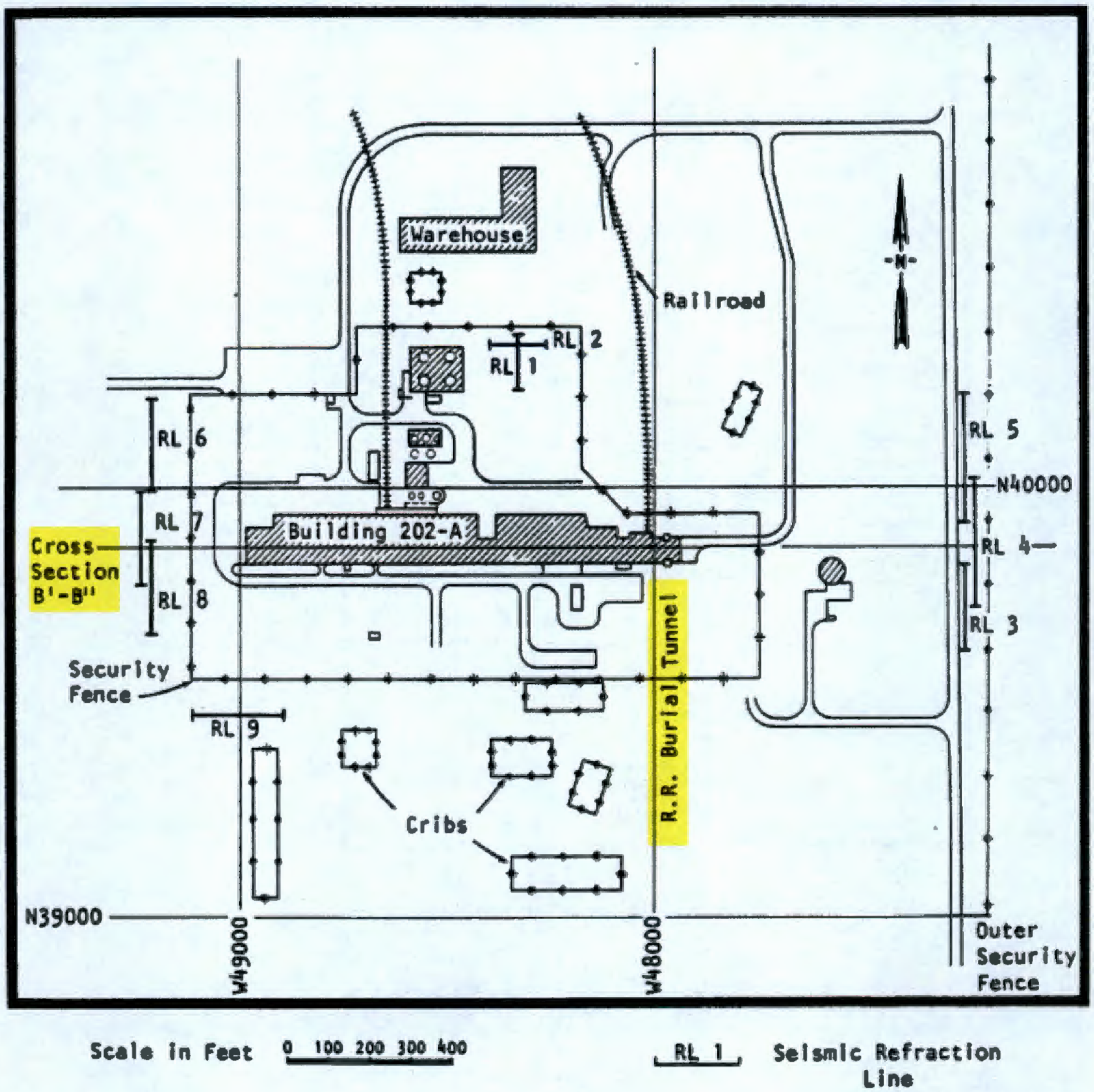

FIGURE 5 PUREX BUILDING SITE PLAN AND SEISMIC REFRACTION LINE LOCATIONS

Exhibit 11 – Site Plan showing location of Cross Section B'-B", located near the northern extent of Tunnel 2

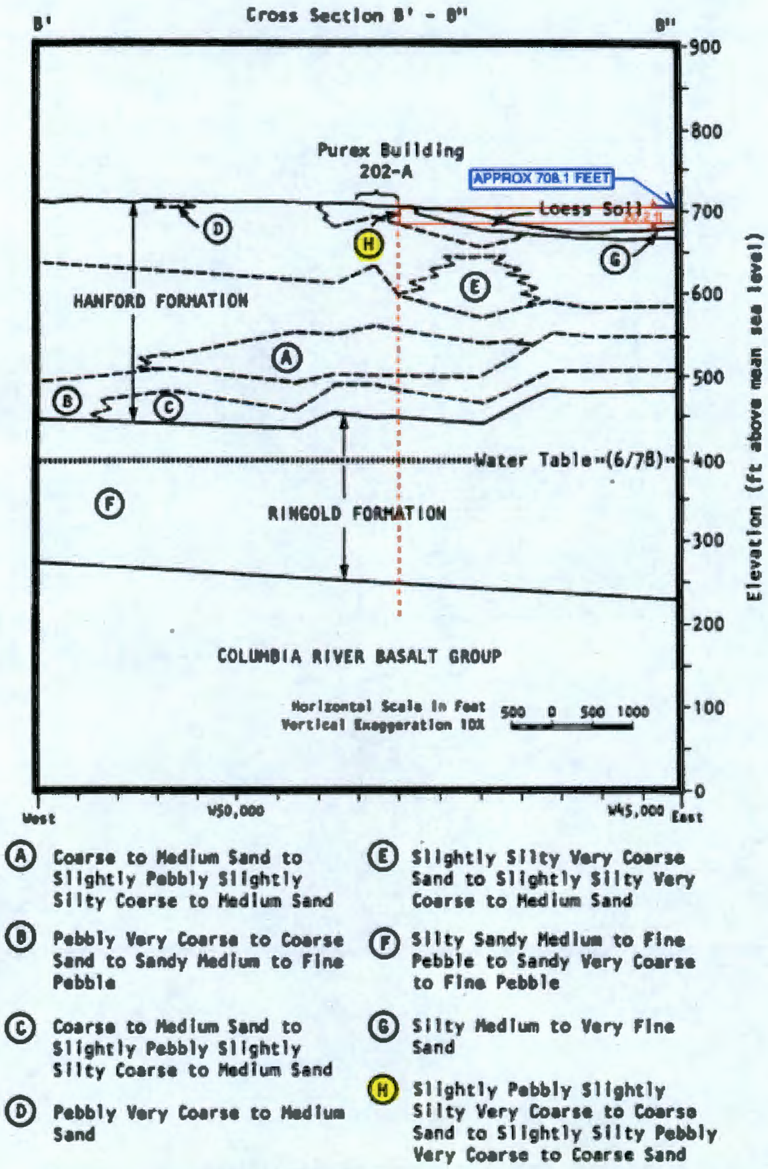

FIGURE 4 GENERALIZED GEOLOGIC CROSS SECTION SHOWING FORMATION NAMES AND SOIL CLASSIFICATION (adapted from Tallman et al., 1979)

Exhibit 12 – Cross Section B'-B". Note descriptions and relative depths of materials and groundwater underlying the PUREX facility. The red dashed line indicates the approximate alignment of the PUREX Storage Tunnels.

Interpretation

Cover soil materials placed over Tunnel 2 were derived from local site soils and processed to remove organic materials and coarse materials larger than 8 inches in diameter.

Project specifications indicate that cover soils were to be "thoroughly compacted," and there is some confusion over which backfill zones were to be applied to the tunnel cover soils. Review of the photos of fill placement with crane and dragline casts doubt on whether the soil was compacted. Construction photos show that the space between the tunnel walls and the tunnel excavation was relatively narrow, and likely did not permit use of compaction equipment, this was further complicated by the challenging dental compaction between the exterior concrete ribs. There are no photos indicating use of lightweight walk-behind compaction equipment.

It is assumed that the material placed against the tunnel walls is silty sand material with occasional gravel as described in the boring logs (Dames & Moore, 1984); geologic descriptions of the Hanford Formation / Pasco Gravels (URS, 1981), and construction photographs (CHPRC, 2017).

Assuming that boring logs from Dames & Moore (1984) are similar to the materials at PUREX Tunnel 2, and that the materials are reasonably well mixed, the fill material is assumed to be as described in the following sections.

3.0 Soil Classification

- The Tunnel 2 cover soils are fill materials obtained from the Tunnel 2 excavation.
- The USCS classification of the soils is Silty Sand with Gravel (SM).
- Fines are expected to be non-plastic.
- Sand is primarily fine to medium size.
- Gravel is fine to medium, subrounded to rounded as visible in photos.

4.0 Specific Gravity

The specific gravity of solid soil particles is assumed to be 2.65.

5.0 Moisture Content

The in-situ moisture content of site soils was estimated by selecting the average in-situ moisture content for 17 samples collected by Dames & Moore (1984) in the top 25 feet of the soil profile. For the reported measurements, the maximum water content observed was 16.7 percent and the minimum was 2.5 percent. The **average in-situ moisture content for the 17 samples was 6 percent** and is recommended for use in tunnel evaluations. Note that actual moisture contents may vary with depth, season, and location along the tunnel alignment.

6.0 Dry Unit Weight

The unit weight of the fill material is difficult to estimate due to the uncertainties in fill placement. Dames & Moore (1984) measured the in-situ dry density of site soils near the PUREX facility. For the 11 field measurements of density taken in the upper 25 feet of the soil profile, the minimum was 100 pcf, the maximum was 122 pcf, and the average was 108 pcf.

Based on a review of site photographs, it is assumed that the cover soils were not well compacted during construction. As such, **the recommended dry unit weight of the loosely placed cover soil is 100 pcf** be used in estimation of moist unit weights.

7.0 Moist Unit Weight

The moist unit weight of the Tunnel 2 cover soil can be estimated using the dry unit weight and the moisture content, using the following fundamental relationship:

$$\gamma_{moist} = \gamma_d \cdot (1 + w\% / 100)$$

where:

- γ_m is the moist unit weight
- γ_d is the dry unit weight
- w(%) is the in-situ water content, as a percent

Substituting 100 pcf for the dry unit weight, and 6% for the moisture content, gives 106 pcf.

Substituting 108 pcf for the dry unit weight and 6% for the moisture content gives 114 pcf.

For structural evaluation of the tunnel, it is recommended that moist unit weights varying form 105 to 115 pcf be considered, with an expected average value of 110 pcf. This recommendation is in general agreement with calculations performed by Rockwell (1980) which used 110 pcf in soil loading calculations.

8.0 Shear Strength

The shear strength of the cover soil was estimated using the published charts in the 1986 Naval Facilities Engineering Command (NAVFAC) Foundations and Earth Structures Design Manual 7.02 (Exhibit 12). Assuming a dry unit weight of 100 pcf and a relative density of 25 to 30 percent for uncompacted soils, **the angle of internal friction, ϕ' is estimated to be approximately 30 degrees. The soil is assumed to be cohesionless ($c' = 0$ psf)**. Drained (effective stress) conditions are expected to govern all loading short term and long term loading scenarios.

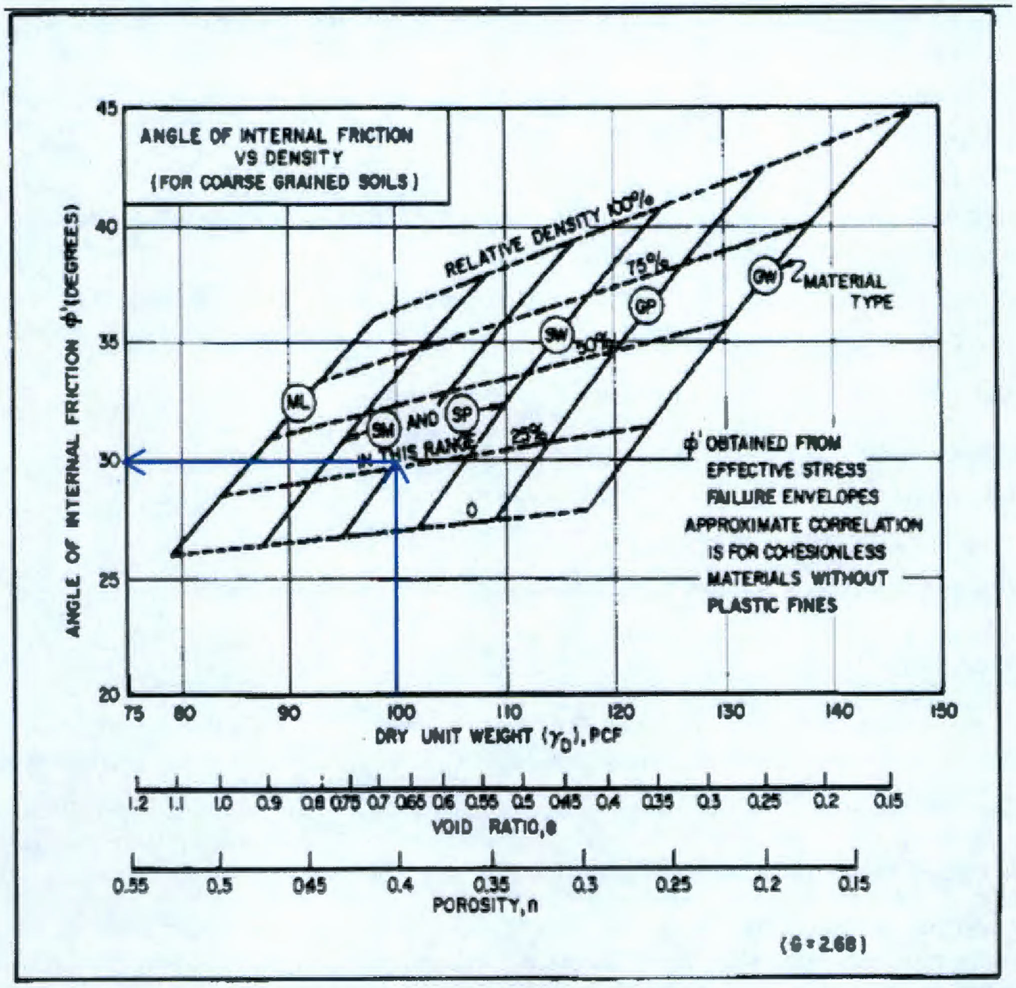

FIGURE 7
Correlations of Strength Characteristics for Granular Soils

Exhibit 12 – Correlation between Dry Unit Weight and Internal Friction Angle for Coarse Grained Soils, Adapted from NAVFAC DM7.02 (1986)

References

CHPRC-03241 Revision 0. PUREX Burial Tunnels, dated March 2017, prepared for the U.S. Department of Energy Assistant Secretary for Environmental Management, prepared by M. A. Maloof CH2M HILL Plateau Remediation Company.

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RHO-R-34-3, Geologic and Seismic Investigation of the PUREX Building Site near Richland, Washington, prepared for Vitro Engineering Corporation, Richland, Washington, dated March 1981, prepared by URS/John A. Blume and Associates, Engineers.

Shannon & Wilson, Inc. (2015) *Geotechnical Engineering Study—West Replacement Footings for 324 Building 'B' Cell Excavation, Hanford Reservation, Washington*. Submitted to Kurion, Inc. 22-1-03078-010. February 27.

ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Attachment B

LIDAR Topography Results

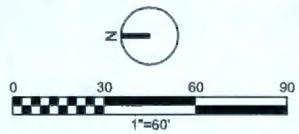
TOPOGRAPHY FROM 2008 *LIDAR CENTRAL PLATEAU REPORT* PREPARED BY AERO-METRIC FOR FLUOR HANFORD. DATA ACQUISITION APRIL 13, 2008. HORIZONTAL DATUM: STATE PLANE NAD83, WASHINGTON SOUTH ZONE, METERS. VERTICAL DATUM: NAVD88, METERS.

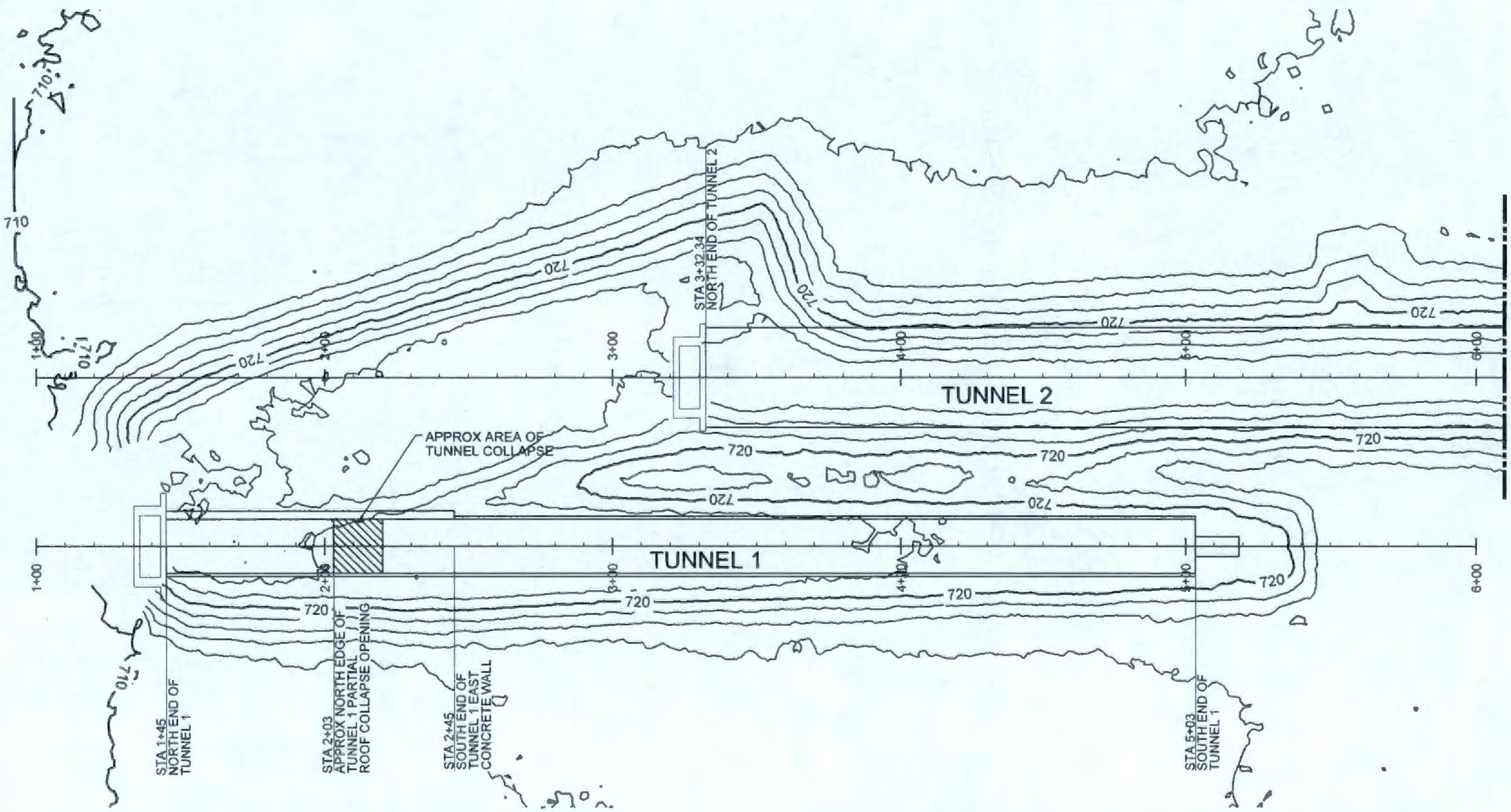
HORIZONTAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41.

VERTICAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41. VERTICAL DATUM SHIFT FROM LIDAR TOPOGRAPHY, -1.100 METERS.

TUNNEL 1 GEOMETRY FROM 1955 AS-BUILT DRAWINGS. FACILITY 218-E-14, DISPOSAL TUNNEL NO. 1 FOR FAILED EQUIPMENT, PROJECT CA-513-A. ISSUED MARCH 10, 1955.

TUNNEL 2 GEOMETRY FROM 1962 AS-BUILT DRAWINGS. FACILITY 218-E-15, DISPOSAL TUNNEL NO. 2 FOR FAILED EQUIPMENT, PROJECT CGC 964. ISSUED SEPTEMBER 1962.





TOPOGRAPHIC SITE PLAN 1 OF 2

PUREX TUNNEL 1
ENGINEERING EVALUATION

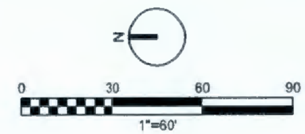
TOPOGRAPHY FROM 2008 *LIDAR CENTRAL PLATEAU REPORT* PREPARED BY AERO-METRIC FOR FLUOR HANFORD. DATA ACQUISITION APRIL 13, 2008. HORIZONTAL DATUM: STATE PLANE NAD83, WASHINGTON SOUTH ZONE, METERS. VERTICAL DATUM: NAVD88, METERS.

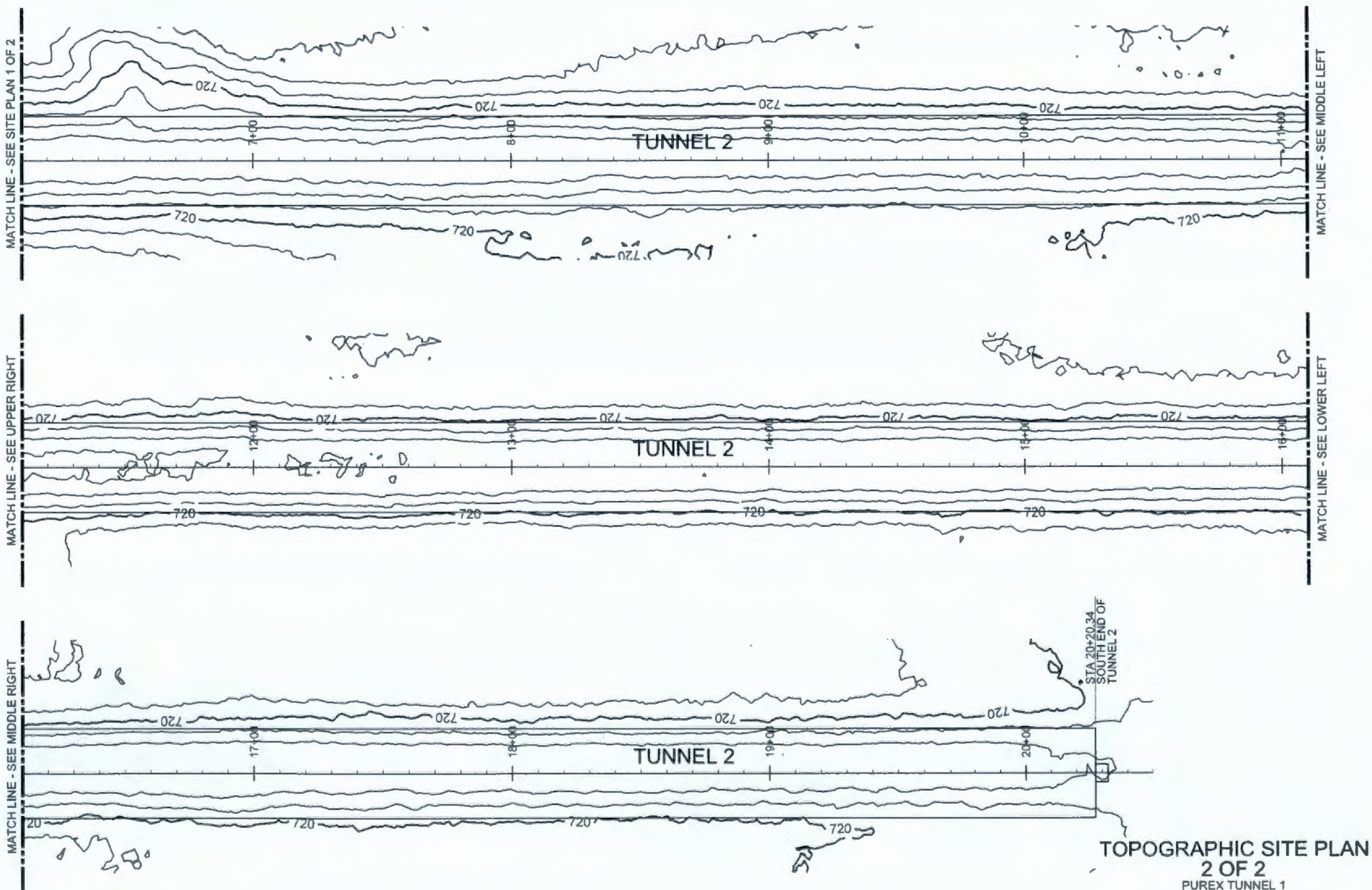
HORIZONTAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41.

VERTICAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41. VERTICAL DATUM SHIFT FROM LIDAR TOPOGRAPHY, -1.100 METERS.

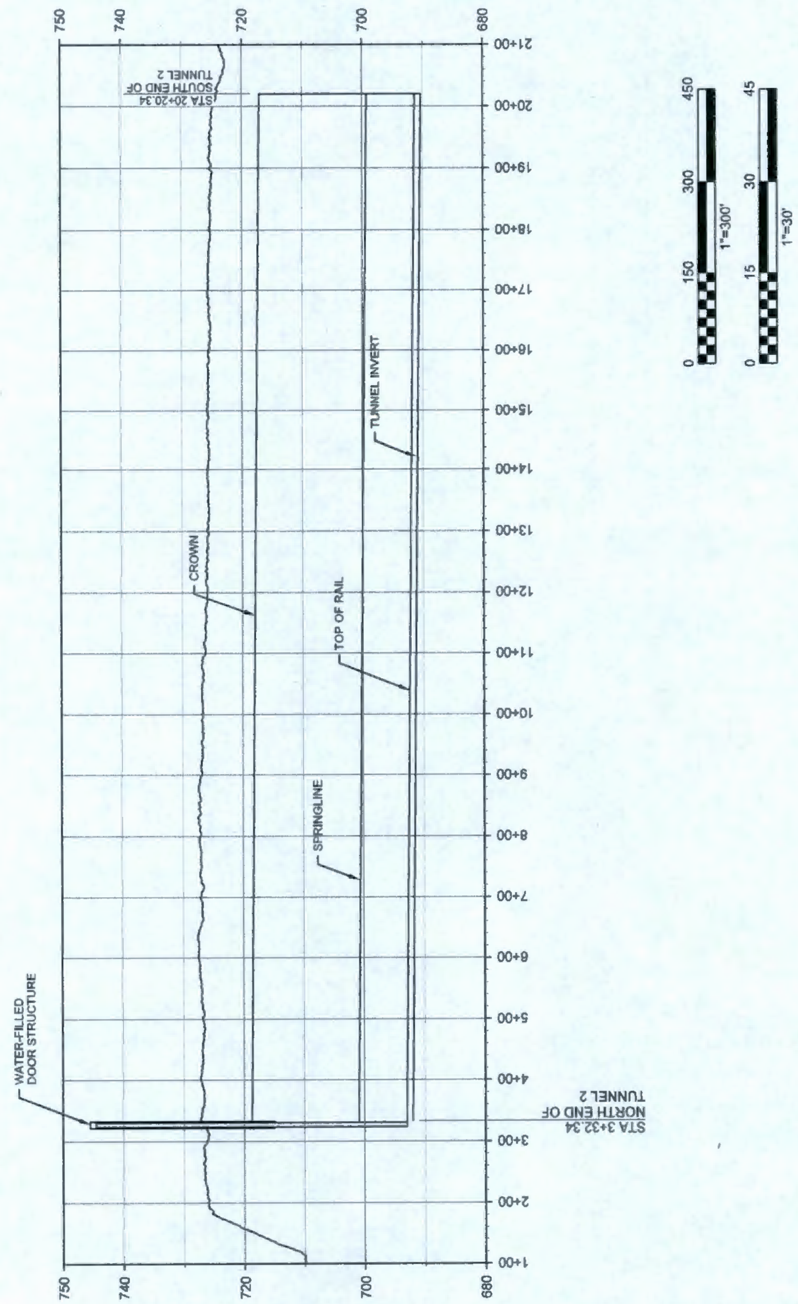
TUNNEL 1 GEOMETRY FROM 1955 AS-BUILT DRAWINGS. FACILITY 218-E-14, DISPOSAL TUNNEL NO. 1 FOR FAILED EQUIPMENT, PROJECT CA-513-A. ISSUED MARCH 10, 1955.

TUNNEL 2 GEOMETRY FROM 1962 AS-BUILT DRAWINGS. FACILITY 218-E-15, DISPOSAL TUNNEL NO. 2 FOR FAILED EQUIPMENT, PROJECT CGC 964. ISSUED SEPTEMBER 1962.

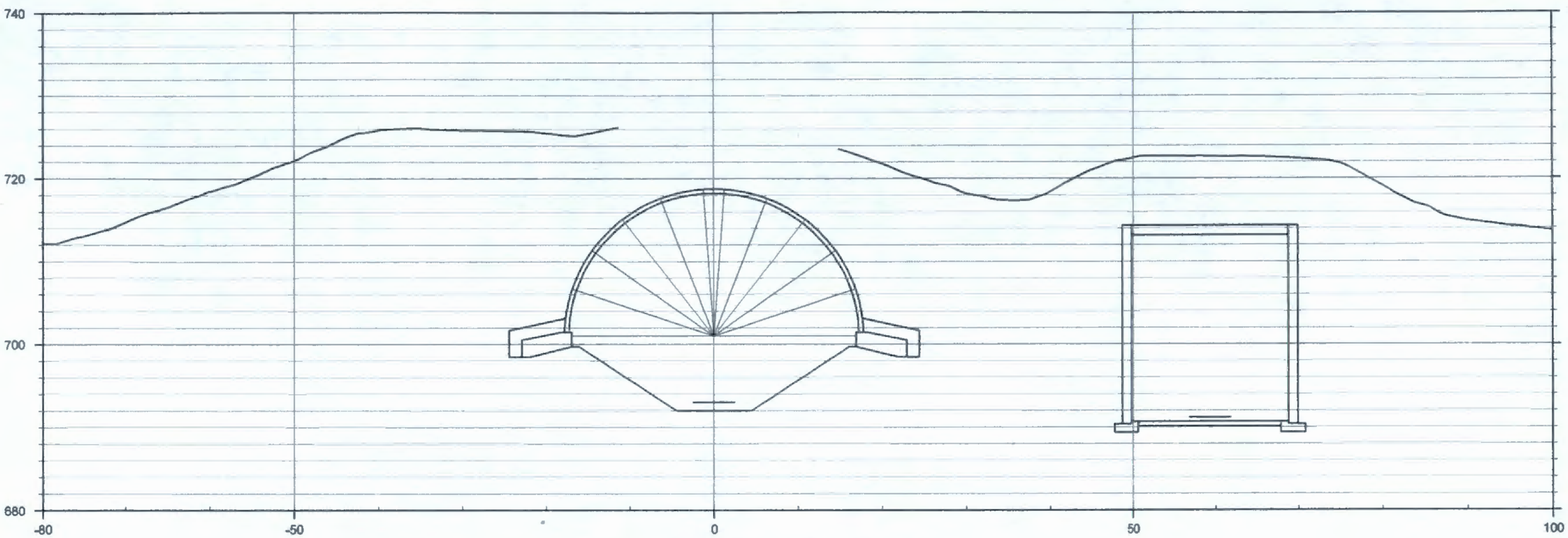




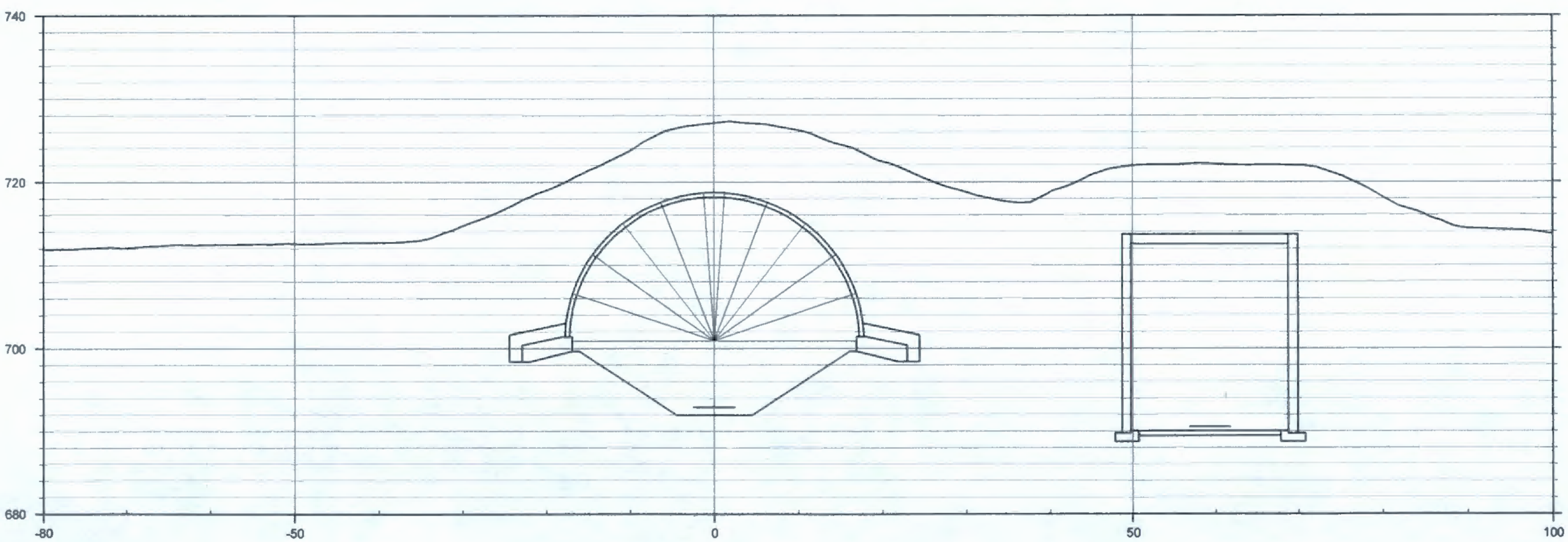
TOPOGRAPHIC SITE PLAN
2 OF 2
PUREX TUNNEL 1
ENGINEERING EVALUATION



TUNNEL 2 PROFILE
PUREX TUNNEL 1
ENGINEERING EVALUATION

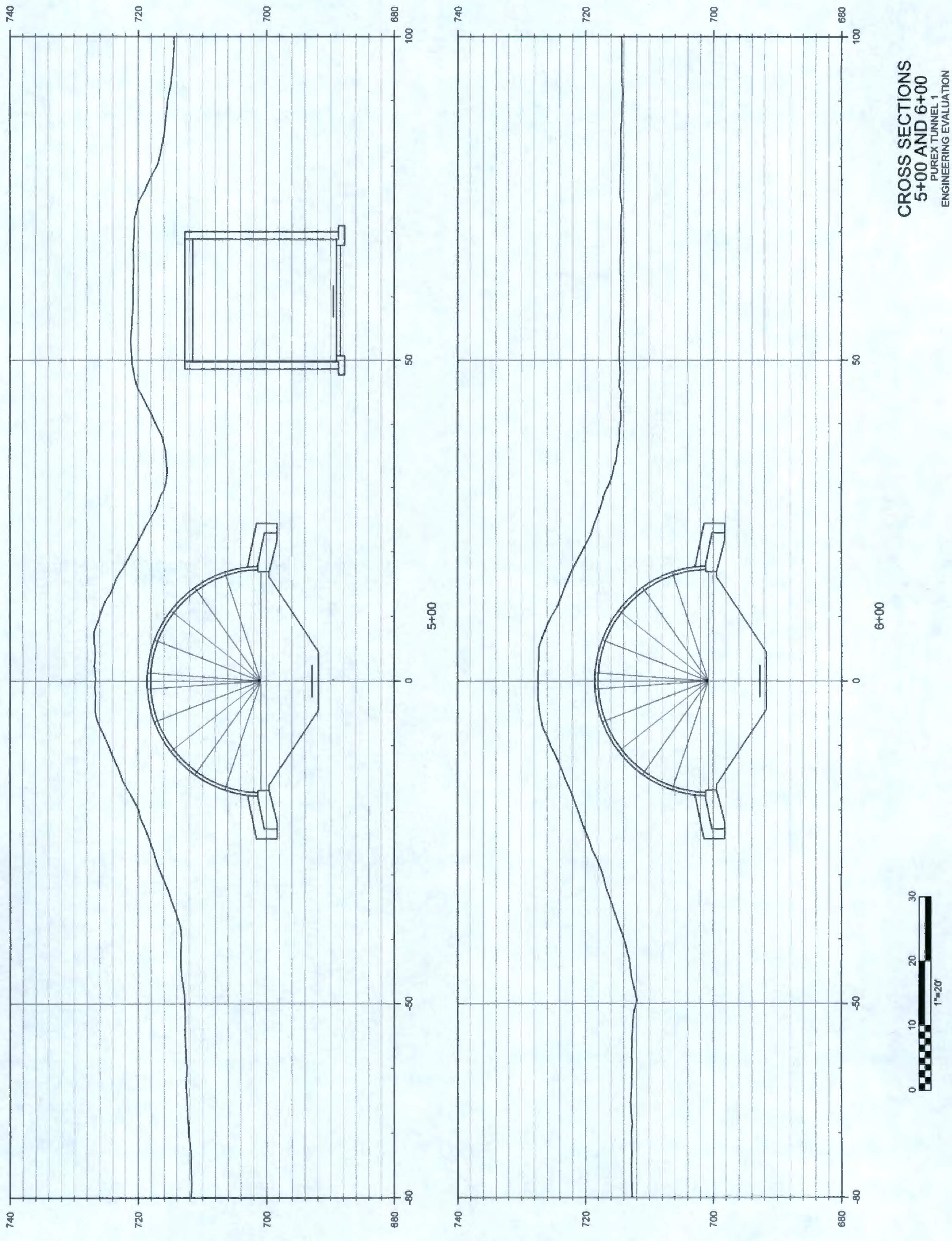


3+32.34 - NORTH END OF TUNNEL 2



4+00

CROSS SECTIONS
3+32.34 AND 4+00
PUREX TUNNEL 1
ENGINEERING EVALUATION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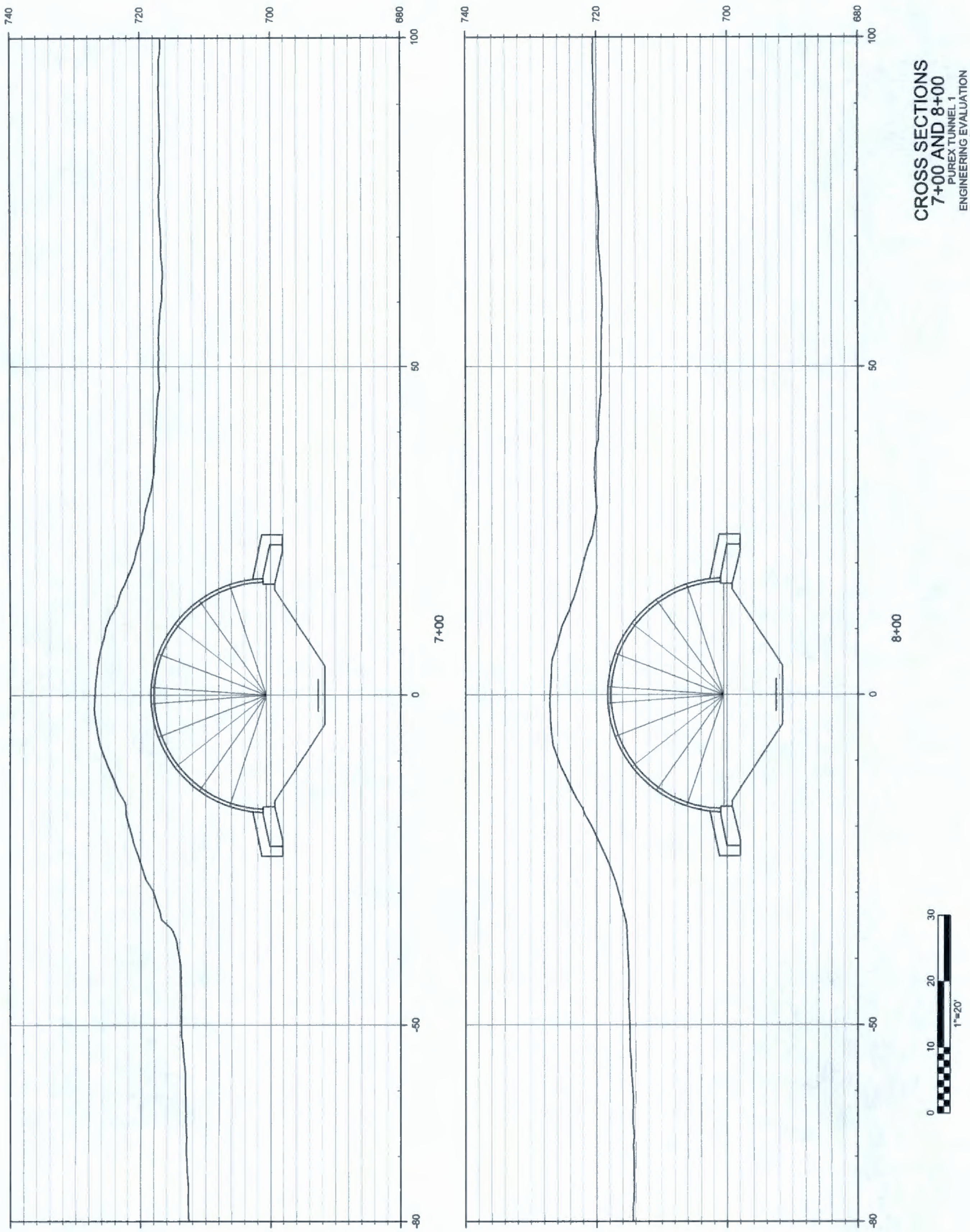
5+00 AND 6+00
PUREX TUNNEL 1
ENGINEERING EVALUATION
5+00
6+00
1"=20'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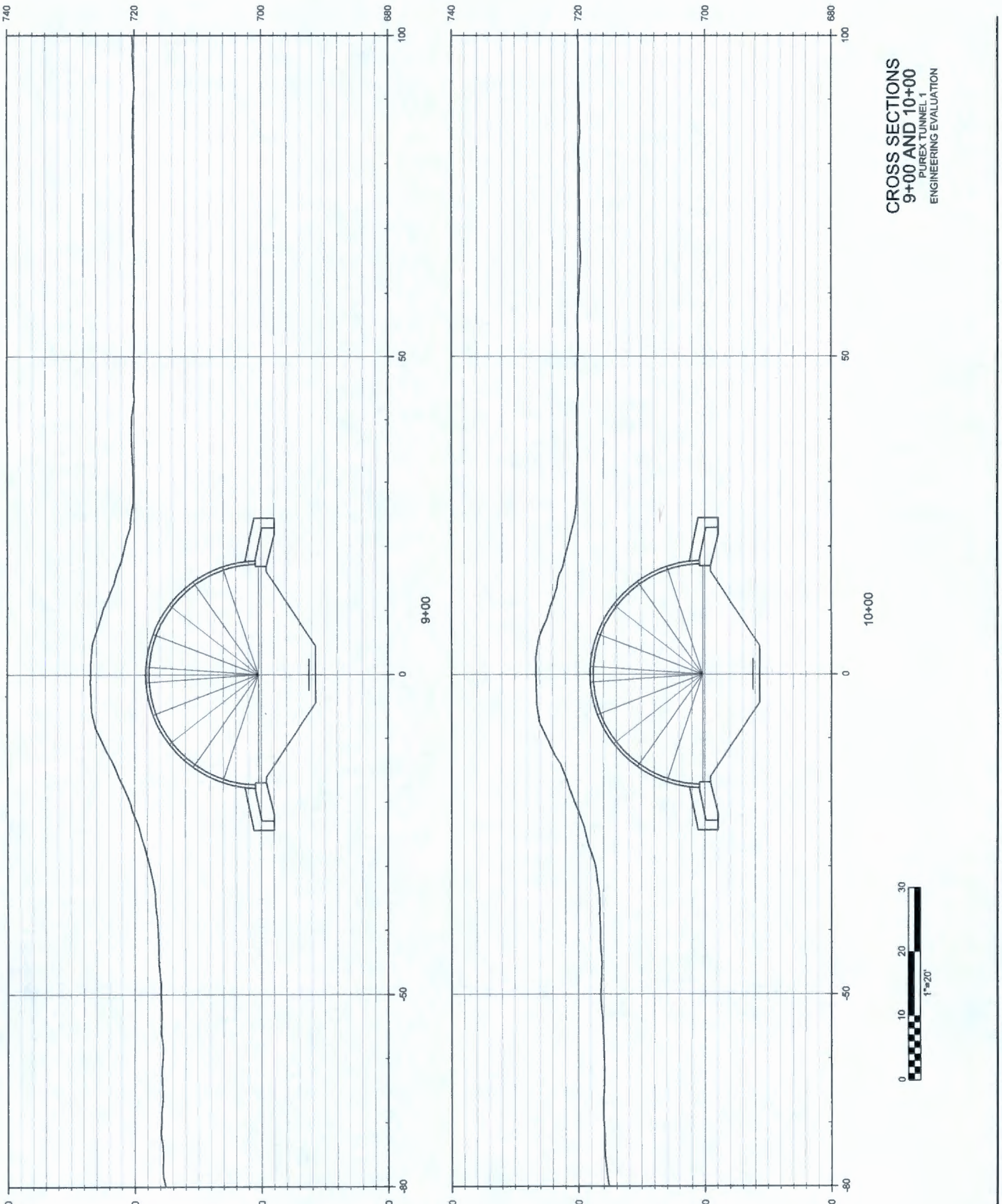
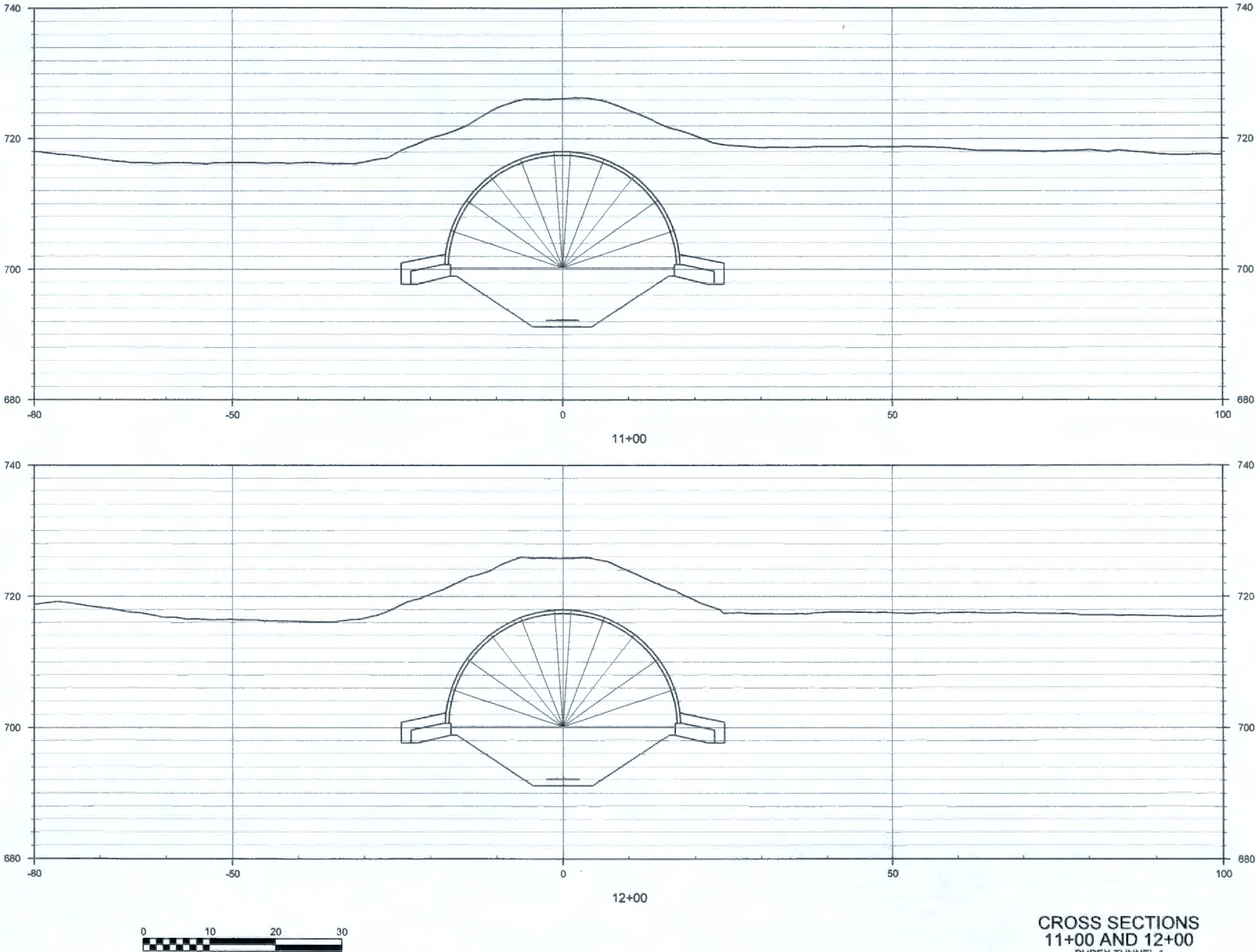
7+00 AND 8+00
PUREX TUNNEL 1
ENGINEERING EVALUATION
7+00
8+00
1"=20'


CROSS SECTIONS
9+00 AND 10+00
PUREX TUNNEL 1
ENGINEERING EVALUATION
9+00
10+00
740
720
700
680
100
50
0
-50
-80
0
10
20
30
1"=20'



CROSS SECTIONS
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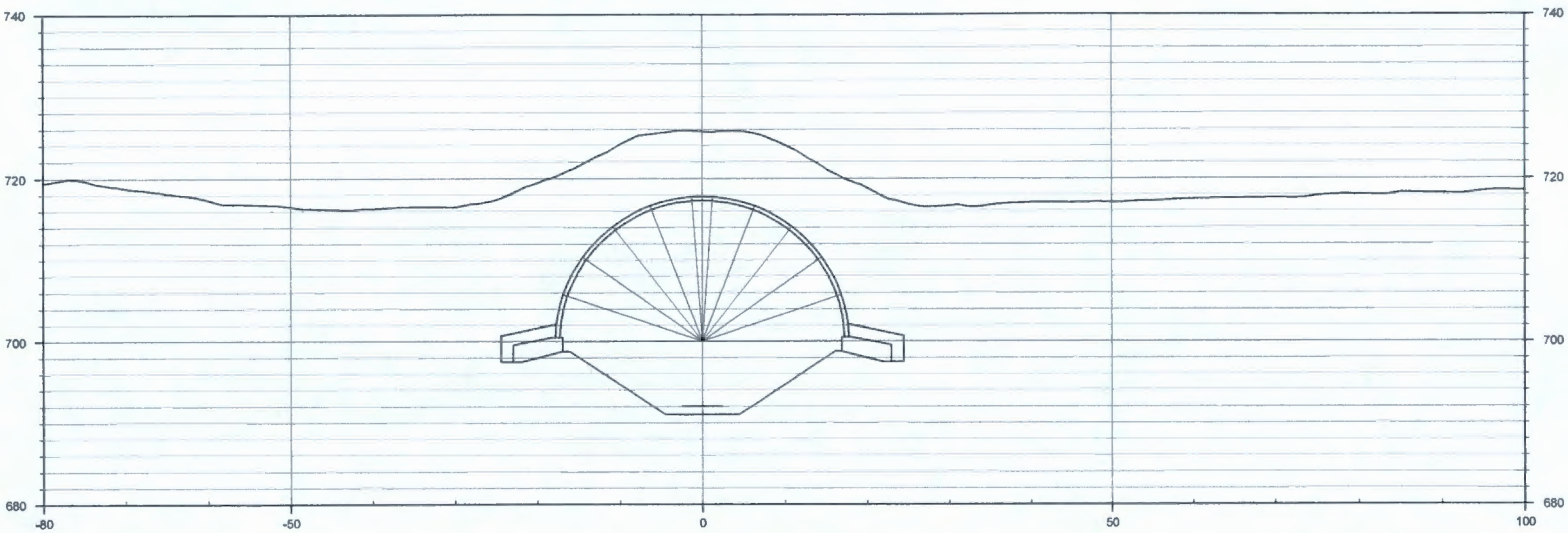
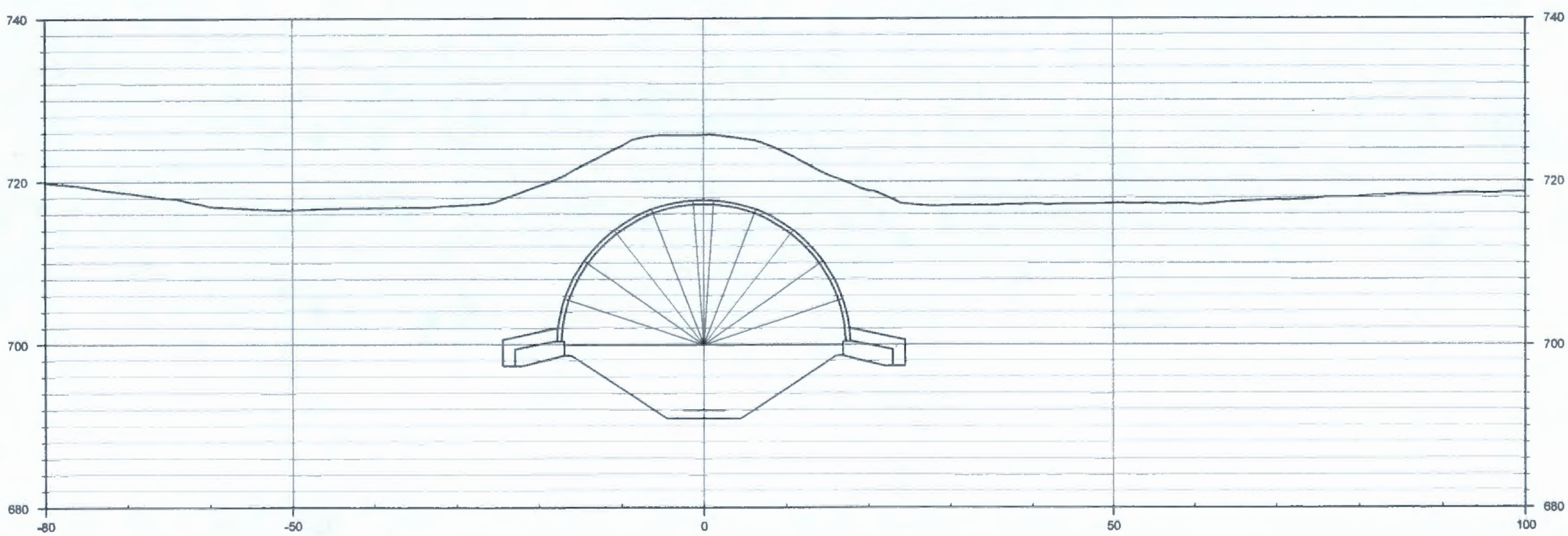
PUREX TUNNEL 1
ENGINEERING EVALUATION

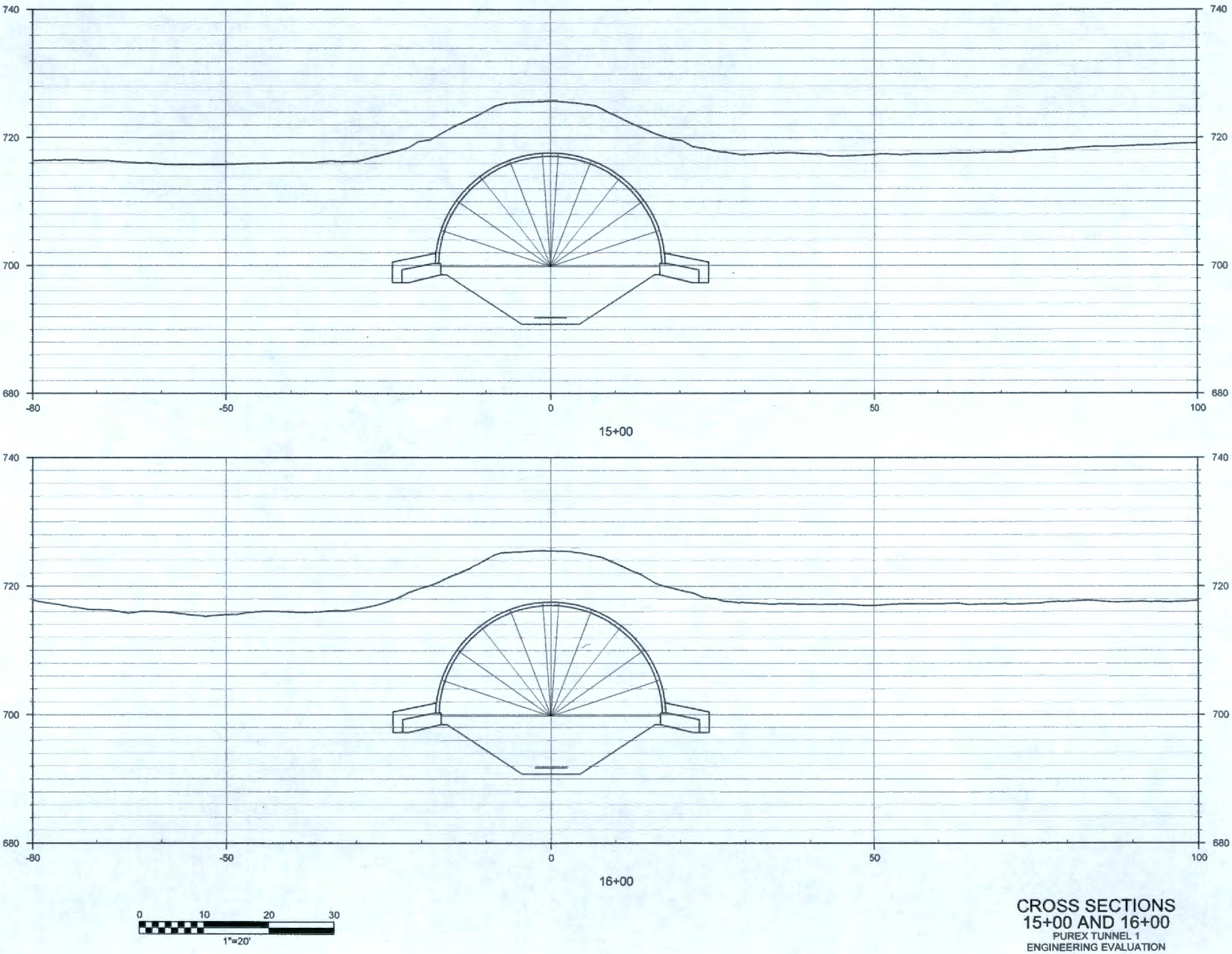


13+00

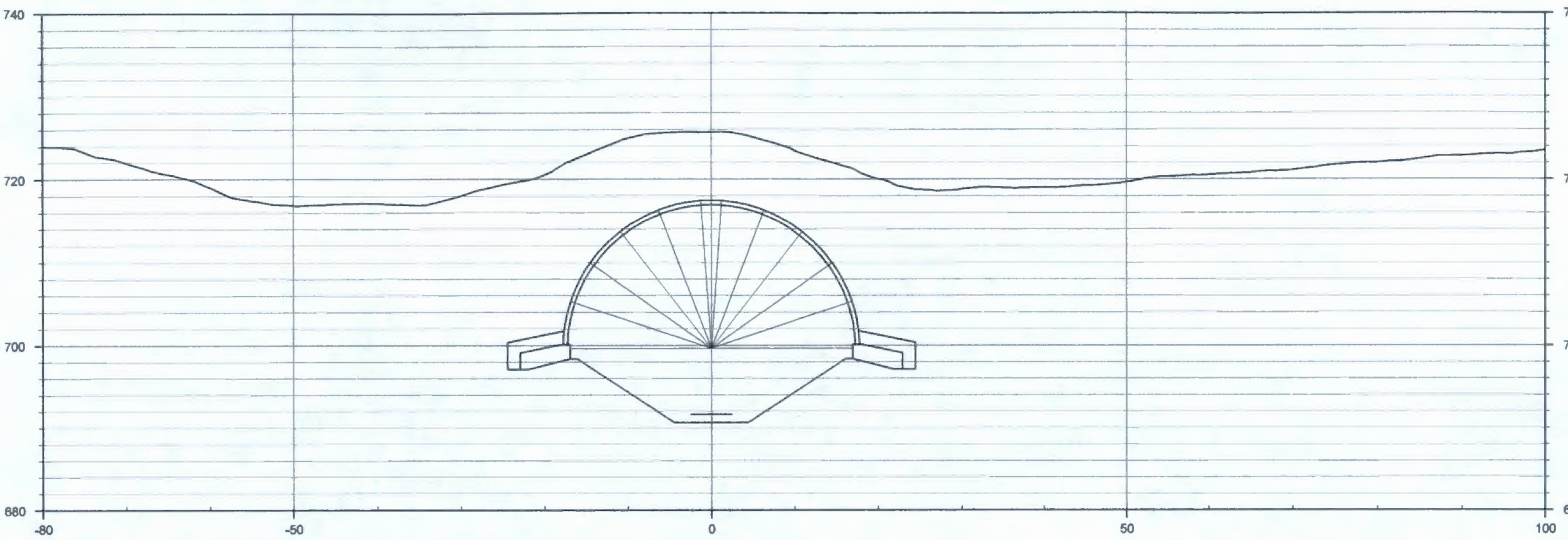


14+00

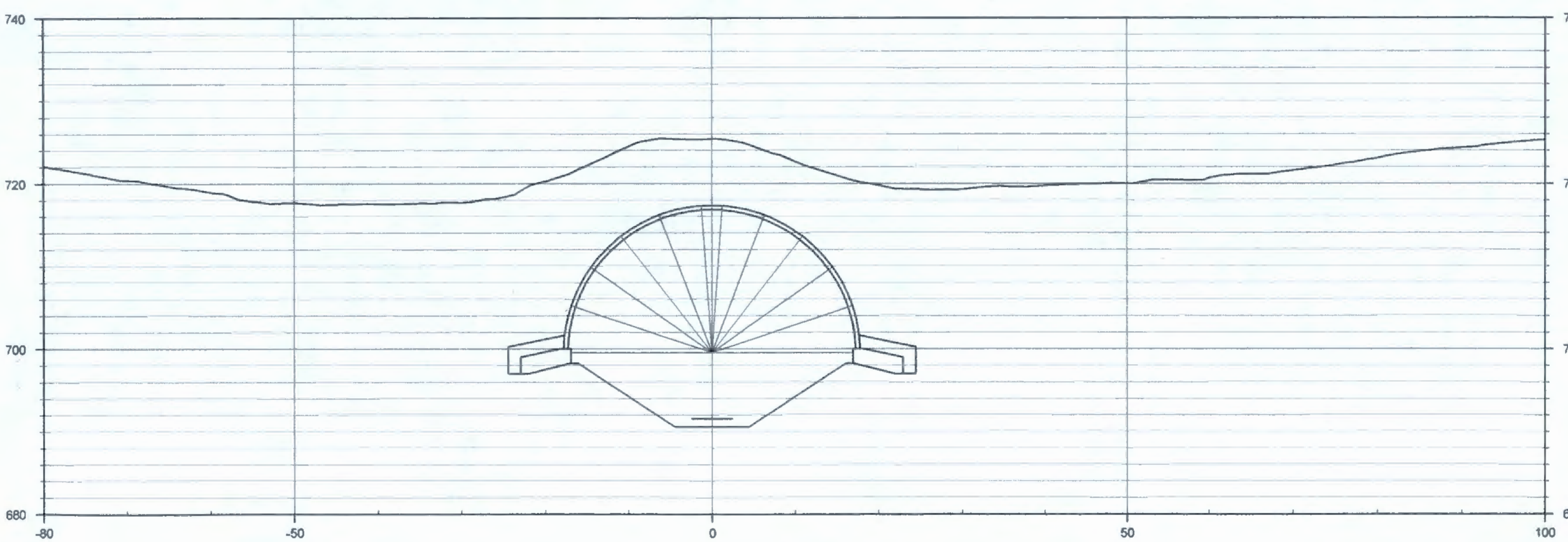
CROSS SECTIONS
13+00 AND 14+00
PUREX TUNNEL 1
ENGINEERING EVALUATION



CROSS SECTIONS
15+00 AND 16+00
PUREX TUNNEL 1
ENGINEERING EVALUATION

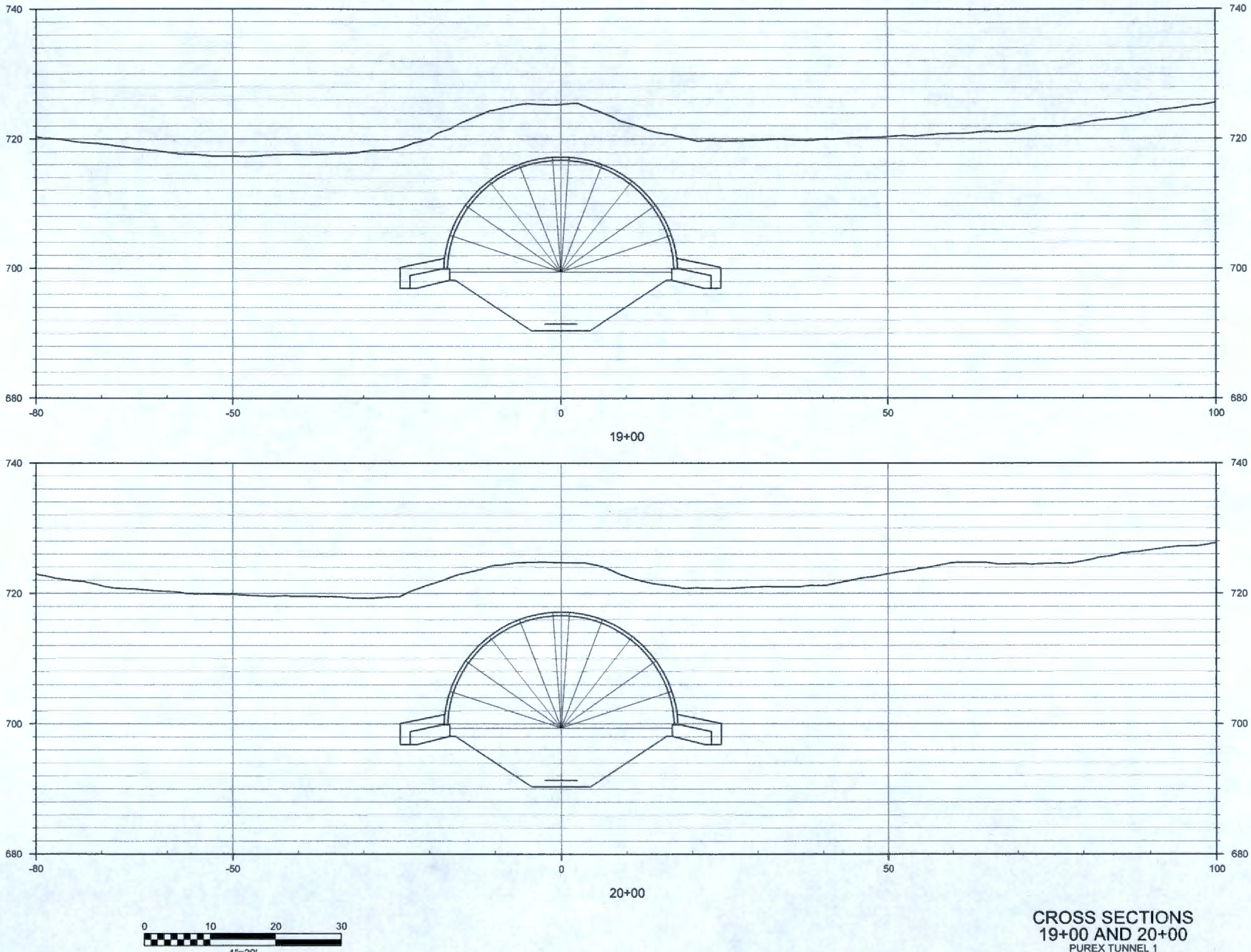


17+00

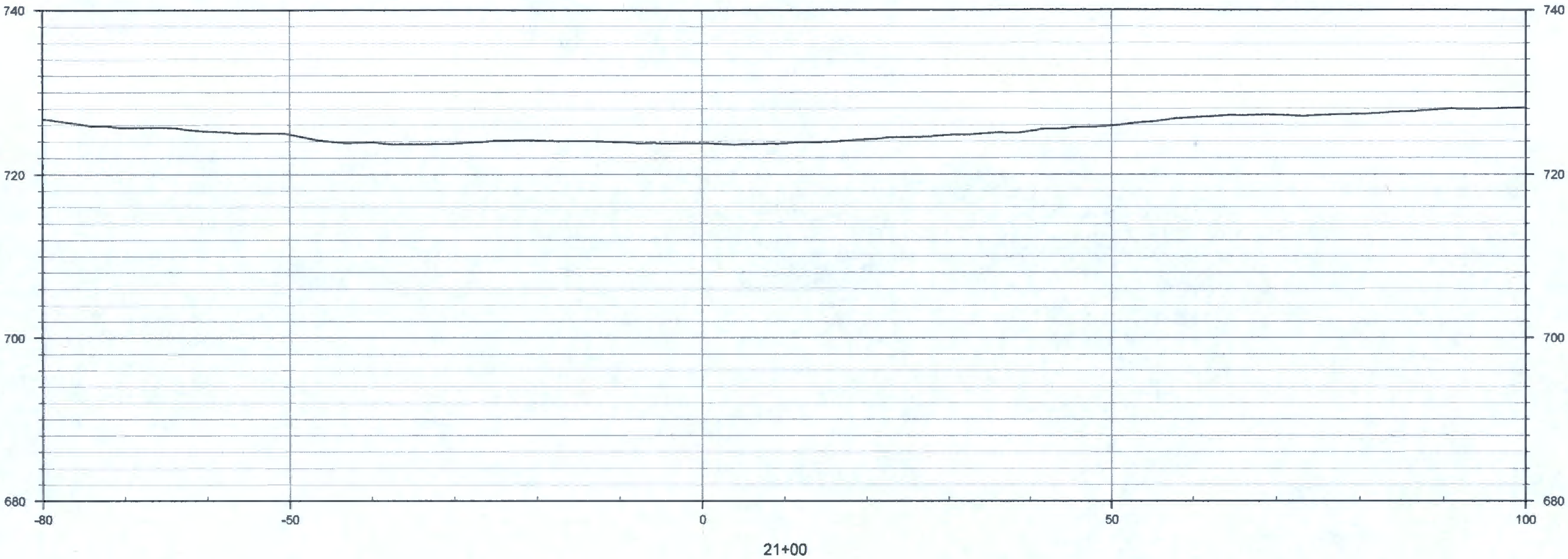


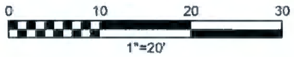
18+00

CROSS SECTIONS
17+00 AND 18+00
PUREX TUNNEL 1
ENGINEERING EVALUATION



CROSS SECTIONS
19+00 AND 20+00
PUREX TUNNEL 1
ENGINEERING EVALUATION





CROSS SECTION 21+00
PUREX TUNNEL 1
ENGINEERING EVALUATION

AERO-METRIC
SEATTLE

FLUOR HANFORD

LiDAR Digital elevation Model(s)
&
Topographic Contour Maps

TABLE OF CONTENTS

AERO-METRIC
SEATTLE

1 Project Area & Synopsis

- This contract consists of obtaining DEM and contour data for the Central Plateau of the Hanford Site. Under a separate contract with Washington Closure Hanford, Aero-Metric completed a LiDAR data acquisition for the entire Hanford site and included most of the Central Plateau. See Exhibit A for project limits. The project area consists of approximately 38,000 acres.
- Aero-Metric obtained Airborne LiDAR data at sufficient density and accuracy to allow for the generation of 0.5m posting DEM grids and 0.3m contours.
- LiDAR survey was supported by on-board Airborne GPS and IMU observations.
- Rogers Surveying was responsible for the ground observations on two base stations during all aerial missions. Aero-Metric was responsible for the computations for the ABGP and IMU measurements.
- Rogers Surveying surveyed and computed the coordinates for approximately 234 vertical points along six profiles and well distributed within the entire Hanford area and representing different terrain types. These points served as true check points to further analyze and correct biases in the LiDAR data.
- See Exhibit B for location of the six selected profiles.

1.1 Coordinate System

- Horizontal system: State Plane NAD83, Washington South Zone, Meters
- Vertical system: NAVD88, Meters

2 LiDAR Survey

2.1 Flight Specifications – See exhibit C for Flight Line Coverage

- Sensor: Optech ALTM.
- Date of data acquisition: April 13, 2008
- Flying Height: 800m / 2634 ft above ground.
- Overlap between flight lines: 50% (100% double coverage)
- System Frequency: 100 KHz
- Scan Frequency: 65 Hz
- Scan Angle: net 24 degrees (12deg on each side)
- Air Speed: 135 kts
- Number of Flight lines: 145
- Geo-Referencing: ABGPS, IMU, and nine ground targets
- Nominal ground resolution: 0.4m
- Mission length: About seven days

2.2 QA/QC Profiles

- See exhibit B for location of the selected QA/QC point profiles.
- See Exhibit D for Point Residual Listing
- About 234 QA/QC points to support analysis and correction to LiDAR data.
- Survey work by Rogers Surveying.

2.3 LiDAR Data Post-Flight / Pre-Processing

- All ABGPS and IMU data, and GPS-obserevations on two base stations are integrated within the computation of the final geo-referencing of each of the flight lines.
- All discrepancies between flight lines are minimized through a number of post-processing algorithms.
- QA/QC points coordinates are used to verify the final accuracy of the derived LiDAR products as described earlier.
- Software used: Optech DASHMAP, Microstation Version 8, TerraSolids TMATCH and TSCAN packages.

AERO-METRIC
SEATTLE

2.4 LiDAR Data Editing and Contour Generation

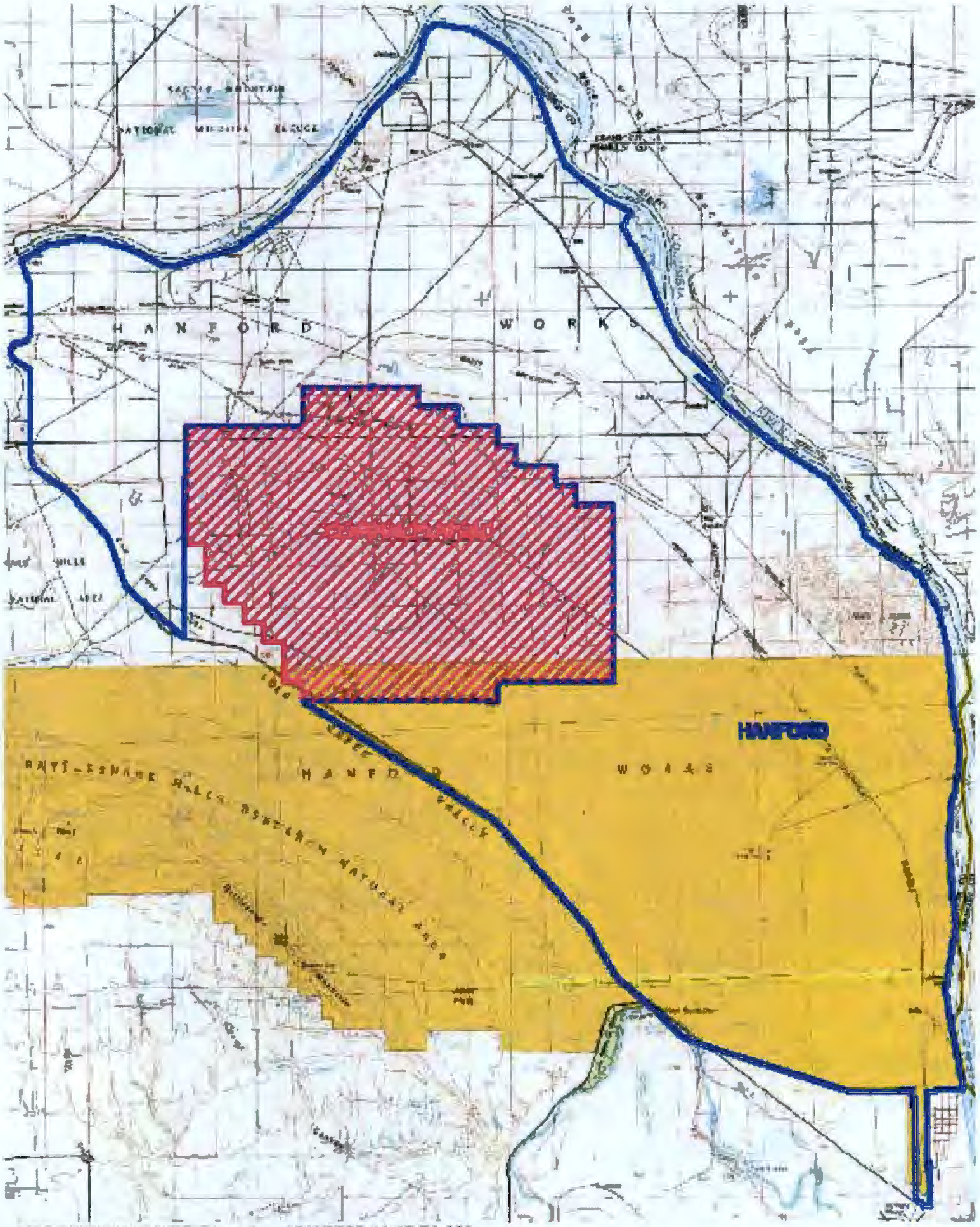
- Post-processed LiDAR data is reduced to 750m by 750m tiles. See exhibit E for Tile Layout and Numbering.
- Classified LiDAR data is visually checked, analyzed, and re-classified if needed. Erroneous points are eliminated.
- After the completion of all editing steps, a LiDAR QC specialist reviewed all data to ensure completeness, conformity to standards, and the accuracy of the data.
- Software used: MicroStation version 8, Terrasolids TSCAN, TMODEL, and TMATCH packages.

3 Final Packaging and Delivery

- The final products are checked against a deliverable list to ensure product completeness. All data used for the project has been archived on permanent archival media for future use if needed by the client.
- The following products are delivered along with this report.
    - Contour data in Microstation Version 8 format.
    - Contour data in Digital Exchange Format (DXF)
    - Contour data in Arc Shapefile format
    - LiDAR data in ASCII .xyz format (All points, First return, Ground, Non-Ground)
    - LiDAR data in .las format
    - DEM Grids in Arc Grid format (All points, First return, Ground, Non-Ground)
    - This LiDAR report including the QA/QC points residuals

AERO-METRIC
SEATTLE

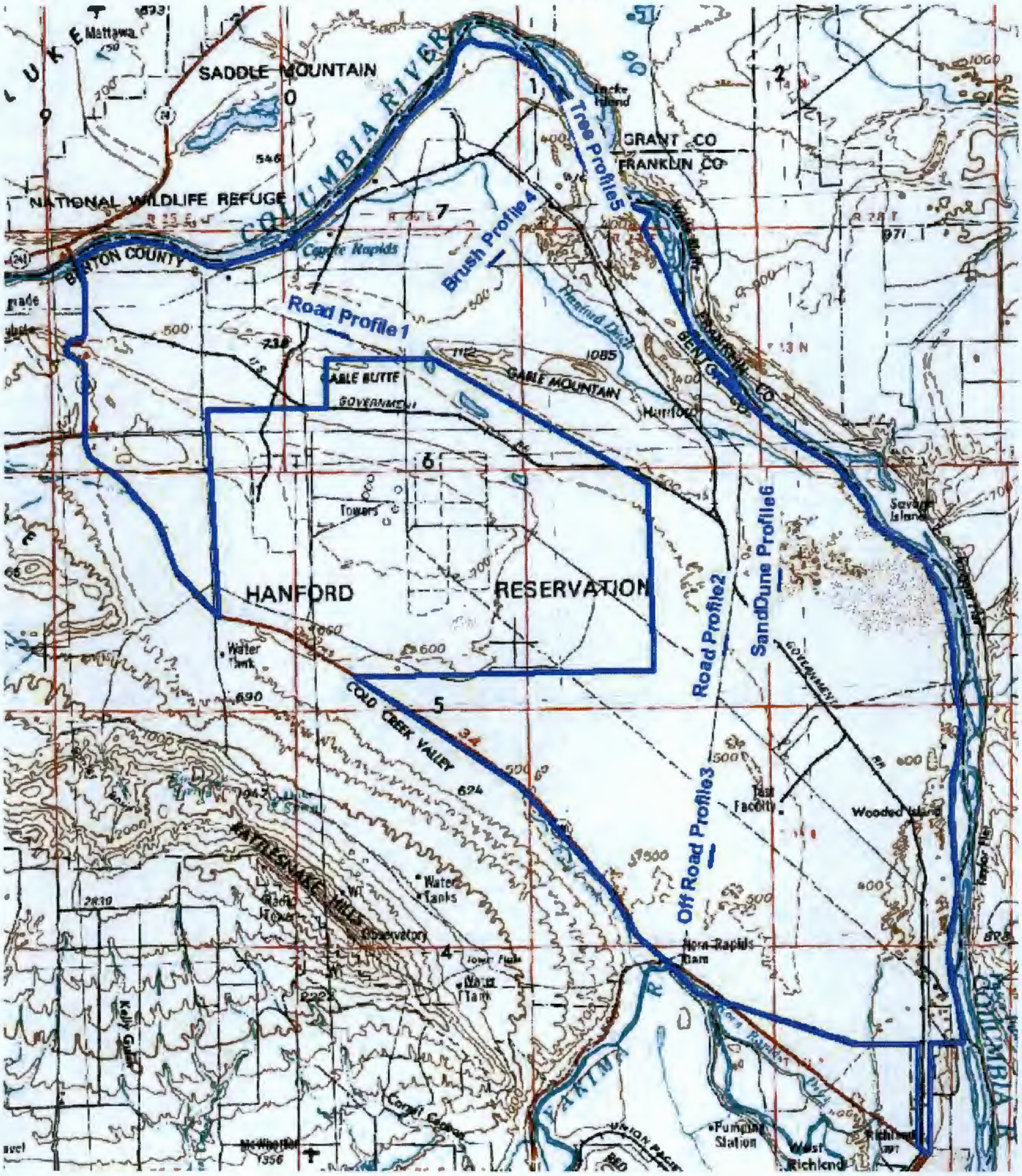
EXHIBIT A – PROJECT AREA



...\2008\080711 FLUOR\Fluor.dgn 12/4/2008 11:15:54 AM

AERO-METRIC
SEATTLE

EXHIBIT B – QA/QC LiDAR PROFILES LOCATION



AERO-METRIC
SEATTLE

EXHIBIT C – LiDAR FLIGHT LINE COVERAGE

AERO-METRIC
SEATTLE

EXHIBIT D – GROUND SURVEYED QA/QC POINTS RESIDUALS (LiDAR minus Survey)

Number	Easting	Northing	Known Z	Laser Z	Dz
1060	587475.238	132228.964	143.798	144.280	+0.482
1249	579340.993	149856.447	118.679	118.970	+0.291
1251	579354.060	149816.955	117.872	118.140	+0.268
1257	579398.173	149685.686	117.363	117.580	+0.217
1250	579348.422	149834.166	118.097	118.270	+0.173
1256	579373.489	149694.794	118.975	119.140	+0.165
1258	579408.160	149654.826	118.016	118.160	+0.144
1263	579450.924	149526.348	117.780	117.920	+0.140
1247	579321.640	149916.351	119.914	120.050	+0.136
1260	579429.732	149589.940	118.158	118.280	+0.122
1259	579419.576	149621.120	118.200	118.310	+0.110
1205	575725.372	145382.413	153.510	153.610	+0.100
1206	575734.716	145392.197	153.144	153.240	+0.096
1235	576160.150	145857.677	140.360	140.450	+0.090
1029	585334.472	130096.641	145.601	145.690	+0.089
1242	579280.772	150039.035	120.312	120.400	+0.088
1084	587531.404	132654.877	148.093	148.180	+0.087
1046	585393.347	130504.843	140.355	140.440	+0.085
1229	576067.969	145757.301	143.657	143.740	+0.083
1074	587504.092	132451.257	144.460	144.540	+0.080
1225	576008.265	145692.311	144.430	144.510	+0.080
1111	584732.979	121081.044	161.161	161.240	+0.079
1106	584722.465	120983.923	162.562	162.640	+0.078
1037	585356.787	130251.641	142.384	142.460	+0.076
1252	579358.353	149803.759	117.784	117.860	+0.076
1063	587481.152	132273.435	144.935	145.010	+0.075
1107	584723.326	120993.677	162.786	162.860	+0.074
1043	585381.737	130425.046	139.898	139.970	+0.072
1104	584718.804	120948.671	160.868	160.940	+0.072
1127	584775.960	121488.399	162.498	162.570	+0.072
1047	585397.229	130530.652	140.739	140.810	+0.071
1090	587543.694	132745.898	144.630	144.700	+0.070
1238	576207.541	145909.804	139.670	139.740	+0.070
1209	575781.473	145443.937	152.011	152.080	+0.069
1239	579254.962	150117.591	120.811	120.880	+0.069
1033	585345.655	130173.495	143.872	143.940	+0.068
1087	587535.486	132683.870	143.213	143.280	+0.067
1241	579270.765	150068.564	120.543	120.610	+0.067
1234	576143.187	145839.927	140.815	140.880	+0.065

Number	Easting	Northing	Known Z	Laser Z	Dz
1105	584720.514	120966.552	161.768	161.830	+0.062
1034	585348.104	130190.540	143.500	143.560	+0.060
1044	585385.662	130451.978	139.930	139.990	+0.060
1013	585285.770	129762.754	159.731	159.790	+0.059
1113	584737.235	121121.823	160.511	160.570	+0.059
1203	575697.710	145352.397	154.161	154.220	+0.059
1068	587493.500	132364.239	147.042	147.100	+0.058
1119	584755.026	121290.156	162.702	162.760	+0.058
1079	587517.153	132544.162	143.644	143.700	+0.056
1233	576126.535	145821.649	141.154	141.210	+0.056
1048	585400.833	130555.520	141.045	141.100	+0.055
1067	587490.288	132341.425	143.815	143.870	+0.055
1202	575684.795	145338.702	154.425	154.480	+0.055
1031	585339.057	130128.201	144.916	144.970	+0.054
1129	584780.205	121525.340	162.716	162.770	+0.054
1058	587470.086	132193.265	145.097	145.150	+0.053
1056	587468.194	132178.359	147.378	147.430	+0.052
1246	579311.631	149944.598	119.948	120.000	+0.052
1262	579444.609	149546.715	117.958	118.010	+0.052
1200	575649.474	145299.913	155.988	156.040	+0.052
1065	587485.476	132308.395	144.339	144.390	+0.051
1240	579262.006	150095.471	120.599	120.650	+0.051
1032	585343.442	130157.930	144.230	144.280	+0.050
1243	579289.207	150013.874	120.320	120.370	+0.050
1244	579297.440	149987.930	120.431	120.480	+0.049
1040	585369.572	130340.238	140.922	140.970	+0.048
1092	587549.771	132792.058	145.612	145.660	+0.048
1095	587555.680	132838.165	145.482	145.530	+0.048
1039	585365.902	130314.026	141.343	141.390	+0.047
1224	575993.975	145676.430	144.603	144.650	+0.047
1248	579330.740	149888.793	119.423	119.470	+0.047
1054	587466.279	132160.286	146.184	146.230	+0.046
1078	587515.376	132531.208	144.984	145.030	+0.046
1254	579351.470	149761.925	120.035	120.080	+0.045
1053	585417.062	130667.336	141.175	141.220	+0.045
1219	575922.100	145597.732	147.805	147.850	+0.045
1066	587486.884	132318.500	143.376	143.420	+0.044
1024	585322.692	130014.839	147.557	147.600	+0.043
1109	584729.398	121043.603	161.517	161.560	+0.043
1226	576025.399	145710.966	143.857	143.900	+0.043
1101	587570.353	132945.220	146.418	146.460	+0.042
1208	575766.562	145427.564	152.239	152.280	+0.041
1006	585262.488	129602.806	162.470	162.510	+0.040

Number	Easting	Northing	Known Z	Laser Z	Dz
1035	585352.545	130221.264	142.901	142.940	+0.039
1030	585336.726	130112.466	145.282	145.320	+0.038
1228	576052.502	145740.052	143.252	143.290	+0.038
1110	584730.962	121062.110	161.533	161.570	+0.037
1253	579341.285	149792.516	120.363	120.400	+0.037
1064	587483.223	132290.597	143.904	143.940	+0.036
1094	587552.304	132812.394	145.675	145.710	+0.035
1207	575750.411	145409.761	152.525	152.560	+0.035
1227	576037.938	145724.396	143.285	143.320	+0.035
1216	575856.934	145526.814	149.476	149.510	+0.034
1073	587502.724	132438.206	147.827	147.860	+0.033
1210	575796.525	145460.724	151.277	151.310	+0.033
1237	576190.571	145891.082	139.908	139.940	+0.032
1080	587519.405	132561.432	143.929	143.960	+0.031
1100	587568.481	132936.009	146.499	146.530	+0.031
1245	579303.030	149972.045	120.070	120.100	+0.030
1261	579438.794	149564.664	118.360	118.390	+0.030
1026	585327.239	130047.124	146.662	146.690	+0.028
1028	585331.994	130079.151	145.972	146.000	+0.028
1108	584725.530	121014.277	161.683	161.710	+0.027
1017	585301.952	129873.589	153.884	153.910	+0.026
1204	575711.747	145367.563	153.994	154.020	+0.026
1236	576176.449	145875.905	140.004	140.030	+0.026
1036	585354.638	130236.508	142.604	142.630	+0.026
1052	585414.120	130646.630	141.215	141.240	+0.025
1083	587529.062	132635.560	145.155	145.180	+0.025
1218	575900.312	145574.535	148.485	148.510	+0.025
1220	575937.207	145614.189	147.205	147.230	+0.025
1093	587551.306	132802.381	145.146	145.170	+0.024
1077	587512.095	132506.571	145.116	145.140	+0.024
1214	575834.228	145501.400	149.636	149.660	+0.024
1115	584744.477	121190.555	160.397	160.420	+0.023
1221	575952.192	145630.292	146.527	146.550	+0.023
1015	585293.665	129816.196	156.978	157.000	+0.022
1021	585313.338	129950.528	149.899	149.920	+0.021
1062	587478.885	132256.844	144.919	144.940	+0.021
1004	585257.252	129565.131	162.220	162.240	+0.020
1022	585316.063	129969.702	149.060	149.080	+0.020
1075	587507.324	132472.236	142.870	142.890	+0.020
1096	587559.724	132865.958	145.550	145.570	+0.020
1009	585271.984	129666.647	162.731	162.750	+0.019
1217	575878.912	145550.191	149.131	149.150	+0.019
1027	585329.591	130063.183	146.312	146.330	+0.018

Number	Easting	Northing	Known Z	Laser Z	Dz
1223	575985.550	145667.458	145.123	145.140	+0.017
1011	585278.672	129712.912	161.833	161.850	+0.017
1019	585308.711	129919.113	151.453	151.470	+0.017
1116	584747.972	121223.200	160.274	160.290	+0.016
1038	585361.199	130281.578	141.915	141.930	+0.015
1076	587510.869	132493.952	143.015	143.030	+0.015
1137	584797.178	121687.712	161.266	161.280	+0.014
1222	575968.795	145648.424	146.196	146.210	+0.014
1000	585246.671	129492.270	161.737	161.750	+0.013
1102	587571.431	132954.897	147.827	147.840	+0.013
1213	575831.101	145497.699	149.727	149.740	+0.013
1117	584751.321	121255.658	160.448	160.460	+0.012
1042	585377.796	130397.331	140.069	140.080	+0.011
1005	585259.702	129583.398	162.299	162.310	+0.011
1128	584777.534	121507.256	162.779	162.790	+0.011
1061	587478.126	132249.504	143.640	143.650	+0.010
1141	584805.858	121768.837	160.970	160.980	+0.010
1122	584760.344	121339.695	163.011	163.020	+0.009
1134	584790.705	121626.756	164.801	164.810	+0.009
1255	579363.387	149725.734	119.651	119.660	+0.009
1057	587468.520	132182.242	147.091	147.100	+0.009
1215	575835.194	145502.674	149.841	149.850	+0.009
1230	576084.177	145775.166	143.871	143.880	+0.009
1192	569862.857	142446.807	162.902	162.910	+0.008
1232	576114.464	145808.402	142.592	142.600	+0.008
1098	587566.081	132914.210	147.343	147.350	+0.007
1201	575671.847	145324.480	155.603	155.610	+0.007
1010	585275.209	129689.221	162.454	162.460	+0.006
1097	587564.037	132898.331	146.784	146.790	+0.006
1126	584772.523	121455.126	161.684	161.690	+0.006
1140	584804.218	121751.800	161.454	161.460	+0.006
1050	585407.594	130601.992	141.325	141.330	+0.005
1086	587533.314	132667.314	147.765	147.770	+0.005
1199	569932.756	142401.189	163.135	163.140	+0.005
1088	587536.923	132696.760	143.995	144.000	+0.005
1023	585320.291	129998.692	148.027	148.030	+0.003
1125	584768.839	121420.448	162.887	162.890	+0.003
1124	584766.584	121399.722	164.638	164.640	+0.002
1211	575812.652	145478.706	150.638	150.640	+0.002
1091	587548.132	132778.387	145.349	145.350	+0.001
1041	585373.808	130368.986	140.440	140.440	+0.000
1114	584740.801	121155.878	160.291	160.290	-0.001
1045	585389.520	130478.627	140.093	140.090	-0.003

AERO-METRIC
SEATTLE

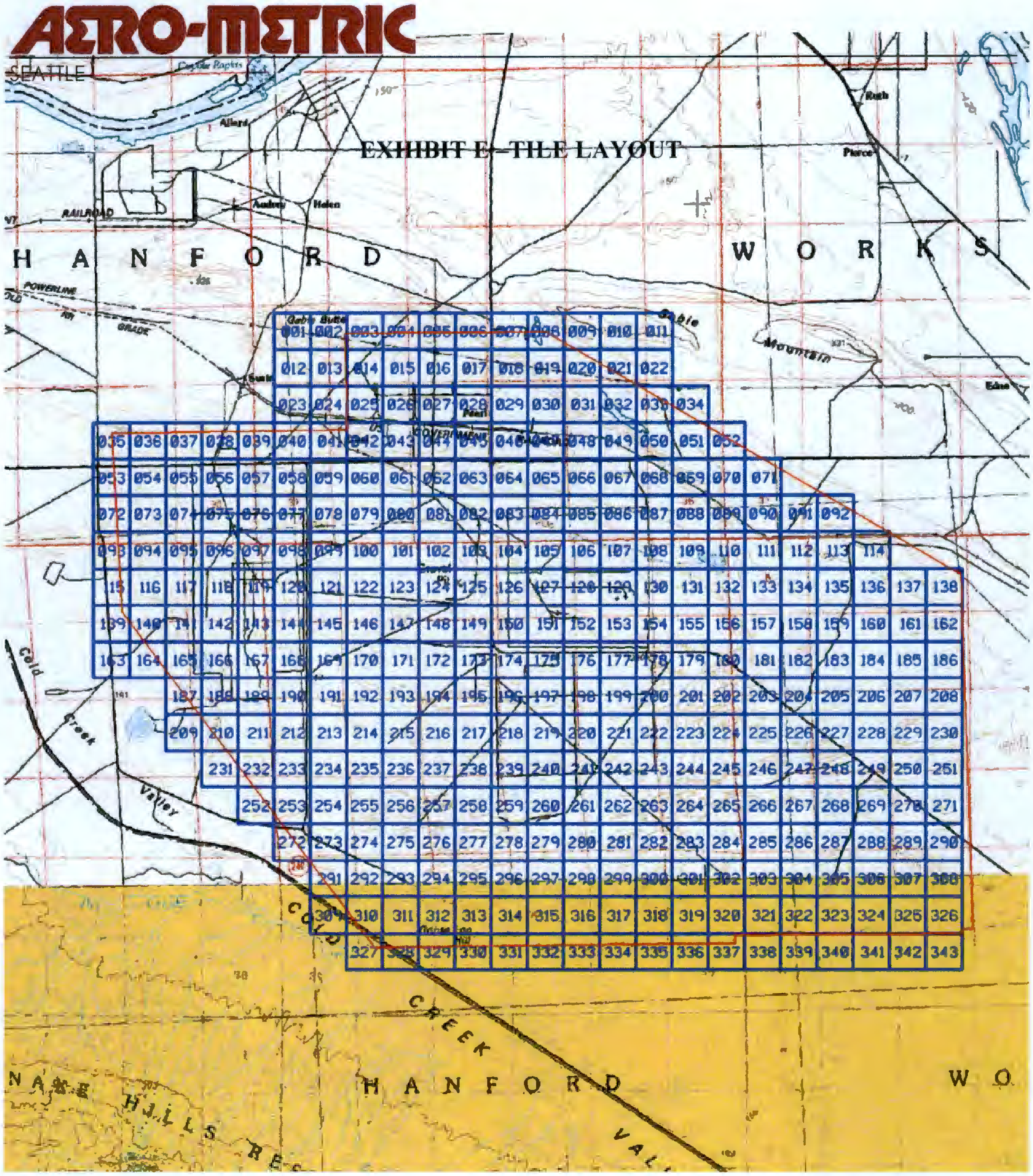
Number	Easting	Northing	Known Z	Laser Z	Dz
1089	587540.288	132723.323	142.843	142.840	-0.003
1003	585254.801	129548.103	162.133	162.130	-0.003
1025	585324.996	130030.991	147.073	147.070	-0.003
1071	587498.852	132409.974	143.704	143.700	-0.004
1008	585268.861	129644.743	162.734	162.730	-0.004
1049	585404.251	130579.220	141.234	141.230	-0.004
1007	585265.531	129623.343	162.595	162.590	-0.005
1103	587573.207	132968.568	147.715	147.710	-0.005
1130	584783.234	121555.343	162.065	162.060	-0.005
1131	584784.841	121571.940	163.065	163.060	-0.005
1018	585306.447	129903.713	152.287	152.280	-0.007
1138	584800.327	121720.404	162.597	162.590	-0.007
1002	585251.722	129525.940	161.938	161.930	-0.008
1118	584753.793	121272.855	161.348	161.340	-0.008
1133	584788.533	121609.581	164.980	164.970	-0.010
1051	585410.866	130624.061	141.312	141.300	-0.012
1139	584802.055	121733.653	162.622	162.610	-0.012
1014	585289.664	129788.968	158.363	158.350	-0.013
1177	569628.397	142530.490	163.243	163.230	-0.013
1012	585282.180	129737.468	160.914	160.900	-0.014
1191	569848.162	142452.023	162.914	162.900	-0.014
1069	587494.380	132371.971	147.055	147.040	-0.015
1135	584792.679	121646.923	163.746	163.730	-0.016
1112	584735.214	121104.017	162.159	162.140	-0.019
1070	587495.528	132385.484	142.999	142.980	-0.019
1182	569706.150	142502.735	163.059	163.040	-0.019
1136	584794.917	121668.615	161.131	161.110	-0.021
1020	585311.009	129934.725	150.683	150.660	-0.023
1123	584763.534	121367.574	162.844	162.820	-0.024
1212	575830.018	145496.613	149.854	149.830	-0.024
1231	576097.714	145790.088	142.735	142.710	-0.025
1016	585297.757	129844.389	155.466	155.440	-0.026
1179	569658.787	142519.618	163.147	163.120	-0.027
1121	584758.670	121323.442	163.868	163.840	-0.028
1195	569908.362	142430.497	162.828	162.800	-0.028
1072	587501.372	132428.969	147.999	147.970	-0.029
1082	587527.493	132623.357	145.660	145.630	-0.030
1099	587567.080	132924.839	149.243	149.210	-0.033
1173	569566.925	142552.223	163.494	163.460	-0.034
1193	569878.215	142441.384	162.844	162.810	-0.034
1178	569643.461	142525.105	163.186	163.150	-0.036
1180	569674.172	142514.127	163.112	163.070	-0.042
1132	584786.451	121589.690	164.235	164.190	-0.045

Number	Easting	Northing	Known Z	Laser Z	Dz
1196	569923.688	142425.157	162.775	162.730	-0.045
1001	585248.956	129507.996	161.826	161.780	-0.046
1197	569938.539	142419.792	162.706	162.660	-0.046
1188	569801.879	142468.503	162.889	162.840	-0.049
1120	584756.750	121307.326	163.880	163.830	-0.050
1194	569893.434	142436.026	162.820	162.770	-0.050
1181	569689.956	142508.539	163.101	163.050	-0.051
1168	569487.341	142580.612	163.714	163.660	-0.054
1198	569953.261	142414.648	162.647	162.590	-0.057
1161	569375.906	142620.454	164.080	164.020	-0.060
1163	569406.553	142609.476	163.960	163.900	-0.060
1185	569752.675	142486.048	162.983	162.920	-0.063
1183	569722.146	142497.138	163.018	162.950	-0.068
1186	569770.259	142479.803	162.948	162.880	-0.068
1174	569581.657	142547.040	163.420	163.350	-0.070
1184	569736.533	142491.981	162.964	162.890	-0.074
1164	569425.572	142602.690	163.896	163.820	-0.076
1172	569550.840	142558.164	163.559	163.480	-0.079
1158	569330.482	142636.593	164.052	163.970	-0.082
1190	569831.975	142457.913	162.892	162.810	-0.082
1153	569246.648	142666.541	164.233	164.150	-0.083
1151	569216.008	142677.606	164.225	164.140	-0.085
1150	569200.706	142683.108	164.215	164.130	-0.085
1176	569612.442	142536.096	163.326	163.240	-0.086
1148	569169.730	142694.183	164.237	164.150	-0.087
1165	569440.403	142597.353	163.857	163.770	-0.087
1169	569502.527	142575.177	163.697	163.610	-0.087
1170	569518.665	142569.451	163.660	163.570	-0.090
1081	587523.830	132593.560	146.301	146.210	-0.091
1159	569345.229	142631.411	164.051	163.960	-0.091
1167	569471.549	142586.268	163.791	163.700	-0.091
1171	569534.668	142563.805	163.611	163.520	-0.091
1160	569360.614	142625.943	164.082	163.990	-0.092
1156	569300.130	142647.349	164.125	164.030	-0.095
1146	569138.005	142705.530	164.279	164.180	-0.099
1143	569092.588	142721.835	164.329	164.230	-0.099
1189	569816.997	142463.222	162.890	162.790	-0.100
1154	569262.345	142660.946	164.172	164.070	-0.102
1157	569314.751	142642.178	164.092	163.990	-0.102
1055	587467.086	132172.439	149.014	148.910	-0.104
1162	569391.019	142614.984	164.016	163.910	-0.106
1166	569456.249	142591.751	163.830	163.720	-0.110
1149	569185.447	142688.599	164.214	164.100	-0.114

AERO-METRIC
SEATTLE

Number	Easting	Northing	Known Z	Laser Z	Dz
1145	569123.233	142710.848	164.295	164.180	-0.115
1085	587532.544	132661.711	148.386	148.270	-0.116
1175	569596.356	142541.784	163.387	163.270	-0.117
1144	569108.301	142716.259	164.329	164.210	-0.119
1187	569786.206	142474.105	162.944	162.820	-0.124
1147	569153.788	142699.953	164.268	164.140	-0.128
1152	569230.707	142672.242	164.238	164.100	-0.138
1155	569282.224	142653.724	164.129	163.990	-0.139
1059	587473.812	132219.970	148.368	148.180	-0.188

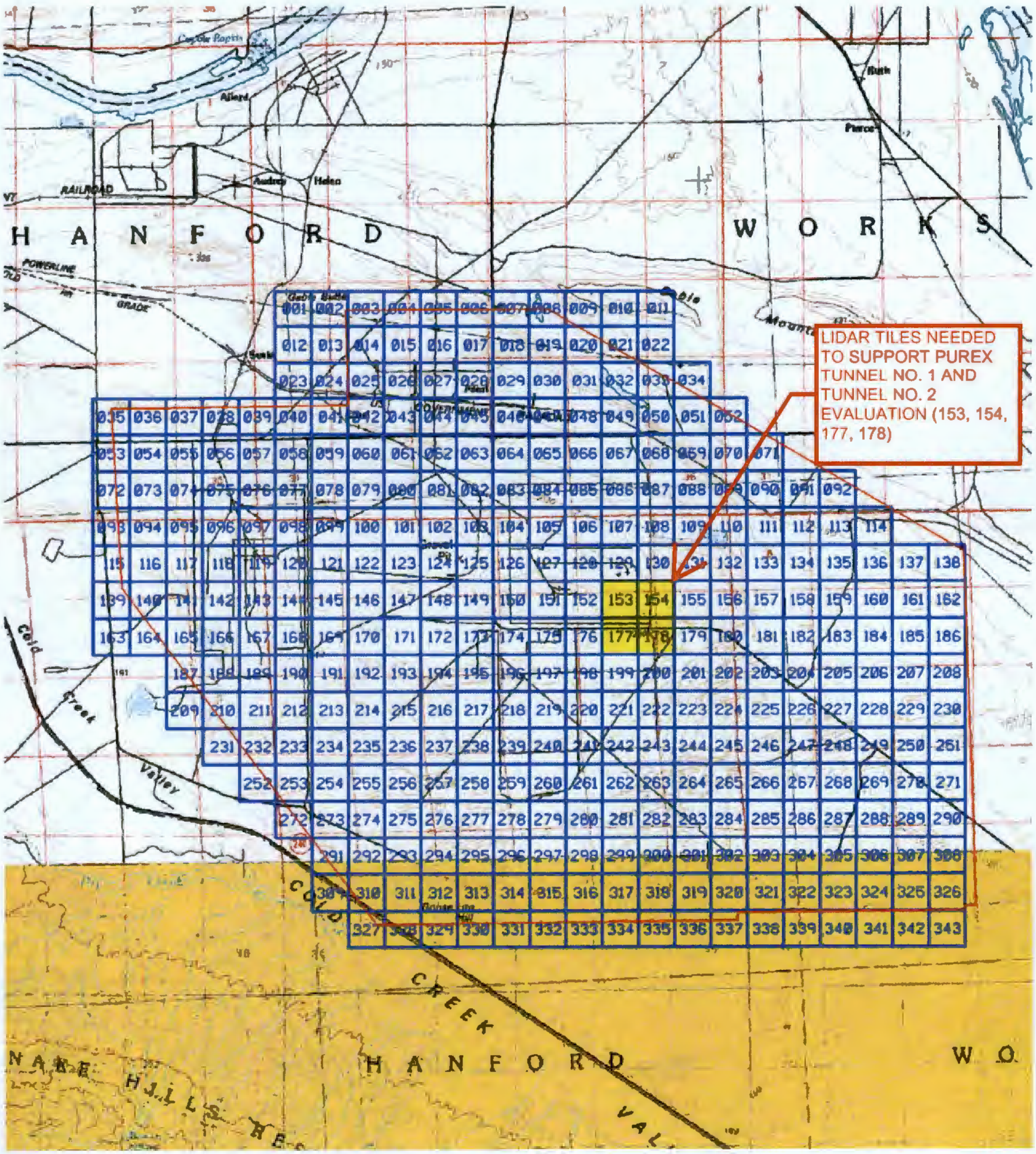
Average dz	+0.011
Minimum dz	-0.188
Maximum dz	+0.482
Average magnitude	0.051
Root mean square	0.072
Std deviation	0.071



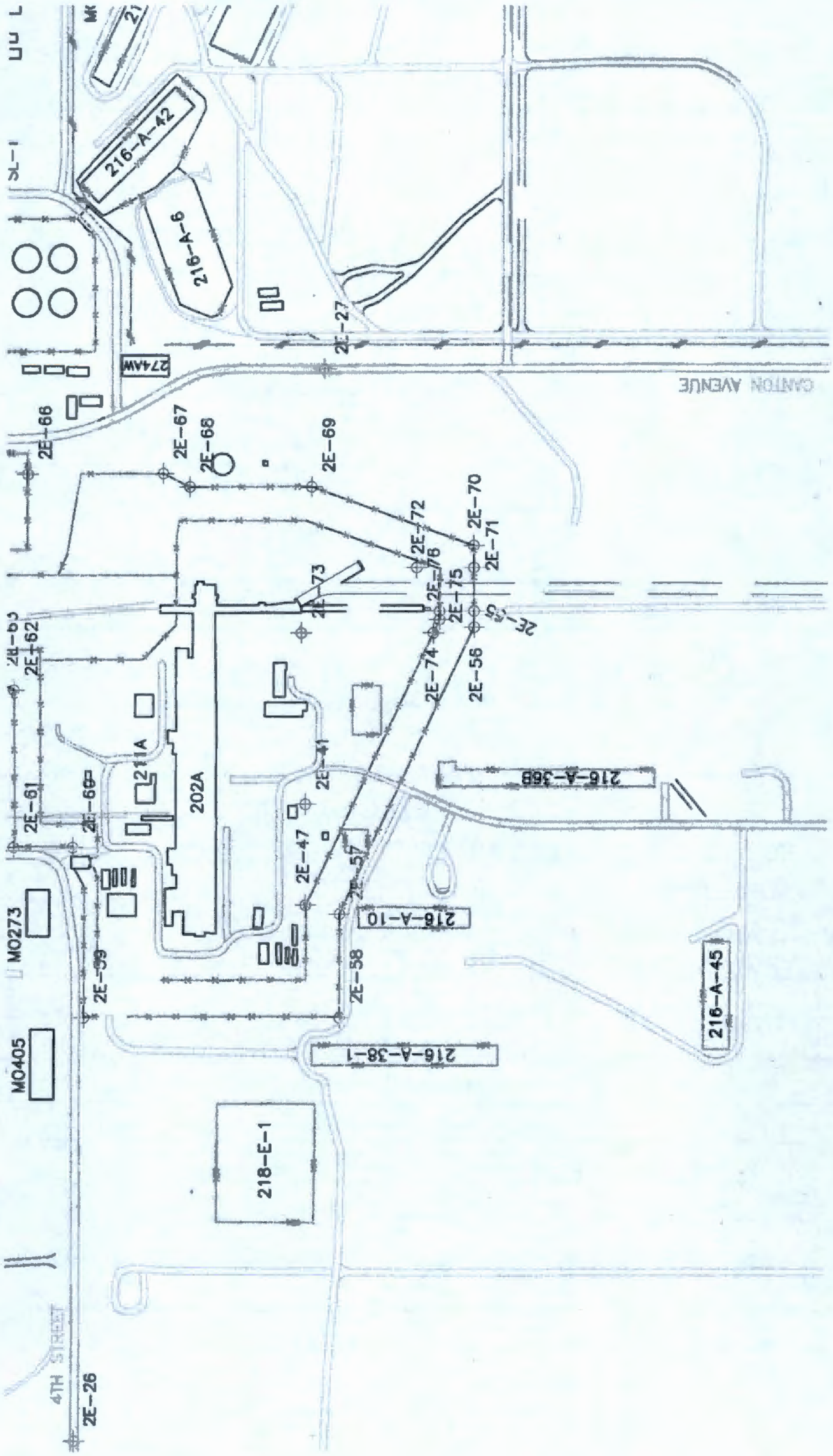
- **Number of Tiles within project area: 343**
- **Tile size: 750m**

AERO-METRIC
SEATTLE

EXHIBIT E –TILE LAYOUT



- **Number of Tiles within project area: 343**
- **Tile size: 750m**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216-A-6
2E-27
274AW
CANTON AVENUE
2E-66
2E-67
2E-68
2E-69
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2E-71
2E-72
2E-73
2E-74
2E-75
2E-76
2E-56
2E-62
211A
202A
2E-61
2E-60
2E-41
2E-47
2E-57
2E-58
2E-59
216-A-36B
216-A-10
216-A-45
216-A-38-1
MO273
MO405
218-E-1
4TH STREET
2E-26

CHPRC-03365, REV. 0

SURVEY MONUMENT DATA

STATION: 2E-41			LOCATION CODE: 200E	
HORIZONTAL			**VERTICAL**	
DATUM	**COORDINATES**		**DATUM**	**HEIGHTS**
	LATITUDE	LONGITUDE		ELLIPSOIDAL
NAD83(1991)	46°32'54.878454"	119°31'15.333733"	NAD83(1991)	196.737 m
	NORTHING	EASTING		ORTHOMETRIC
WCS83S(1991)	135,539.989 m	575,080.970 m	NAVD88	218.115 m
	N	W		ORTHOMETRIC
200E AREA (PUREX CONTROL)	39,557.00	48,600.00	NGVD29	712.216 usft
				ORTHOMETRIC
			200E (STAMPED)	711.99

DESCRIPTION

BRASS CAP MONUMENT ON SOUTH SIDE PUREX BLDG 202-A, INSIDE PUREX YARD FENCE. SOUTHEAST OF PIPEFITTERS SHOP, SOUTH OF STEAMLINE.

HORIZONTAL CONTROL

DATUM	INST./METHOD	MONUMENTS USED	LENGTH	MISCLOSURE	ADJUST
NAD 83/91	GPS/NETWORK	USACE GPS NET			TRIMNET
WCS83S/91	"	"			"
200E	— HELD STAMPED VALUES FOR PUREX CONTROL — NOT TIED TO 200E NETWORK				

VERTICAL CONTROL

DATUM	INST./METHOD	MONUMENTS USED	LENGTH	MISC. (mm/√k)	ADJUST
NAVD88	NA-2/ 3-WIRE	USACE VERTICAL NET			TRIMNET
NGVD29	"	"			"

REFERENCE

DATUM	FILE NO.	REQ. NO.	BERNOULLI	OTHER
NAD 83/91	2ESE-087	962-108		
200E (H&V)	HELD STAMPED VALUES FOR PUREX CONTROL			
NAVD 88	2ESE-087 2EXX-001	971-032	PROJ 1 200E 88	L-272
NGVD29	"	"	" 200E 29	"

248

ch2m:	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Attachment C

Earth Pressure Recommendations

Tunnel 2 Soil Loading

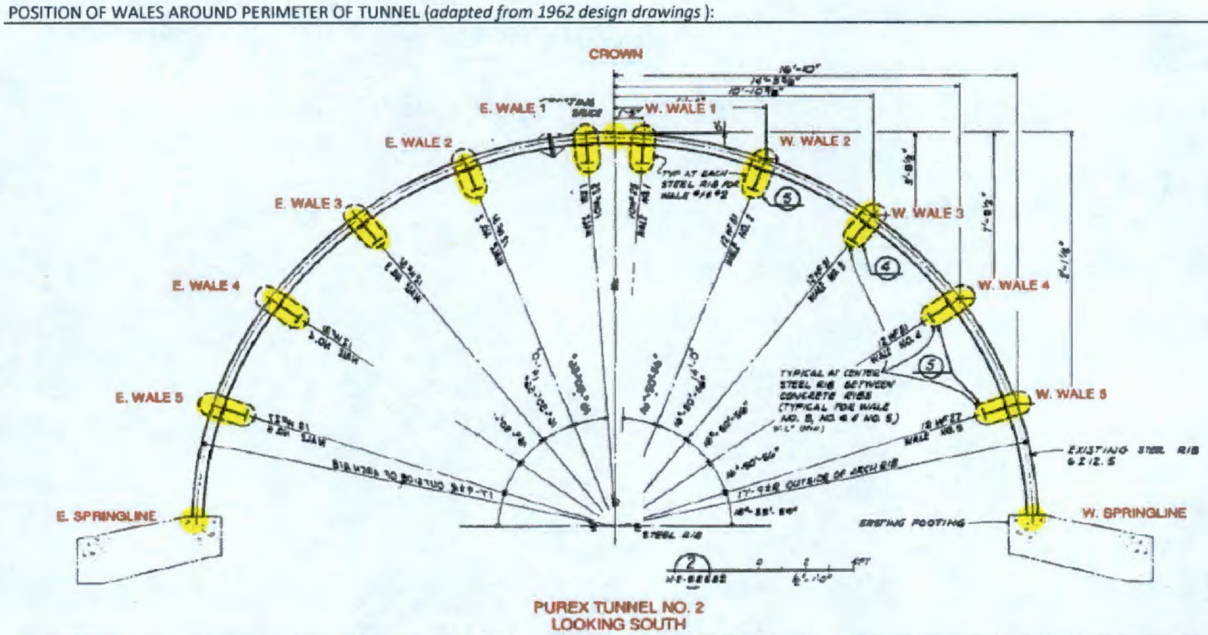
Prepared by:	M. Kacmarcik	6/12/2017
Reviewed by:	Y. Bougataya	6/13/2017

Embankment Soil Unit Weight	110 pcf		*Range is 105 to 115*
Internal Friction Angle of Cover Soil	30 deg		
At-Rest Lateral Earth Pressure Coefficient	0.5 –		Horizontal ground surface
Snow Load	15 psf		Provided by Structural Engineer

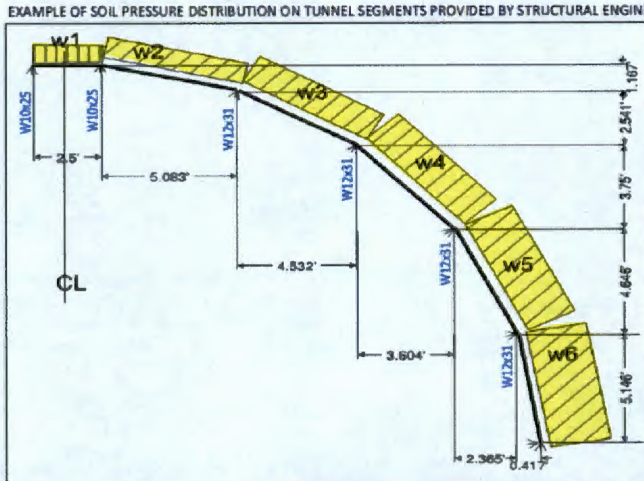
Location of Wales around Tunnel Perimeter (angle from vertical):

Deg	Min	Sec	Dec Deg	Cum Deg	Loc
0	0	0	0.00	0.0	Crown
4	2	17	4.04	4.0	Wale No. 1
16	50	56	16.85	20.9	Wale No. 2
16	50	56	16.85	37.7	Wale No. 3
16	50	56	16.85	54.6	Wale No. 4
16	50	56	16.85	71.4	Wale No. 5
18	33	59	18.57	90.0	Springline

POSITION OF WALES AROUND PERIMETER OF TUNNEL (*adapted from 1962 design drawings*):



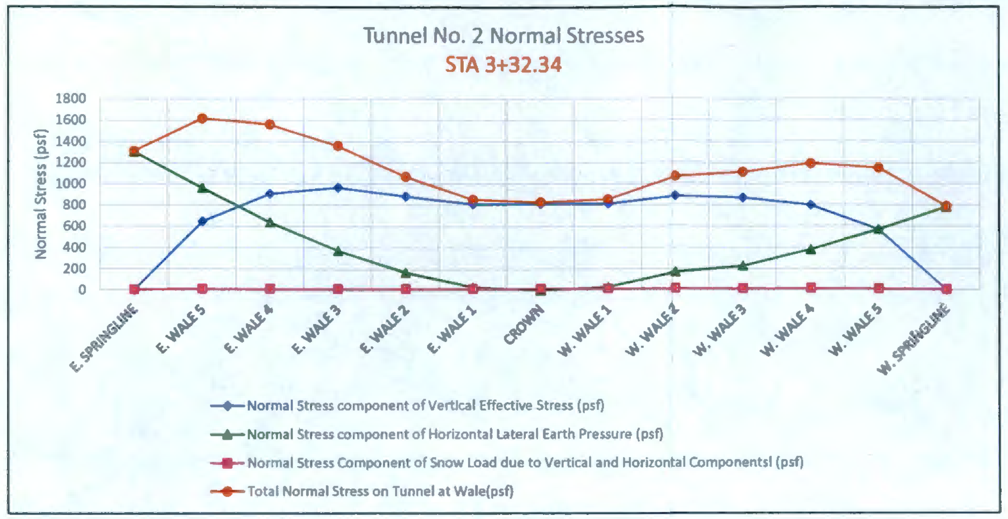
EXAMPLE OF SOIL PRESSURE DISTRIBUTION ON TUNNEL SEGMENTS PROVIDED BY STRUCTURAL ENGINEER:



TUNNEL NO. 2

STA 3+32.34

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	23.7	2607.0	0.0*	0.50	1303.5	0.0	0.00	0.0	1303.5	7.5	1311.0
E. WALE 5	18.4	2024.0	0.0	0.50	1012.0	18.6	0.32	644.4	959.3	11.9	1615.7
E. WALE 4	14.2	1562.0	0.0	0.50	781.0	35.4	0.62	905.2	636.5	14.8	1556.5
E. WALE 3	11.1	1221.0	0.0	0.50	610.5	52.3	0.91	965.6	373.6	16.5	1355.7
E. WALE 2	8.6	946.0	0.0	0.50	473.0	69.1	1.21	883.8	168.6	16.7	1069.2
E. WALE 1	7.4	814.0	0.0	0.50	407.0	86.0	1.50	812.0	28.7	15.5	856.1
CROWN	7.4	814.0	0.0	0.50	407.0	90.0	1.57	814.0	0.0	15.0	829.0
W. WALE 1	7.4	814.0	0.0	0.50	407.0	86.0	1.50	812.0	28.7	15.5	856.1
W. WALE 2	8.6	946.0	0.0	0.50	473.0	69.1	1.21	883.8	168.6	16.7	1069.2
W. WALE 3	10.0	1100.0	19.0	0.34	370.9	52.3	0.91	869.9	227.0	16.5	1113.4
W. WALE 4	12.5	1375.0	19.0	0.34	463.7	35.4	0.62	796.8	377.9	14.8	1189.5
W. WALE 5	16.2	1782.0	19.0	0.34	600.9	18.6	0.32	567.4	569.6	11.9	1148.9
W. SPRINGLINE	21.1	2321.0	19.0	0.34	782.7	0.0	0.00	0.0	782.7	7.5	790.2

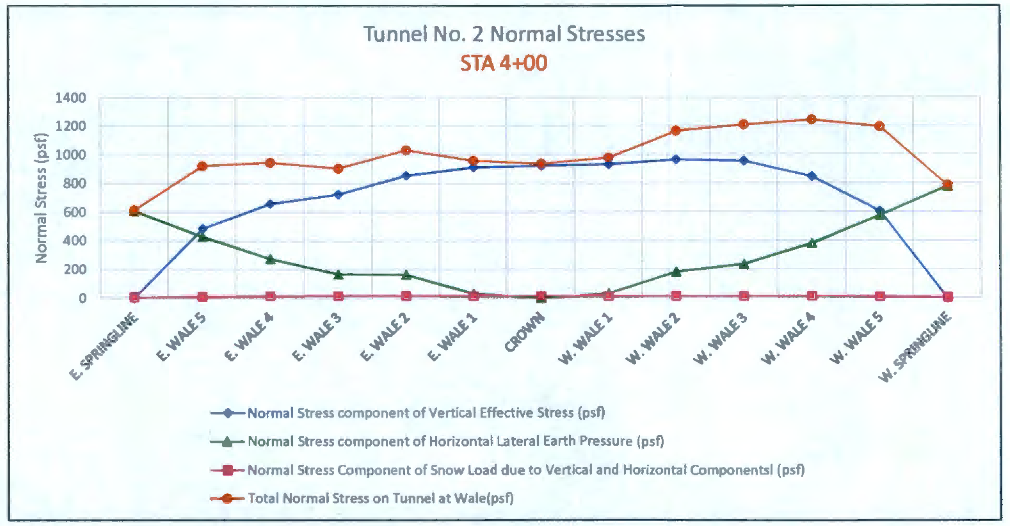


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	1463.3
W5 EAST	1586.1
W4 EAST	1456.1
W3 EAST	1212.4
W2 EAST	962.6
W1	847.1
W2 WEST	962.6
W3 WEST	1091.3
W4 WEST	1151.4
W5 WEST	1169.2
W6 WEST	969.6

TUNNEL NO. 2

STA 4+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	18.6	2046.0	24.0	0.30	606.9	0.0	0.00	0.0	606.9	7.5	614.4
E. WALE 5	13.8	1518.0	24.0	0.30	450.3	18.6	0.32	483.3	426.9	11.9	922.1
E. WALE 4	10.3	1133.0	24.0	0.30	336.1	35.4	0.62	656.6	273.9	14.8	945.3
E. WALE 3	8.3	913.0	24.0	0.30	270.8	52.3	0.91	722.0	165.8	16.5	904.2
E. WALE 2	8.3	913.0	0.0	0.50	456.5	69.1	1.21	853.0	162.8	16.7	1032.4
E. WALE 1	8.3	913.0	0.0	0.50	456.5	86.0	1.50	910.7	32.1	15.5	958.4
CROWN	8.4	924.0	0.0	0.50	462.0	90.0	1.57	924.0	0.0	15.0	939.0
W. WALE 1	8.5	935.0	0.0	0.50	467.5	86.0	1.50	932.7	32.9	15.5	981.1
W. WALE 2	9.4	1034.0	0.0	0.50	517.0	69.1	1.21	966.1	184.3	16.7	1167.1
W. WALE 3	11.0	1210.0	21.0	0.32	388.2	52.3	0.91	956.9	237.6	16.5	1210.9
W. WALE 4	13.3	1463.0	21.0	0.32	469.4	35.4	0.62	847.8	382.5	14.8	1245.1
W. WALE 5	17.3	1903.0	21.0	0.32	610.5	18.6	0.32	605.9	578.7	11.9	1196.5
W. SPRINGLINE	22.1	2431.0	21.0	0.32	779.9	0.0	0.00	0.0	779.9	7.5	787.4

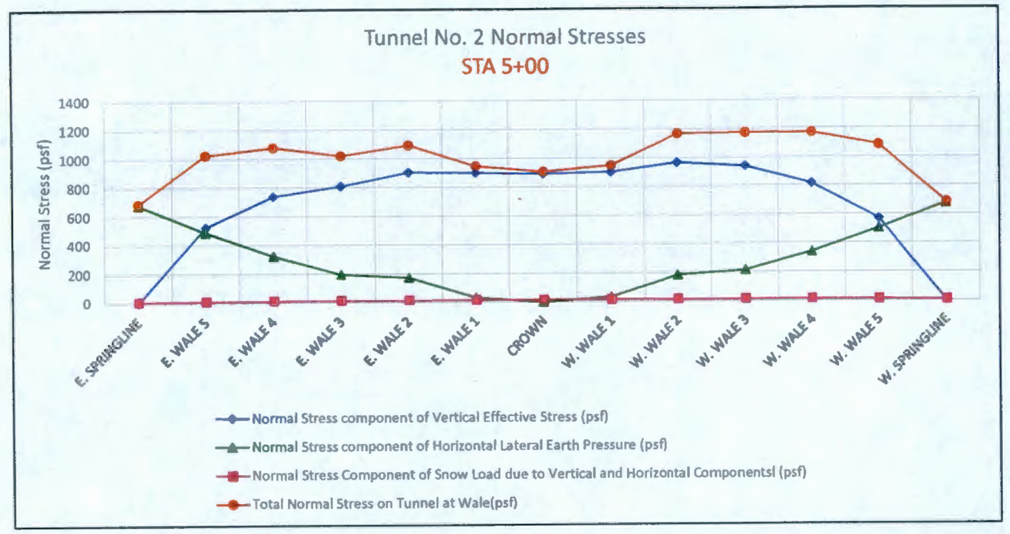


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	768.2
W5 EAST	933.7
W4 EAST	924.8
W3 EAST	968.3
W2 EAST	995.4
W1	959.5
W2 WEST	1074.1
W3 WEST	1189.0
W4 WEST	1228.0
W5 WEST	1220.8
W6 WEST	992.0

TUNNEL NO. 2

STA 5+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	19.7	2167.0	22.0	0.31	677.6	0.0	0.00	0.0	677.6	7.5	685.1
E. WALE 5	15.0	1650.0	22.0	0.31	515.9	18.6	0.32	525.4	489.1	11.9	1026.3
E. WALE 4	11.6	1276.0	22.0	0.31	399.0	35.4	0.62	739.4	325.2	14.8	1079.4
E. WALE 3	9.3	1023.0	22.0	0.31	319.9	52.3	0.91	809.0	195.8	16.5	1021.3
E. WALE 2	8.8	968.0	0.0	0.50	484.0	69.1	1.21	904.4	172.6	16.7	1093.6
E. WALE 1	8.2	902.0	0.0	0.50	451.0	86.0	1.50	899.8	31.8	15.5	947.0
CROWN	8.1	891.0	0.0	0.50	445.5	90.0	1.57	891.0	0.0	15.0	906.0
W. WALE 1	8.2	902.0	0.0	0.50	451.0	86.0	1.50	899.8	31.8	15.5	947.0
W. WALE 2	9.4	1034.0	0.0	0.50	517.0	69.1	1.21	966.1	184.3	16.7	1167.1
W. WALE 3	10.8	1188.0	24.0	0.30	352.4	52.3	0.91	939.5	215.7	16.5	1171.6
W. WALE 4	12.8	1408.0	24.0	0.30	417.7	35.4	0.62	815.9	340.4	14.8	1171.1
W. WALE 5	16.3	1793.0	24.0	0.30	531.9	18.6	0.32	570.9	504.2	11.9	1087.0
W. SPRINGLINE	20.8	2288.0	24.0	0.30	678.7	0.0	0.00	0.0	678.7	7.5	686.2

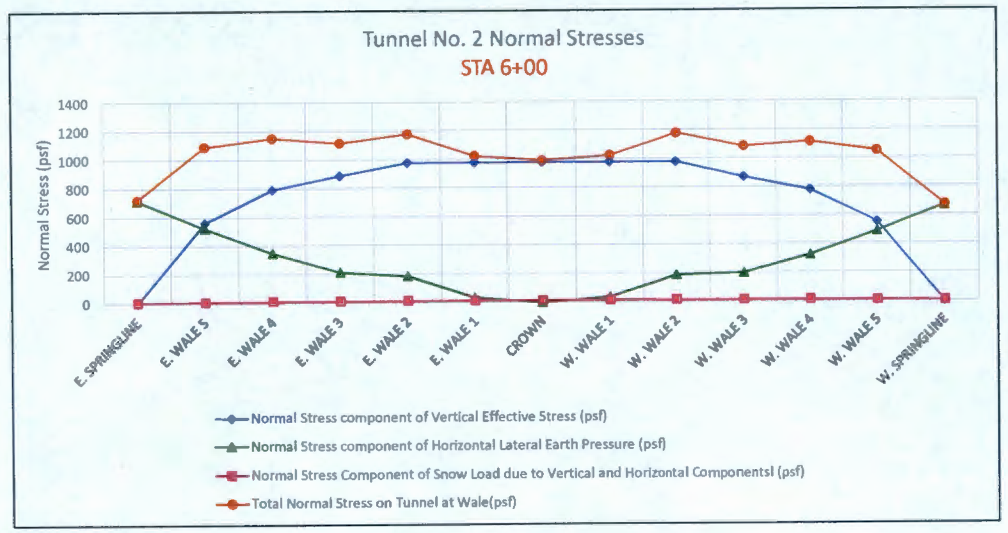


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	855.7
W5 EAST	1052.9
W4 EAST	1050.3
W3 EAST	1057.4
W2 EAST	1020.3
W1	933.3
W2 WEST	1057.0
W3 WEST	1169.4
W4 WEST	1171.4
W5 WEST	1129.0
W6 WEST	886.6

TUNNEL NO. 2

STA 6+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	20.8	2288.0	22.0	0.31	715.5	0.0	0.00	0.0	715.5	7.5	723.0
E. WALE 5	16.0	1760.0	22.0	0.31	550.3	18.6	0.32	560.4	521.7	11.9	1094.0
E. WALE 4	12.4	1364.0	22.0	0.31	426.5	35.4	0.62	790.4	347.6	14.8	1152.8
E. WALE 3	10.2	1122.0	22.0	0.31	350.8	52.3	0.91	887.3	214.7	16.5	1118.5
E. WALE 2	9.5	1045.0	0.0	0.50	522.5	69.1	1.21	976.3	186.3	16.7	1179.3
E. WALE 1	8.9	979.0	0.0	0.50	489.5	86.0	1.50	976.6	34.5	15.5	1026.5
CROWN	8.9	979.0	0.0	0.50	489.5	90.0	1.57	979.0	0.0	15.0	994.0
W. WALE 1	8.9	979.0	0.0	0.50	489.5	86.0	1.50	976.6	34.5	15.5	1026.5
W. WALE 2	9.5	1045.0	0.0	0.50	522.5	69.1	1.21	976.3	186.3	16.7	1179.3
W. WALE 3	10.0	1100.0	24.0	0.30	326.3	52.3	0.91	869.9	199.7	16.5	1086.1
W. WALE 4	12.2	1342.0	24.0	0.30	398.1	35.4	0.62	777.7	324.4	14.8	1116.9
W. WALE 5	15.8	1738.0	24.0	0.30	515.5	18.6	0.32	553.4	488.7	11.9	1054.0
W. SPRINGLINE	20.5	2255.0	24.0	0.30	668.9	0.0	0.00	0.0	668.9	7.5	676.4

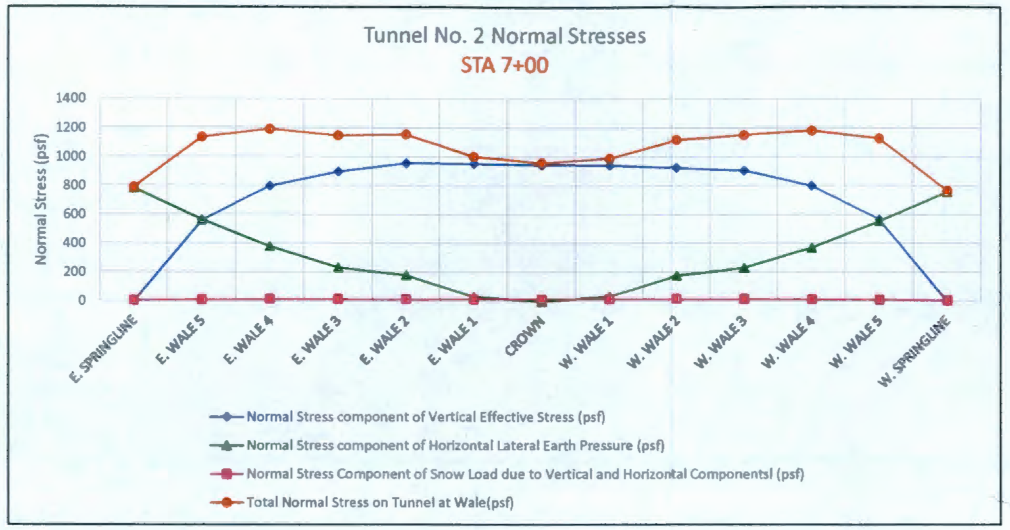


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	908.5
W5 EAST	1123.4
W4 EAST	1135.7
W3 EAST	1148.9
W2 EAST	1102.9
W1	1015.7
W2 WEST	1102.9
W3 WEST	1132.7
W4 WEST	1101.5
W5 WEST	1085.5
W6 WEST	865.2

TUNNEL NO. 2

STA 7+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	21.1	2321.0	19.0	0.34	782.7	0.0	0.00	0.0	782.7	7.5	790.2
E. WALE 5	16.0	1760.0	19.0	0.34	593.5	18.6	0.32	560.4	562.6	11.9	1134.9
E. WALE 4	12.5	1375.0	19.0	0.34	463.7	35.4	0.62	796.8	377.9	14.8	1189.5
E. WALE 3	10.3	1133.0	19.0	0.34	382.1	52.3	0.91	896.0	233.8	16.5	1146.3
E. WALE 2	9.3	1023.0	0.0	0.50	511.5	69.1	1.21	955.8	182.4	16.7	1154.8
E. WALE 1	8.7	957.0	0.0	0.50	478.5	86.0	1.50	954.6	33.7	15.5	1003.8
CROWN	8.6	946.0	0.0	0.50	473.0	90.0	1.57	946.0	0.0	15.0	961.0
W. WALE 1	8.6	946.0	0.0	0.50	473.0	86.0	1.50	943.7	33.3	15.5	992.5
W. WALE 2	9.0	990.0	0.0	0.50	495.0	69.1	1.21	924.9	176.5	16.7	1118.1
W. WALE 3	10.4	1144.0	20.0	0.33	376.4	52.3	0.91	904.7	230.3	16.5	1151.5
W. WALE 4	12.5	1375.0	20.0	0.33	452.4	35.4	0.62	796.8	368.7	14.8	1180.3
W. WALE 5	16.1	1771.0	20.0	0.33	582.6	18.6	0.32	563.9	552.3	11.9	1128.1
W. SPRINGLINE	20.9	2299.0	20.0	0.33	756.3	0.0	0.00	0.0	756.3	7.5	763.8

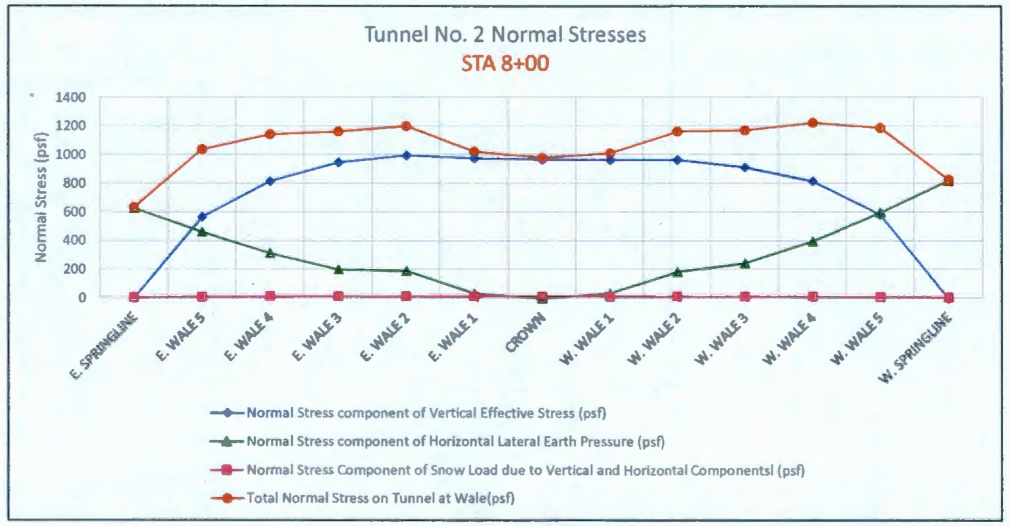


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	962.5
W5 EAST	1162.2
W4 EAST	1167.9
W3 EAST	1150.6
W2 EAST	1079.3
W1	985.8
W2 WEST	1055.3
W3 WEST	1134.8
W4 WEST	1165.9
W5 WEST	1154.2
W6 WEST	946.0

TUNNEL NO. 2

STA 8+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	20.9	2299.0	27.0	0.27	627.6	0.0	0.00	0.0	627.6	7.5	635.1
E. WALE 5	16.2	1782.0	27.0	0.27	486.5	18.6	0.32	567.4	461.2	11.9	1040.5
E. WALE 4	12.8	1408.0	27.0	0.27	384.4	35.4	0.62	815.9	313.3	14.8	1144.0
E. WALE 3	10.9	1199.0	27.0	0.27	327.3	52.3	0.91	948.2	200.3	16.5	1165.0
E. WALE 2	9.7	1067.0	0.0	0.50	533.5	69.1	1.21	996.9	190.2	16.7	1203.8
E. WALE 1	8.9	979.0	0.0	0.50	489.5	86.0	1.50	976.6	34.5	15.5	1026.5
CROWN	8.8	968.0	0.0	0.50	484.0	90.0	1.57	968.0	0.0	15.0	983.0
W. WALE 1	8.8	968.0	0.0	0.50	484.0	86.0	1.50	965.6	34.1	15.5	1015.2
W. WALE 2	9.4	1034.0	0.0	0.50	517.0	69.1	1.21	966.1	184.3	16.7	1167.1
W. WALE 3	10.5	1155.0	18.0	0.35	399.0	52.3	0.91	913.4	244.2	16.5	1174.1
W. WALE 4	12.8	1408.0	18.0	0.35	486.5	35.4	0.62	815.9	396.4	14.8	1227.2
W. WALE 5	16.6	1826.0	18.0	0.35	630.9	18.6	0.32	581.4	598.0	11.9	1191.3
W. SPRINGLINE	21.6	2376.0	18.0	0.35	820.9	0.0	0.00	0.0	820.9	7.5	828.4

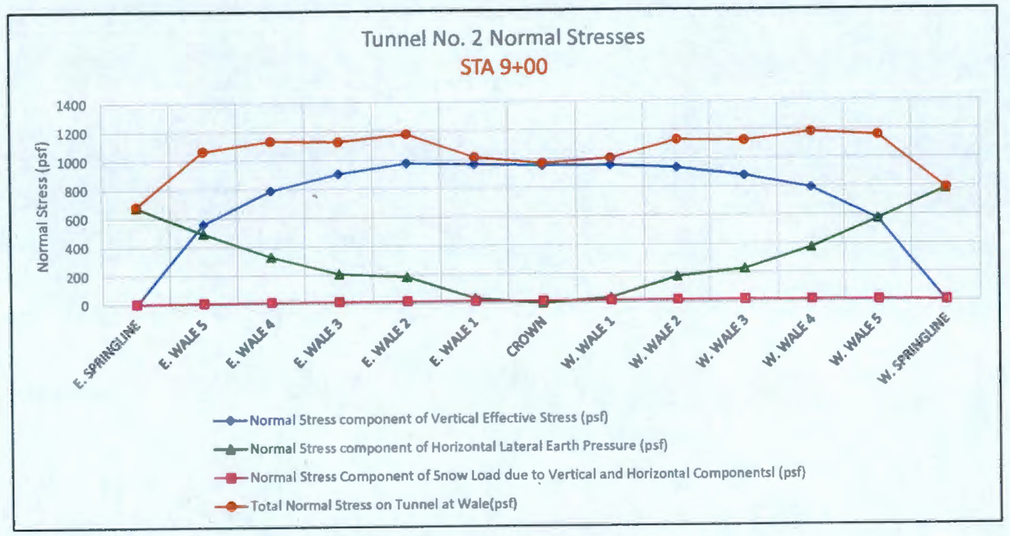


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	837.8
W5 EAST	1092.2
W4 EAST	1154.5
W3 EAST	1184.4
W2 EAST	1115.2
W1	1008.2
W2 WEST	1091.1
W3 WEST	1170.6
W4 WEST	1200.6
W5 WEST	1209.3
W6 WEST	1009.9

TUNNEL NO. 2

STA 9+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	20.7	2277.0	24.0	0.30	675.4	0.0	0.00	0.0	675.4	7.5	682.9
E. WALE 5	16.0	1760.0	24.0	0.30	522.1	18.6	0.32	560.4	494.9	11.9	1067.2
E. WALE 4	12.4	1364.0	24.0	0.30	404.6	35.4	0.62	790.4	329.7	14.8	1135.0
E. WALE 3	10.4	1144.0	24.0	0.30	339.3	52.3	0.91	904.7	207.7	16.5	1128.9
E. WALE 2	9.5	1045.0	0.0	0.50	522.5	69.1	1.21	976.3	186.3	16.7	1179.3
E. WALE 1	8.8	968.0	0.0	0.50	484.0	86.0	1.50	965.6	34.1	15.5	1015.2
CROWN	8.7	957.0	0.0	0.50	478.5	90.0	1.57	957.0	0.0	15.0	972.0
W. WALE 1	8.7	957.0	0.0	0.50	478.5	86.0	1.50	954.6	33.7	15.5	1003.8
W. WALE 2	9.1	1001.0	0.0	0.50	500.5	69.1	1.21	935.2	178.4	16.7	1130.3
W. WALE 3	10.1	1111.0	19.0	0.34	374.6	52.3	0.91	878.6	229.3	16.5	1124.4
W. WALE 4	12.4	1364.0	19.0	0.34	460.0	35.4	0.62	790.4	374.9	14.8	1180.1
W. WALE 5	16.3	1793.0	19.0	0.34	604.6	18.6	0.32	570.9	573.2	11.9	1155.9
W. SPRINGLINE	21.1	2321.0	19.0	0.34	782.7	0.0	0.00	0.0	782.7	7.5	790.2

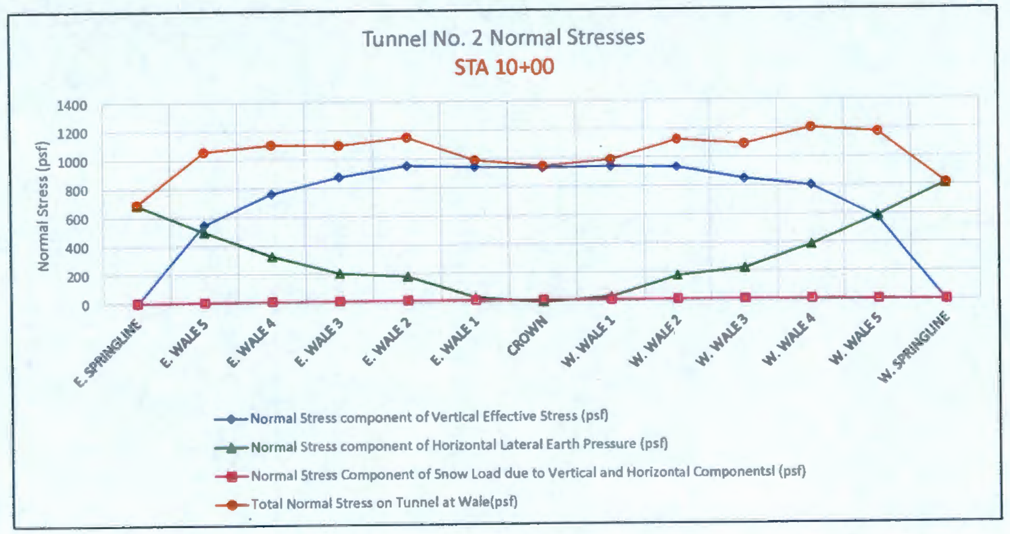


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	875.1
W5 EAST	1101.1
W4 EAST	1131.9
W3 EAST	1154.1
W2 EAST	1097.2
W1	997.0
W2 WEST	1067.1
W3 WEST	1127.4
W4 WEST	1152.2
W5 WEST	1168.0
W6 WEST	973.1

TUNNEL NO. 2

STA 10+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	20.5	2255.0	23.0	0.30	687.0	0.0	0.00	0.0	687.0	7.5	694.5
E. WALE 5	15.7	1727.0	23.0	0.30	526.1	18.6	0.32	549.9	498.7	11.9	1060.5
E. WALE 4	12.0	1320.0	23.0	0.30	402.1	35.4	0.62	764.9	327.7	14.8	1107.5
E. WALE 3	10.1	1111.0	23.0	0.30	338.4	52.3	0.91	878.6	207.1	16.5	1102.2
E. WALE 2	9.3	1023.0	0.0	0.50	511.5	69.1	1.21	955.8	182.4	16.7	1154.8
E. WALE 1	8.6	946.0	0.0	0.50	473.0	86.0	1.50	943.7	33.3	15.5	992.5
CROWN	8.5	935.0	0.0	0.50	467.5	90.0	1.57	935.0	0.0	15.0	950.0
W. WALE 1	8.6	946.0	0.0	0.50	473.0	86.0	1.50	943.7	33.3	15.5	992.5
W. WALE 2	9.1	1001.0	0.0	0.50	500.5	69.1	1.21	935.2	178.4	16.7	1130.3
W. WALE 3	9.8	1078.0	18.0	0.35	372.4	52.3	0.91	852.5	227.9	16.5	1096.9
W. WALE 4	12.6	1386.0	18.0	0.35	478.9	35.4	0.62	803.2	390.3	14.8	1208.2
W. WALE 5	16.4	1804.0	18.0	0.35	623.3	18.6	0.32	574.4	590.8	11.9	1177.1
W. SPRINGLINE	21.4	2354.0	18.0	0.35	813.3	0.0	0.00	0.0	813.3	7.5	820.8

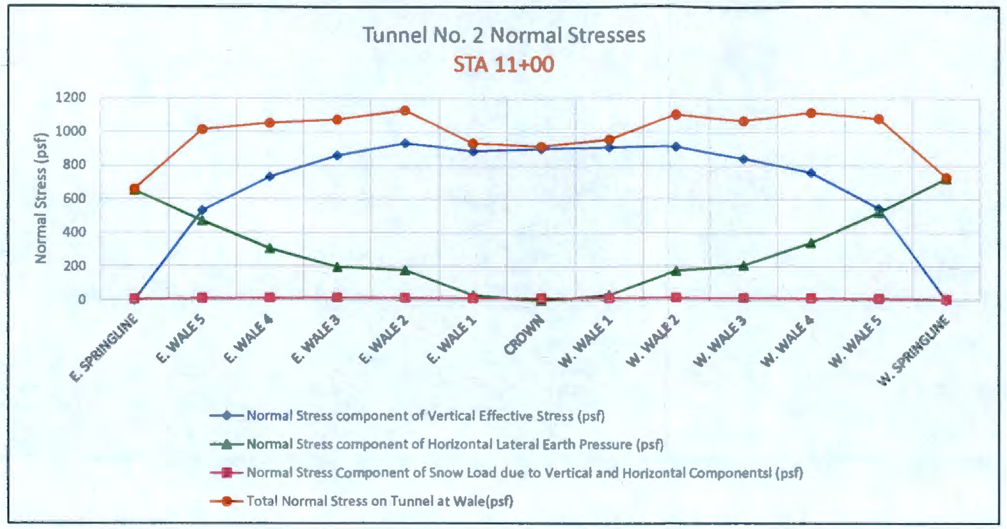


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	877.5
W5 EAST	1084.0
W4 EAST	1104.8
W3 EAST	1128.5
W2 EAST	1073.6
W1	978.3
W2 WEST	1061.4
W3 WEST	1113.6
W4 WEST	1152.6
W5 WEST	1192.7
W6 WEST	999.0

TUNNEL NO. 2

STA 11+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	20.0	2200.0	24.0	0.30	652.6	0.0	0.00	0.0	652.6	7.5	660.1
E. WALE 5	15.2	1672.0	24.0	0.30	496.0	18.6	0.32	532.4	470.2	11.9	1014.4
E. WALE 4	11.5	1265.0	24.0	0.30	375.2	35.4	0.62	733.1	305.8	14.8	1053.7
E. WALE 3	9.9	1089.0	24.0	0.30	323.0	52.3	0.91	861.2	197.7	16.5	1075.4
E. WALE 2	9.1	1001.0	0.0	0.50	500.5	69.1	1.21	935.2	178.4	16.7	1130.3
E. WALE 1	8.1	891.0	0.0	0.50	445.5	86.0	1.50	888.8	31.4	15.5	935.7
CROWN	8.2	902.0	0.0	0.50	451.0	90.0	1.57	902.0	0.0	15.0	917.0
W. WALE 1	8.3	913.0	0.0	0.50	456.5	86.0	1.50	910.7	32.1	15.5	958.4
W. WALE 2	8.9	979.0	0.0	0.50	489.5	69.1	1.21	914.7	174.5	16.7	1105.9
W. WALE 3	9.7	1067.0	21.0	0.32	342.3	52.3	0.91	843.8	209.5	16.5	1069.8
W. WALE 4	11.9	1309.0	21.0	0.32	419.9	35.4	0.62	758.6	342.2	14.8	1115.6
W. WALE 5	15.6	1716.0	21.0	0.32	550.5	18.6	0.32	546.4	521.9	11.9	1080.1
W. SPRINGLINE	20.5	2255.0	21.0	0.32	723.4	0.0	0.00	0.0	723.4	7.5	730.9

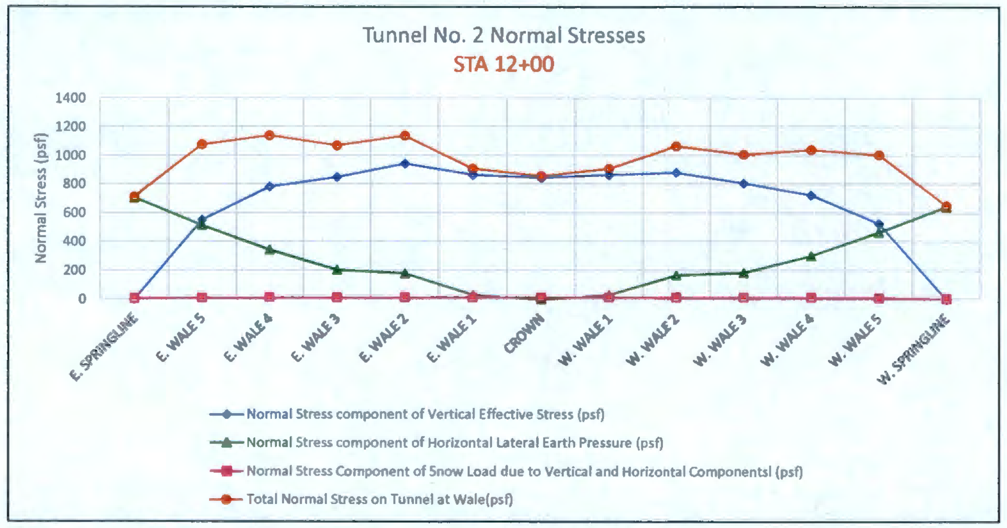


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	837.3
W5 EAST	1034.0
W4 EAST	1064.5
W3 EAST	1102.9
W2 EAST	1033.0
W1	937.0
W2 WEST	1032.1
W3 WEST	1087.8
W4 WEST	1092.7
W5 WEST	1097.9
W6 WEST	905.5

TUNNEL NO. 2

STA 12+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	20.6	2266.0	22.0	0.31	708.6	0.0	0.00	0.0	708.6	7.5	716.1
E. WALE 5	15.8	1738.0	22.0	0.31	543.5	18.6	0.32	553.4	515.2	11.9	1080.5
E. WALE 4	12.3	1353.0	22.0	0.31	423.1	35.4	0.62	784.1	344.8	14.8	1143.7
E. WALE 3	9.8	1078.0	22.0	0.31	337.1	52.3	0.91	852.5	206.3	16.5	1075.3
E. WALE 2	9.2	1012.0	0.0	0.50	506.0	69.1	1.21	945.5	180.4	16.7	1142.6
E. WALE 1	7.9	869.0	0.0	0.50	434.5	86.0	1.50	866.8	30.6	15.5	912.9
CROWN	7.7	847.0	0.0	0.50	423.5	90.0	1.57	847.0	0.0	15.0	862.0
W. WALE 1	7.9	869.0	0.0	0.50	434.5	86.0	1.50	866.8	30.6	15.5	912.9
W. WALE 2	8.6	946.0	0.0	0.50	473.0	69.1	1.21	883.8	168.6	16.7	1069.2
W. WALE 3	9.3	1023.0	24.0	0.30	303.5	52.3	0.91	809.0	185.7	16.5	1011.2
W. WALE 4	11.4	1254.0	24.0	0.30	372.0	35.4	0.62	726.7	303.2	14.8	1044.6
W. WALE 5	15.1	1661.0	24.0	0.30	492.7	18.6	0.32	528.9	467.1	11.9	1007.8
W. SPRINGLINE	19.8	2178.0	24.0	0.30	646.1	0.0	0.00	0.0	646.1	7.5	653.6

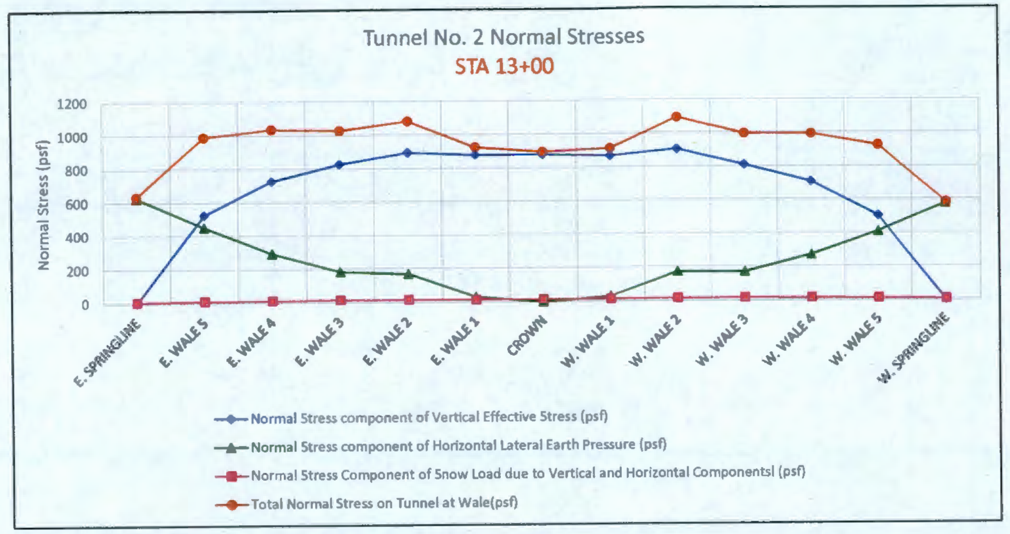


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	898.3
W5 EAST	1112.1
W4 EAST	1109.5
W3 EAST	1108.9
W2 EAST	1027.8
W1	896.0
W2 WEST	991.0
W3 WEST	1040.2
W4 WEST	1027.9
W5 WEST	1026.2
W6 WEST	830.7

TUNNEL NO. 2

STA 13+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	19.7	2167.0	25.0	0.29	625.6	0.0	0.00	0.0	625.6	7.5	633.1
E. WALE 5	15.0	1650.0	25.0	0.29	476.3	18.6	0.32	525.4	451.5	11.9	988.8
E. WALE 4	11.4	1254.0	25.0	0.29	362.0	35.4	0.62	726.7	295.0	14.8	1036.5
E. WALE 3	9.5	1045.0	25.0	0.29	301.7	52.3	0.91	826.4	184.6	16.5	1027.5
E. WALE 2	8.7	957.0	0.0	0.50	478.5	69.1	1.21	894.1	170.6	16.7	1081.4
E. WALE 1	8.0	880.0	0.0	0.50	440.0	86.0	1.50	877.8	31.0	15.5	924.3
CROWN	8.0	880.0	0.0	0.50	440.0	90.0	1.57	880.0	0.0	15.0	895.0
W. WALE 1	7.9	869.0	0.0	0.50	434.5	86.0	1.50	866.8	30.6	15.5	912.9
W. WALE 2	8.8	968.0	0.0	0.50	484.0	69.1	1.21	904.4	172.6	16.7	1093.6
W. WALE 3	9.3	1023.0	27.0	0.27	279.3	52.3	0.91	809.0	170.9	16.5	996.4
W. WALE 4	11.1	1221.0	27.0	0.27	333.3	35.4	0.62	707.6	271.7	14.8	994.0
W. WALE 5	14.4	1584.0	27.0	0.27	432.4	18.6	0.32	504.4	409.9	11.9	926.2
W. SPRINGLINE	19.2	2112.0	27.0	0.27	576.6	0.0	0.00	0.0	576.6	7.5	584.1

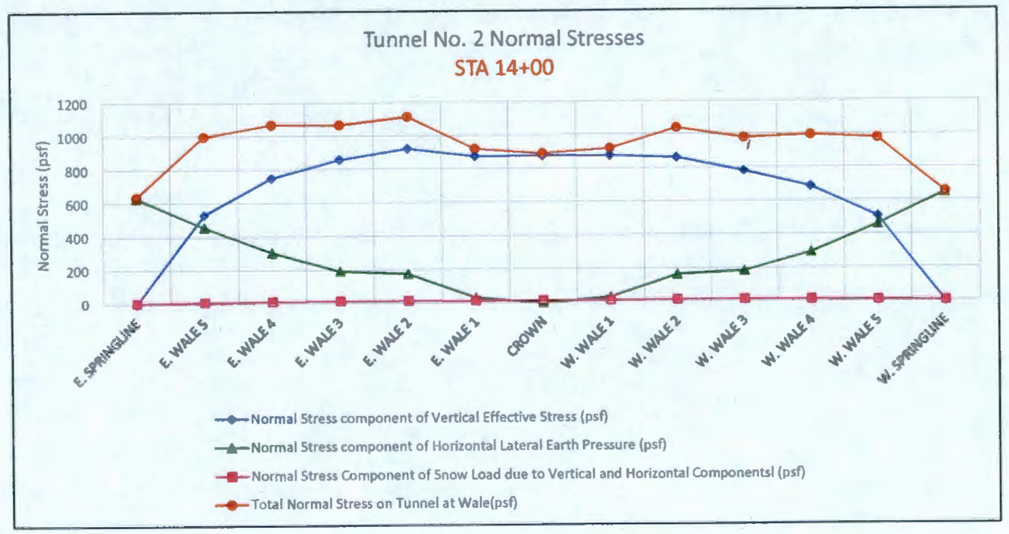


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	810.9
W5 EAST	1012.7
W4 EAST	1032.0
W3 EAST	1054.5
W2 EAST	1002.8
W1	910.7
W2 WEST	1003.3
W3 WEST	1045.0
W4 WEST	995.2
W5 WEST	960.1
W6 WEST	755.1

TUNNEL NO. 2

STA 14+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	19.9	2189.0	25.0	0.29	631.9	0.0	0.00	0.0	631.9	7.5	639.4
E. WALE 5	15.2	1672.0	25.0	0.29	482.7	18.6	0.32	532.4	457.6	11.9	1001.8
E. WALE 4	11.8	1298.0	25.0	0.29	374.7	35.4	0.62	752.2	305.4	14.8	1072.4
E. WALE 3	9.9	1089.0	25.0	0.29	314.4	52.3	0.91	861.2	192.4	16.5	1070.1
E. WALE 2	9.0	990.0	0.0	0.50	495.0	69.1	1.21	924.9	176.5	16.7	1118.1
E. WALE 1	8.0	880.0	0.0	0.50	440.0	86.0	1.50	877.8	31.0	15.5	924.3
CROWN	8.0	880.0	0.0	0.50	440.0	90.0	1.57	880.0	0.0	15.0	895.0
W. WALE 1	8.0	880.0	0.0	0.50	440.0	86.0	1.50	877.8	31.0	15.5	924.3
W. WALE 2	8.4	924.0	0.0	0.50	462.0	69.1	1.21	863.3	164.7	16.7	1044.7
W. WALE 3	9.0	990.0	23.0	0.30	301.6	52.3	0.91	782.9	184.6	16.5	984.0
W. WALE 4	10.8	1188.0	23.0	0.30	361.9	35.4	0.62	688.4	294.9	14.8	998.2
W. WALE 5	14.5	1595.0	23.0	0.30	485.9	18.6	0.32	507.9	460.6	11.9	980.3
W. SPRINGLINE	19.4	2134.0	23.0	0.30	650.1	0.0	0.00	0.0	650.1	7.5	657.6

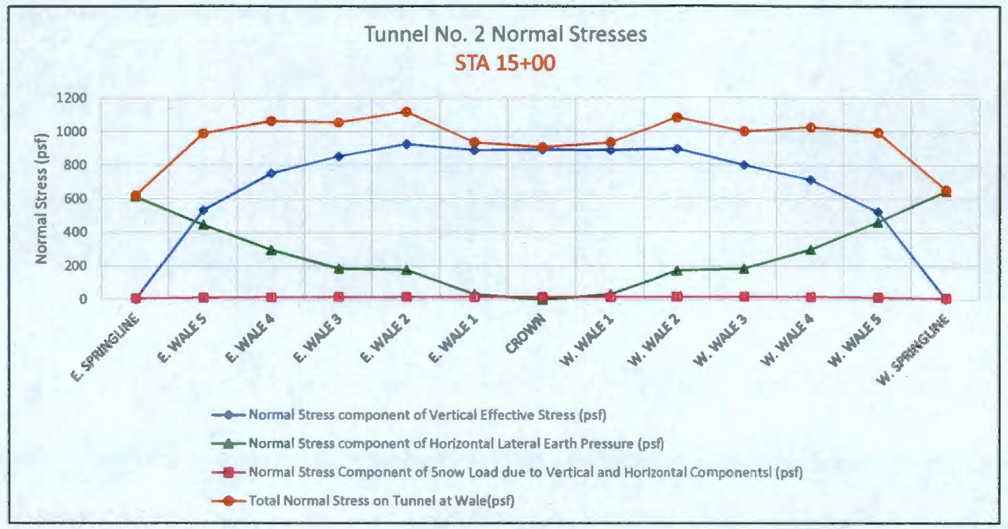


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	820.6
W5 EAST	1037.1
W4 EAST	1071.2
W3 EAST	1094.1
W2 EAST	1021.2
W1	914.5
W2 WEST	984.5
W3 WEST	1014.3
W4 WEST	991.1
W5 WEST	989.3
W6 WEST	819.0

TUNNEL NO. 2

STA 15+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	19.8	2178.0	26.0	0.28	611.6	0.0	0.00	0.0	611.6	7.5	619.1
E. WALE 5	15.2	1672.0	26.0	0.28	469.5	18.6	0.32	532.4	445.1	11.9	989.3
E. WALE 4	11.8	1298.0	26.0	0.28	364.5	35.4	0.62	752.2	297.1	14.8	1064.0
E. WALE 3	9.8	1078.0	26.0	0.28	302.7	52.3	0.91	852.5	185.3	16.5	1054.2
E. WALE 2	9.0	990.0	0.0	0.50	495.0	69.1	1.21	924.9	176.5	16.7	1118.1
E. WALE 1	8.1	891.0	0.0	0.50	445.5	86.0	1.50	888.8	31.4	15.5	935.7
CROWN	8.1	891.0	0.0	0.50	445.5	90.0	1.57	891.0	0.0	15.0	906.0
W. WALE 1	8.1	891.0	0.0	0.50	445.5	86.0	1.50	888.8	31.4	15.5	935.7
W. WALE 2	8.7	957.0	0.0	0.50	478.5	69.1	1.21	894.1	170.6	16.7	1081.4
W. WALE 3	9.2	1012.0	24.0	0.30	300.2	52.3	0.91	800.3	183.7	16.5	1000.5
W. WALE 4	11.2	1232.0	24.0	0.30	365.5	35.4	0.62	713.9	297.8	14.8	1026.6
W. WALE 5	14.9	1639.0	24.0	0.30	486.2	18.6	0.32	521.9	460.9	11.9	994.6
W. SPRINGLINE	19.8	2178.0	24.0	0.30	646.1	0.0	0.00	0.0	646.1	7.5	653.6

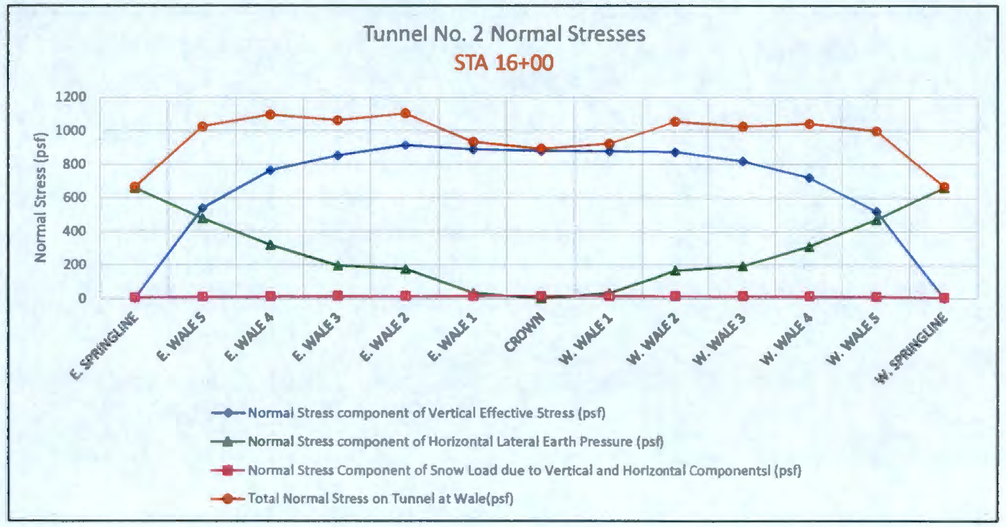


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	804.2
W5 EAST	1026.7
W4 EAST	1059.1
W3 EAST	1086.2
W2 EAST	1026.9
W1	925.8
W2 WEST	1008.5
W3 WEST	1041.0
W4 WEST	1013.5
W5 WEST	1010.6
W6 WEST	824.1

TUNNEL NO. 2

STA 16+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	20.2	2222.0	24.0	0.30	659.1	0.0	0.00	0.0	659.1	7.5	666.6
E. WALE 5	15.4	1694.0	24.0	0.30	502.5	18.6	0.32	539.4	476.3	11.9	1027.6
E. WALE 4	12.0	1320.0	24.0	0.30	391.6	35.4	0.62	764.9	319.1	14.8	1098.8
E. WALE 3	9.8	1078.0	24.0	0.30	319.8	52.3	0.91	852.5	195.7	16.5	1064.7
E. WALE 2	8.9	979.0	0.0	0.50	489.5	69.1	1.21	914.7	174.5	16.7	1105.9
E. WALE 1	8.1	891.0	0.0	0.50	445.5	86.0	1.50	888.8	31.4	15.5	935.7
CROWN	8.0	880.0	0.0	0.50	440.0	90.0	1.57	880.0	0.0	15.0	895.0
W. WALE 1	8.0	880.0	0.0	0.50	440.0	86.0	1.50	877.8	31.0	15.5	924.3
W. WALE 2	8.5	935.0	0.0	0.50	467.5	69.1	1.21	873.6	166.7	16.7	1056.9
W. WALE 3	9.4	1034.0	23.0	0.30	315.0	52.3	0.91	817.7	192.8	16.5	1027.0
W. WALE 4	11.3	1243.0	23.0	0.30	378.7	35.4	0.62	720.3	308.6	14.8	1043.7
W. WALE 5	14.8	1628.0	23.0	0.30	495.9	18.6	0.32	518.4	470.1	11.9	1000.4
W. SPRINGLINE	19.7	2167.0	23.0	0.30	660.1	0.0	0.00	0.0	660.1	7.5	667.6

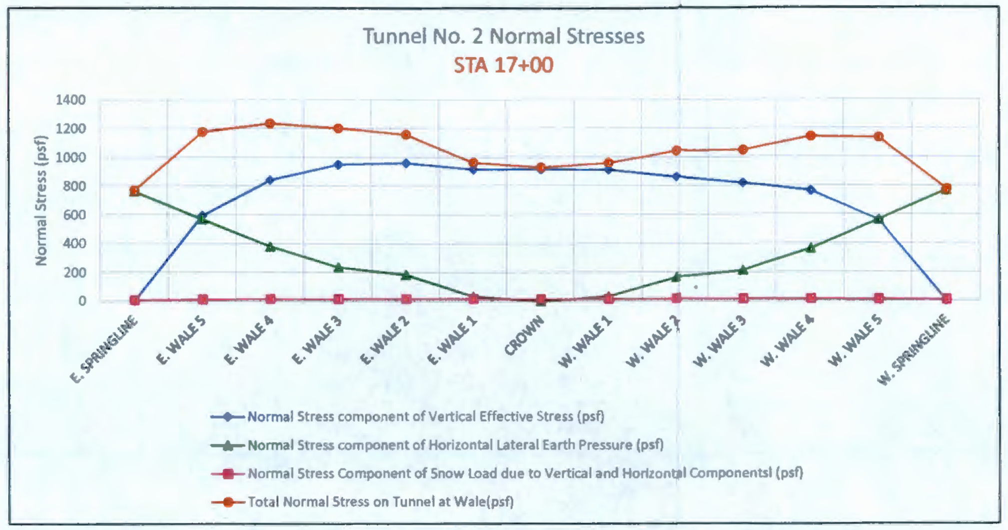


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	847.1
W5 EAST	1063.2
W4 EAST	1081.8
W3 EAST	1085.3
W2 EAST	1020.8
W1	918.3
W2 WEST	990.6
W3 WEST	1041.9
W4 WEST	1035.3
W5 WEST	1022.0
W6 WEST	834.0

TUNNEL NO. 2

STA 17+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	21.6	2376.0	21.0	0.32	762.3	0.0	0.00	0.0	762.3	7.5	769.8
E. WALE 5	17.0	1870.0	21.0	0.32	599.9	18.6	0.32	595.4	568.7	11.9	1176.0
E. WALE 4	13.2	1452.0	21.0	0.32	465.8	35.4	0.62	841.4	379.6	14.8	1235.9
E. WALE 3	10.9	1199.0	21.0	0.32	384.7	52.3	0.91	948.2	235.4	16.5	1200.1
E. WALE 2	9.3	1023.0	0.0	0.50	511.5	69.1	1.21	955.8	182.4	16.7	1154.8
E. WALE 1	8.3	913.0	0.0	0.50	456.5	86.0	1.50	910.7	32.1	15.5	958.4
CROWN	8.3	913.0	0.0	0.50	456.5	90.0	1.57	913.0	0.0	15.0	928.0
W. WALE 1	8.3	913.0	0.0	0.50	456.5	86.0	1.50	910.7	32.1	15.5	958.4
W. WALE 2	8.4	924.0	0.0	0.50	462.0	69.1	1.21	863.3	164.7	16.7	1044.7
W. WALE 3	9.4	1034.0	19.0	0.34	348.7	52.3	0.91	817.7	213.4	16.5	1047.6
W. WALE 4	12.0	1320.0	19.0	0.34	445.1	35.4	0.62	764.9	362.8	14.8	1142.5
W. WALE 5	16.0	1760.0	19.0	0.34	593.5	18.6	0.32	560.4	562.6	11.9	1134.9
W. SPRINGLINE	20.7	2277.0	19.0	0.34	767.8	0.0	0.00	0.0	767.8	7.5	775.3

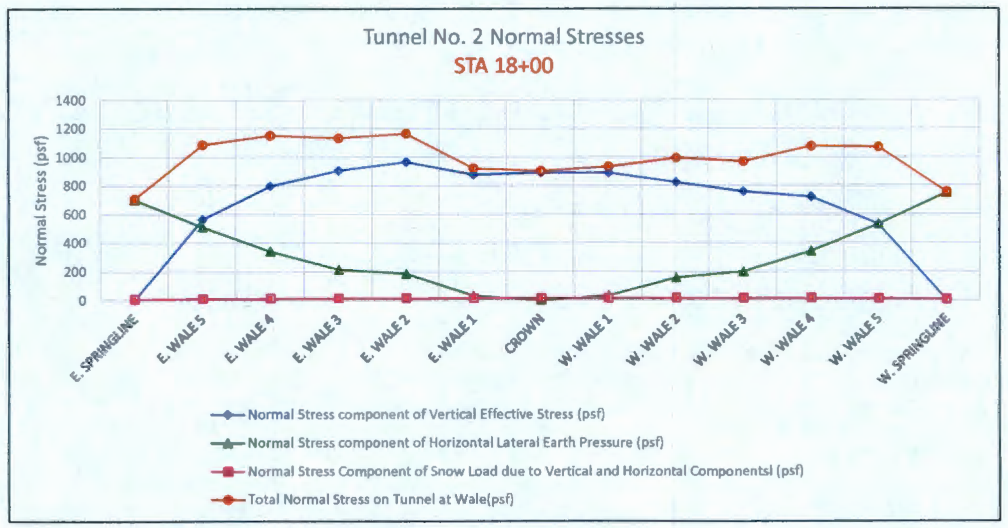


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	972.9
W5 EAST	1205.9
W4 EAST	1218.0
W3 EAST	1177.5
W2 EAST	1056.6
W1	948.2
W2 WEST	1001.5
W3 WEST	1046.1
W4 WEST	1095.0
W5 WEST	1138.7
W6 WEST	955.1

TUNNEL NO. 2

STA 18+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	20.9	2299.0	23.0	0.30	700.4	0.0	0.00	0.0	700.4	7.5	707.9
E. WALE 5	16.1	1771.0	23.0	0.30	539.5	18.6	0.32	563.9	511.4	11.9	1087.2
E. WALE 4	12.5	1375.0	23.0	0.30	418.9	35.4	0.62	796.8	341.4	14.8	1153.0
E. WALE 3	10.4	1144.0	23.0	0.30	348.5	52.3	0.91	904.7	213.3	16.5	1134.5
E. WALE 2	9.4	1034.0	0.0	0.50	517.0	69.1	1.21	966.1	184.3	16.7	1167.1
E. WALE 1	8.0	880.0	0.0	0.50	440.0	86.0	1.50	877.8	31.0	15.5	924.3
CROWN	8.1	891.0	0.0	0.50	445.5	90.0	1.57	891.0	0.0	15.0	906.0
W. WALE 1	8.1	891.0	0.0	0.50	445.5	86.0	1.50	888.8	31.4	15.5	935.7
W. WALE 2	8.0	880.0	0.0	0.50	440.0	69.1	1.21	822.2	156.9	16.7	995.7
W. WALE 3	8.7	957.0	19.0	0.34	322.7	52.3	0.91	756.8	197.5	16.5	970.8
W. WALE 4	11.3	1243.0	19.0	0.34	419.2	35.4	0.62	720.3	341.6	14.8	1076.7
W. WALE 5	15.1	1661.0	19.0	0.34	560.1	18.6	0.32	528.9	531.0	11.9	1071.7
W. SPRINGLINE	20.2	2222.0	19.0	0.34	749.3	0.0	0.00	0.0	749.3	7.5	756.8

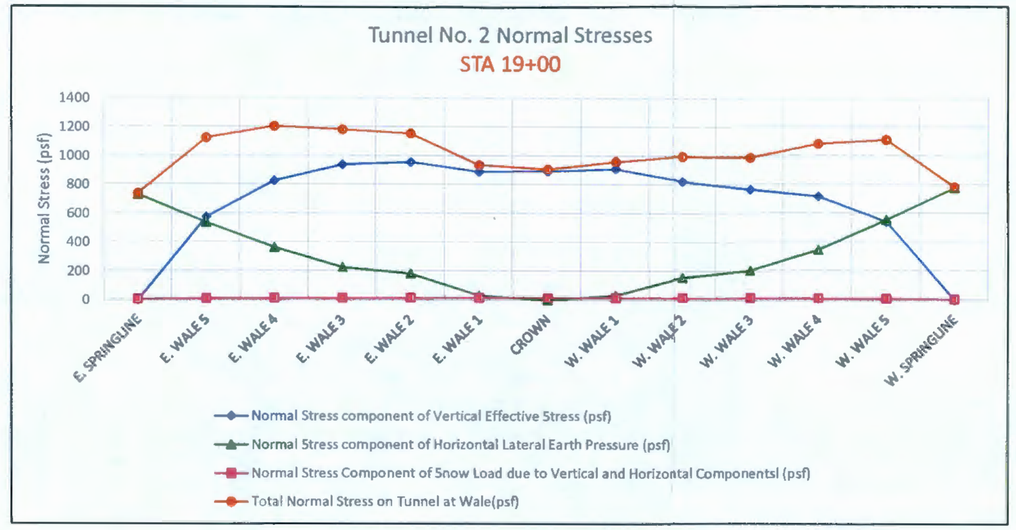


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	897.5
W5 EAST	1120.1
W4 EAST	1143.7
W3 EAST	1150.8
W2 EAST	1045.7
W1	922.0
W2 WEST	965.7
W3 WEST	983.3
W4 WEST	1023.8
W5 WEST	1074.2
W6 WEST	914.3

TUNNEL NO. 2

STA 19+00

Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	21.3	2343.0	22.0	0.31	732.6	0.0	0.00	0.0	732.6	7.5	740.1
E. WALE 5	16.5	1815.0	22.0	0.31	567.5	18.6	0.32	577.9	538.0	11.9	1127.8
E. WALE 4	13.0	1430.0	22.0	0.31	447.2	35.4	0.62	828.7	364.4	14.8	1207.9
E. WALE 3	10.8	1188.0	22.0	0.31	371.5	52.3	0.91	939.5	227.4	16.5	1183.3
E. WALE 2	9.3	1023.0	0.0	0.50	511.5	69.1	1.21	955.8	182.4	16.7	1154.8
E. WALE 1	8.1	891.0	0.0	0.50	445.5	86.0	1.50	888.8	31.4	15.5	935.7
CROWN	8.1	891.0	0.0	0.50	445.5	90.0	1.57	891.0	0.0	15.0	906.0
W. WALE 1	8.3	913.0	0.0	0.50	456.5	86.0	1.50	910.7	32.1	15.5	958.4
W. WALE 2	8.0	880.0	0.0	0.50	440.0	69.1	1.21	822.2	156.9	16.7	995.7
W. WALE 3	8.8	968.0	18.0	0.35	334.4	52.3	0.91	765.5	204.7	16.5	986.7
W. WALE 4	11.3	1243.0	18.0	0.35	429.4	35.4	0.62	720.3	350.0	14.8	1085.1
W. WALE 5	15.5	1705.0	18.0	0.35	589.1	18.6	0.32	542.9	558.4	11.9	1113.2
W. SPRINGLINE	20.5	2255.0	18.0	0.35	779.1	0.0	0.00	0.0	779.1	7.5	786.6

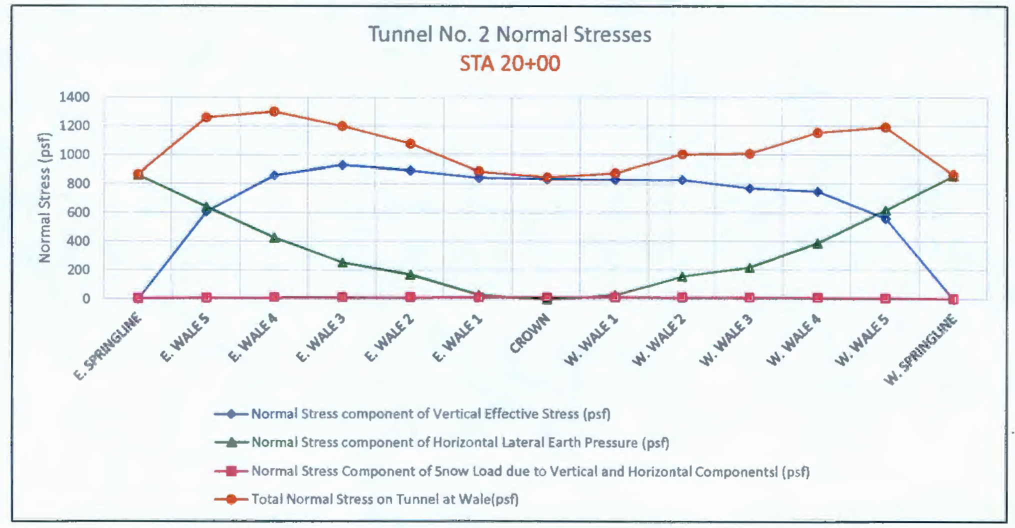


Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	934.0
W5 EAST	1167.9
W4 EAST	1195.6
W3 EAST	1169.1
W2 EAST	1045.2
W1	933.3
W2 WEST	977.1
W3 WEST	991.2
W4 WEST	1035.9
W5 WEST	1099.1
W6 WEST	949.9

TUNNEL NO. 2

STA 20+00

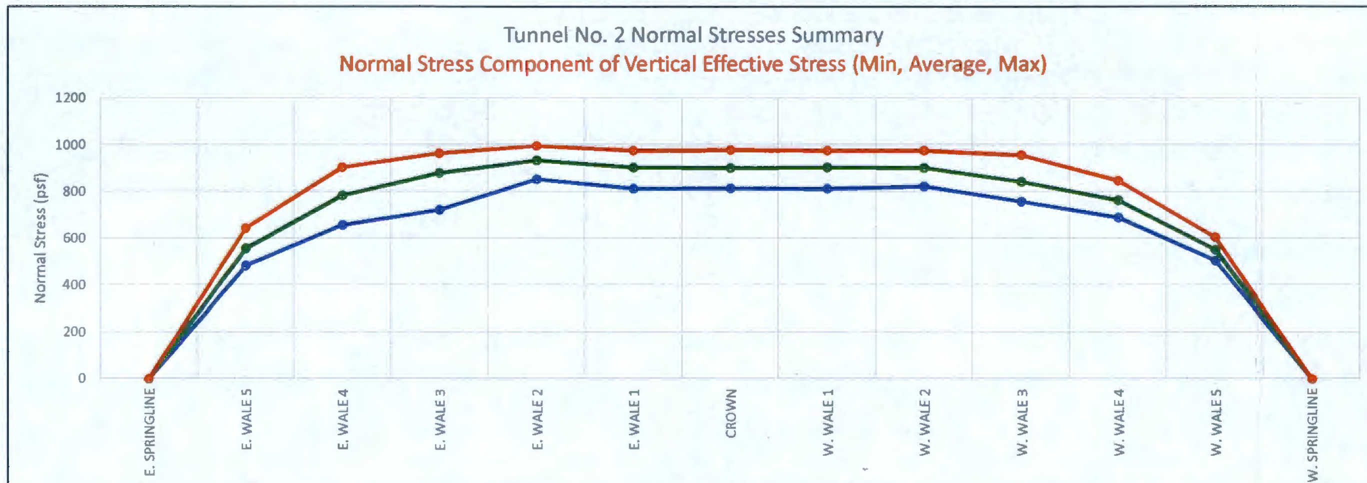
Point No.	Height of Soil Fill (feet)	Vertical Effective Stress (psf)	Average Ground Surface Slope (deg from horizontal)	Adjusted At-Rest Earth Pressure Coefficient, Koi	Horizontal Lateral Earth Pressure (psf)	Angle from Horizontal (deg)	Angle from Horizontal (rad)	Normal Stress: Normal Stress component of Vertical Effective Stress (psf)	Normal Stress: Normal Stress component of Horizontal Lateral Earth Pressure (psf)	Normal Stress: Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)	Normal Stress: Total Normal Stress on Tunnel at Wale(psf)
E. SPRINGLINE	22.2	2442.0	17.0	0.35	864.0	0.0	0.00	0.0	864.0	7.5	871.5
E. WALE 5	17.4	1914.0	17.0	0.35	677.2	18.6	0.32	609.4	642.0	11.9	1263.3
E. WALE 4	13.5	1485.0	17.0	0.35	525.4	35.4	0.62	860.6	428.2	14.8	1303.6
E. WALE 3	10.7	1177.0	17.0	0.35	416.4	52.3	0.91	930.8	254.9	16.5	1202.1
E. WALE 2	8.7	957.0	0.0	0.50	478.5	69.1	1.21	894.1	170.6	16.7	1081.4
E. WALE 1	7.7	847.0	0.0	0.50	423.5	86.0	1.50	844.9	29.8	15.5	890.2
CROWN	7.6	836.0	0.0	0.50	418.0	90.0	1.57	836.0	0.0	15.0	851.0
W. WALE 1	7.6	836.0	0.0	0.50	418.0	86.0	1.50	833.9	29.4	15.5	878.9
W. WALE 2	8.1	891.0	0.0	0.50	445.5	69.1	1.21	832.4	158.8	16.7	1008.0
W. WALE 3	8.9	979.0	15.0	0.37	362.8	52.3	0.91	774.2	222.0	16.5	1012.7
W. WALE 4	11.8	1298.0	15.0	0.37	481.0	35.4	0.62	752.2	392.0	14.8	1159.0
W. WALE 5	16.1	1771.0	15.0	0.37	656.3	18.6	0.32	563.9	622.2	11.9	1197.9
W. SPRINGLINE	21.1	2321.0	15.0	0.37	860.1	0.0	0.00	0.0	860.1	7.5	867.6

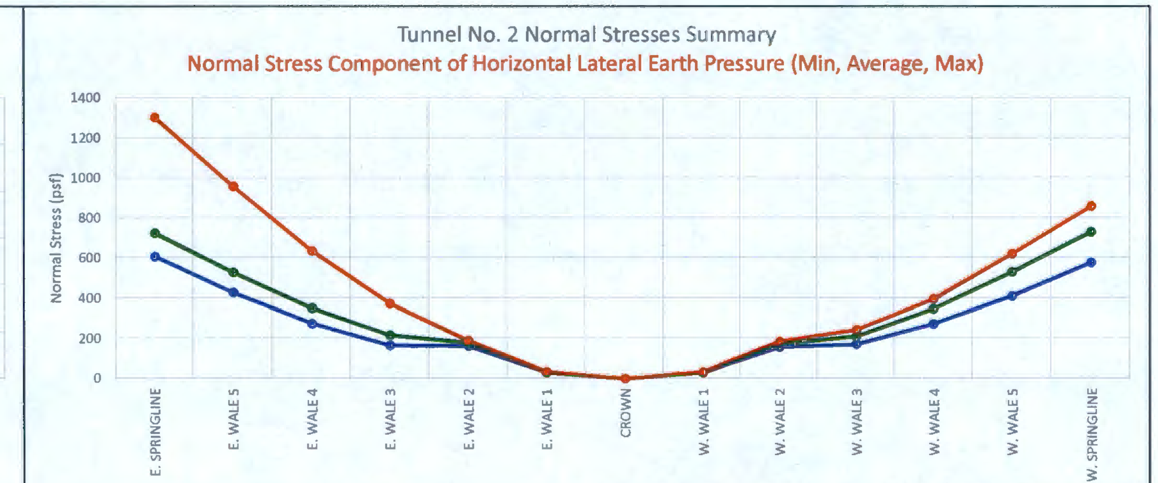


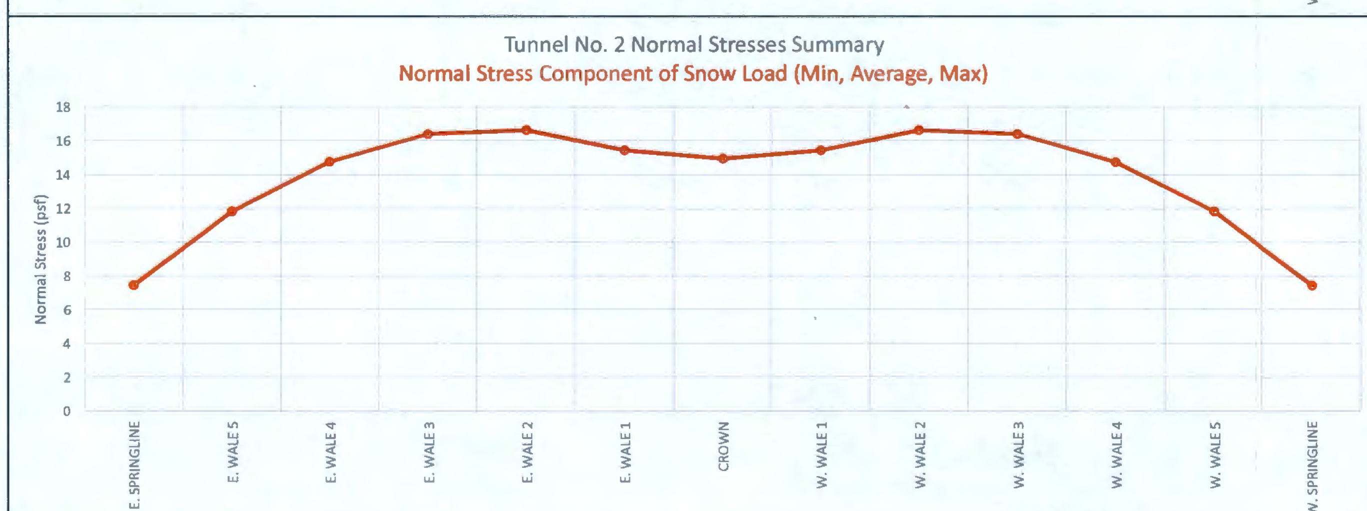
Segment	Average Orthogonal Soil Pressure (psf)
W6 EAST	1067.4
W5 EAST	1283.4
W4 EAST	1252.9
W3 EAST	1141.8
W2 EAST	985.8
W1	873.4
W2 WEST	943.4
W3 WEST	1010.4
W4 WEST	1085.9
W5 WEST	1178.5
W6 WEST	1032.8

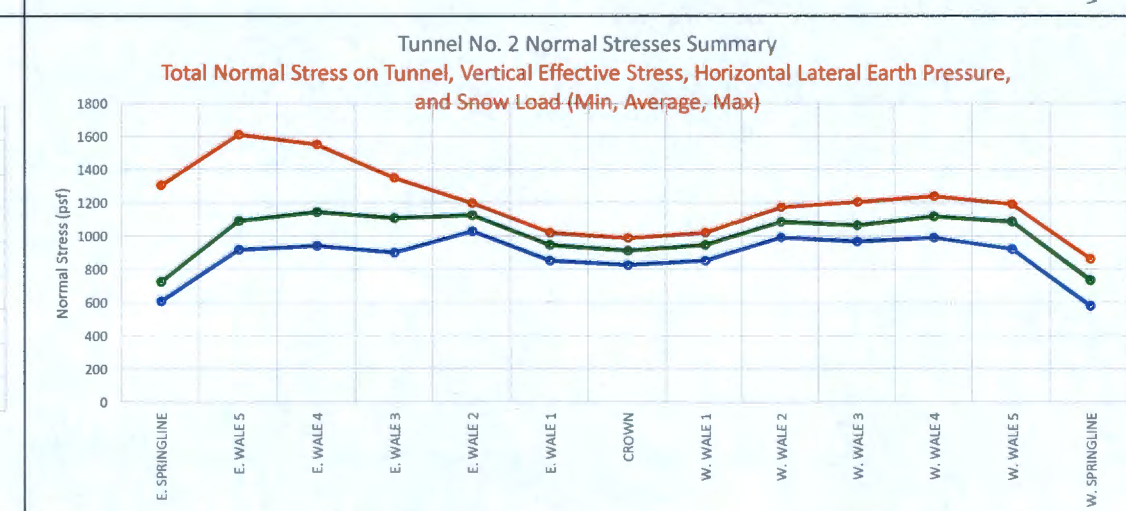
TUNNEL NO. 2

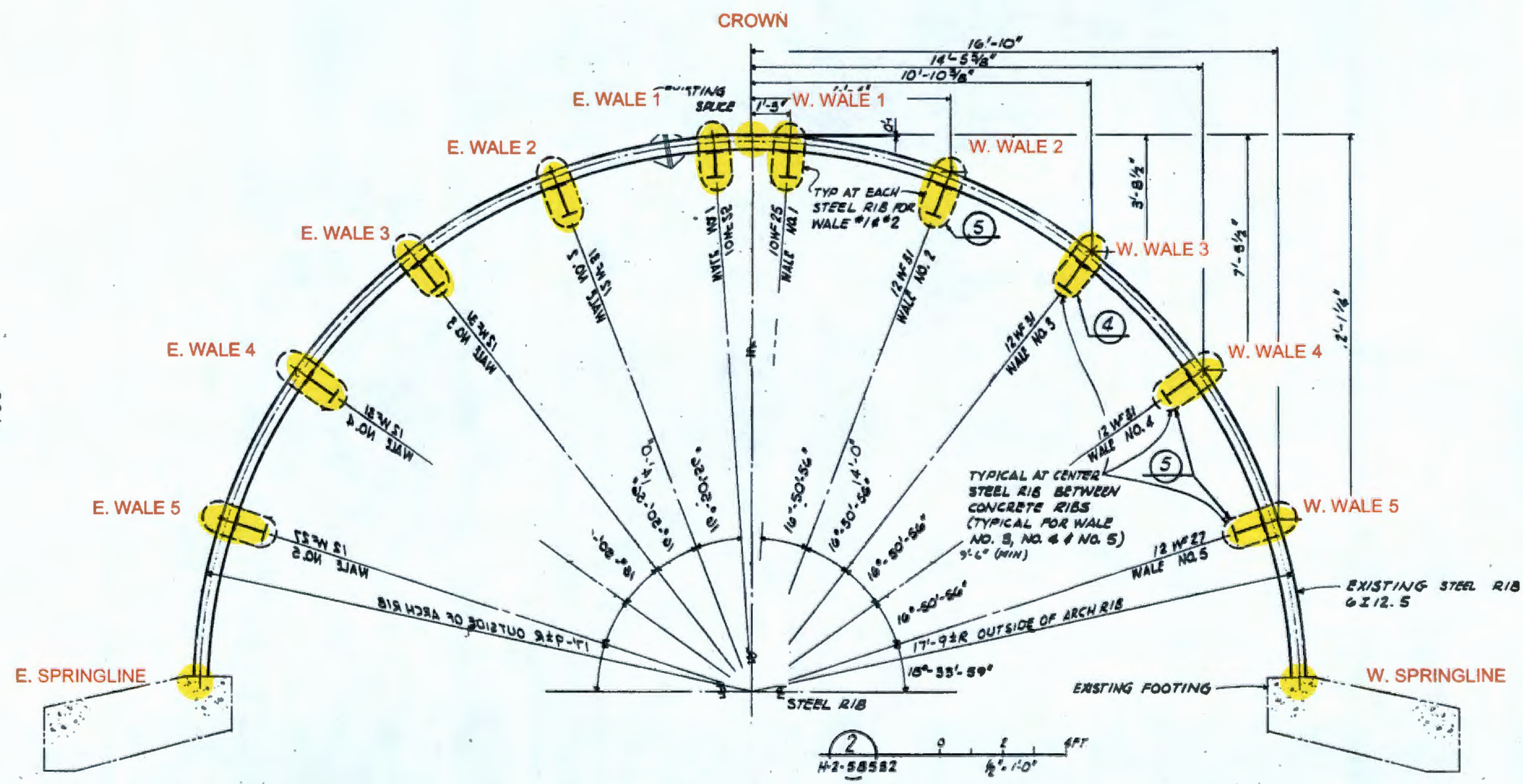
SUMMARY	Normal Stress component of Vertical Effective Stress (psf)			Normal Stress component of Horizontal Lateral Earth Pressure (psf)			Normal Stress Component of Snow Load due to Vertical and Horizontal Componentsl (psf)			Total Normal Stress on Tunnel (psf)		
Point No.	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX
E. SPRINGLINE	0.0	0.0	0.0	606.9	723.60	1303.5	7.5	7.5	7.5	614.4	731.1	1311.0
E. WALE 5	483.3	556.3	644.4	426.9	527.24	959.3	11.9	11.9	11.9	922.1	1095.4	1615.7
E. WALE 4	656.6	783.4	905.2	273.9	350.70	636.5	14.8	14.8	14.8	945.3	1148.9	1556.5
E. WALE 3	722.0	880.1	965.6	165.8	216.21	373.6	16.5	16.5	16.5	904.2	1112.7	1355.7
E. WALE 2	853.0	934.1	996.9	162.8	178.22	190.2	16.7	16.7	16.7	1032.4	1129.0	1203.8
E. WALE 1	812.0	902.8	976.6	28.7	31.87	34.5	15.5	15.5	15.5	856.1	950.2	1026.5
CROWN	814.0	901.4	979.0	0.0	0.00	0.0	15.0	15.0	15.0	829.0	916.4	994.0
W. WALE 1	812.0	903.4	976.6	28.7	31.89	34.5	15.5	15.5	15.5	856.1	950.8	1026.5
W. WALE 2	822.2	901.5	976.3	156.9	172.01	186.3	16.7	16.7	16.7	995.7	1090.2	1179.3
W. WALE 3	756.8	842.4	956.9	170.9	209.81	244.2	16.5	16.5	16.5	970.8	1068.6	1210.9
W. WALE 4	688.4	762.1	847.8	271.7	345.57	396.4	14.8	14.8	14.8	994.0	1122.5	1245.1
W. WALE 5	504.4	550.7	605.9	409.9	528.90	622.2	11.9	11.9	11.9	926.2	1091.4	1197.9
W. SPRINGLINE	0.0	0.0	0.0	576.6	730.12	860.1	7.5	7.5	7.5	584.1	737.6	867.6



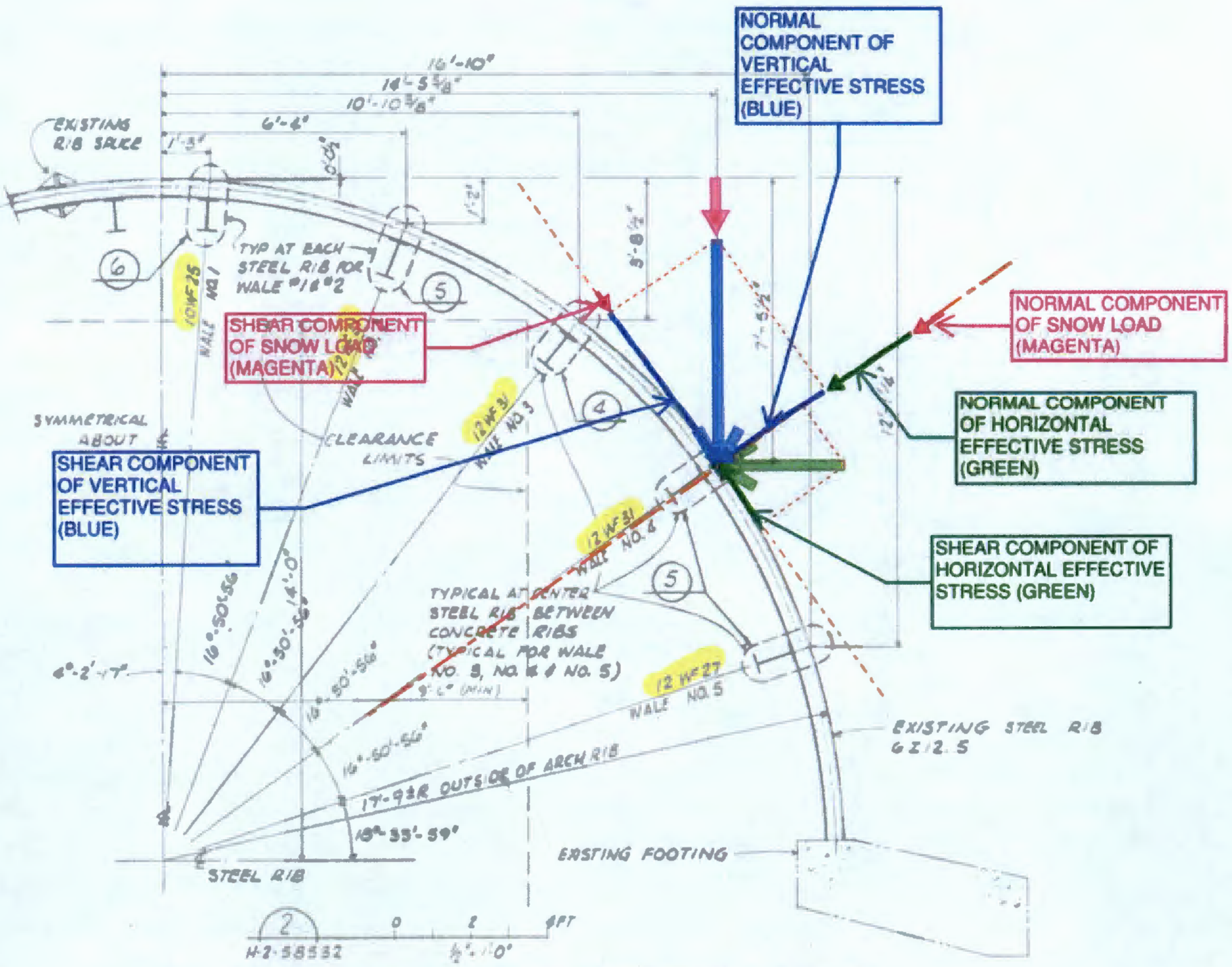








PUREX TUNNEL NO. 2
LOOKING SOUTH



EXAMPLE OF NORMAL STRESSES AND SHEAR STRESSES RESULTING FROM VERTICAL EFFECTIVE STRESS (BLUE), HORIZONTAL LATERAL EARTH PRESSURES (GREEN), AND SNOW LOAD (MAGENTA) AT WALE NO. 4.
[NOT TO SCALE]

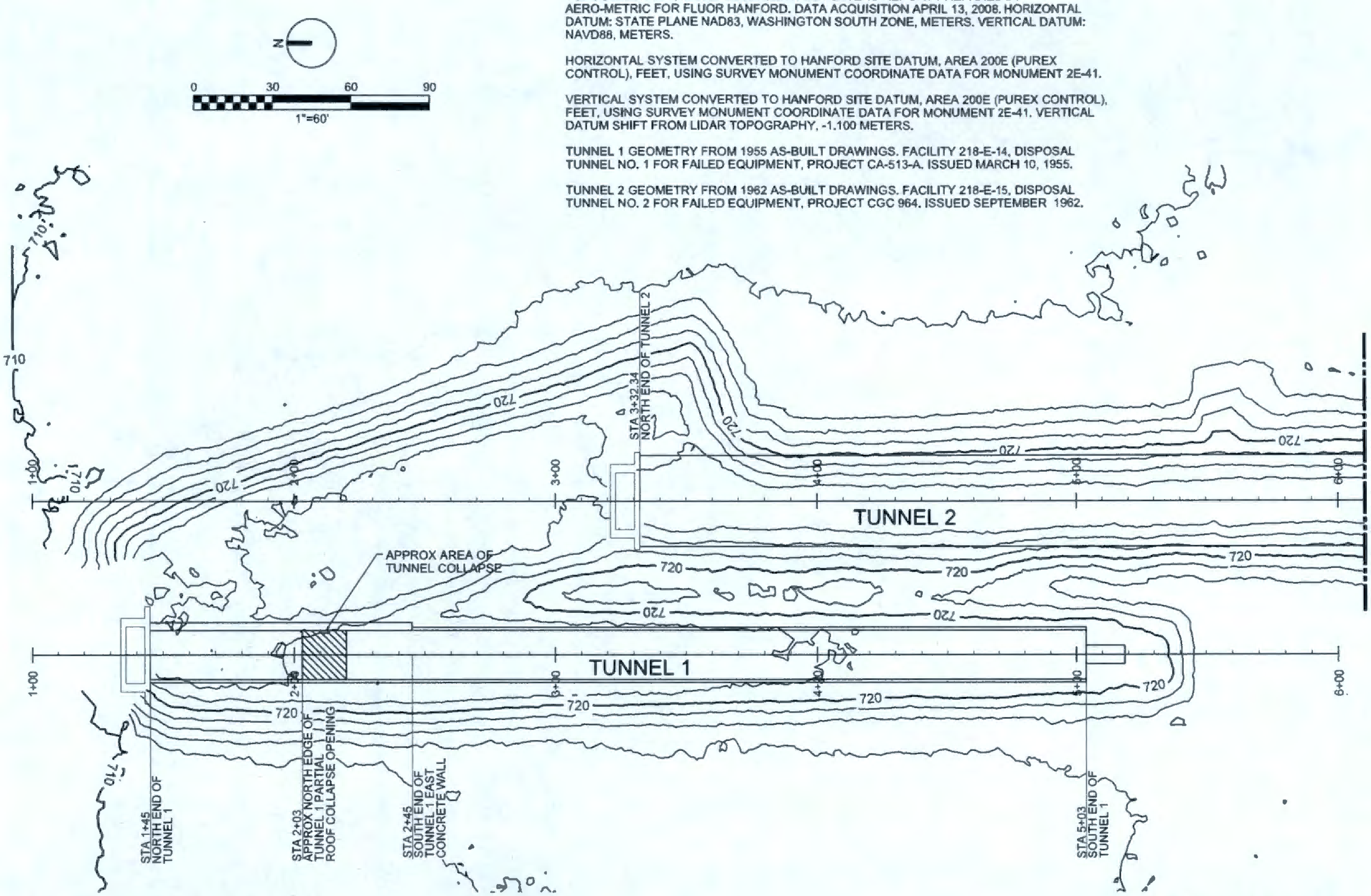
TOPOGRAPHY FROM 2008 *LIDAR CENTRAL PLATEAU REPORT* PREPARED BY AERO-METRIC FOR FLUOR HANFORD. DATA ACQUISITION APRIL 13, 2008. HORIZONTAL DATUM: STATE PLANE NAD83, WASHINGTON SOUTH ZONE, METERS. VERTICAL DATUM: NAVD88, METERS.

HORIZONTAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41.

VERTICAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41. VERTICAL DATUM SHIFT FROM LIDAR TOPOGRAPHY, -1.100 METERS.

TUNNEL 1 GEOMETRY FROM 1955 AS-BUILT DRAWINGS. FACILITY 218-E-14, DISPOSAL TUNNEL NO. 1 FOR FAILED EQUIPMENT, PROJECT CA-513-A. ISSUED MARCH 10, 1955.

TUNNEL 2 GEOMETRY FROM 1962 AS-BUILT DRAWINGS. FACILITY 218-E-15, DISPOSAL TUNNEL NO. 2 FOR FAILED EQUIPMENT, PROJECT CGC 964. ISSUED SEPTEMBER 1962.



TOPOGRAPHIC SITE PLAN
1 OF 2
PUREX TUNNEL 1
ENGINEERING EVALUATION

TOPOGRAPHY FROM 2008 *LIDAR CENTRAL PLATEAU REPORT* PREPARED BY AERO-METRIC FOR FLUOR HANFORD. DATA ACQUISITION APRIL 13, 2008. HORIZONTAL DATUM: STATE PLANE NAD83, WASHINGTON SOUTH ZONE, METERS. VERTICAL DATUM: NAVD88, METERS.

HORIZONTAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41.

VERTICAL SYSTEM CONVERTED TO HANFORD SITE DATUM, AREA 200E (PUREX CONTROL), FEET, USING SURVEY MONUMENT COORDINATE DATA FOR MONUMENT 2E-41. VERTICAL DATUM SHIFT FROM LIDAR TOPOGRAPHY, -1.100 METERS.

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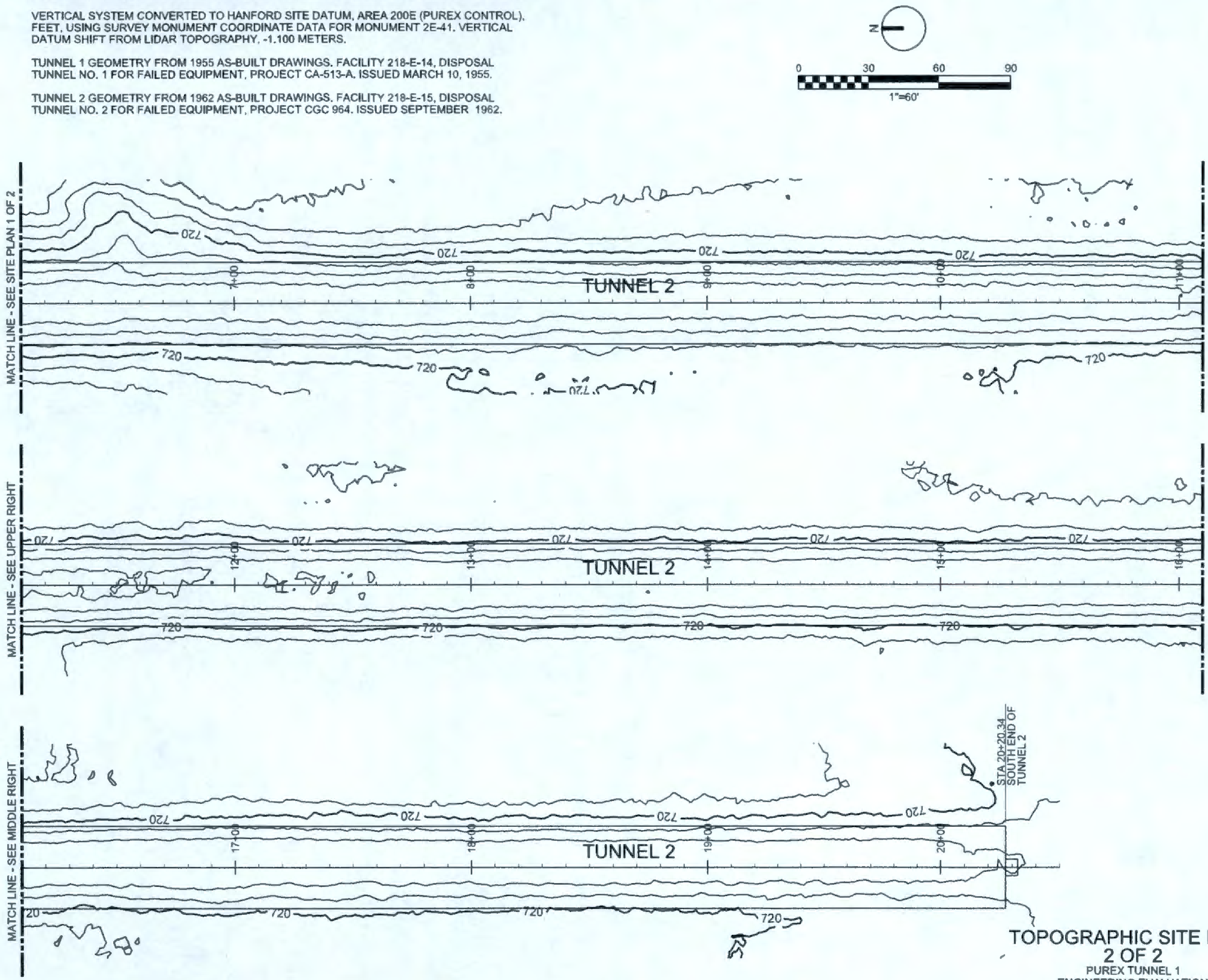
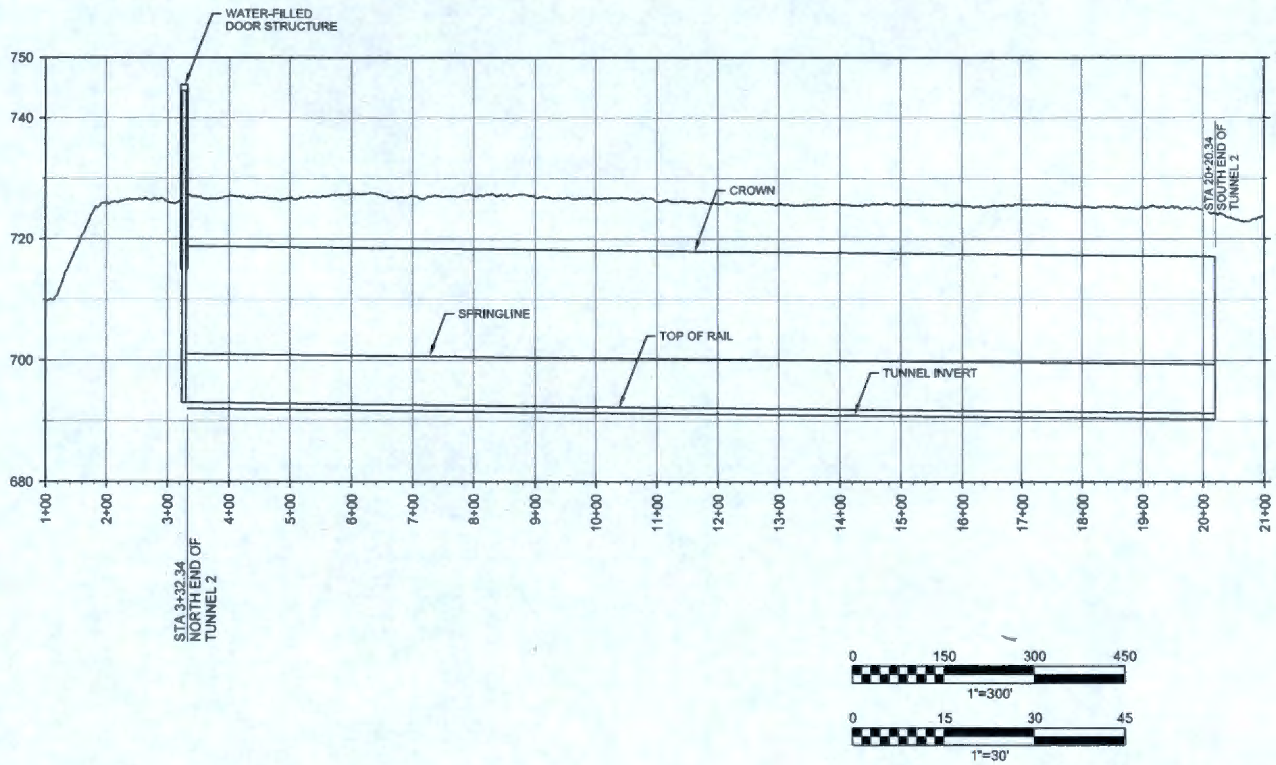
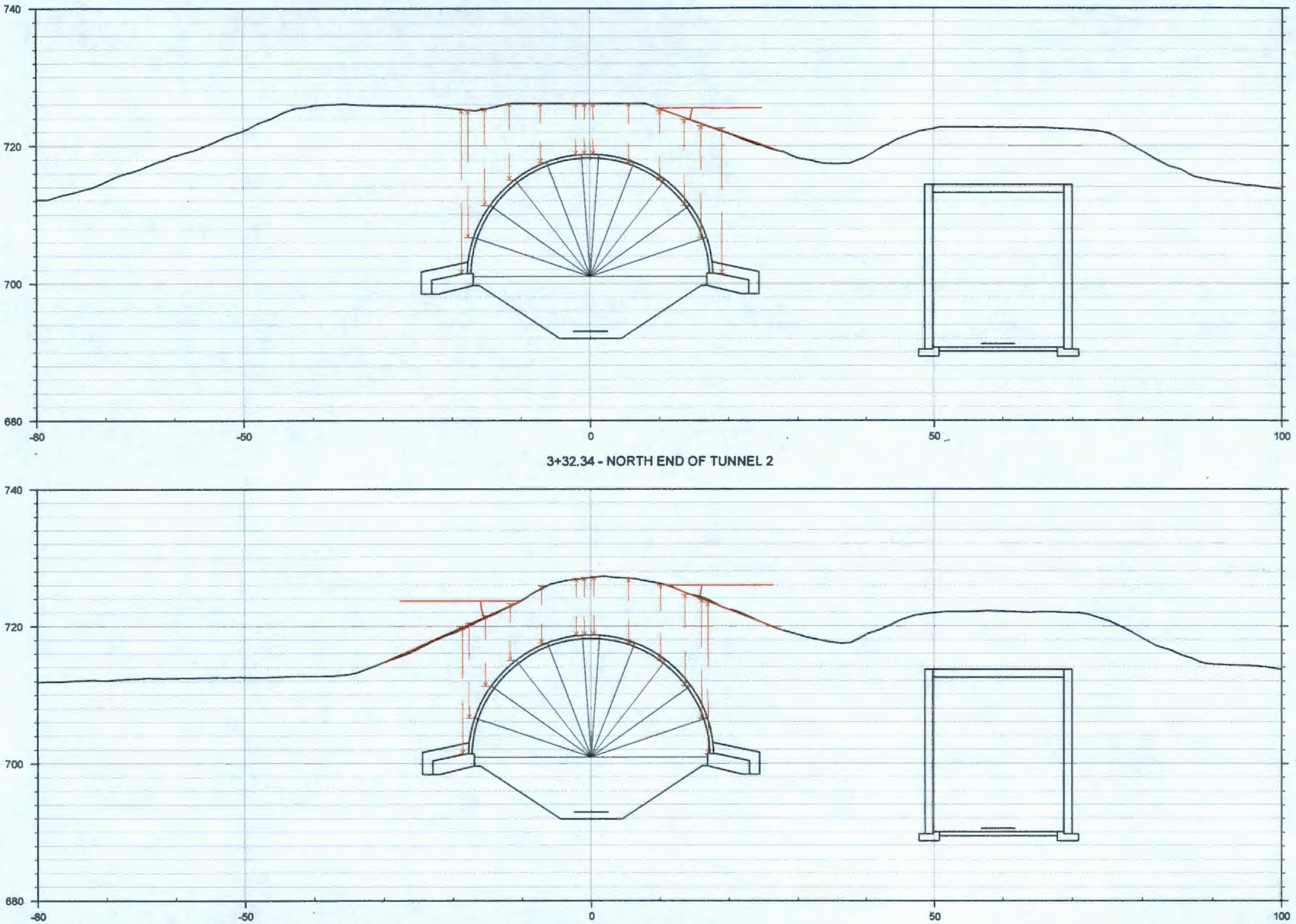


TOPOGRAPHIC SITE PLAN
2 OF 2
PUREX TUNNEL 1
ENGINEERING EVALUATION

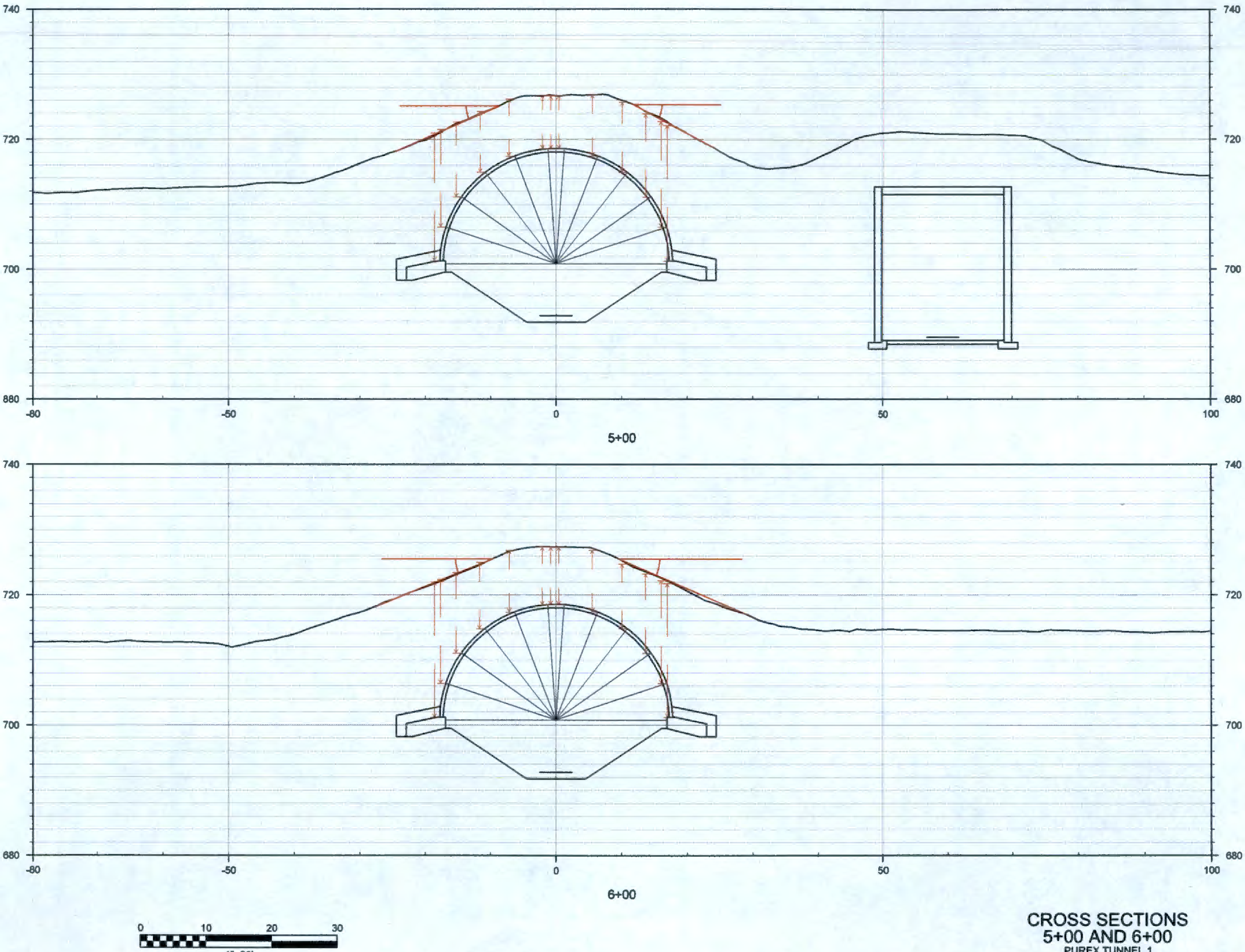


TUNNEL 2 PROFILE
PUREX TUNNEL 1
ENGINEERING EVALUATION

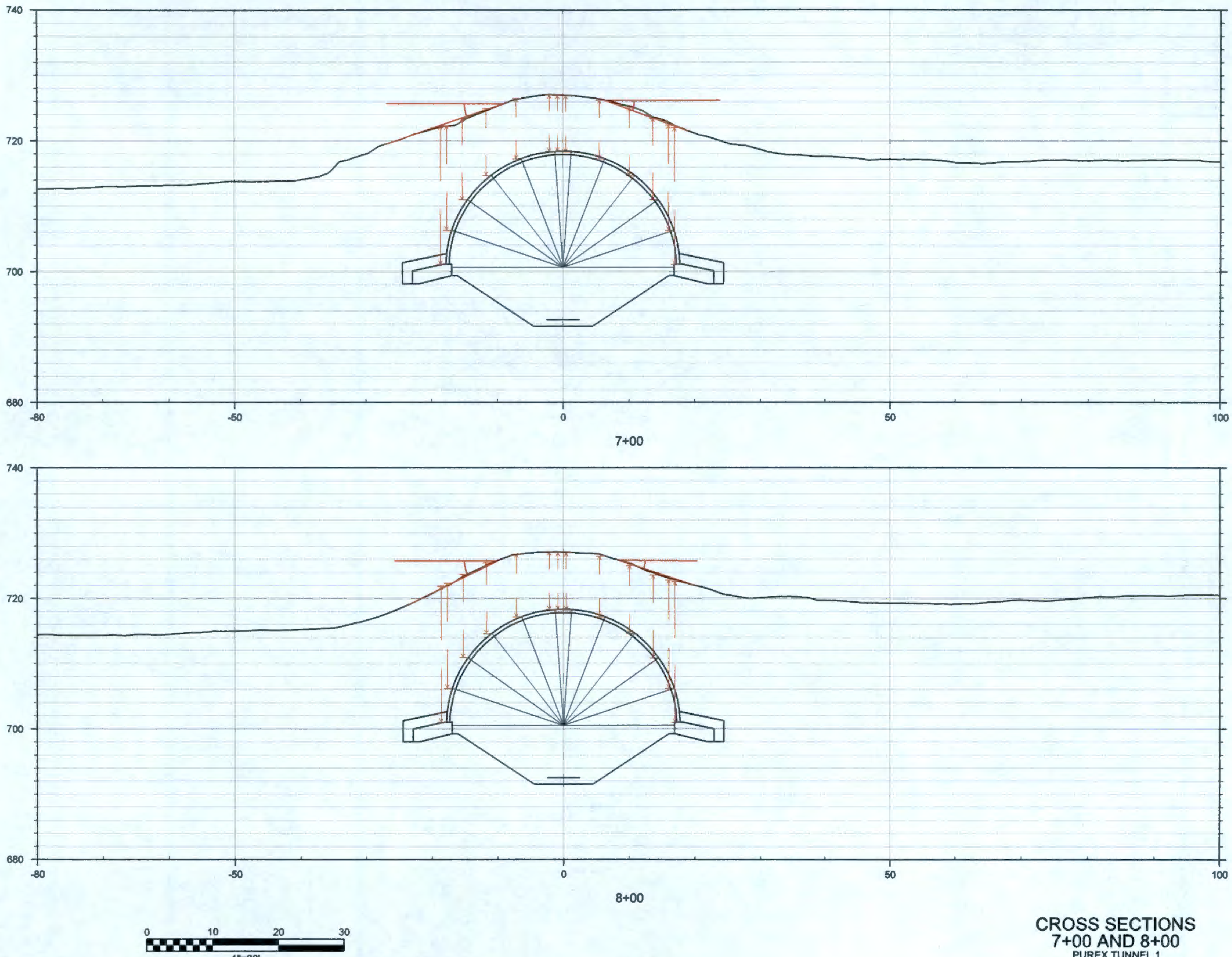


0 10 20 30
1"=20'

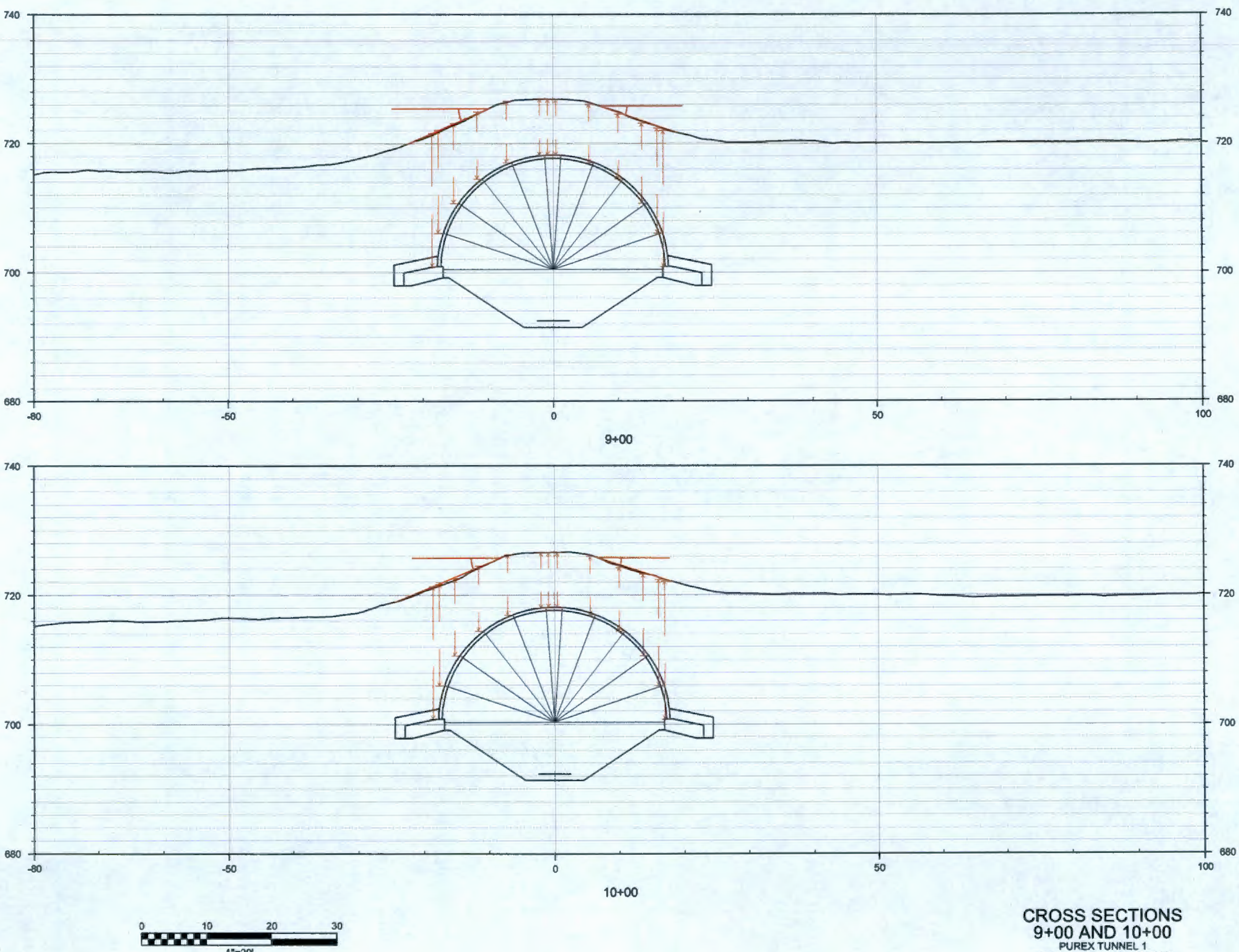
CROSS SECTIONS
3+32.34 AND 4+00
PUREX TUNNEL 1
ENGINEERING EVALUATION



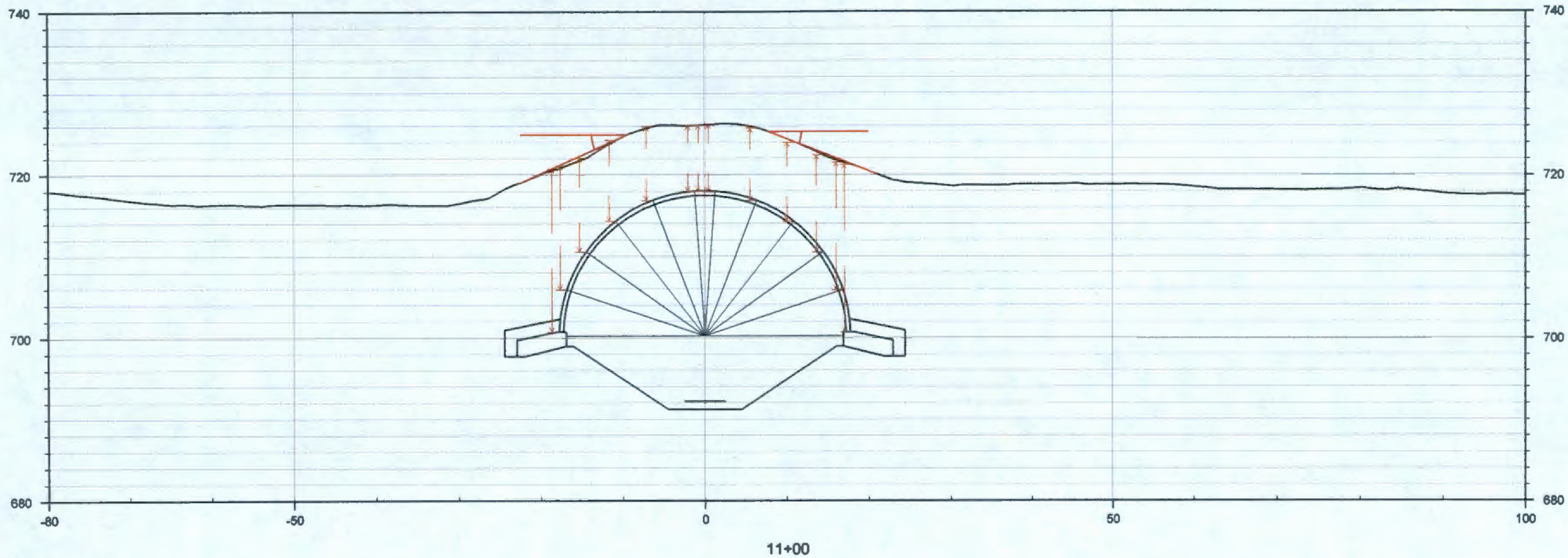
CROSS SECTIONS
5+00 AND 6+00
PUREX TUNNEL 1
ENGINEERING EVALUATION

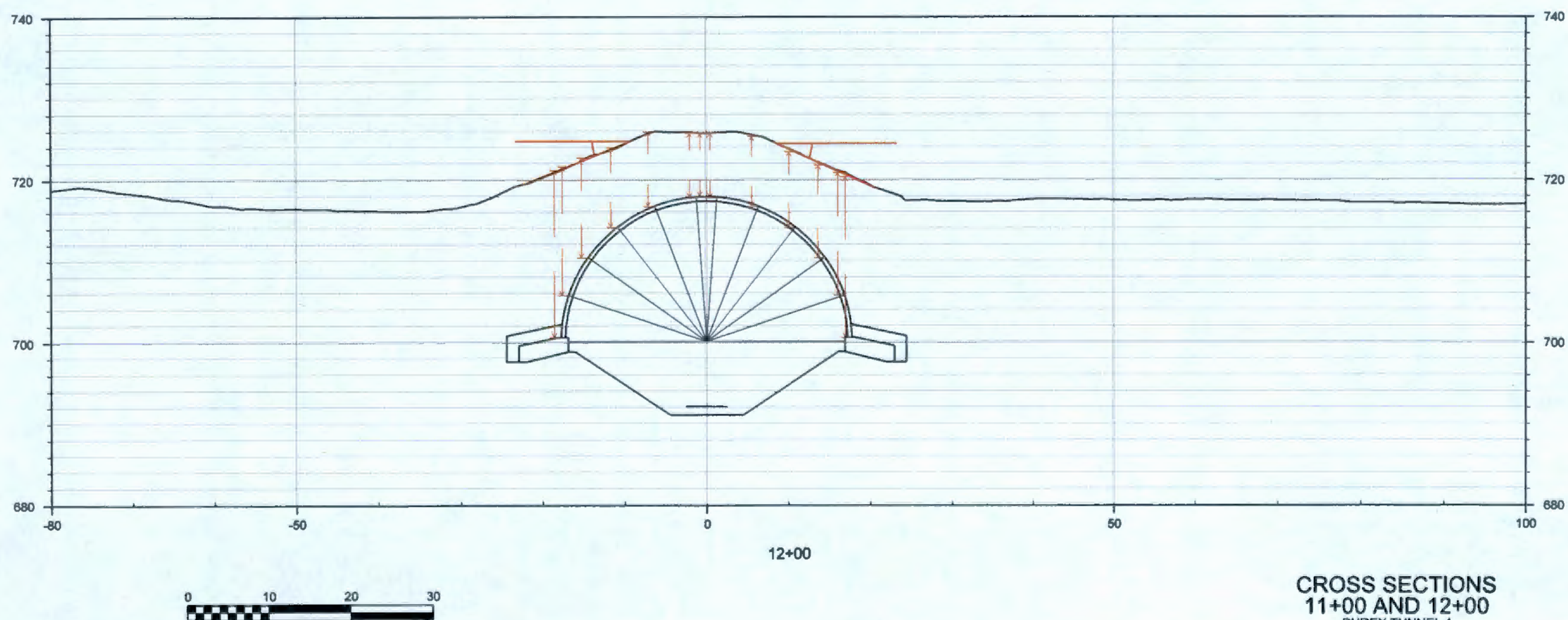


CROSS SECTIONS
7+00 AND 8+00
PUREX TUNNEL 1
ENGINEERING EVALUATION

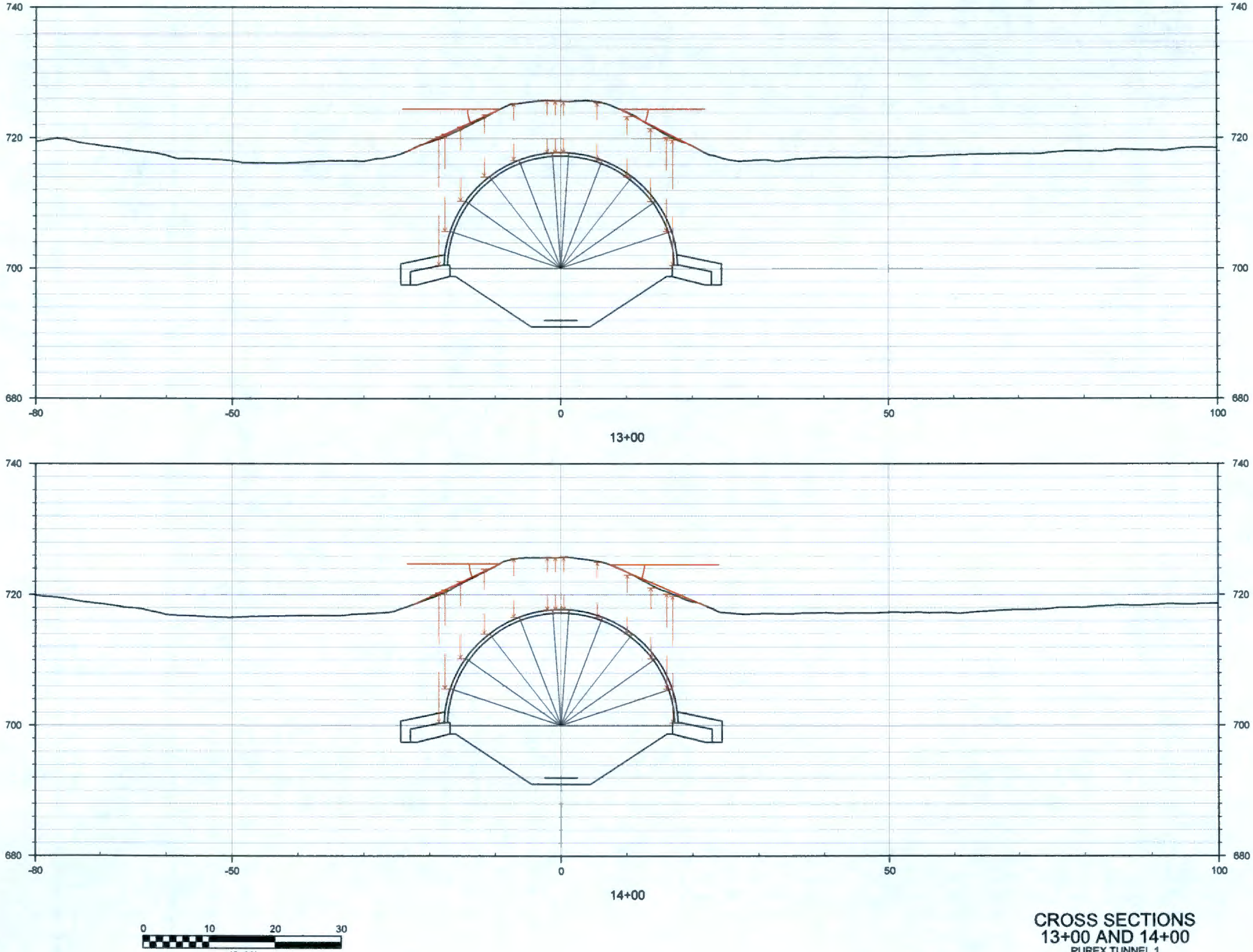


CROSS SECTIONS
9+00 AND 10+00
PUREX TUNNEL 1
ENGINEERING EVALUATION

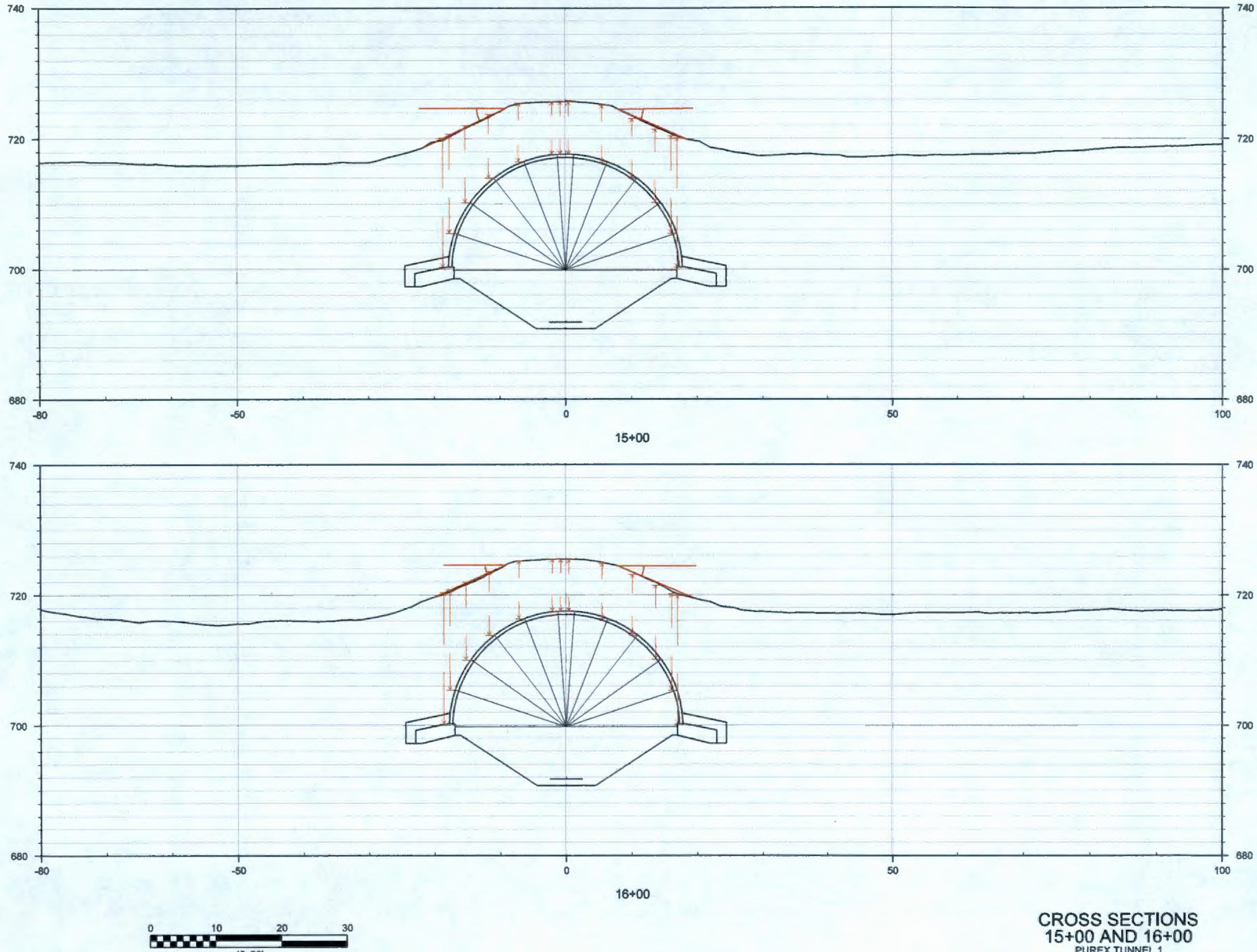




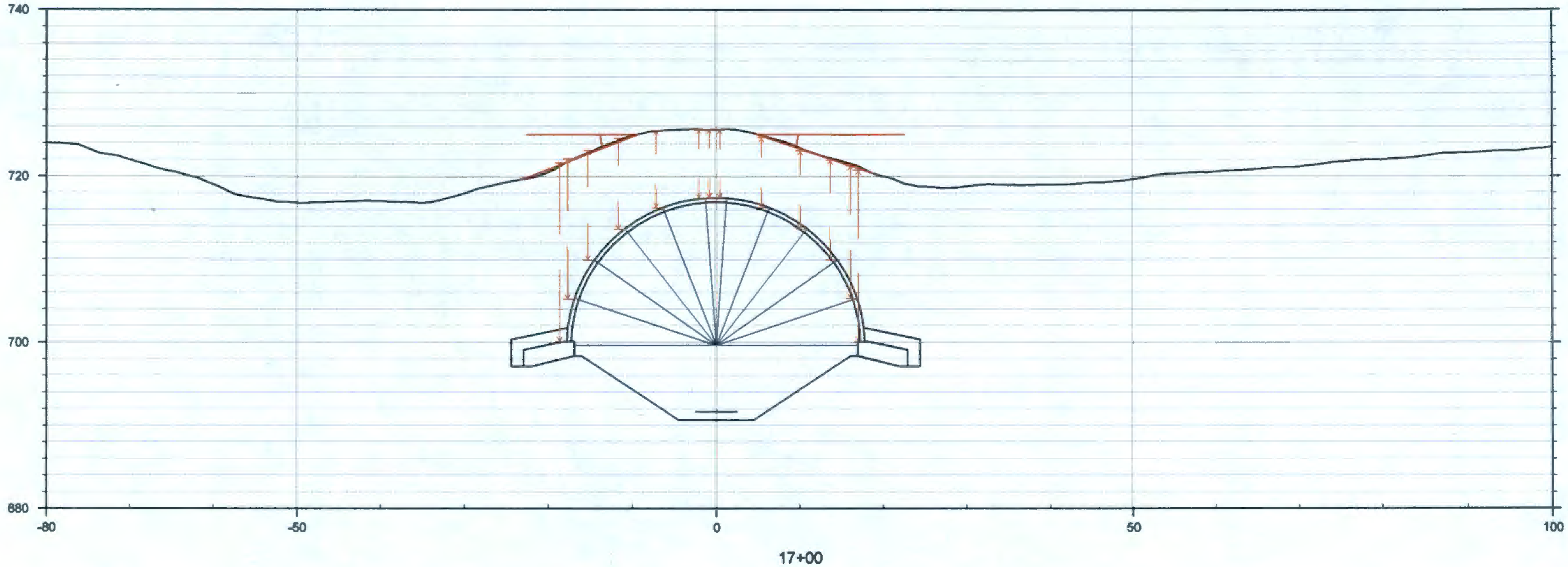
CROSS SECTIONS
11+00 AND 12+00
PUREX TUNNEL 1
ENGINEERING EVALUATION

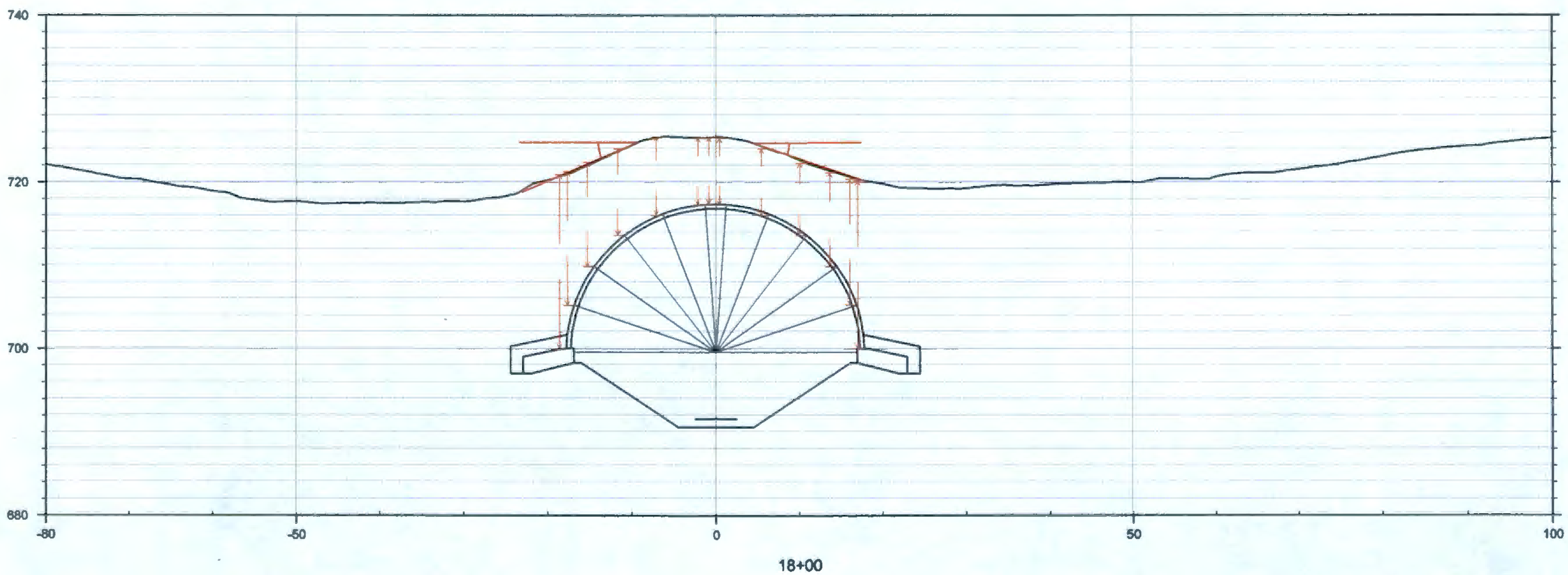


CROSS SECTIONS
13+00 AND 14+00
PUREX TUNNEL 1
ENGINEERING EVALUATION

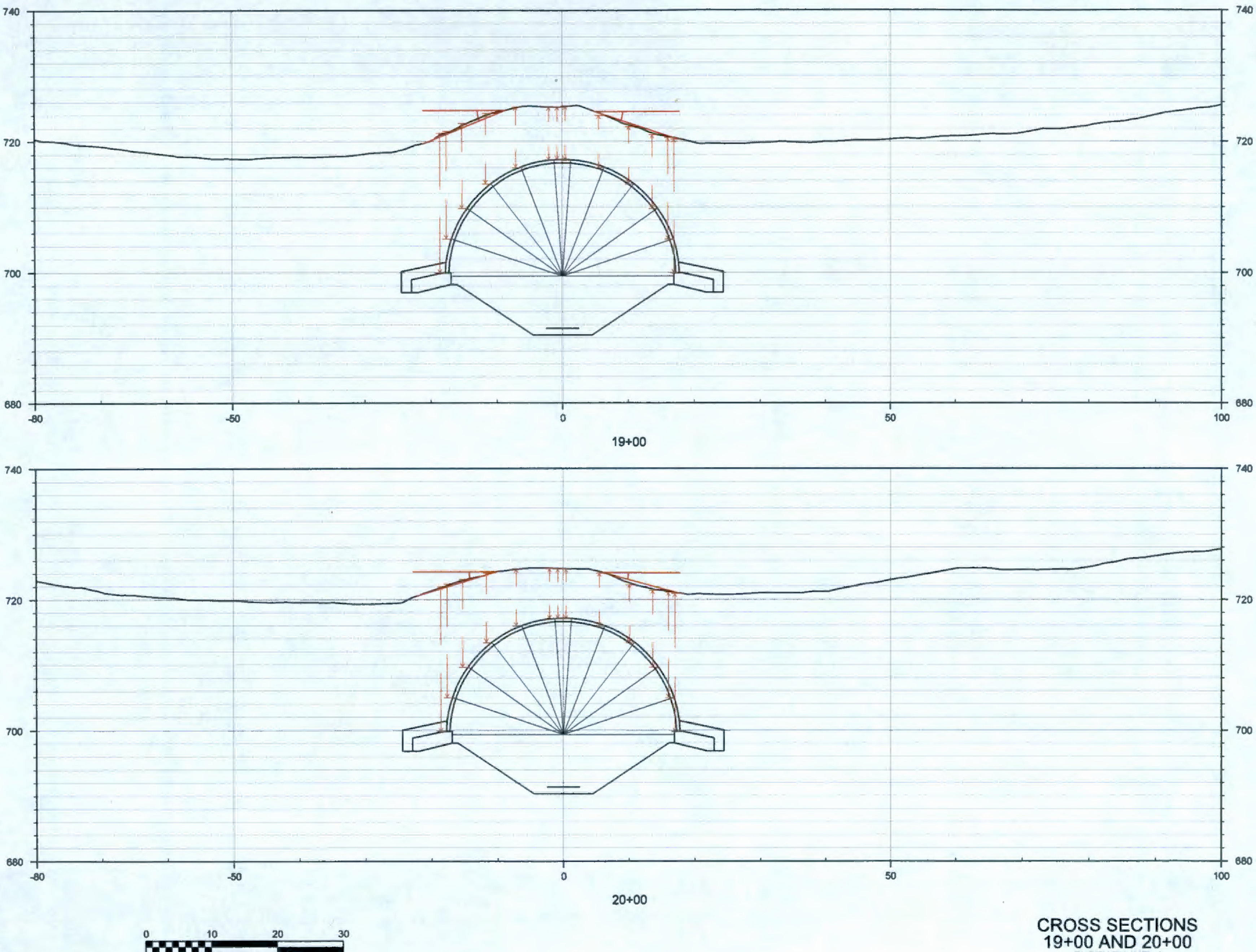


CROSS SECTIONS
15+00 AND 16+00
PUREX TUNNEL 1
ENGINEERING EVALUATION

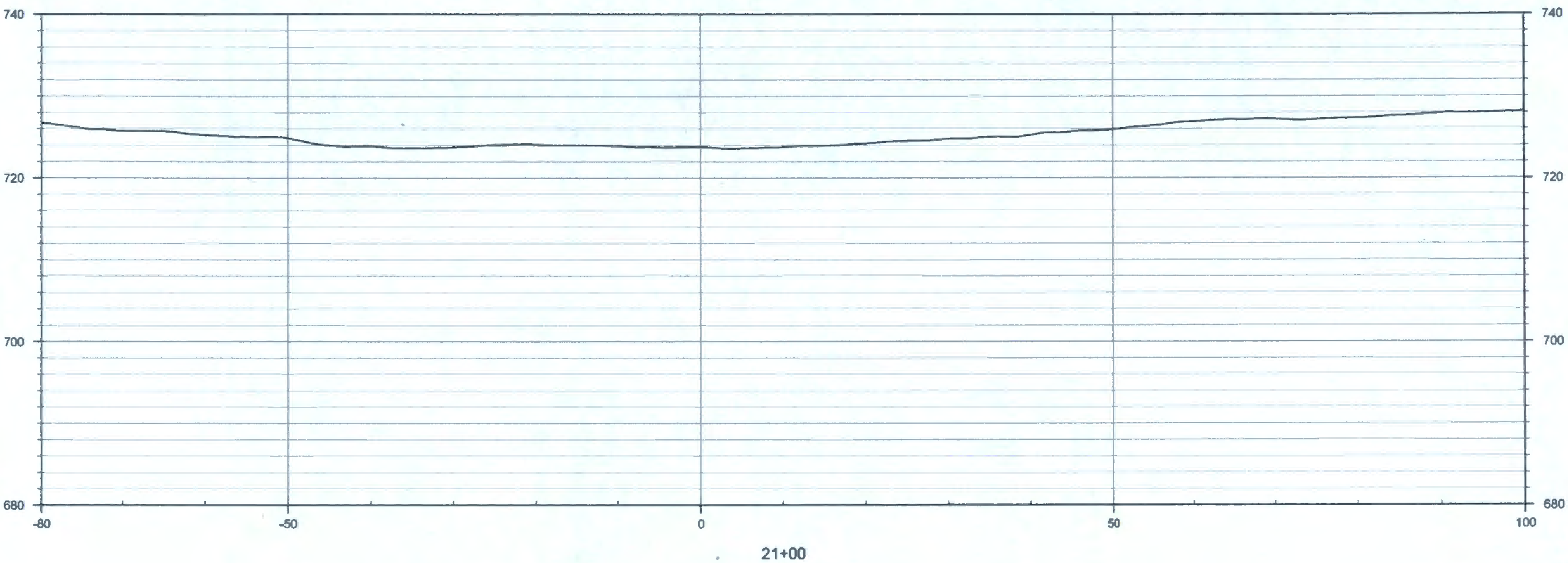


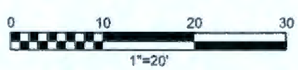


CROSS SECTIONS
17+00 AND 18+00
PUREX TUNNEL 1
ENGINEERING EVALUATION



CROSS SECTIONS
19+00 AND 20+00
PUREX TUNNEL 1
ENGINEERING EVALUATION





CROSS SECTION 21+00
PUREX TUNNEL 1
ENGINEERING EVALUATION

ch2m	Calculation Title: PUREX Tunnel 2 Engineering Evaluation	Project Number: 693839.BS Project: PUREX Tunnel 2 Client: CHPRC

Attachment D

Foundation Bearing Pressure Evaluation

Bearing Capacity Evaluation

ch2m:

PROJECT: Hanford PUREX Tunnel No. 2 Evaluation
PROJECT#: 693839.BS.02
CREATED BY: Mark Kacmarcik/CVO **DATE:** 6/9/2017 **MODIFIED:** 6/24/2017
REVIEWED BY: Youssef Bougataya/SEA **DATE:** 6/12/2017

Given: Tunnel No. 2 Design Drawings
Tunnel No. 2 Construction Specification
Tunnel No. 2 Historical Photos

Find: Ultimate Bearing Capacity of Tunnel 2 Strip Footings
Recommended Allowable Bearing Capacity of Tunnel 2 Strip Footings

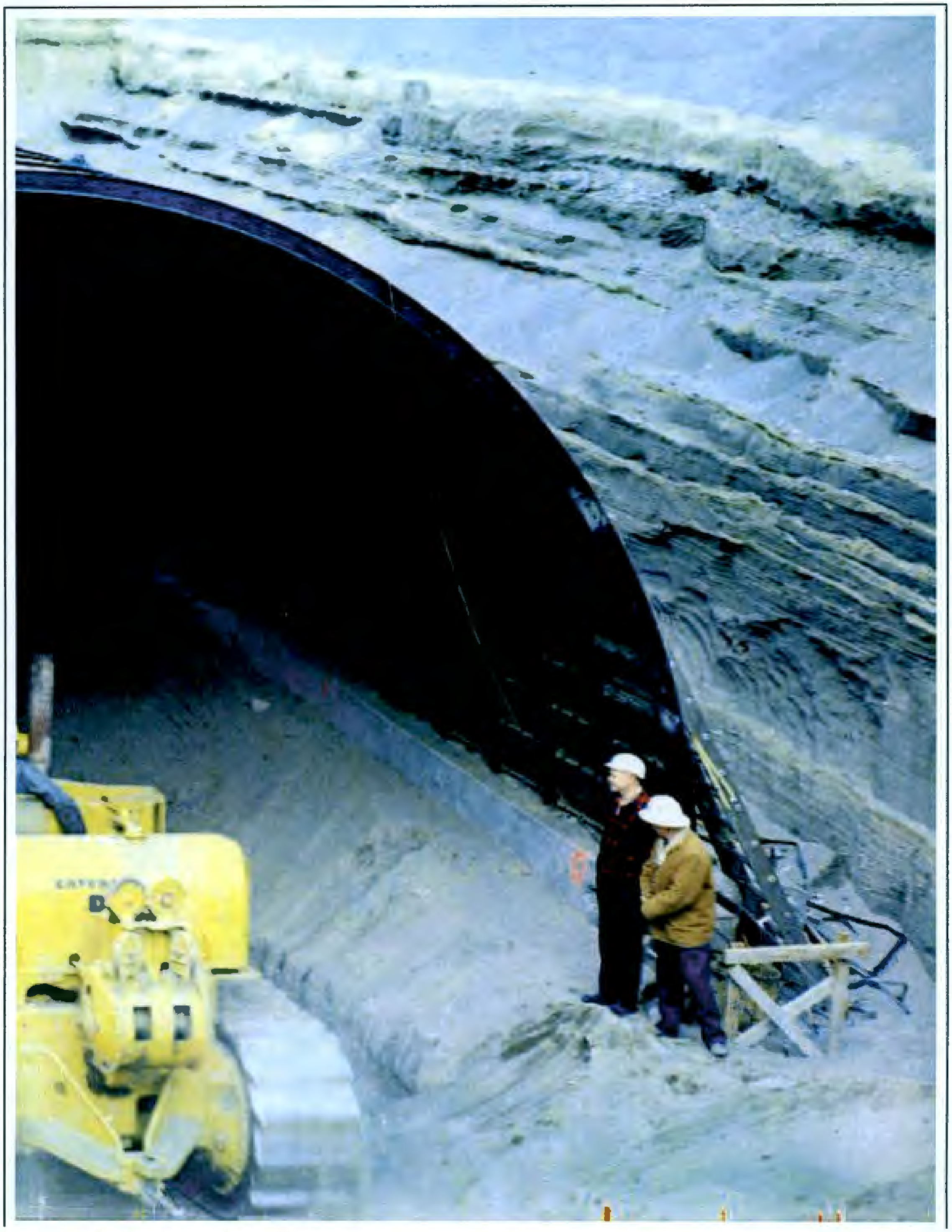
Assumptions: Noted below in calculation.

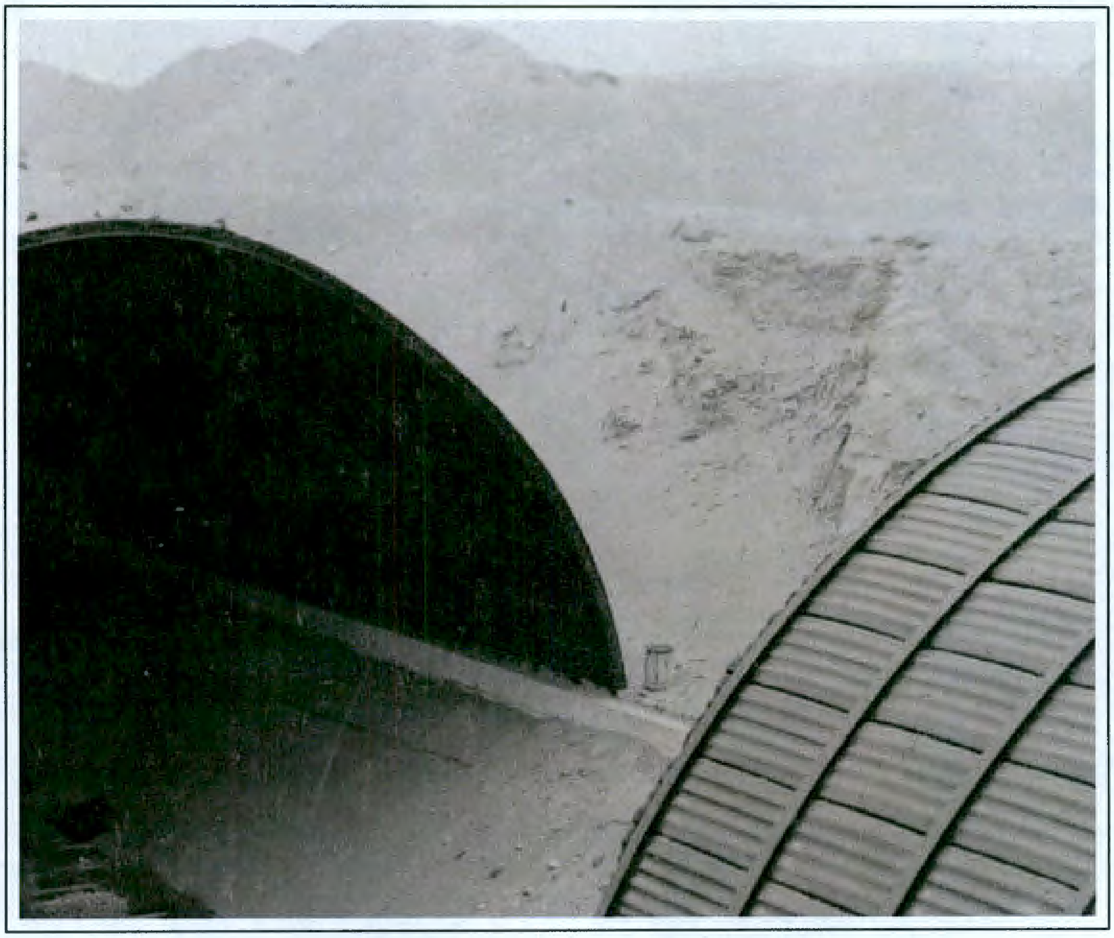
References:
Coduto, D. *Foundation Design*. Prentice Hall. New Jersey. 2000.
Gemperline, M.C. 1988. Centrifuge Modeling of Shallow Foundations. Proc, ASCE Spring Convention. ASCE.
Shields, D., Chandler, N., and Garnier, J. 1990. Bearing Capacity of Foundations in Slopes. Journal of Geotechnical Engineering, 116 (3), March.
McCarthy, D. 2002. Essentials of Soil Mechanics and Foundations. 6th Ed. Prentice Hall.

1.0 Soil Properties

At this time, there is no site specific geotechnical data available. Soil properties are based uon the interpretation of construction photographs, and from a 1984 Dames and Moore report which provides foundation recommendations for a proposed Process Facility Modifications approximately 0.25 miles west of the PUREX storage tunnels, in similar subsurface materials.

Original Tunnel 2 Construction Photograph. Original strip footings 6 feet wide cast against undisturbed earth.





Subsurface Properties:
From construction photos, undisturbed earth appears to be dense fluvial/glaciofluvial deposits of the Hanford Formation. Excavation walls stand vertical to near vertical in many places, with some ravelling to angle of repose. There is no apparent shoring used. There is neither groundwater nor dewatering infrastructure visible, and groundwater is noted to be deep at the PUREX facility. Photos of footing subgrade are not available. It is assumed that the material beneath the footings is similar to the material visible at and above the footings. Ravelling may be due to loss of apparent coehsion due to negative pore pressure in moist soils, or may be attributed to natural cementation. Properties assumed herein should be checked against available geologic literature and available geotechnical studies in similar materials, if available.

$\phi := 34deg$ Internal friction angle, from 1984 Dames and Moore Report

$c := 0psf$ Effective stress cohesion, from 1984 Dames and Moore Report

$\gamma_{moist} := 125pcf$ Assumed average moist unit weight of in-situ soils.

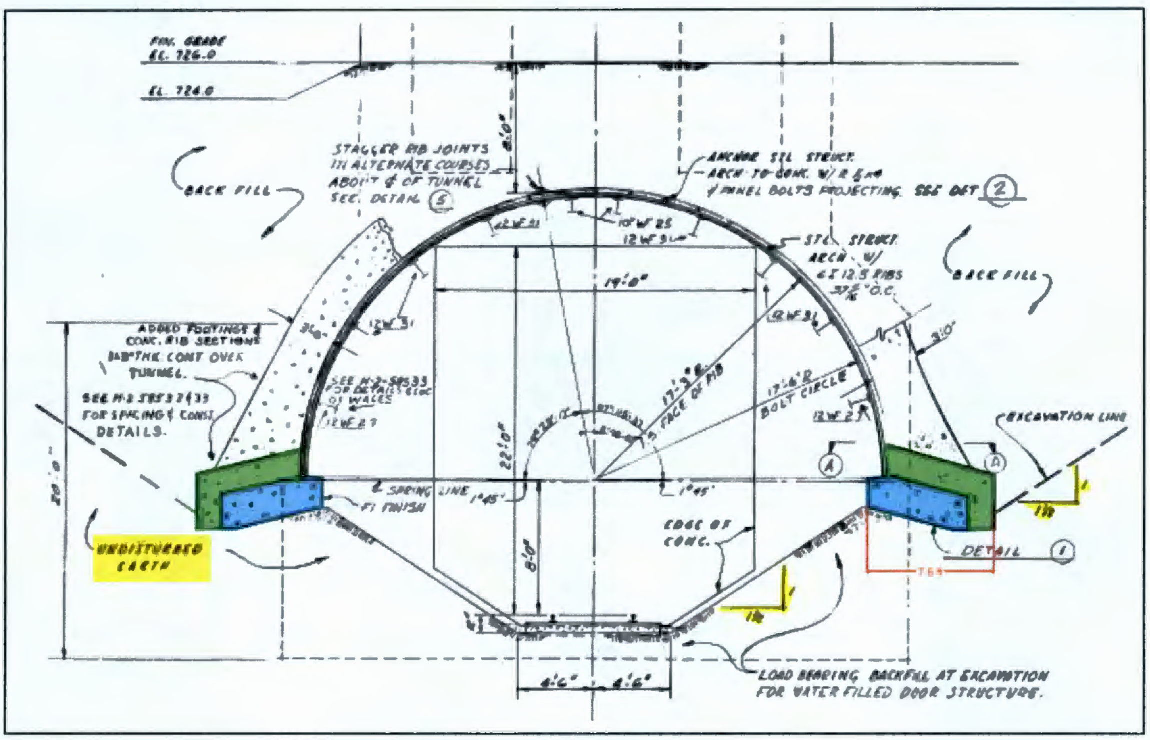
$\gamma_{water} := 62.4pcf$ Unit weight of water.

2.0 Subsurface Profile

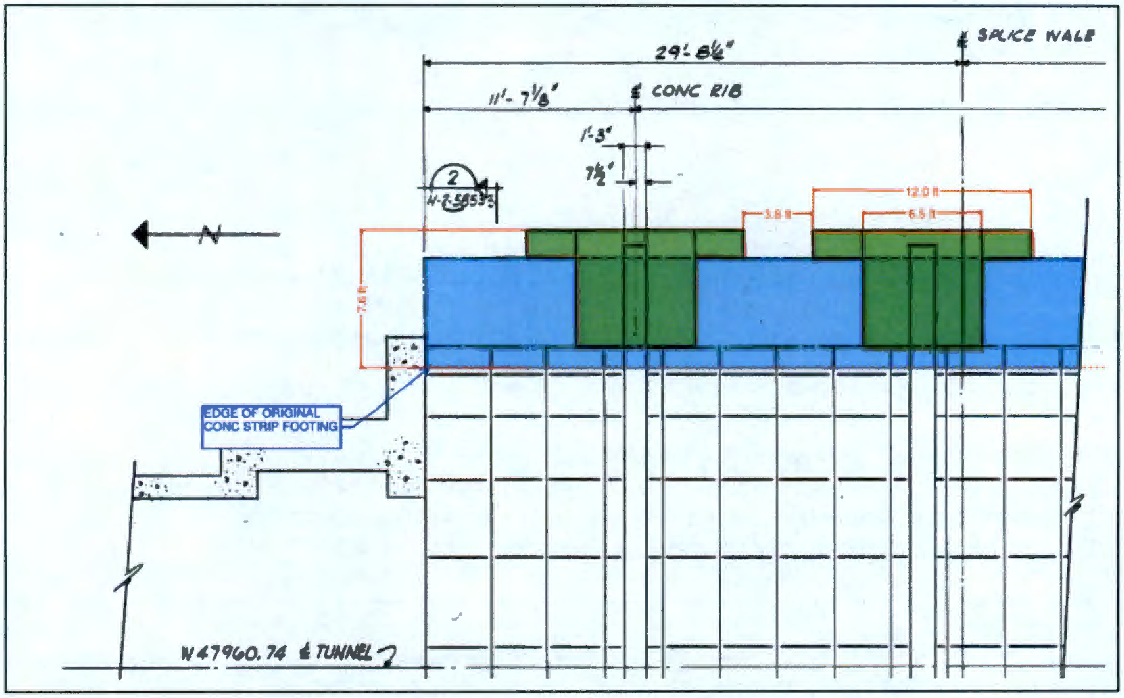
The subsurface profile is assumed to be uniform within the depths of stress influence beneath the footings.
The drawings indicate that footings were to be cast against undisturbed earth, this is assumed to be the case.
Groundwater is assumed to be significantly deeper than the footings, and total stresses are equal to effective stresses.

3.0 Footing Geometry

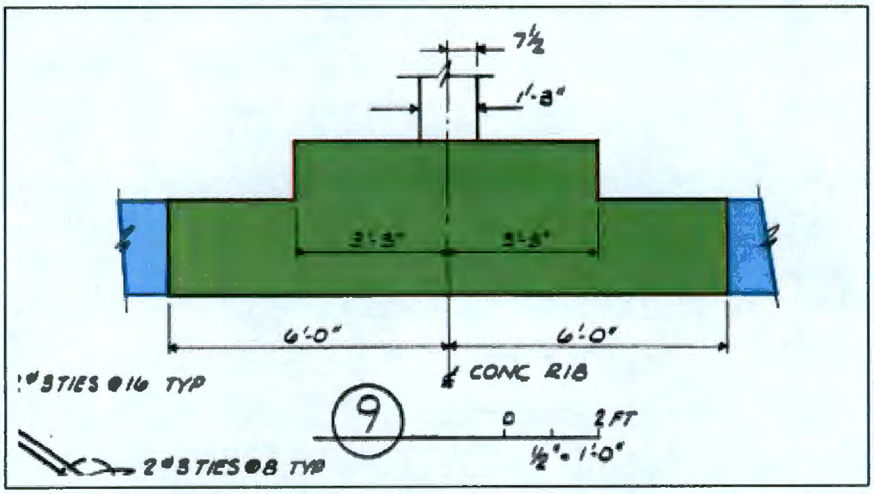
The footings for Tunnel 2 consist of two parallel strip footings.
The footings were initally constructed as strip footings 6.0 feet wide as indicated in CYAN below, then later modified to include 12 foot wide arch support footings (indicated in GREEN below) at 15.8 foot center-to-center spacing.
For analysis footings are treated as individual footings at the spacing of the concrete ribs (15.8 feet)



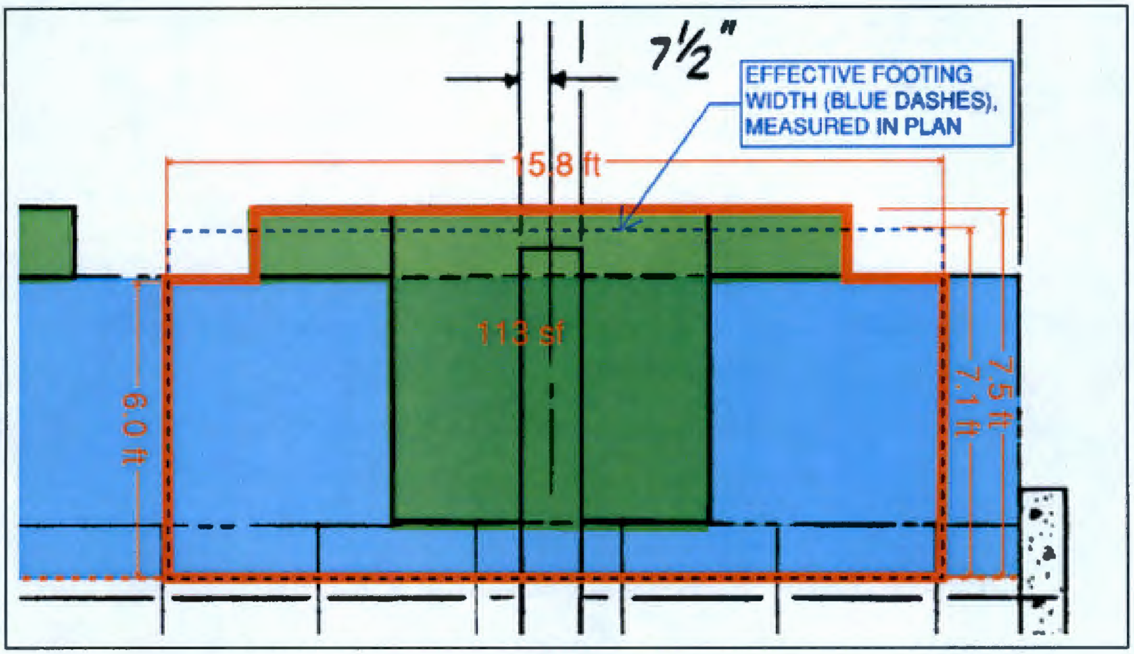
Typical Plan View of Footing (Original in CYAN, Modification in GREEN)



Profile View of Footing (Original in CYAN, Modification in GREEN):



4.0 Footing Geometry:

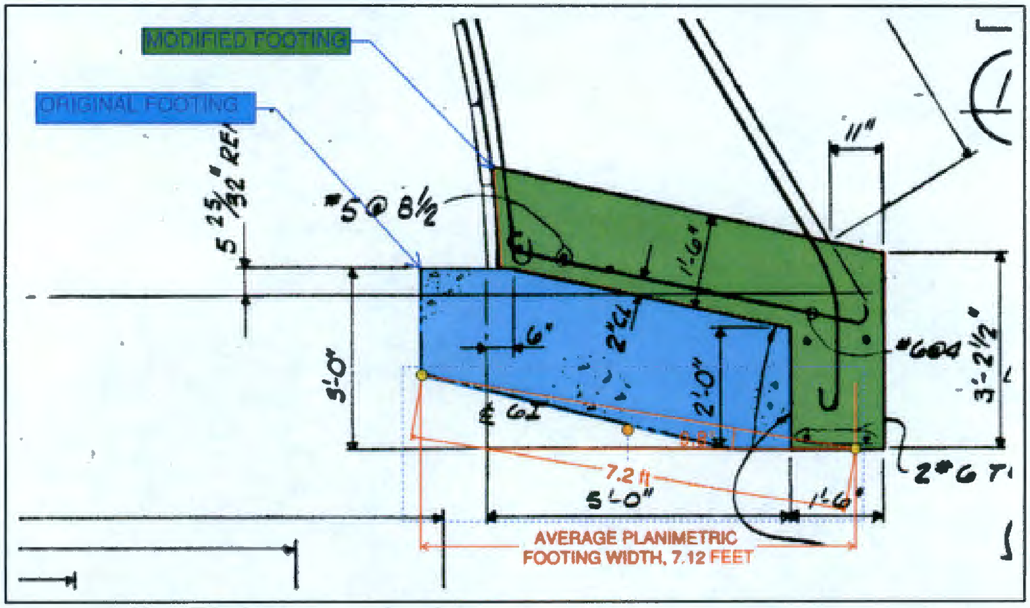


Due to irregular geometry of footing, determine average width by dividing representative footing area by the footing length. For Analysis, treat continuous footing as individual footings centered around concrete arch footings.

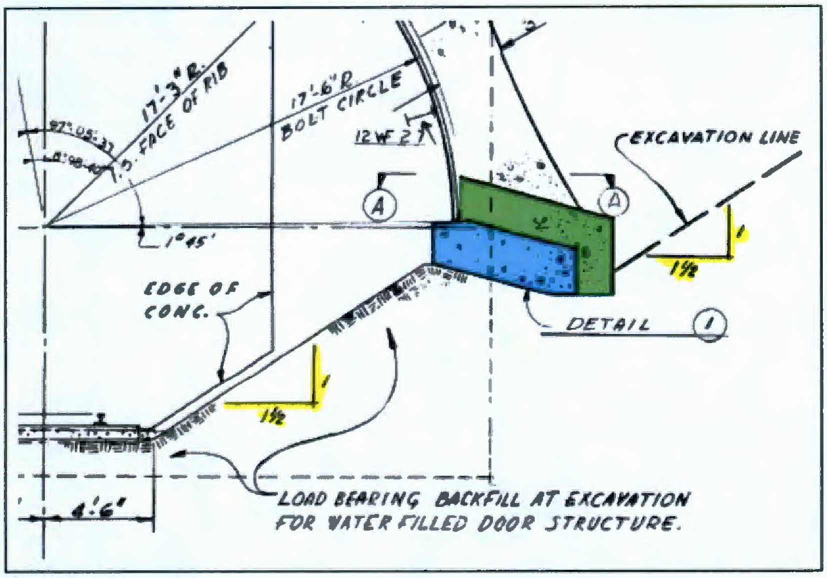
$$B_{ftg.avg} := \frac{112.5ft^2}{15.8ft} = 7.12\,ft$$

Planimetric average footing width

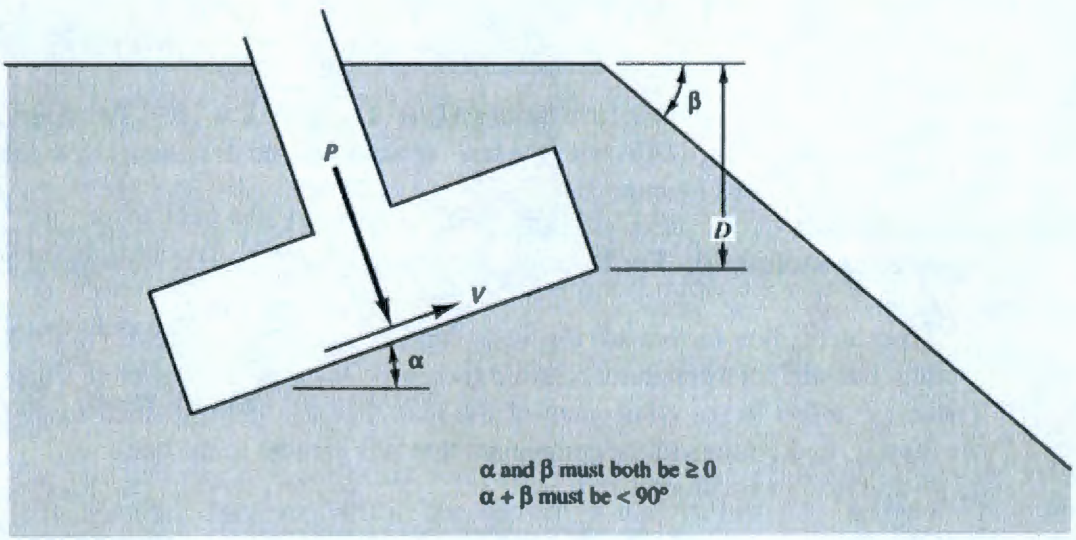
Actual footing surface is inclined convert planimentric average footing width to actual average footing width:



$\alpha := 10deg$	Footing inclination
$B_{ftg} := \frac{B_{ftg.avg}}{\cos(\alpha)} = 7.23\ ft$	Actual average footing width, measured along angle α
$L_{ftg} := 99999999999ft$	Footing length. Extended to represent 2-D plain strain conditions similar to SLIDE.
$\beta := atan\left(\frac{1}{1.5}\right) = 33.7 \cdot deg$	Slope inside tunnel is 1.5H:1V
$D_{ftg} := 0ft$	Footing depth
$\sigma_{zD} := D_{ftg} \cdot \gamma_{moist} = 0 \cdot psf$	In-situ vertical effective stress at depth, D



6.2 Estimate Bearing Capacity Using Vesic's Bearing Capacity Formula:



Footing Parameters for Vesic's Bearing Capacity Formula (adapted from Coduto (2001) Figure 6.8).

Function to calculate ultimate bearing capacity using Vesic's factors:

$$q_{ult} := c \cdot N_c \cdot s_c \cdot d_c \cdot i_c \cdot b_c \cdot g_c + \sigma_{zD}(D_{ftg}) \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot b_q \cdot g_q + 0.5 \cdot \gamma \cdot B \cdot N_\gamma \cdot s_\gamma \cdot d_\gamma \cdot i_\gamma \cdot b_\gamma \cdot g_\gamma$$

where: s_c, s_q, s_γ = shape factors
d_c, d_q, d_γ = depth factors
i_c, i_q, i_γ = load inclination factors
b_c, b_q, b_γ = base inclination factors
g_c, g_q, g_γ = ground inclination factors

Vesic's Bearing Capacity Factors:

$$N_q := e^{\pi \tan(\phi)} \tan\left(45 \cdot deg + \frac{\phi}{2}\right)^2 \qquad N_q = 29.44$$

$$N_c := \begin{cases} 5.14 & \text{if } \phi = 0 \\ \dfrac{N_q - 1}{\tan(\phi)} & \text{otherwise} \end{cases} \qquad N_c = 42.164$$

$$N_\gamma := 2\left(N_q + 1\right)\tan(\phi) \qquad N_\gamma = 41.064$$

Vesic's Footing Shape Factors

$$s_c := 1.0 + \left(\frac{N_q}{N_c}\right)\left(\frac{B_{ftg}}{L_{ftg}}\right) \qquad s_c = 1$$

$$s_q := 1.0 + \left(\frac{B_{ftg}}{L_{ftg}}\right) \cdot \tan(\phi) \qquad s_q = 1$$

$$s_\gamma := 1.0 - 0.4 \cdot \left(\frac{B_{ftg}}{L_{ftg}}\right) \qquad s_\gamma = 1$$

Vesic's Depth Factors:

$$k\left(D_{ftg}\right) := \begin{cases} \dfrac{D_{ftg}}{B_{ftg}} & \text{if } \dfrac{D_{ftg}}{B_{ftg}} \le 1.0 \\ \operatorname{atan}\left(\dfrac{D_{ftg}}{B_{ftg}}\right) & \text{otherwise} \end{cases} \qquad D_{ftg} = 0 \cdot ft \qquad k\left(D_{ftg}\right) = 0$$

$$d_c := 1 + 0.4 \cdot k\left(D_{ftg}\right) \qquad d_c = 1$$

$$d_q := 1 + 2 \cdot \tan(\phi) \cdot (1 - \sin(\phi))^2 \cdot k\left(D_{ftg}\right) \qquad d_q = 1$$

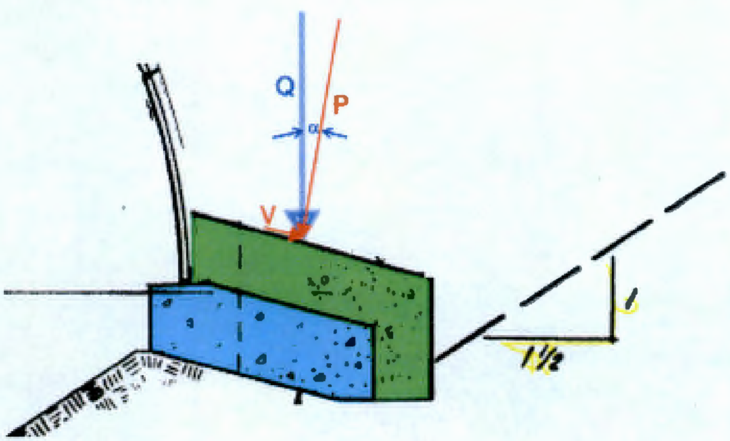
$$d_\gamma := 1.00 \quad \text{for all } \phi \qquad d_\gamma = 1$$

Vesic's Load Inclination Factors:

$Q := 400000lbf$ — Total footing load, magnitude is not relevant, used only to establish ratio of normal to shear forces in calculation of "i" factors below.

$V := 0lbf \qquad P := Q$ — For comparision, consider that load is vertical only.

$A := B_{ftg} \cdot L_{ftg}$ — Base area of footing



$$m := \frac{2 + \frac{B_{ftg}}{L_{ftg}}}{1 + \frac{B_{ftg}}{L_{ftg}}} = 2$$

For load inclination transverse to axis of tunnel

$$i_q := \left(1 - \frac{V}{P + \frac{A \cdot c}{\tan(\phi)}}\right)^m \qquad i_q = 1$$

$$i_\gamma := \left(1 - \frac{V}{P + \frac{A \cdot c}{\tan(\phi)}}\right)^{m+1} \qquad i_\gamma = 1$$

$$i_c := i_q - \left(\frac{1 - i_q}{N_c \cdot \tan(\phi)}\right) \qquad i_c = 1$$

Ground Inclination Factors:

Vesic's factors for accounting for inclined ground surface

$\beta = 33.7 \cdot deg$ $\qquad \frac{1}{\tan(\beta)} = 1.5$ $\qquad$ 1.5H:1V slope

$$g_c := 1 - \frac{\beta}{147deg} \qquad g_c = 0.771$$

$$g_q := (1 - \tan(\beta))^2 \qquad g_q = 0.111$$

$$g_\gamma := g_q \qquad g_\gamma = 0.111$$

Base Inclination Factors:

Vesic's factors for inclined base of footing.

$\alpha = 10 \cdot deg$ $\qquad$ Angle of inclination of base of footing.

$$b_c := 1 - \frac{\alpha}{147deg} \qquad b_c = 0.932$$

$$b_q := \left(1 - \frac{\alpha \cdot \tan(\phi)}{57deg}\right)^2 \qquad b_q = 0.777$$

$$b_\gamma := b_q \qquad b_\gamma = 0.777$$

Estimate Ultimate and Allowable Bearing Capacity Using Vesic's Extended Bearing Capacity Equation:

$$q_{ult.vesic} := c \cdot N_c \cdot s_c \cdot d_c \cdot i_c \cdot b_c \cdot g_c + \sigma_{zD} \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot b_q \cdot g_q + 0.5 \cdot \gamma_{moist} \cdot B_{ftg} \cdot N_\gamma \cdot s_\gamma \cdot d_\gamma \cdot i_\gamma \cdot b_\gamma \cdot g_\gamma$$

$c = 0 \cdot psf$	$\sigma_{zD} = 0 \cdot psf$	$\gamma_{moist} = 125 \cdot pcf$	$B_{ftg} = 7.23\ ft$
$N_c = 42.164$	$N_q = 29.44$	$N_\gamma = 41.064$	
$s_c = 1$	$s_q = 1$	$s_\gamma = 1$	
$d_c = 1$	$d_q = 1$	$d_\gamma = 1$	
$i_c = 1$	$i_q = 1$	$i_\gamma = 1$	
$b_c = 0.932$	$b_q = 0.777$	$b_\gamma = 0.777$	
$g_c = 0.771$	$g_q = 0.111$	$g_\gamma = 0.111$	

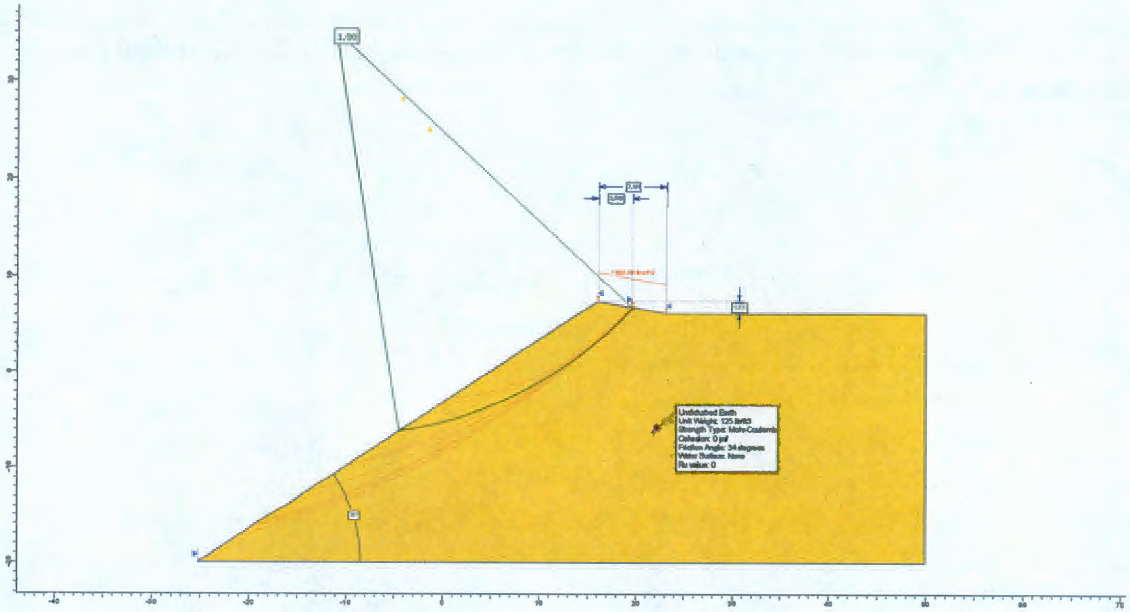
$q_{ult.vesic} = 1603 \cdot psf$ Ultimate Bearing Capacity (FS=1.0)

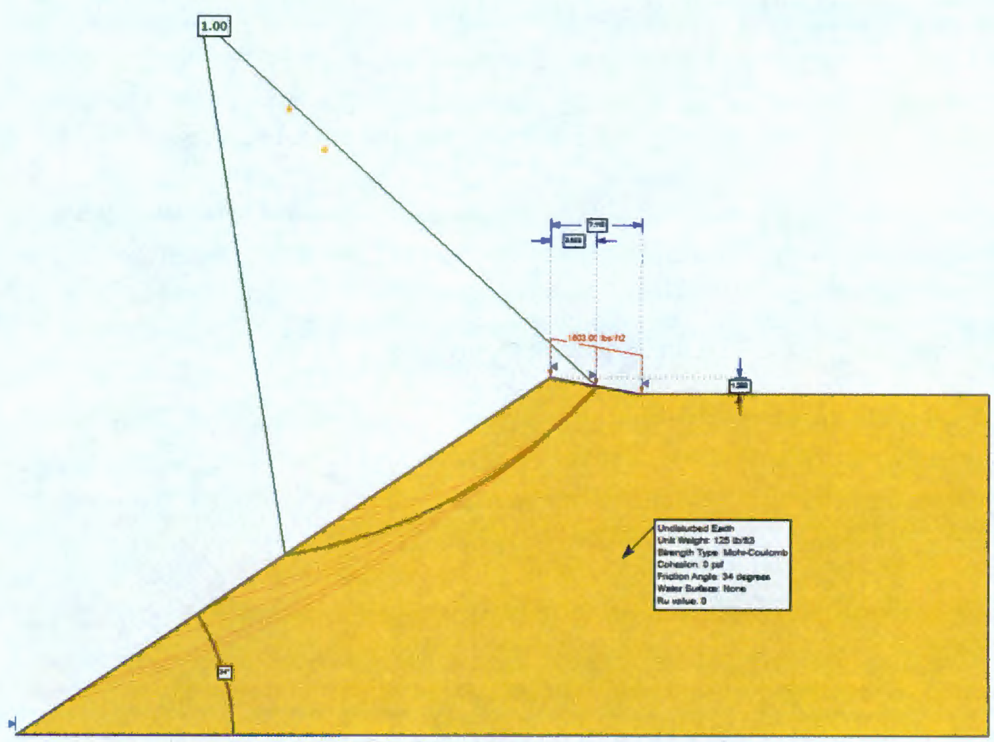
$FS := 3$ factor of safety recommended for bearing capacity. Higher FS may be justified considering the poorly-defined subsurface conditions and the consequences of failure

$q_{allow.vesic} := \frac{q_{ult.vesic}}{FS} = 534 \cdot psf$ Allowable Bearing Capacity for noted Factor of Safety

Check using SLIDE 2-D Limit Equilibrium Analysis:

Simplified Geometry Used in SLIDE to Compare to Vesic:


1.00


1.00
1603.00 lbs/ft2
Undisturbed Earth
Unit Weight: 125 lb/ft3
Strength Type: Mohr-Coulomb
Cohesion: 0 psf
Friction Angle: 34 degrees
Water Surface: None
Ru value: 0

$q_{ult.SLIDE} := 1603psf$ for FS = 1.0

Comparison of Vesic's method, used herein, and 2D Limit Equilibrium Method in SLIDE produces identical results for simila loading adjacent to sloping ground surface. Within SLIDE, Spencer's method was used, along with a unit weight of 125 pcf, an internal friction angle of 34 degrees, a cohesion of 0 psf, vertical footing stresses, footing inclination of 10 degrees, and a slope angle of 1.5H:1V as shown in the attached screen captures. It was found necessary to move the slope limits to a distance of B/2 to produce identical results.

Through this exercise, it is concluded that SLIDE is an acceptable tool for evaluating bearing capacity of footings, and can b used to account for the complex geometry of Tunnel 2.

END OF CALCULATION

Tunnel 2 Soil Loading

Estimated Actual Bearing Pressure on Footings

Spot Check Soil Prism Geometry to Confirm Soil Loading

γ_{moist}	110	pcf
Snow Load	15	psf
Footing Width	7.5	feet

Moist unit weight expected to vary between 105 and 115pcf

STA	Footing	Soil Volume per LF (FT^3)	Soil Weight (LB)	Snow Load Width (feet)	Snow Load (LB)	Total Vertical Load on Footing (SOIL + SNOW)	Estimated Bearing Pressure (PSF)
3+32	Left (East)	377	41470	24.5	367.5	41837.5	5578
3+32	Right (West)	329	36190	24.5	367.5	36557.5	4874
6+00	Left (East)	342	37620	24.5	367.5	37987.5	5065
6+00	Right (West)	337	37070	24.5	367.5	37437.5	4992
7+00	Left (East)	344	37840	24.5	367.5	38207.5	5094
7+00	Right (West)	338	37180	24.5	367.5	37547.5	5006
10+00	Left (East)	334	36740	24.5	367.5	37107.5	4948
10+00	Right (West)	344	37840	24.5	367.5	38207.5	5094
14+00	Left (East)	326	35860	24.5	367.5	36227.5	4830
14+00	Right (West)	312	34320	24.5	367.5	34687.5	4625
20+00	Left (East)	352	38720	24.5	367.5	39087.5	5212
20+00	Right (West)	334	36740	24.5	367.5	37107.5	4948
						MIN	**4625**
						AVG	**5022**
						MAX	**5578**

NOTES:

Does not include weight of structure

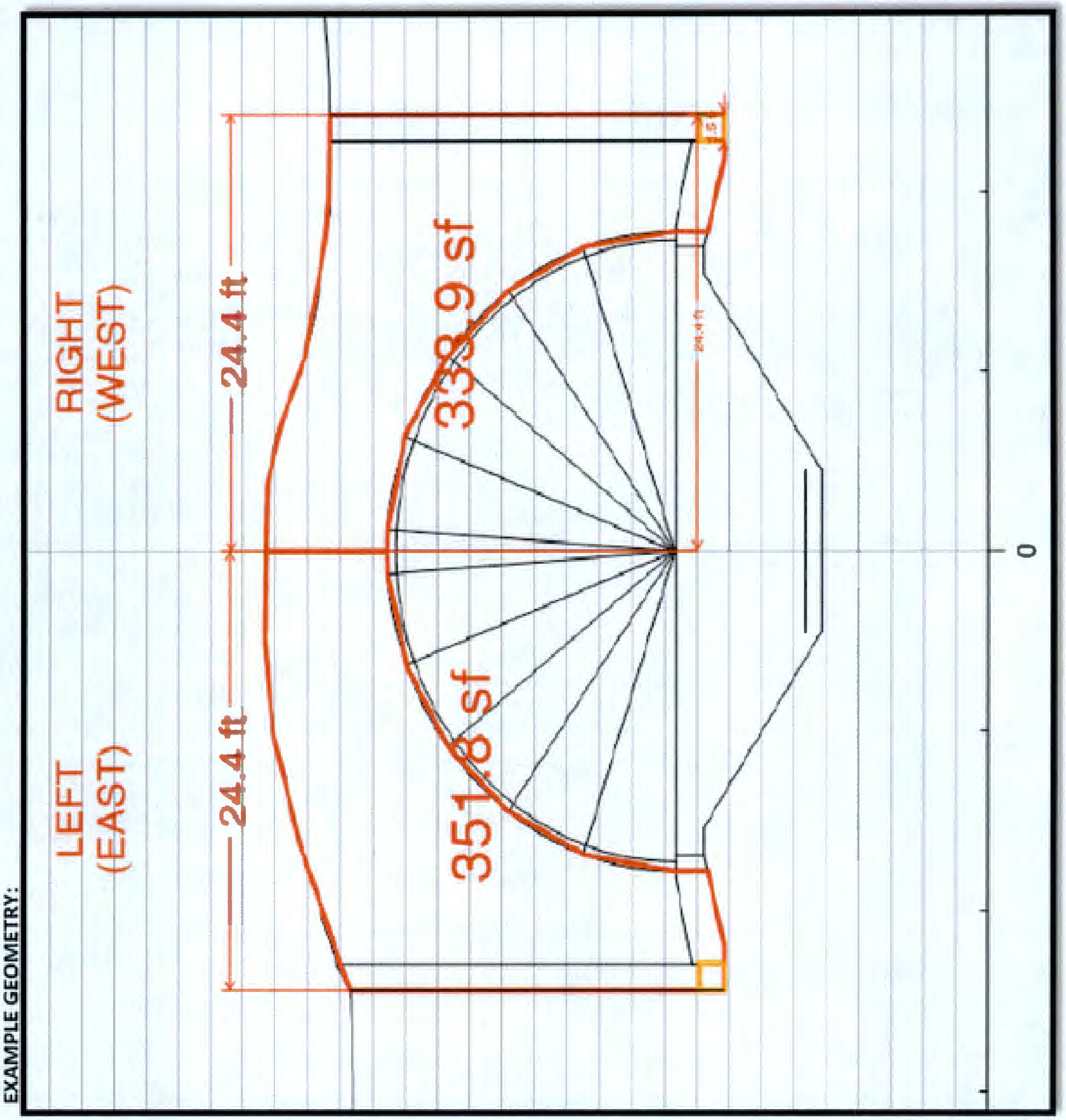
Does not include weight of concrete footing

Assumes vertical projection of soil over footing as shown

View in cross sections is looking down-station, left side is east of centerline, right side is west of centerline

This is not a comparison against expected ultimate or allowable bearing pressures

CHPRC-03365, REV. 0



Tunnel No. 2 Bearing Pressure Evalutation:

Maximum Bearing Pressure is approximately 5600 psf, as interpreted from 2008 LIDAR topography and design tunnel geometry.
Bearing Pressure estimated as weight Tunnel 2 cover soil, using unit weight of soil of 110 pcf, snow load of 15 psf, footing width of 7.5 feet.
Bearing pressure assumed to act vertically.
Weight of structure and concrete footing not included.
Actual bearing pressures may vary.

Shear strength of Upper Hanford Formation and Hanford Formation from Shannon and Wilson (2015):

TABLE 1
INTERPRETED RANGE OF ENGINEERING SOIL PARAMETERS

Geologic Formation	General Material Description[1]	Moist Unit Weight[2], γ (pcf)	Shear Strength, τ		Modulus of Subgrade Reaction[2], k_s (pci)	Young's Modulus[2], E (ksi)
			Internal Friction Angle[2], ϕ (deg)	Cohesion[2], C (psf)		
Dune sand/ Upper Hanford Formation	Loose to medium dense, trace silt to silty fine to medium SAND to fine sandy SILT	115 – 130	32 – 37	0	100 – 400 (200)	1.5 – 3.5
Hanford Formation	Loose to dense, silty to clean, sandy gravel and gravelly sand. Subangular to subrounded cobbles and boulders are common, as large as several feet in diameter.	120 – 130	38 – 54	0	400 – 1,600 (700 – 1,000)	10 – 25

Notes:
1. See the report text for an explanation of the geologic units, including more detailed discussion of the material descriptions. The Unified Soil Classification System (USCS) definitions are provided in Appendix B, Figure B-1.
2. The parameters above are based on index properties, laboratory tests, published correlations, testing from previous projects, and engineering judgment. Second line values in (), where provided, are recommended values. Please refer to the report text for additional information.
deg – degrees; ft = foot; ksi = kips per square inch; pcf = pounds per cubic foot; pci = pounds per cubic inch; psf = pounds per square foot

Recommended Geotechnical Properties for PUREX Site from Dames and Moore (1984):

- o angle of internal friction (Ø) = 34 degrees
- o cohesion (C) = 0 psf
- o mass density (γ) = 110 pcf

Internal Friction Angle, ϕ' (deg)	Cohesion, c' (psf)	Unit Weight of Soil, γ_m (psf)	Applied Bearing Pressure, q (psf)	Factor of Safety	
32	0	125	5600	0.8	Minimum soil strength for Upper Hanford Formation from Shannon and Wilson (2015)
34	0	125	5600	0.9	Soil properties from Dames & Moore (1984)
37	0	125	5600	1.0	Maximum soil strength for Upper Hanford Formation from Shannon and Wilson (2015)
38	0	125	5600	1.0	Minimum soil strength for Hanford Formation described by Shannon and Wilson (2015)
40	0	125	5600	1.1	
42	0	125	5600	1.2	
44	0	125	5600	1.3	
46	0	125	5600	1.3	Midpoint of range for Hanford Formation described by Shannon and Wilson (2015)
48	0	125	5600	1.4	
50	0	125	5600	1.5	
52	0	125	5600	1.7	
54	0	125	5600	1.8	Maximum soil strength for Hanford Formation described by Shannon and Wilson (2015)

SLIDE has been calibrated against Vesic's method to verify similar results, SLIDE is utilized for bearing capacity evaluation in this case due to it's ability to incorporate irregular geometry of slopes and footings. The 2D limit equilibrium approach used by slide is appropriate considering the length of the tunnel (very closely approximates plane-strain conditions)

Tunnel 2 has not failed, and has not shown evidence of foundation distress.

Shear strength of subgrade is uncertain.

Shear strength estimate provided by Dames and Moore (1984) for PUREX Process Facility Mods project indicates inadequate bearing capacity (FS=0.87) under expected loading.

Range of strenghts provided by Shannon and Wilson (2015) for Hanford Formation result in ultimate bearing capacity factors of safety greater than unity.

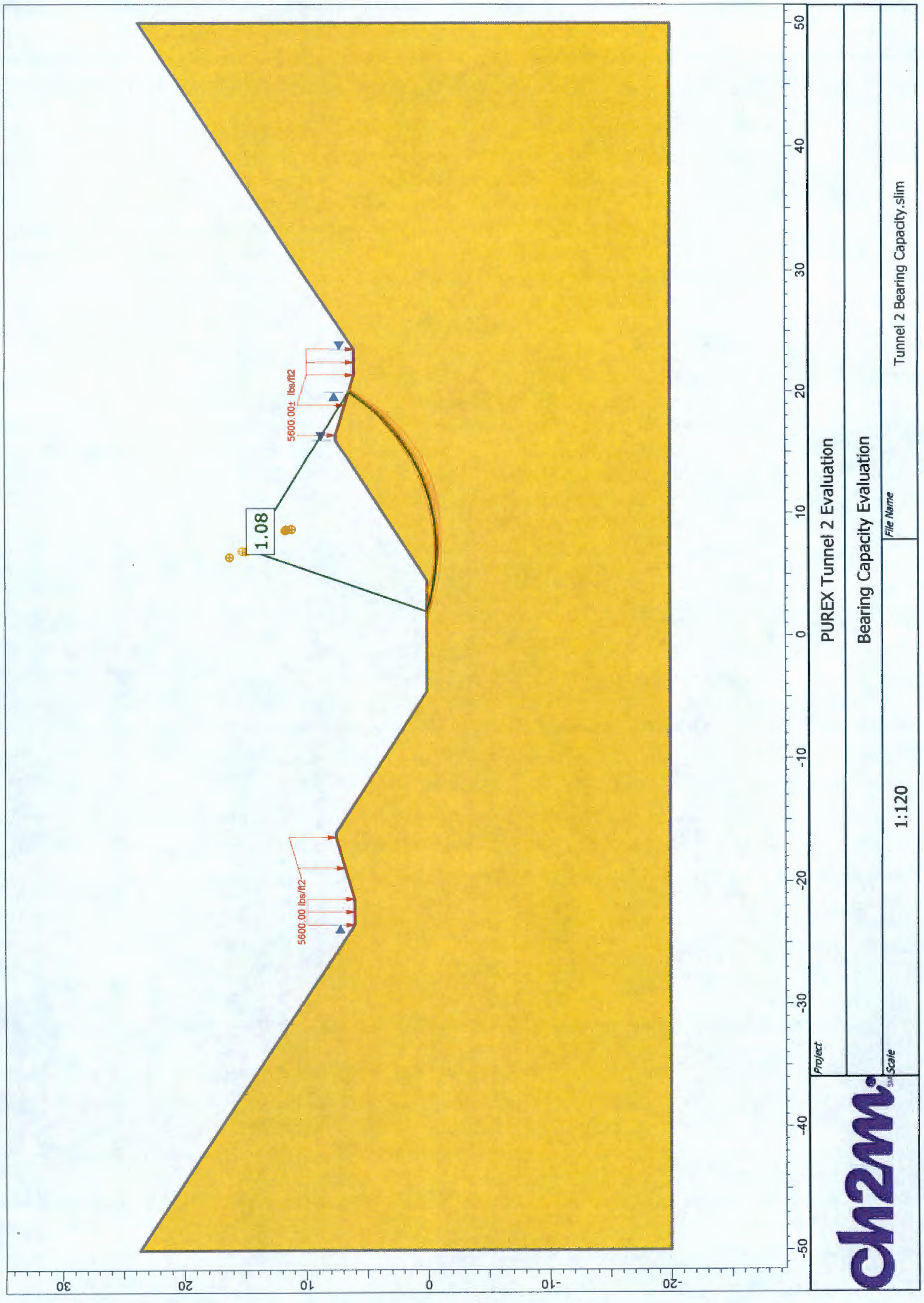
It is assumed that the bearing capacity of the existing footings has a factor of safety of at least 1.1

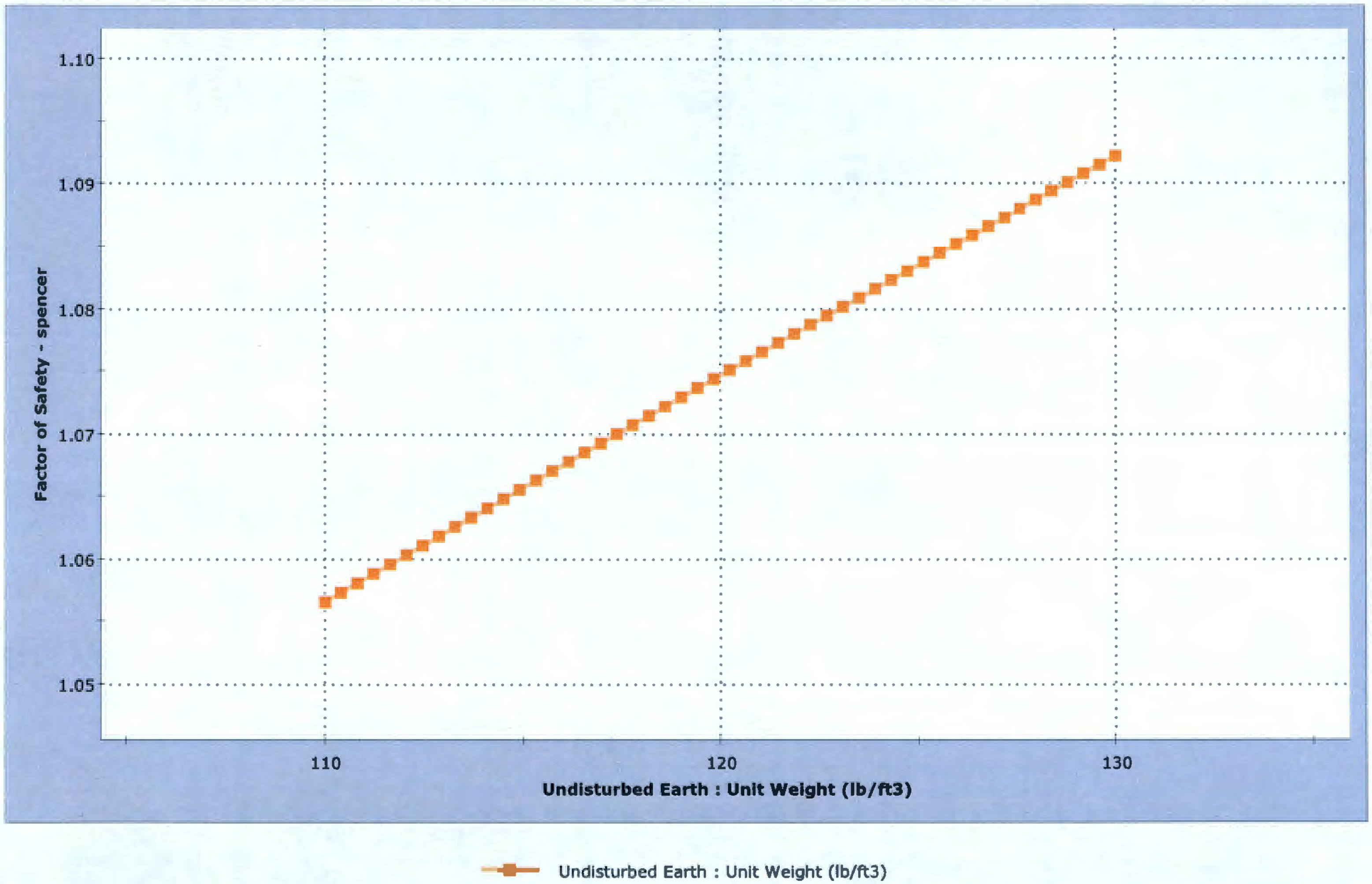
Subgrade soils with a unit weight of 125 pcf, a friction angle of 40 degrees, and a cohesion of 0 provide this factor of safety.

These geotechnical properties are within the range of recommended strengths provided by Shannon and Wilson (2015)

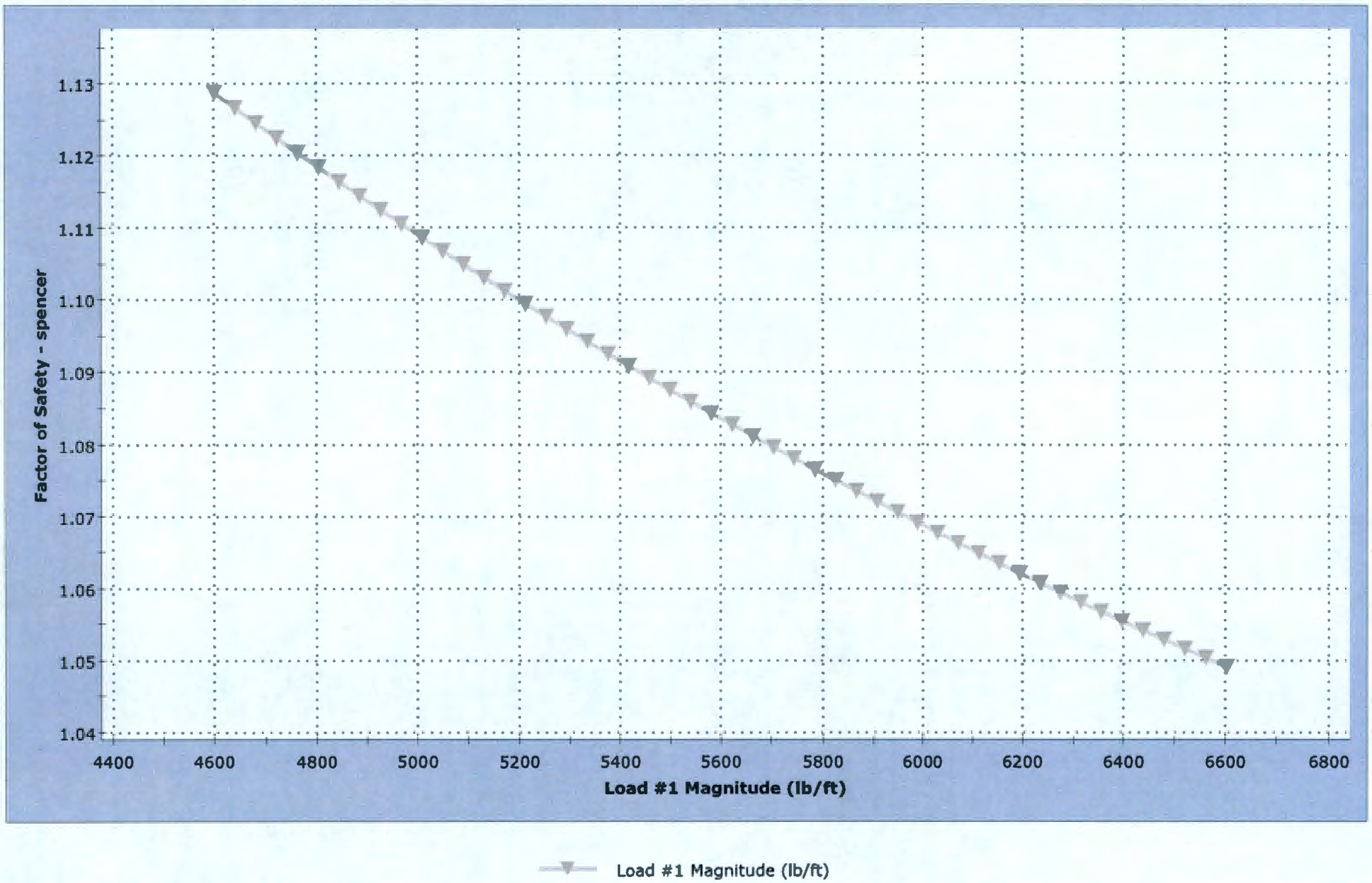
Factors of safety of 3.0 are commonly used in geotechnical practice for development of allowable bearing pressures for footings, higher factors of safety may be justified commensurate with uncertainty in subsurface conditions and consequences of failure.

The estimated factor of safety using the upper end of the shear strengh properties provided by Shannon and Wilson (2015) gives a factor of safety of 1.8 for the expected in-situ loading condition.

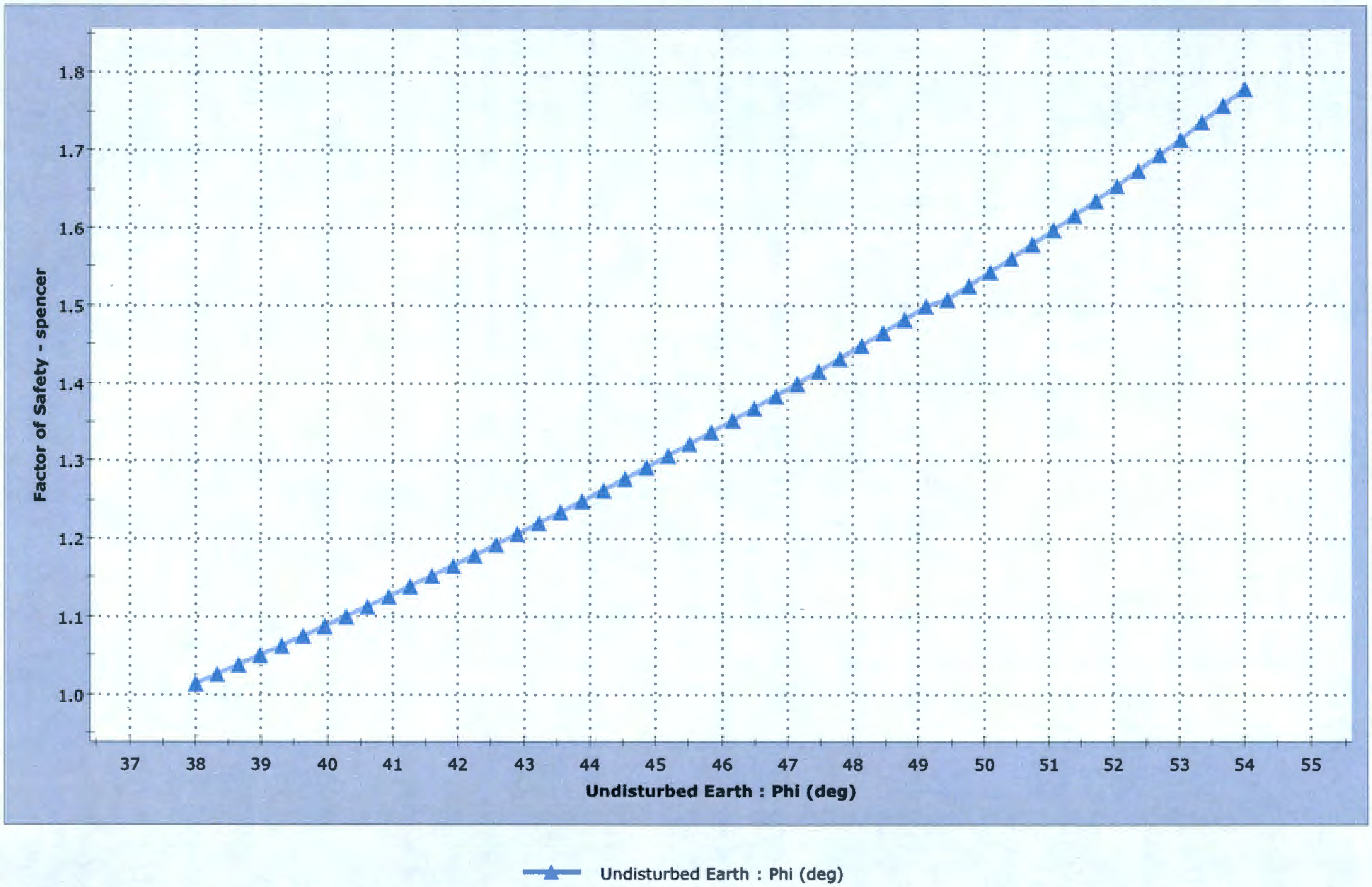

1.08
5600.00± lbs/ft2
5600.00 lbs/ft2
Project
PUREX Tunnel 2 Evaluation
Bearing Capacity Evaluation
Scale
1:120
File Name
Tunnel 2 Bearing Capacity.slim



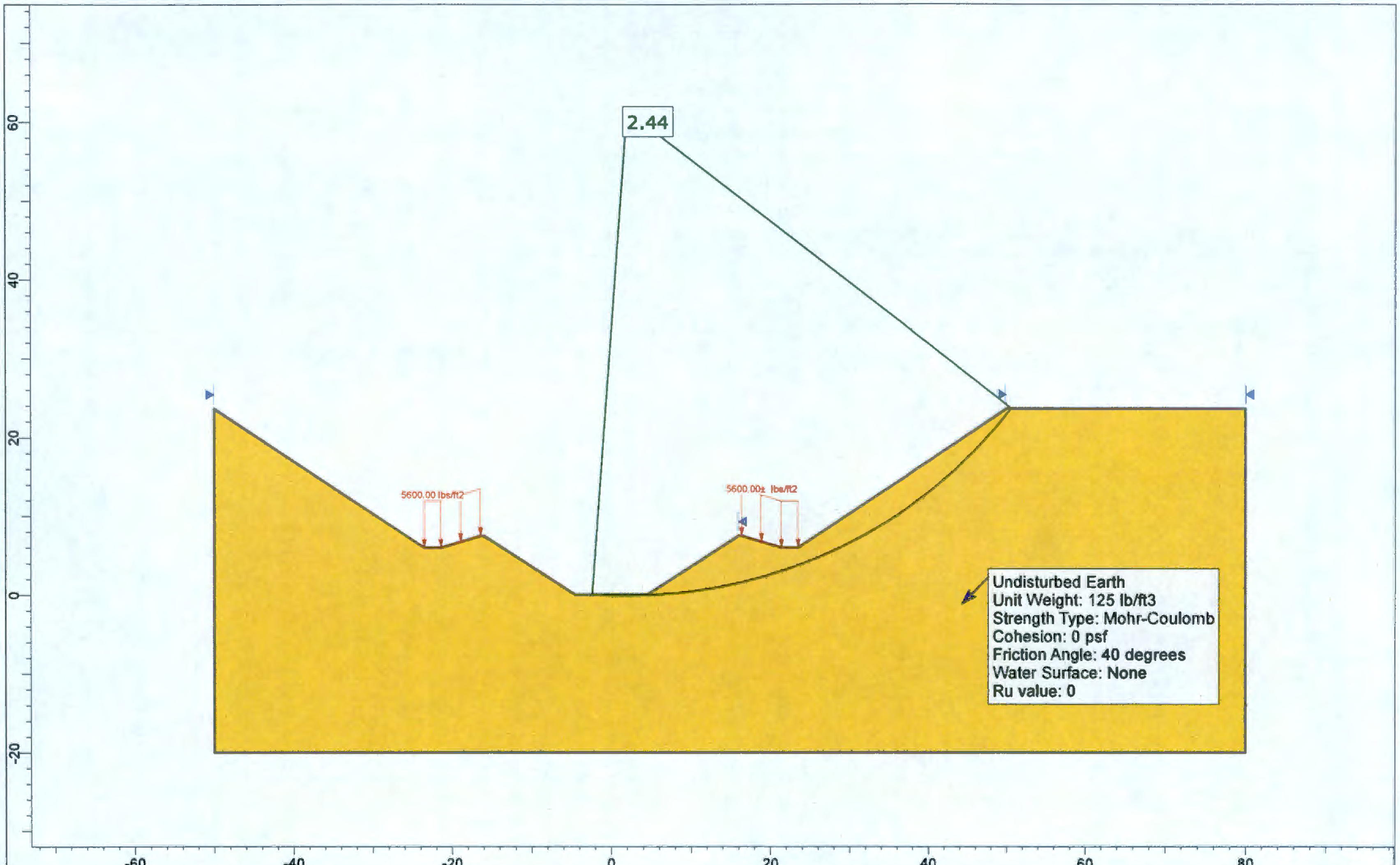
ch2m	Project: PUREX Tunnel 2 Evaluation	
	Bearing Capacity Evaluation	
	Scale	File Name: Tunnel 2 Bearing Capacity.slim



ch2m	Project	PUREX Tunnel 2 Evaluation
		Bearing Capacity Evaluation
	Scale	File Name: Tunnel 2 Bearing Capacity.slim



ch2m	Project: PUREX Tunnel 2 Evaluation	
	Bearing Capacity Evaluation	
	Scale	File Name: Tunnel 2 Bearing Capacity.slim



ch2m	*Project*	
	PUREX Tunnel 2 Evaluation	
	Global Stability Check	
	Scale 1:200	*File Name* Tunnel 2 Global Stability.slim

PUREX STORAGE TUNNELS
CHAPTER 11.0
CLOSURE AND FINANCIAL ASSURANCE

CHANGE CONTROL LOG

Change Control Logs ensure that changes to this unit are performed in a methodical, controlled, coordinated, and transparent manner. Each unit addendum will have its own change control log with a modification history table. The "**Modification Number**" represents Ecology's method for tracking the different versions of the permit. This log will serve as an up to date record of modifications and version history of the unit.

Modification History Table

Modification Date	Modification Number
10/2006	

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CHAPTER 11.0
CLOSURE AND FINANCIAL ASSURANCE

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CHAPTER 11.0
CLOSURE AND FINANCIAL ASSURANCE

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TABLES

FIGURES

11.0 CLOSURE AND FINANCIAL ASSURANCE

This addendum details closure activities for the Plutonium Uranium Extraction (PUREX) Storage Tunnels Operating Unit Group 2. This Operating Unit Group consists of Tunnel Number 1 and Tunnel Number 2 dangerous waste management units (DWMUs).

11.1 Introduction

The PUREX Storage Tunnels are permitted and managed as *Resource Conservation and Recovery Act of 1976* (RCRA) miscellaneous units; however, the tunnels are no longer in active operation. In May 2017, workers discovered a portion of Tunnel Number 1 had collapsed, prompting an immediate response action to protect workers and the environment. A structural evaluation revealed the threat of further failure of Tunnel Number 1. An interim stabilization measure to fill Tunnel Number 1 with engineered grout was taken under Section J.4.5 of the PUREX Tunnels Contingency Plan and Permit Condition III.2.A.1 of the Hanford Facility RCRA Permit. Grouting in Tunnel Number 1 was completed in November 2017. Filling the tunnel void spaces with grout improved tunnel stability, provided additional radiological protection, and increased durability while not precluding final closure actions. Tunnel Number 1 will receive no new waste and will continue to store the existing encapsulated waste until final closure.

At the same time, a structural evaluation also revealed the threat of future failure of Tunnel Number 2. To protect stored waste containers from potential damage caused by a tunnel failure event (e.g., puncture of a container by a falling structural member) and to prevent any associated release of dangerous waste constituents to the environment, an interim closure action to cover the stored waste and fill Tunnel Number 2 void spaces around the waste with engineered grout is being taken. No waste has been added to Tunnel Number 2 since 1996 and no waste will be added or removed, nor will personnel entry be permitted prior to grouting because of the threat of structural failure. Following implementation of the interim closure action, Tunnel Number 2 will store encapsulated waste until final closure.

Interim closure activities will ensure safe storage of dangerous waste until final closure can be completed. The response action to grout Tunnel Number 1 serves as the interim closure action for Tunnel Number 1 and is described in Section 11.5.5. Interim closure of Tunnel Number 2 will be completed in accordance with the activities described in Section 11.5.6. Following completion of the interim closure activities, an extended closure period will commence and the tunnels will be monitored and maintained until final closure. Final closure activities will be completed concurrent with remediation of the PUREX Plant as described in Section 11.6.

11.2 Facility Contact Information

PUREX Operator and Property Owner:
Doug S. Shoop, Manager
U.S. Department of Energy, Richland Operations Office
P.O. Box 550
Richland, WA 99352
(509) 376-7395

PUREX Co-Operator:
L. Ty Blackford, President and Chief Executive Officer
CH2M HILL Plateau Remediation Company
P.O. Box 1600
Richland, WA 99352
(509) 373-0293

11.3 Facility Description

The PUREX Plant is located in the southeast portion of the 200 East Area. The PUREX Plant was used for the recovery of uranium and plutonium from irradiated reactor fuel. The PUREX Plant was built in 1956 and operated until 1972. It was restarted in 1983 and operated until 1989.

The PUREX Storage Tunnels are permitted as miscellaneous units under WAC 173-303-680, but are no longer in active operation and comprise Closing Unit Group 19.

Both tunnels are planned for closure, and no new waste will be accepted for placement into the tunnels.

PUREX Tunnel Number 1. Construction of PUREX Storage Tunnel Number 1 was completed in 1956. Tunnel Number 1 is approximately 5.8 meters (19 feet) wide by 6.7 meters (22 feet) high by 109 meters (358 feet) long and provides storage space for eight railcars. The maximum process design capacity for storage in Tunnel Number 1 is approximately 4,129 cubic meters (5,400 cubic yards). The tunnel experienced a partial roof collapse in May 2017. An interim stabilization was taken, and the tunnel was filled with grout in October and November 2017.

PUREX Tunnel Number 2. Construction of PUREX Storage Tunnel Number 2 was completed in 1964. The storage area of Tunnel Number 2 is approximately 5.8 meters (19 feet) wide by 6.7 meters (22 feet) high by 514.5 meters (1,688 feet) long and provides storage space for 40 railcars. The maximum process design capacity for storage in Tunnel Number 2 is approximately 19,878 cubic meters (26,000 cubic yards). Due to the potential of roof collapse, the tunnel will be interim closed by grout filling of the waste in 2018.

Diagrams of the layout of Tunnel Numbers 1 and 2 are shown in the PUREX Storage Tunnels Part A.

11.3.1 Maximum Waste Inventory

The PUREX Tunnels currently store eight railcars in Tunnel Number 1 and 28 railcars in Tunnel Number 2. The waste volume in Tunnel Number 1 is approximately 596 cubic meters (780 cubic yards). The waste volume in Tunnel Number 2 is approximately 2,204 cubic meters (2,883 cubic yards). This is the maximum waste inventory as no additional waste will be stored.

11.4 Closure Performance Standards

Closure performance standards for final closure of the PUREX Storage Tunnels will be based on WAC 173-303-610(2)(a)(i)-(iii), which requires closure of the facility in a manner that accomplishes the following objectives:

- Minimizes the need for further maintenance.
- Controls, minimizes, or eliminates to the extent necessary to protect human health and the environment, post-closure escape of dangerous waste, dangerous constituents, leachate, contaminated runoff, or dangerous waste decomposition products to the ground, surface water, groundwater, or the atmosphere.
- Returns the land to the appearance and use of surrounding land areas, to the degree possible, given the nature of the previous dangerous waste activity.

Annual surveillance of the PUREX Storage Tunnels will be conducted as described in Addendum I, *Inspection Requirements.* During the closure period until final closure activities are conducted, the miscellaneous unit performance standards identified in WAC 173-303-680(2)(b)(i) through (4), as required by WAC 173-303-610(2)(b), will apply. Compliance with these standards is addressed in Table 11.1.

11.4.1 Closure Decision

This closure plan describes interim closure actions through the filling of the PUREX Storage Tunnels DWMUs with grout. The final closure decision for the PUREX Tunnels DWMUs has not been made, and will be made together with the remedial actions decisions for the 200-CP-1 Operable Unit. There are two options for closure of the PUREX Tunnels:

1. Clean Closure. For more detailed description of clean closure of the PUREX Tunnels, see Section 11.6.1. Clean closure requires removal of all waste and confirmation of clean closure levels for the dangerous waste constituents. The grout will cure to a strength to provide structural support in less than 24 hours. After 28 days, the grout will have a minimum strength of 1200 to 2000 pounds per square inch and could be cut with a diamond wire saw or other technology to enable removal of the equipment. The clean closure levels will be adopted from the Record of Decision (ROD) for the 200-CP-1 Operable Unit.

2. Landfill Closure. For more detailed description of landfill closure of the PUREX Tunnels, see Section 11.6.2. Landfill closure leaves waste in place and requires that a final cover is constructed over the landfill. The cover design must meet the standards in WAC 173-303-806(4)(h)(v) and WAC 173-303-665(6)(a). In addition, the permittees must comply with all the post-closure requirements in WAC 173-303-665(6)(b).

It should be noted that the closure decision is made on a DWMU level. Thus, a different closure decision can be made for each of the PUREX Tunnels.

11.5 Interim Closure Activities

The following sections describe activities supporting closure of the PUREX Storage Tunnels.

11.5.1 Training Requirements

Training requirements are described in Hanford Facility RCRA Permit (WA7890008967), Attachment 5, *Hanford Facility Personnel Training Program*, and PUREX Storage Tunnels Addendum G, *Personnel Training.*

11.5.2 Security

Located within the 200 Area of the Hanford Facility, the PUREX Storage Tunnels must comply with access control and warning sign requirements pursuant to WAC 173-303-310. Hanford Facility access is controlled by 24-hour surveillance as described in the Hanford Facility RCRA Permit (WA7890008967) Attachment 3, *Security*, and PUREX Storage Tunnels Addendum E, *Security.*

11.5.3 Preparedness, Prevention, and Emergency Procedures

PUREX Storage Tunnels preparedness, prevention, and emergency procedures are described in Hanford Facility RCRA Permit (WA7890008967) Attachment 4, *Hanford Emergency Management Plan* (DOE/RL-94-02), and PUREX Storage Tunnels Addendum F, *Preparedness and Prevention.*

11.5.4 Inspections

To prevent threats to human health and the environment during the extended closure period, the PUREX Storage Tunnels will be inspected in accordance with WAC 173-303-320(2). Inspections will be performed as described in Addendum I, *Inspection Requirements*, until the final closure certification is approved by Ecology.

Table 11.1. WAC 173-303-680(2) through (4) Requirements

Requirement	Method of Compliance
(2) Environmental performance standards. A miscellaneous unit must be located, designed, constructed, operated, maintained, and closed in a manner that will ensure protection of human health and the environment. Permits for miscellaneous units are to contain such terms and provisions as necessary to protect human health and the environment, including, but not limited to, as appropriate, design and operating requirements, detection and monitoring requirements, and requirements for responses to releases of dangerous waste or dangerous constituents from the unit. Permit terms and provisions must include those requirements in WAC 173-303-630 through 173-303-670, 40 CFR Subparts AA through CC, which are incorporated by reference at WAC 173-303-690 through 173-303-692, WAC 173-303-800 through 173-303-806, 40 CFR, Part 63 Subpart EEE (which is incorporated by reference at WAC 173-400-075 (5)(a)), and 40 CFR, Part 146 that are appropriate for the miscellaneous units being permitted. Protection of human health and the environment includes, but is not limited to:	The PUREX Storage Tunnels will be managed and monitored in a manner that will ensure protection of human health and the environment.
(a) Prevention of any releases that may have adverse effects on human health or the environment due to migration of wastes constituents in the groundwater or subsurface environment, considering: (i) The volume and physical and chemical characteristics of the waste in the unit, including its potential for migration through soil, liners, or other containing structures; (ii) The hydrologic and geologic characteristics of the unit and the surrounding area; (iii) The existing quality of groundwater, including other sources of contamination and their cumulative impact on the groundwater; (iv) The quantity and direction of groundwater flow; (v) The proximity to and withdrawal rates of current and potential groundwater users; (vi) The patterns of land use in the region; (vii) The potential for deposition or migration of waste constituents into subsurface physical structures, and into the root zone of food-chain crops and other vegetation; (viii) The potential for health risks caused by human exposure to waste constituents; and (ix) The potential for damage to domestic animals, wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents.	The interim closure activity to grout the PUREX Storage Tunnels will prevent migration of dangerous waste constituents to the groundwater or subsurface environment below the tunnels during the extended closure period.
(b) Prevention of any release that may have adverse effects on human health or the environment due to migration of waste constituents in surface water, or wetlands or on the soil surface considering: (i) The volume and physical and chemical characteristics of the waste in the unit;	The interim closure activity to grout the PUREX Storage Tunnels will prevent migration of dangerous waste constituents to the soil under the

Table 11.1. WAC 173-303-680(2) through (4) Requirements

Requirement	Method of Compliance
(ii) The effectiveness and reliability of containing, confining, and collecting systems and structures in preventing migration; (iii) The hydrologic characteristics of the unit and the surrounding area, including the topography of the land around the unit (iv) The patterns of precipitation in the region; (v) The quantity, quality, and direction of groundwater flow; (vi) The proximity of the unit to surface waters; (vii) The current and potential uses of nearby surface waters and any water quality standards established for those surface waters; (viii) The existing quality of surface waters and surface soils, including other sources of contamination and their cumulative impact on surface waters and surface soils; (ix) The patterns of land use in the region; (x) The potential for health risks caused by human exposure to waste constituents; and (xi) The potential for damage to domestic animals, wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents.	tunnels. There are no surface waters or wetlands near the PUREX Storage Tunnels.
(c) Prevention of any release that may have adverse effects on human health or the environment due to migration of waste constituents in the air, considering: (i) The volume and physical and chemical characteristics of the waste in the unit, including its potential for the emission and dispersal of gases, aerosols and particulates; (ii) The effectiveness and reliability of systems and structures to reduce or prevent emissions of dangerous constituents to the air; (iii) The operating characteristics of the unit; (iv) The atmospheric, meteorologic, and topographic characteristics of the unit and the surrounding area; (v) The existing quality of the air, including other sources of contamination and their cumulative impact on the air; (vi) The potential for health risks caused by human exposure to waste constituents; and	The interim closure activity to grout the PUREX Storage Tunnels will prevent migration of dangerous waste constituents to the air outside of the tunnels. During grouting, contamination control methods, such as plastic sleeving, will be used when penetrations to the tunnel are opened. As the grout flows into placement locations, air will be displaced by the grout. Portable ventilation systems described in Sections 11.5.5.3.3 and 11.5.6.3 collect and filter the displaced air to prevent the spread of contamination to the environment.

Table 11.1. WAC 173-303-680(2) through (4) Requirements

Requirement	Method of Compliance
(vii) The potential for damage to domestic animals, wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents.	
(3) Monitoring, analysis, inspection, response, reporting, and corrective action. Monitoring, testing, analytical data, inspections, response, and reporting procedures and frequencies must ensure compliance with subsection (2) of this section, WAC 173-303-320, 173-303-340(1), 173-303-390, and 173-303-64620 as well as meet any additional requirements needed to protect human health and the environment as specified in the permit.	The stabilized tunnels will be maintained in a manner that prevents threats to human health and the environment and monitored through routine radiation surveillances, using radiation as an indication of contamination outside the stabilized tunnels. • Inspections required by WAC 173-303-320 are conducted as described in Addendum I. • Preparedness and Prevention measures required by WAC 173-303-340(1) are described in Addendum F. • Facility Reporting required by WAC 173-303-390 is met in accordance with Hanford Facility RCRA Permit Conditions I.E.22 and II.B. • There have been no releases from the PUREX Storage Tunnels subject to Corrective Action requirements from WAC 173-303-64620.
(4) Post-closure care. A miscellaneous unit that is a disposal unit must be maintained in a manner that complied with subsection (2) of this section during the post-closure care period. In addition, if a treatment or storage unit has contaminated soils or groundwater that cannot be completely removed or decontaminated during closure, then that unit must also meet the requirements of subsection (2) of this section during post-closure care. The post-closure plan under WAC 173-303-610(8) must specify the procedures that will be used to satisfy this requirement.	A post-closure plan will be developed if required depending on the final closure option selected.

11.5.5 Interim Closure of Tunnel Number 1

The response action to grout Tunnel Number 1 in accordance with Section J.4.5 of the PUREX Storage Tunnels Contingency Plan and Permit Condition III.2.A.1 of the Hanford Facility RCRA Permit serves as the interim closure action for Tunnel Number 1 and is described in the following sections. The tunnel will be monitored and maintained during an extended closure period until final closure. Final closure activities will be completed concurrent with remediation of the PUREX Plant as described in Section 11.6.

11.5.5.1 Interim Response Activities

On May 9, 2017, workers discovered a collapse in a portion of the Tunnel 1 wood timber roof structure resulting in a hole approximately 5.8 meters (19 feet) wide by 5.2 meters (17 feet) long. Immediate and follow-on actions included the following:

- The Emergency Operations Center was activated to manage the immediate response to the event, including response actions necessary to protect personnel (May 9).
- Informational notification was made to Ecology that the RCRA contingency plan was being implemented, although no evidence of release from the unit was found (May 9).
- Fifty-three truckloads of soil fill were placed through the roof opening at the collapsed area to provide contamination control, shielding, protection from ambient conditions, and stabilization of the tunnel support walls (May 10).
- A temporary protective cover was installed over the full length of Tunnel 1 (May 20).
- A 15-day report was prepared and submitted to Ecology in compliance with Permit Condition II.A.1 because the contingency plan was implemented (May 24).
- DOE notified Ecology of its plan to address the significant threat of further failure of Tunnel Number 1 by void filling the tunnel with grout (May 31).
- Ecology approved the plan to grout Tunnel Number 1 as an interim stabilization measure for the tunnel structure that will not preclude future closure or remedial decisions (June 8).
- Grouting was initiated on October 2 and completed on November 11.

The response action taken under the contingency plan performed the steps necessary to achieve interim closure of Tunnel Number 1. The response action stabilized contaminated equipment by filling the tunnel with engineered grout to improve tunnel stability, provide additional radiological protection, and increase durability while not precluding any final closure actions. The following sections describe the technical details of the response action taken for Tunnel Number 1.

11.5.5.2 Records Review

The structural evaluation conducted for Tunnel Number 1 reviewed tunnel drawings and specifications as well as structural properties of the tunnel components and adjacent soil. The structural evaluation is described in Chapter 4, *Process Information*, Appendix 4A. Tunnel inventory as described in Chapter 3, *Waste Analysis Plan*, was also reviewed to identify dangerous waste constituents within Tunnel Number 1.

11.5.5.3 Site Preparation and modifications made prior to stabilization

Figure 11.1 and Figure 11.2 show the layout and location for the grouting equipment in relation to Tunnel Number 1.The piping system for grout injection was placed at the location of the roof collapse. Two systems were provided, one servicing the south section of the tunnel (area from the location of the roof opening where fill soil was added to the southern end of the tunnel) and one servicing the north section. The individual pipes in each system were inserted into the top of the soil mound and routed underneath the existing roof timbers bordering each side of the collapsed roof area. The mechanism for insertion of the pipes was developed by mockup testing. Once the pipes were inserted, this area was backfilled with soil to provide a 4 foot (nominal) covering over the area. The existing 4-inch and 1.5-inch-diameter tunnel roof penetrations were used for camera and lighting placement.

11.5.5.3.1 Piping System

Figure 11.3, Figure 11.4, and Figure 11.5 illustrate detail for the piping systems. Two systems were required, one to service the north section of the tunnel and one for the south section. Each system consisted of the following:

- Two 8-inch steel pipes for grouting
- One 8-inch steel pipe for camera and lighting
- One 8-inch steel pipe for passive ventilation

Each individual pipe was inserted into a box embedded in the top of the fill soil mound and routed underneath the existing roof timbers. Pipe ends terminated into the internal space of each tunnel section.

Once all piping was placed, thrust blocks of concrete were placed in the boxes, and soil was backfilled over the area to a height of 4 feet (nominal) above the top of the exiting roof timbers. Additionally, concrete and grout were poured on the outside of the boxes to prevent the soil from collapsing into the tunnel. The vertical load of the pipe was supported by the soil mound.

11.5.5.3.2 Work Platform

A work platform was placed across the east/west centerline of collapsed roof section. The work platform facilitated the grouting operation, camera/light placement, and connection of the ventilation system. Figure 11.1 and Figure 11.2 show the placement of the work platform in relation to Tunnel Number 1. Figure 11.3 provides details of the work platform. The work platform met the following requirements:

- The platform was ground supported with 45-foot clear span and a 6-foot minimum wide working area.
- The platform was designed in accordance with the 2012 International Building Code (IBC) with a uniform live loading of 100 pounds per square foot with two 1,000-pound concentrated loads applied at midspan (one on each side of the platform).
- The platform was designed for end bearing condition based on 1,500 pounds per square foot allowable soil-bearing pressure.
- The platform included a guardrail system along each side designed in accordance with 2012 IBC provisions for non-public access with openings that prevent passage of a 21-inch-diameter sphere.

11.5.5.3.3 Ventilation System

Passive ventilation was provided during the grouting operation to control contamination in accordance with the Washington Department of Health License (EU 1471 NOC 1262 for Tunnel Number 1) conditions and limitations. Figure 11.6 shows details of the high-efficiency particulate air (HEPA) filter skid and assembly. The passive ventilation HEPA filter skids were located to one side of the tunnel berm and connected to the piping vent pipe with flex hose. Displaced air from the tunnel was routed via the vent pipe through a HEPA filter. Condensate from displaced air was collected prior to the inlet of the filter.

11.5.5.4 Stabilization activities

Grouting of Tunnel Number 1 was conducted in October and November 2017. The grout used and the actions taken to stabilize the tunnel are described in the following sections.

11.5.5.4.1 Grout Design

During development of the grout design, the Waste Encapsulation and Storage Facility (WESF) Hot Cell A through F grouting project was reviewed to identify lessons learned that were applicable to grouting the PUREX tunnels. The differences in how the grout was inserted and the spaces to fill proved to be the major difference between the WESF and PUREX tunnel grouting activities. The WESF grout formulation demonstrated desirable characteristics that matched tunnel grout fill design requirements. Minor modifications were made to reduce cement content while maintaining overall cementitious materials (cement plus fly ash) content to reduce compressive strength and heat of hydration while maintaining stable and uniform batching and placement behavior characteristics. The grout was tested using a mockup facility to verify performance. In addition, tests were conducted to determine when the compressive strength of a grout lift was sufficient to allow the next lift to be poured. Testing demonstrated that 1-day curing time was adequate.

The standard grout formulation used in Tunnel Number 1 was established after mockup testing and is shown in Table 11.2. The grout was a flowable, nonaggregate void-filling grout formulated to meet the functional requirements listed below.

- The grout will be able to flow easily to the extent of the tunnel length and flow into open spaces in and between rail cars and equipment.
- The grout will minimize the amount of heat generated during curing.
- The target range of minimum compressive strength is 1200 to 2000 pounds per square inch after 28 days.
- The grout will provide extended placement time (typically a minimum of 3 hours) to facilitate batching and placement during construction.

Table 11.2. Standard Grout Formulation

Constituent	Quantity (per yard)
Sand	2,105 lb
Type III cement	374 lb
Fly ash	796 lb
Water	56 gal
Viscosity-modifying admixture	60 oz
Hydration-controlling admixture	60 oz
Water-reducing admixture	22 oz
Workability-retaining admixture	22 oz

The grout will have sufficient strength to provide structural support for the Tunnel. The formula was developed to also allow it to be cut using a diamond wire saw or other technology if Clean Closure is selected as the final closure action.

Minor adjustments were made to the contents as needed based on factors such as weather conditions and location in the tunnel to achieve functional requirements. A quality assurance testing program was used to ensure that the grout used for Tunnel Number 1 complied with project specifications. Engineering and laboratory-scale testing was performed to confirm that the grout formulation met the performance criteria prior to the addition of grout to PUREX Tunnel Number 1. Field inspection and testing was performed during the grouting operation. A minimum of one set of grout samples (two cylinders) was cast and tested for every 170 cubic yards of grout placed per day. Samples were taken from randomly selected trucks. Visual inspection of each truck was performed by the structural engineer (or designated representative) to visually confirm grout flowability characteristics were consistent with grout batch test results. Testing was performed in accordance with:

- ASTM C1611, *Standard Test Method for Slump Flow of Self-Consolidating Concrete*
- ASTM C1064, *Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete*
- ASTM C138, *Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*
- ASTM C39, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*

11.5.5.4.2 Evaluations Conducted During Design

The grout design process included several evaluations to determine how well the grout would perform under conditions expected at PUREX.

Over long time periods, concrete structures may degrade as a result of exposure to ionizing radiation. A conservative calculation has been performed that shows that the time frame necessary for the recognized cumulative exposure threshold associated with concrete degradation is greater than 110 years. A more realistic, yet still conservative, calculation conducted for WESF Hot Cells A through F closure shows that the time frame necessary to reach a radiation exposure of concern is in excess of 590 years (CHPRC-02499, *W-130 Project Calculation: Estimate of Impacts to Grout as a Result of Radiation Exposure*). Radiation fields in the PUREX Storage Tunnels are much lower than those encountered in the WESF Hot Cells. No significant degradation of grout due to radiation exposure in the near time frame is expected.

Grout can also be affected by exposure to high temperature. The grout design limits temperatures due to heat of hydration to 160°F, which will not negatively affect the grout or structural concrete. Potential impacts to the grout as a result of heat of hydration and decay heat have been evaluated (CHPRC-02499), and there are no deleterious effects.

11.5.5.4.3 Grout Delivery

Grout was prepared offsite and trucked to Tunnel Number 1. Figure 11.7 includes a site plan for the grouting operations. Grout samples were collected and tested during daily placements. A grout pump vehicle was placed on the west side of the tunnel entrance.

After equipment installation, the grouting was performed by connecting a grouting pipe from the grout pumping vehicle to the pipe system. Addition of the grout into each section of the tunnel displaced air from the tunnel. The displaced air was routed through a flex hose to the HEPA filter skids described in Section 11.5.5.3.3. A second skid, collocated next to the primary filter skid, served as backup.

Cameras with lighting were used to monitor the progress of the fill and to provide visual confirmation that the spaces being grouted were filled to maximum extent possible. A temporary washout pit was set up to the south of PUREX along PUREX Drive and was part of the exit route for the delivery vehicles.

11.5.5.4.4 Grout Placement

Placement of grout began at the location of the roof collapse and subsequent soil fill. This location allowed both ends of the tunnel on either side of the soil fill to be grouted from a single point. Each section of the tunnel (north and south) used a dedicated piping arrangement to facilitate grouting. The sequence for grouting is described below.

The grout in the south end of the tunnel was placed in a series of lifts to prevent the equipment on the railcars from floating. The initial pours were approximately 1 to 2 feet of grout to reach from the floor to the bottom of the railcars. The initial pours were allowed to set up before additional grout was added. Subsequent lifts locked the equipment in place on the railcars. The final additions of grout were conducted to totally encapsulate the equipment and fill the south end to the maximum extent practicable.

The grout in the north section of the tunnel was placed in 1- to 2-foot lifts. This was done to capture the equipment on the rail cars and also to limit the hydraulic pressure on the seals of the water-fillable door. The grout additions continued in small increments until all of the equipment was covered in grout and the north section was filled to the maximum extent practicable.

Grout was distributed from the grout pump vehicle located west of the tunnel. Valves were used at the fill connections to enable quick shutoff of grout once the volume is filled. As grout flowed into the tunnel, air was displaced by the grout. The displaced air contained water vapor and was considered potentially radioactively contaminated. To control contamination during grouting, portable ventilation systems, described in Section 11.5.5.3.3, were used to collect and filter the displaced air. A total of 4,396 cubic yards of grout was placed into Tunnel 1. This totally encapsulated the equipment to within approximately 6 inches from the roof timbers.

The work platform and ventilation equipment were removed after grouting was completed and soil fill was placed in the area to match the profile of existing tunnel soil cover. The piping system and camera and lighting components added on to the existing tunnel penetrations were abandoned in place.

11.5.6 Interim Closure of Tunnel Number 2

Interim closure of Tunnel Number 2 will be completed as described in the following sections. Following completion of interim closure, an extended closure period will commence and the tunnel will be monitored and maintained until final closure.

11.5.6.1 Records Review

The structural evaluation conducted for Tunnel Number 2 reviewed tunnel drawings and specifications as well as structural properties of the tunnel components and adjacent soil. The structural evaluation is described in Chapter 4, *Process Information*, Appendix 4B. Tunnel inventory as described in Chapter 3, *Waste Analysis Plan*, was also reviewed to identify dangerous waste constituents within Tunnel Number 2.

11.5.6.2 Site Preparation

The Tunnel Number 2 area will be prepared to enable the safe insertion of the engineered grout while limiting the risks to the workers and the environment. Roads required for the grout trucks will be prepared to provide a stable platform to deliver the grout. The path of the trucks will be designed to limit the potential for interfering with the normal traffic patterns of the area. A site plan for Tunnel Number 2 activities is shown in Figure 11.8.

Additionally, investigative work was performed to verify the assumptions utilized in the engineering design process. This included removing a 3-inch plug in an existing 30-inch tunnel riser plug to enable samples to be taken in the interior of the tunnel and ensuring the main plug can be removed. These samples included industrial hygiene (e.g., flammable gas, volatile organics, or hazardous materials) and radiological samples to determine the status of the atmosphere and the potential for radiation exposure from both direct radiation and airborne. The 30-inch plugs on the risers that will be utilized for grout insertion were pulled and put back in place to confirm the plugs could be removed. The investigation also revealed that the length and configuration of some of the railcars was different than previously assumed. The artist's rendition of Tunnel Number 2, shown in Figure 4.2 and Figure 11.11, show the updated configuration.

11.5.6.3 Modifications Made Prior to Stabilization

Modifications will be required to prepare the tunnel for the insertion of the grout. Plugs in existing riser positions that will be utilized during the grouting process will be removed. The plug will then be replaced with an engineered replacement to allow grout insertion as well as provide locations for cameras and necessary lighting (Figure 11.9 and Figure 11.10). Work on the tunnel is being done using lifts and cranes. No work platform is required.

Additionally, a riser will be modified to connect the ventilation system to capture the air expelled from the tunnel during the grouting activities. Projected riser locations for cameras, lighting, and ventilation equipment are shown in Figure 11.11.

A passive ventilation system skid similar to that used for Tunnel Number 1 will be utilized to filter air discharged from the tunnel during grouting (Figure 11.6). The system will be designed and licensed in accordance with the Hanford Site Air Operating Permit (AOP 00-05-006).

11.5.6.4 Stabilization Activities

The stabilization activities for Tunnel Number 2 are described in the following sections. To the extent possible, materials and process used for stabilization of Tunnel Number 1 will be used for Tunnel Number 2.

11.5.6.4.1 Grout Design

The grout design that will be utilized for Tunnel Number 2 will be similar to the grout that was utilized in Tunnel Number 1 with the only difference being Type I/II cement will be utilized in Tunnel 2 instead of Type III. Functional requirements and formulation of the grout shown in Section 11.5.5.4.1.

11.5.6.4.2 Grout Delivery

The grout will be delivered through the modified riser plugs located along the top of the tunnel. To prevent loading the top of the tunnel, the piping will be a goose-neck type delivery system located off the tunnel surface (Figure 11.12). The piping will be connected to the modified riser plug shown in Figure 11.9 and Figure 11.10 utilizing industrial concrete rubber hose. The projected location for grout insertion is shown in Figure 11.11. This will limit the load on the tunnel while enabling the grout insertion into the tunnel.

11.5.6.4.3 Grout Placement

It is estimated that Tunnel 2 will require approximately 43,000 cubic yards to stabilize. The grout will be placed in the tunnel in layers. The layers will be small enough to prevent the possibility of creating a buoyant force to lift the equipment on the railcars in the tunnel. It will be delivered in multiple locations to ensure the grout flows and covers the entire tunnel.

A ventilation skid with a passive HEPA filter system will be connected to one of the risers. This will enable the air in the tunnel to escape through a filtered media to prevent the release of airborne contamination. The skid will have equipment to collect the condensate from the system.

During the evolution to grout the tunnel, standard radiological controls will be utilized to prevent the release and/or spread of contamination. This may include the use of sleeving, glovebags, negative air machines, etc. The type of control will be selected based on the risk of the work being performed and the potential for a release. Quality control testing will be conducted during grout placement in the same manner used for Tunnel Number 1 as described in Section 11.5.5.4.1. Grout that does not meet the grout design standards listed in Section 11.5.5.4.1 will be returned to the vendor and will not be used for the tunnel.

11.6 Final Closure Activities

Final closure of the PUREX Storage Tunnels will be coordinated with closure/remediation of the PUREX Plant in accordance with the *Hanford Federal Facility Agreement and Consent Order* (HFFACO or Tri-Party Agreement), Section 5.5. The final closure decision for the PUREX Storage Tunnels will be deferred until the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) remedial action for the 200-CP-1 Operable Unit because the close proximity of the two facilities will impact the final disposition of each facility. Coordination of the RCRA unit closure and the CERCLA operable unit investigation and remediation is necessary to prevent overlap and duplication of work.

The CERCLA remedial investigation process will be initiated in accordance with the schedule established in Tri-Party Agreement Milestone M-085-80. The nature and extent of contamination and alternatives to mitigate risks to human health and the environment will be evaluated in a CERCLA feasibility study.

A feasibility study evaluates alternatives for compliance with applicable or relevant and appropriate requirements, including substantive closure requirements defined in WAC 173-303-610. A CERCLA proposed plan identifies a preferred alternative for remediation and is submitted for public comment in accordance with the Hanford Public Involvement Plan (http://www.hanford.gov/files.cfm/FacAgreementand-Consent-Order_FINAL.pdf). Following consideration of public comment, a Record of Decision documents the selected remedial alternative. A remedial design/remedial action work plan documents the design and schedule for remediation activities.

DOE will work with Ecology to integrate the CERCLA decision information as it becomes effective into the closure plan. The final closure plan will meet the requirements of WAC 173-303-140 and WAC 173-303-610. Potential final closure options for the PUREX Storage Tunnels are described in Sections 11.6.1 and 11.6.2. These options may be modified and additional options may be developed based on the remedial investigation results and the examination of available technologies.

11.6.1 Retrieval/Clean Closure Options

As part of an interim stabilization measure in response to a collapse event discovered by workers on May 9, 2017, Tunnel Number 1 was filled with grout to improve tunnel stability, provide additional radiological protection, and increase durability while not precluding final closure actions. Because of the threat of future failure of Tunnel Number 2, interim closure activities are being taken to stabilize Tunnel Number 2 with grout.

Clean closure by retrieval could be implemented if the results of the decision-making process determine that it is practicable, protective of human health and the environment, and in compliance with applicable regulations. If clean closure is the selected option, the closure action might consider but will not be limited to the options described in Sections 11.6.1.1, 11.6.1.2, and 11.6.1.3. These options could be modified based on the remedial investigation results and the examination of available technologies.

11.6.1.1 Retrieval and Disposal in the PUREX Plant

In this option, railcars and grout in both tunnels would be retrieved after excavation of the tunnel by cutting and removal using water jets, wire saws, excavation equipment, or other technologies. A detailed excavation plan, including specific cut locations, would be developed as part of the final remediation/closure evaluation described in Section 11.6. Waste material would be moved from the tunnels to the PUREX Plant canyon deck area or an alternate location if disposal in the plant is the selected alternative. Waste such as empty railcars that could not be placed in the PUREX Plant for disposal (e.g., insufficient space) would be removed for final disposition at other approved disposal facilities.

Final disposition of the waste transferred to the plant, including characterization or size reduction as needed as well as disposition of the tunnel structure, would be completed as part of the coordination with the 200-CP-1 Operable Unit remedial action. Closure activities would be conducted in compliance with applicable Washington Administrative Code (WAC) requirements. The excavation plan and waste disposition processes would be developed to ensure that the silver nitrate contained in Tunnel Number 2 is not exposed to conditions that would cause it to ignite and that mercury contained in Tunnel Number 2 is not released to the environment. Verification sampling would be performed in accordance with an approved sampling and analysis plan.

11.6.1.2 Retrieval and Physical Processing (Size Reduction) in the PUREX Plant and Subsequent Disposal

In this option, retrieval of waste material stored in the tunnels would be similar to that described in the previous section if physical processing in the plant and disposal elsewhere is the selected alternative in the remedial action decision for the 200-CP-1 Operable Unit. Once the waste material was transferred to the PUREX Plant canyon deck area or alternate location within the plant, characterization and size reduction of waste material would proceed as needed. An area located on the canyon deck, in a process cell, or in an alternate location would be modified to include all necessary equipment to perform characterization, size reduction, and packaging activities. Size reduction would be performed through various technologies that include but are not limited to flame cutting, water jet cutting, sawing, or other technologies.

Final disposition of the processed waste material either onsite or offsite, as well as disposition of the tunnel structure, would be completed as part of the coordination with the 200-CP-1 Operable Unit remedial action. Closure activities would be conducted in compliance with applicable WAC requirements. The excavation plan and waste disposition processes would be developed to ensure that the silver nitrate contained in Tunnel Number 2 is not exposed to conditions that would cause it to ignite and that mercury contained in Tunnel Number 2 is not released to the environment. Verification sampling would be performed in accordance with an approved sampling and analysis plan

11.6.1.3 Construction of a New Facility for Retrieval, Processing, and Treatment of Equipment for Disposal

This option involves the construction of a new facility that is either mobile or stationary to remove and treat waste material stored in the tunnels. The facility would be constructed in a manner consistent with the retrieval and handling requirements for large, contaminated waste material. Retrieval of the waste and grout from Tunnel Numbers 1 and 2 could involve cutting and removal using water jets, wire saws, excavation equipment, or other technologies. Following retrieval, treatment and disposition of the waste material, as well as disposition of the tunnel structure, would be completed as part of the coordination with the 200-CP-1 Operable Unit remedial action.

Closure activities would be conducted in compliance with applicable WAC requirements. The excavation plan and waste disposition processes would be developed to ensure that the silver nitrate contained in Tunnel Number 2 is not exposed to conditions that would cause it to ignite and that mercury contained in Tunnel Number 2 is not released to the environment. Verification sampling would be performed in accordance with an approved sampling and analysis plan.

11.6.2 In Situ Disposal (Landfill Closure)

As part of an interim stabilization measure in response to a collapse event discovered by workers on May 9, 2017, Tunnel Number 1 was filled with grout to improve tunnel stability, provide additional radiological protection, and increase durability while not precluding final closure actions. Because of the threat of future failure of Tunnel Number 2, interim closure activities are being taken to fill Tunnel Number 2 with grout.

In situ disposal (landfill closure) of Tunnel Numbers 1 and 2 could be implemented if the results of the decision-making process determine that landfill disposal of the stored waste is protective of human health and the environment and in compliance with applicable regulations. If in situ disposal (landfill closure) is the selected option, the closure action might consider but will not be limited to the option described in

Section 11.6.2.1. This option could be modified based on the remedial investigation results and the examination of available technologies.

11.6.2.1 Maintain Grout and Install Landfill Cover

This option would involve maintaining the grout fill placed in Tunnel Numbers 1 and 2 as part of the interim stabilization/interim closure measures described in Sections 11.5.5 and 11.5.6. At final closure, remaining external equipment (e.g., risers or monitoring equipment) would be removed from the tunnel surface if necessary. Final closure activities would comply with applicable WAC requirements for landfill closure, including construction of a surface barrier that meets RCRA landfill cover requirements to prevent water from leaching mixed waste contained in the tunnels. Final landfill cover design and installation would be completed as part of the coordination with the 200-CP-1 Operable Unit remedial action.

11.6.3 Identifying and Managing Contaminated Media

If contaminated media removal is required during final closure, it will be managed as a newly generated waste stream in accordance with WAC 173-303-610(5). The contaminated media must be handled in accordance with all applicable requirements of WAC 173-303-170 through WAC 173-303-230, containerized, labeled, characterized in accordance with WAC 173-303-070 requirements, designated as a dangerous or non-dangerous waste, stored, and transported to an appropriate disposal facility. It will be treated (if necessary) to meet Land Disposal Restriction requirements in 40 CFR 268, incorporated into WAC 173-303-140(2)(a) by reference, then ultimately disposed.

11.6.4 Role of Independent Qualified Registered Professional Engineer

An independent, qualified, registered professional engineer (IQRPE) will be retained to provide certification of final closure, as required by WAC 173-303-610(6). The IQRPE will be responsible for observing field activities and reviewing documents associated with closure of the PUREX Storage Tunnels.

The IQRPE will perform a number of field activities. However, these field activities are dependent on the closure decision and will be defined when the closure decision has been made.

The IQRPE will record his or her observations and reviews in a written report that will be retained in the operating record. The resulting report will be used to develop the closure certification, which will then be provided to Ecology.

11.6.5 Certification of Closure

In accordance with WAC 173-303-610(6), within 60 days of completing final closure activities for the PUREX Storage Tunnels, certification that closure activities have been completed in accordance with the approved closure plan will be submitted to Ecology by registered mail or other means that establish proof of receipt (including applicable electronic means). The certification will be signed by the owner or operator and signed and certified by an IQRPE. Information supporting IQRPE closure certification will be submitted upon request by Ecology.

11.6.6 Conditions That Will Be Achieved When Closure Is Complete

Depending on the final closure decision, the PUREX Storage Tunnels will be demolished, and components removed and disposed, or they will be closed as a landfill with a surface barrier that meets RCRA landfill cover requirements.

11.7 Closure Schedule and Time Frame

Preparation for and implementation of interim closure activities are being completed to target start of stabilization of Tunnel Number 2 in 2018. Final closure activities for the PUREX Storage Tunnels will take place in conjunction with the remedial actions for the PUREX Plant and the 200-CP-1 Operable Unit. It is anticipated that a number of years will elapse before remedial actions for the PUREX Plant can be initiated. The first step in the remedial action process – developing a draft remedial investigation/feasibility study work plan – is subject to TPA Milestone M-085-80.

Continued storage of dangerous waste in the tunnels will necessitate an extension to the 180 days to complete final closure activities required in WAC 173-303-610(4)(b). This extension is being requested in accordance with WAC 173-303-610(4)(b)(i). Stabilization of the PUREX Storage Tunnels with grout as described in Sections 11.5.5 and 11.5.6 mitigates the potential for exposing workers to dangerous wastes or releasing dangerous wastes into the environment until final closure can be completed.

Approval of this closure plan will grant the Hanford Facility an extended closure period for performance of final closure activities, in accordance with WAC 173-303-610(4)(b), and a separate extension request will not be filed.

During this extended closure period, the Hanford Facility will comply with all applicable requirements of the permit. Additionally, the PUREX Storage Tunnels will be maintained in a manner that prevents threats to human health and the environment. Interim closure activities will be initiated within 60 days after receipt of approved permit. Interim closure activities and extended closure period expected durations are outlined in the closure activities schedule in Table 11.2.

Table 11.2. PUREX Storage Tunnels Closure Activities Schedule

Activity Description	Expected Duration/Date
Interim Closure of Tunnel Number 2	
Preparation (construction of piping systems, ventilation system, etc.)	5 months
Grouting	6 months
Submit interim closure report	60 days after interim closure activities complete
Extended Closure Period	
Extended closure period deferring closure to be concurrent with remedial action of PUREX Plant and 200-CP-1 Operable Unit, including continued surveillance and inspection	To be determined
Initiate remedial action process (TPA M-085-80, "Submit Remedial Investigation/Feasibility Study Work Plan for 200-CP-1 to Ecology")	9/30/2020
Implementation of final closure decision (clean closure or landfill closure)	To be determined
Completion of Closure Activities	
Submit final closure certification	60 days after final closure activities complete
Post-closure (if required)	
Groundwater monitoring and reporting	As required by post-closure plan
Maintenance and monitoring of waste containment systems	As required by post-closure plan

11.8 Cost of Closure

A detailed written estimate outlining updated projections of anticipated closure costs for the Hanford Facility TSD units having final status is not required per Permit Condition II.H.

11.9 References

ASTM C39/C39M-17b, 2017, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, ASTM International, West Conshohocken, Pennsylvania. Available at: https://www.astm.org/Standards/C39.htm.

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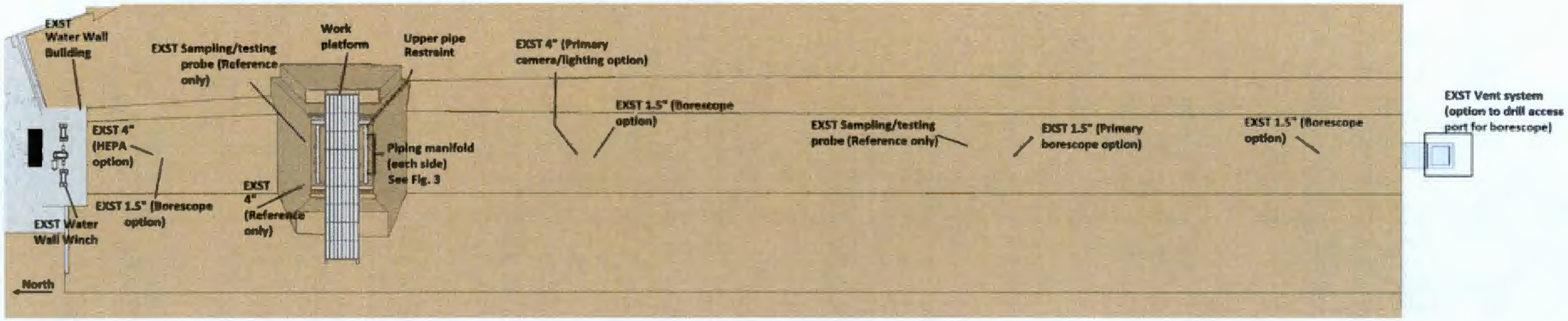

Figure 11.1. Plan View of Tunnel Number 1 with Equipment Placement and Layout

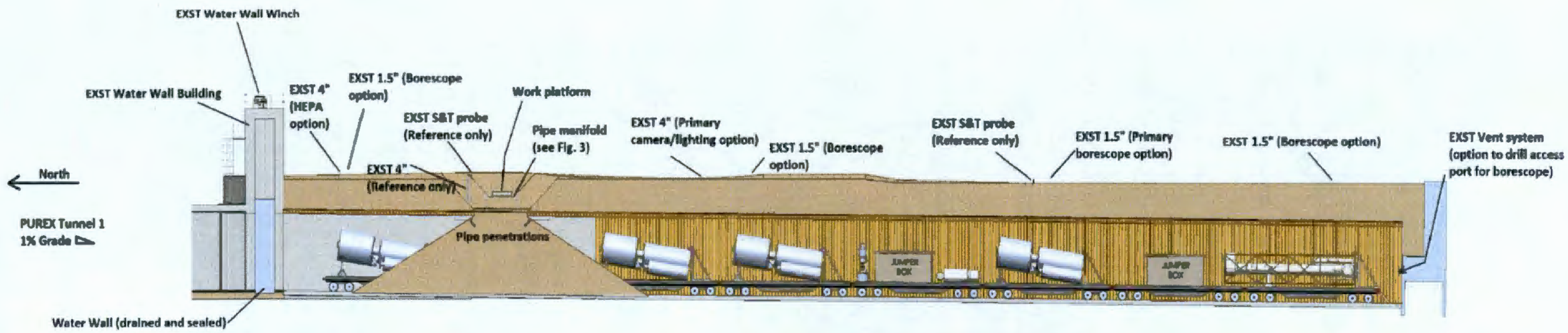

Figure 11.2. West Elevation of Tunnel Number 1 with Equipment Placement

Note: Water wall refers to the water-fillable door.

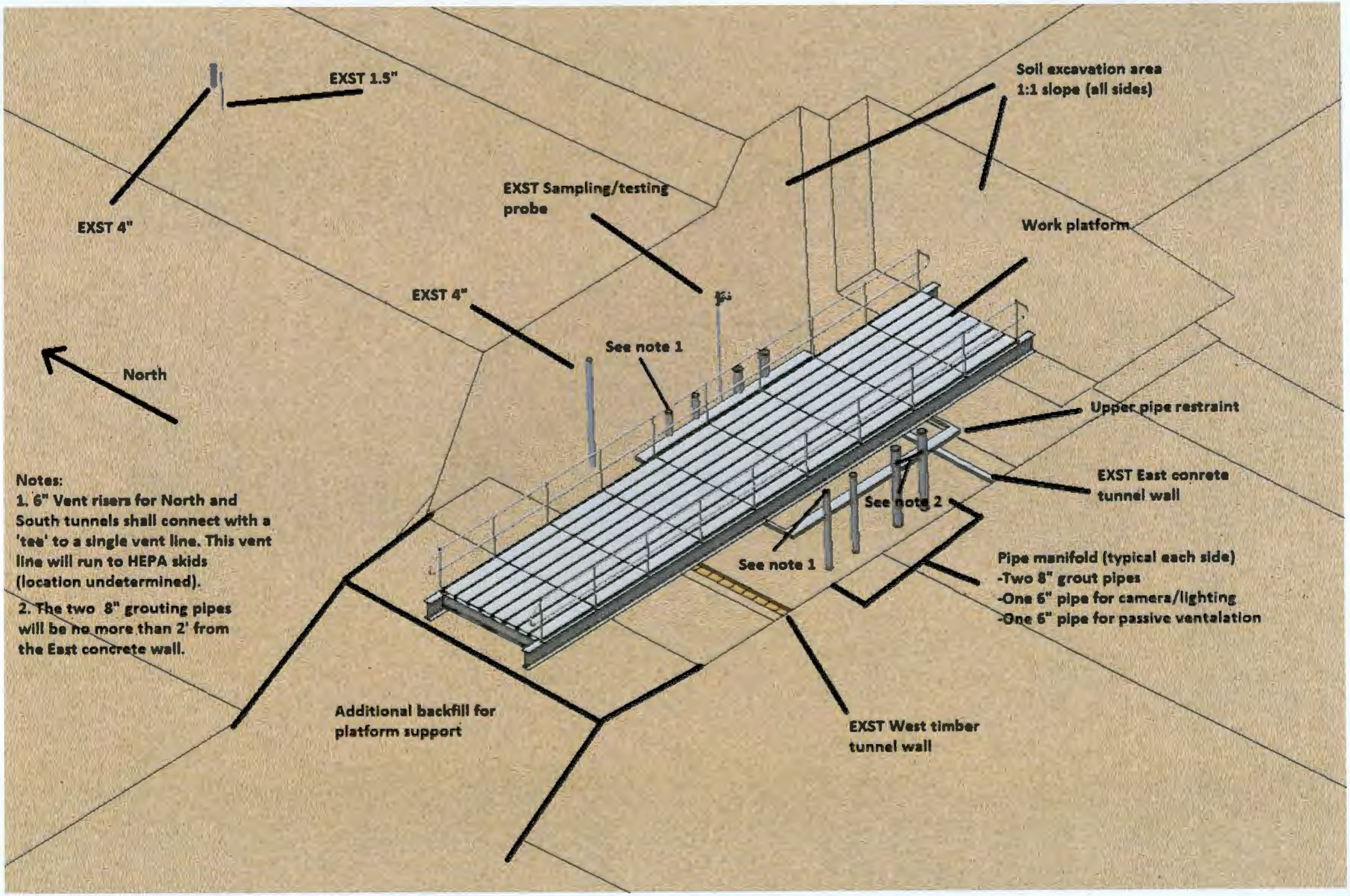

Figure 11.3. Isometric of Tunnel Number 1 Grouting Equipment – Platform and Piping Arrangement

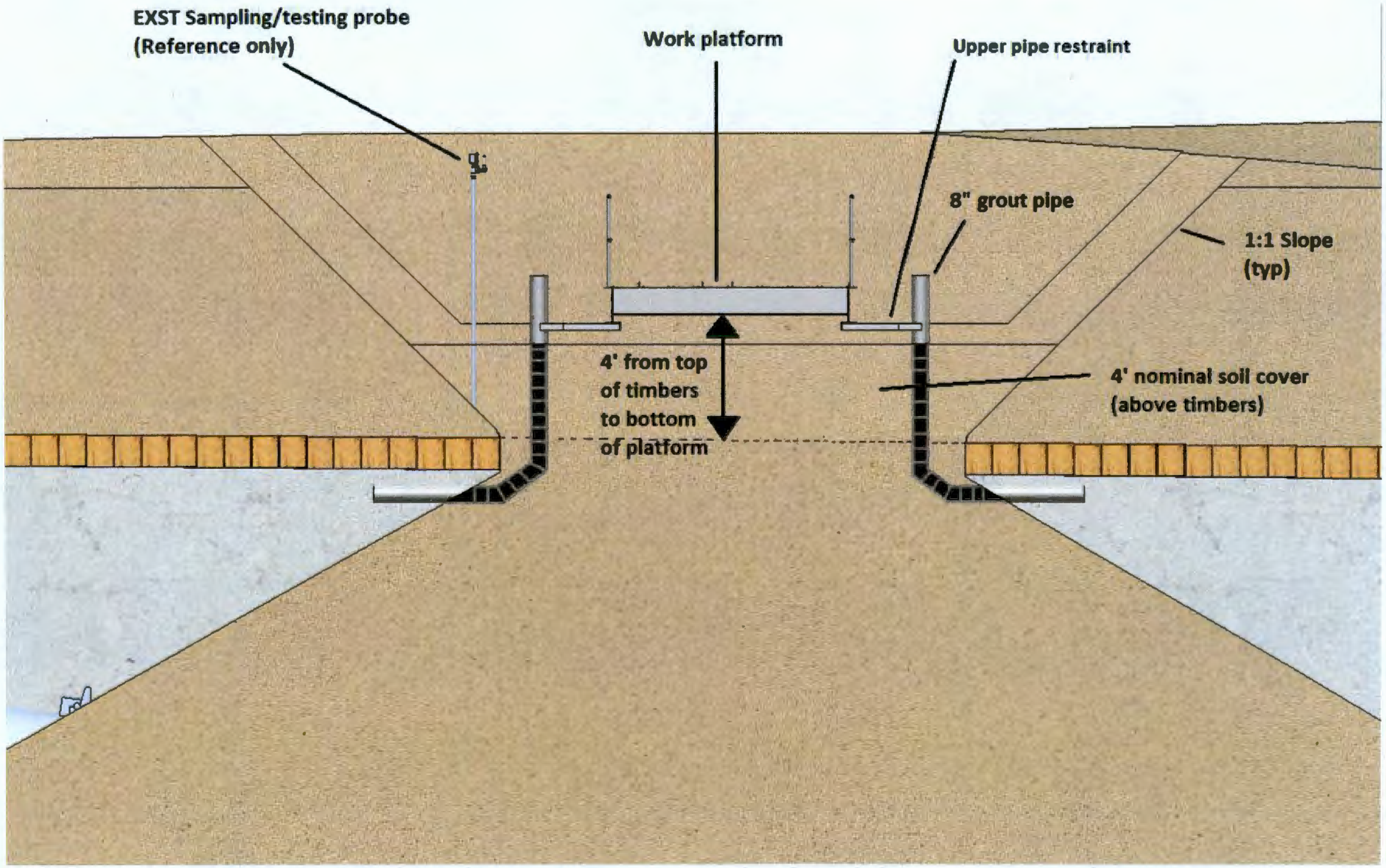

Figure 11.4. West Elevation of Tunnel Number 1 Grouting Equipment – Platform and Piping

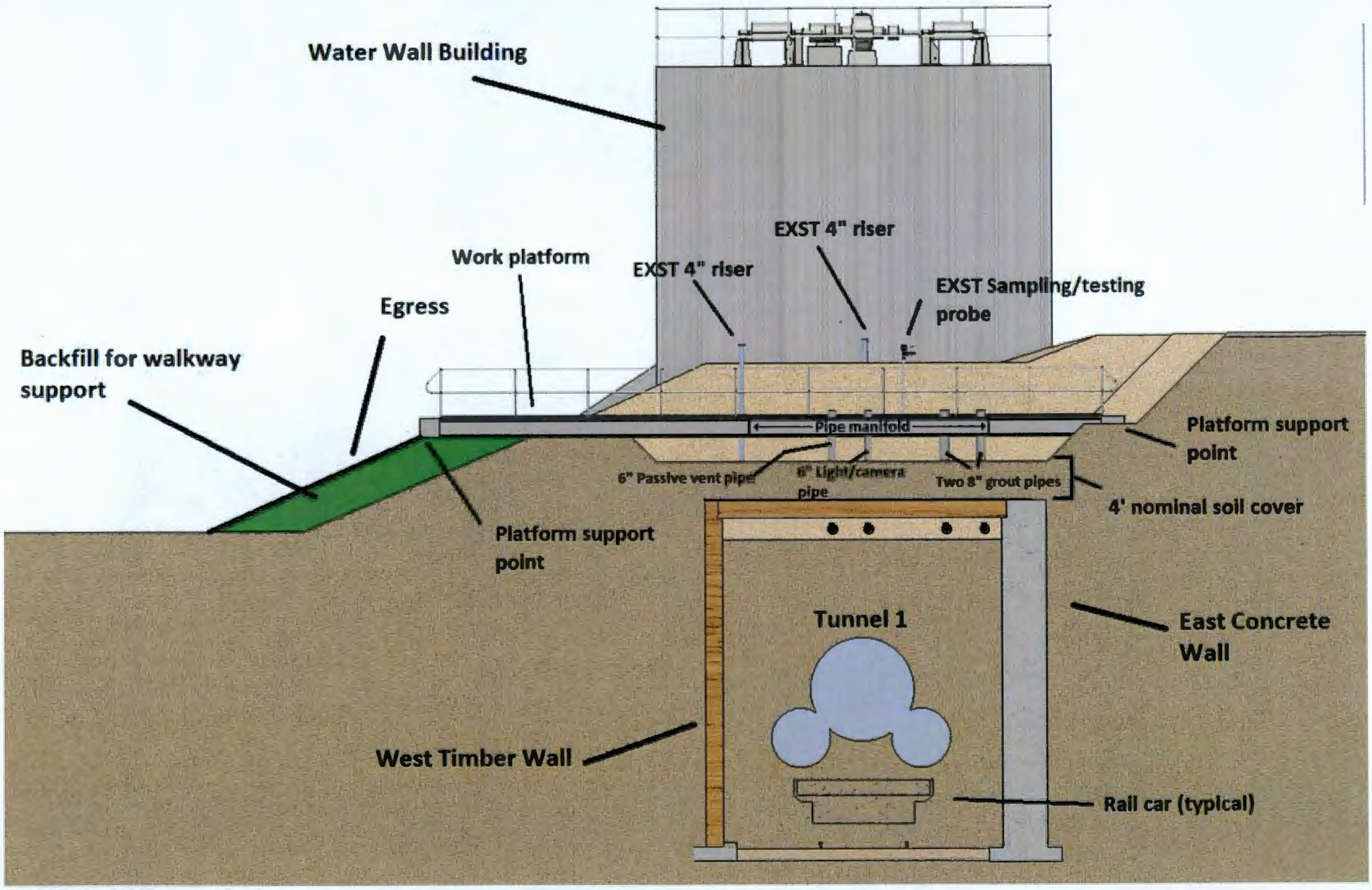

Figure 11.5. South Elevation of Tunnel Number 1 Grouting Equipment – Platform and Piping

Note: Water wall refers to the water-fillable door.

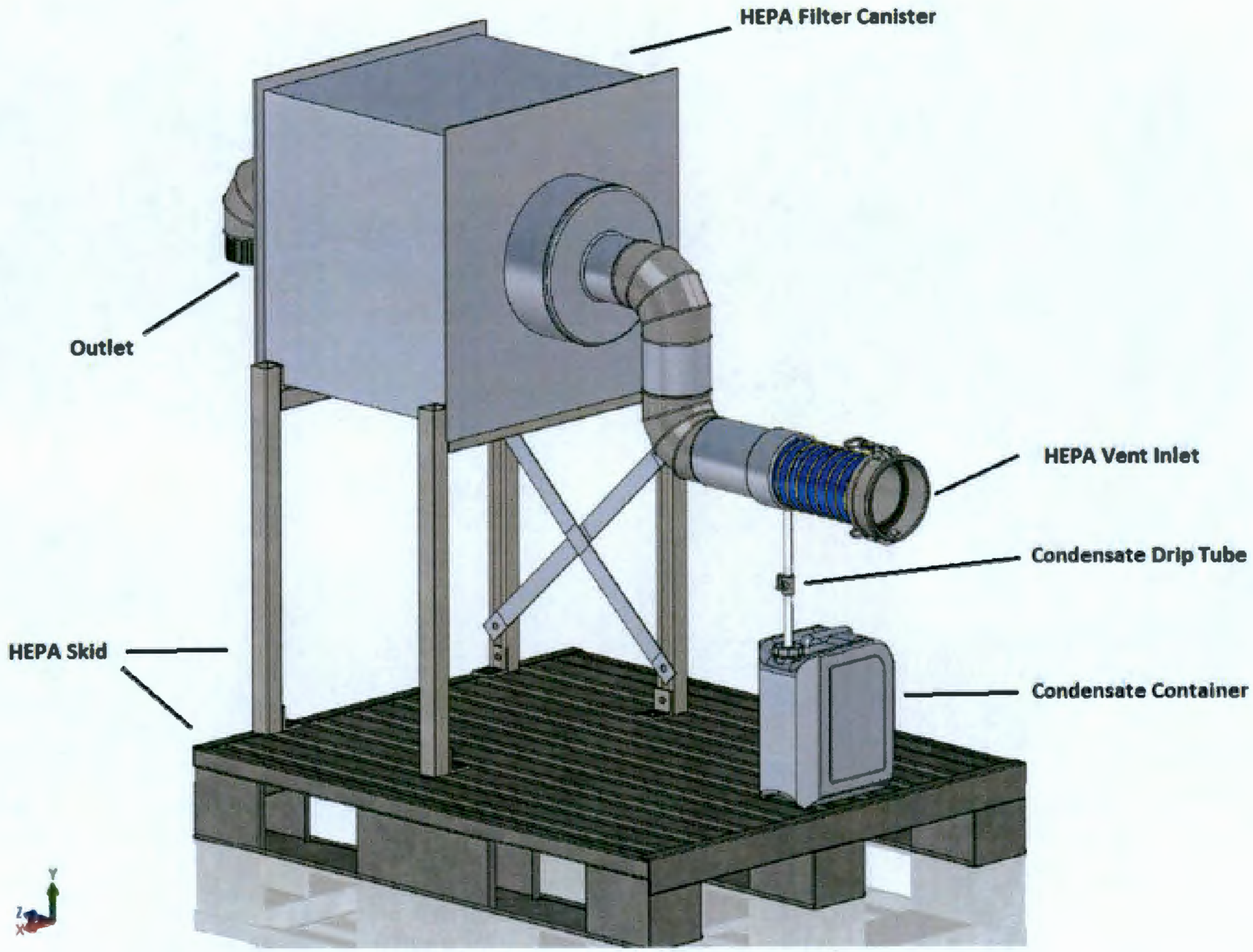

Figure 11.6. Passive Ventilation Filter Assembly for Tunnel Number 1

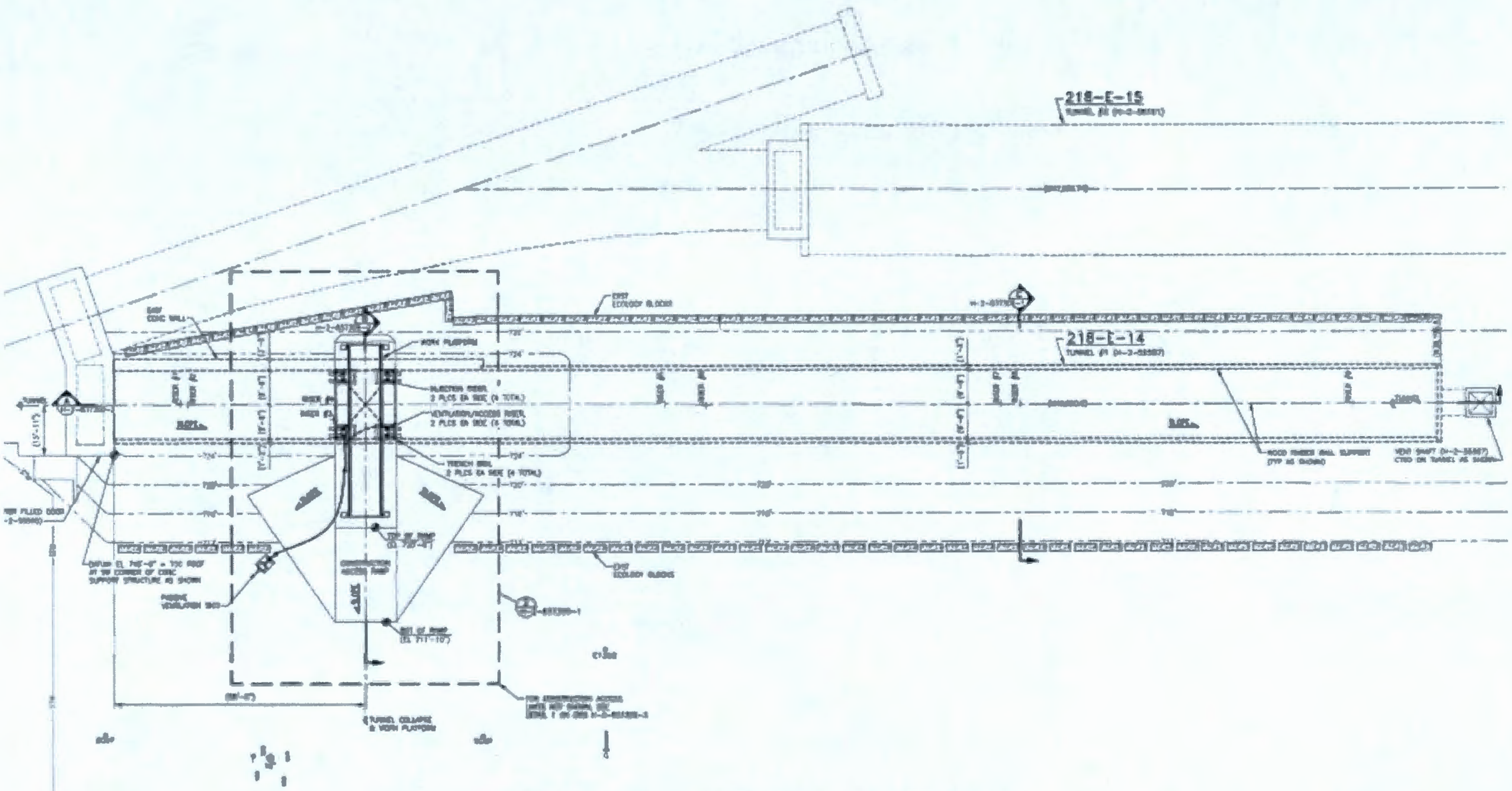

Figure 11.7. Tunnel Number 1 Site Plan

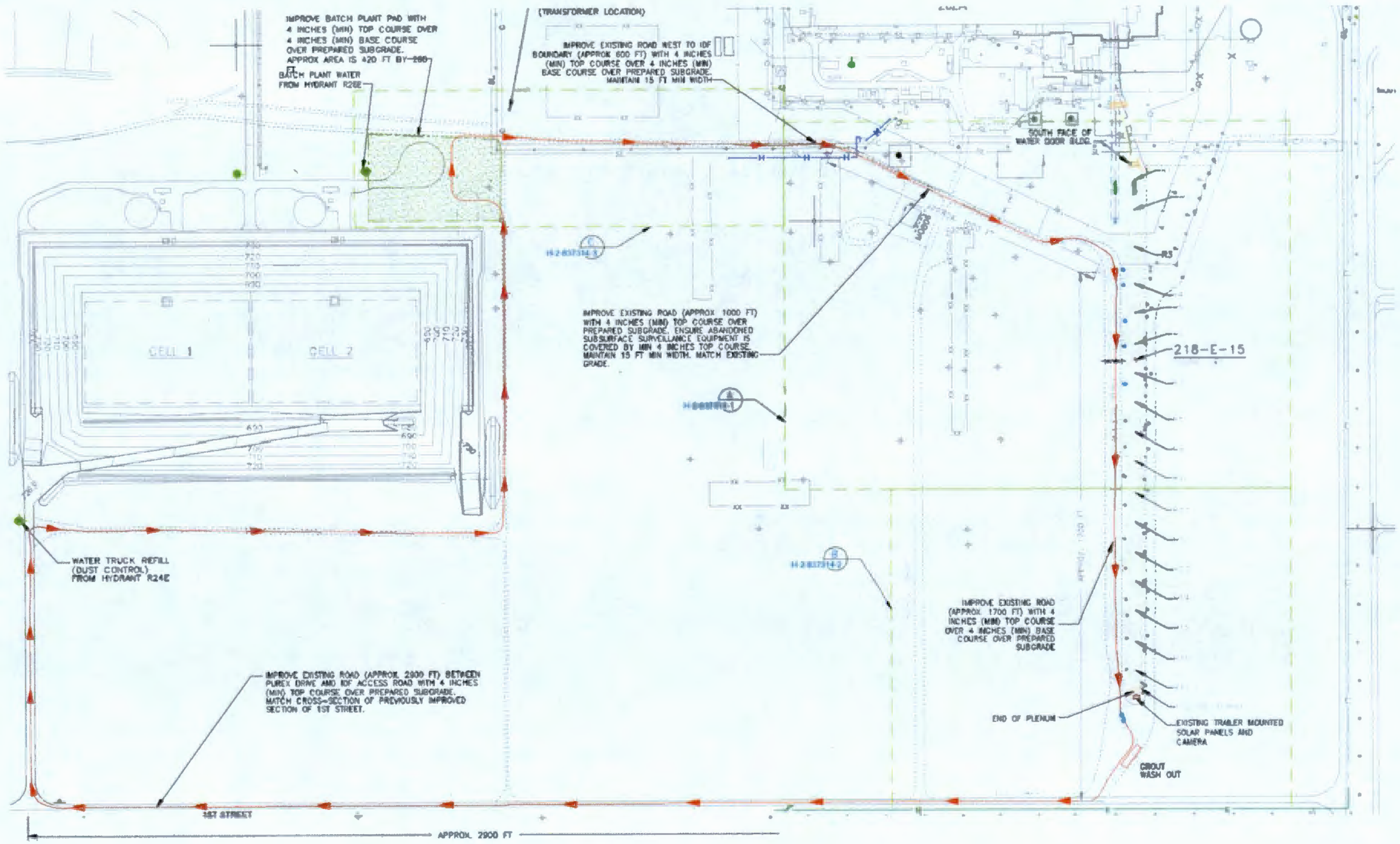

Figure 11.8. Tunnel Number 2 Site Plan

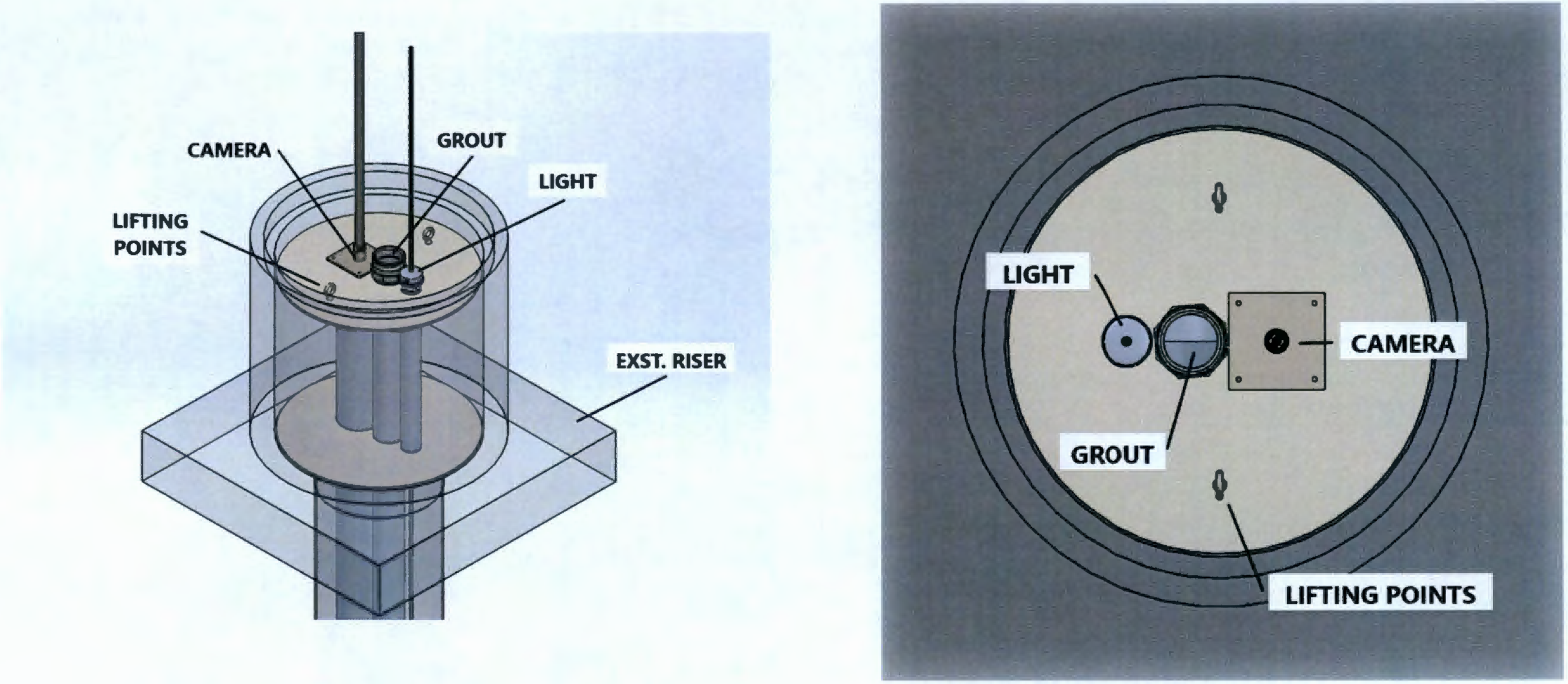

Figure 11.9. Plug Replacement for Existing Riser in Tunnel Number 2 (Isometric and Plan Views)

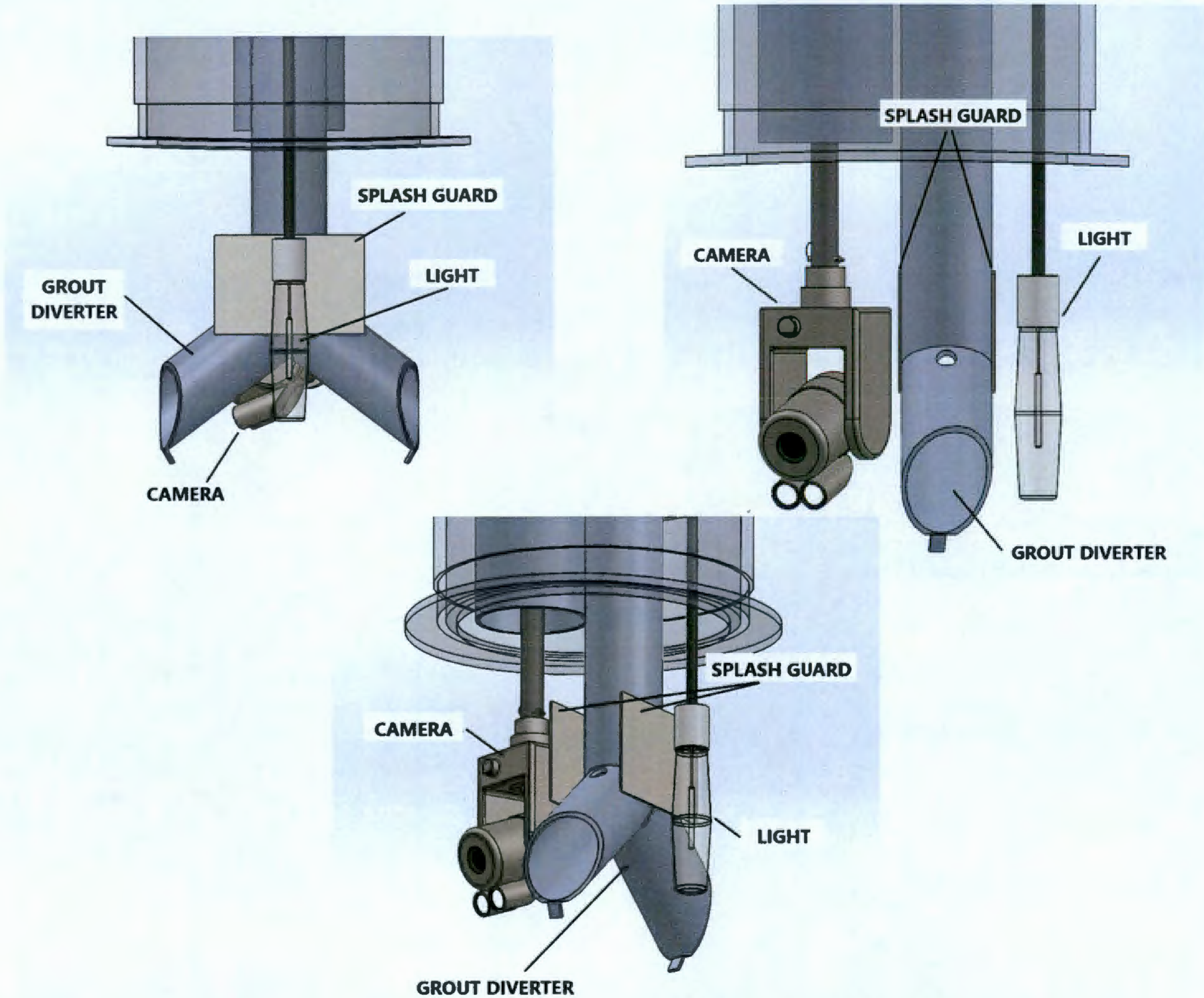

Figure 11.10. Equipment to be Deployed Through Existing Riser in Tunnel Number 2 (Two Elevations and Isometric)

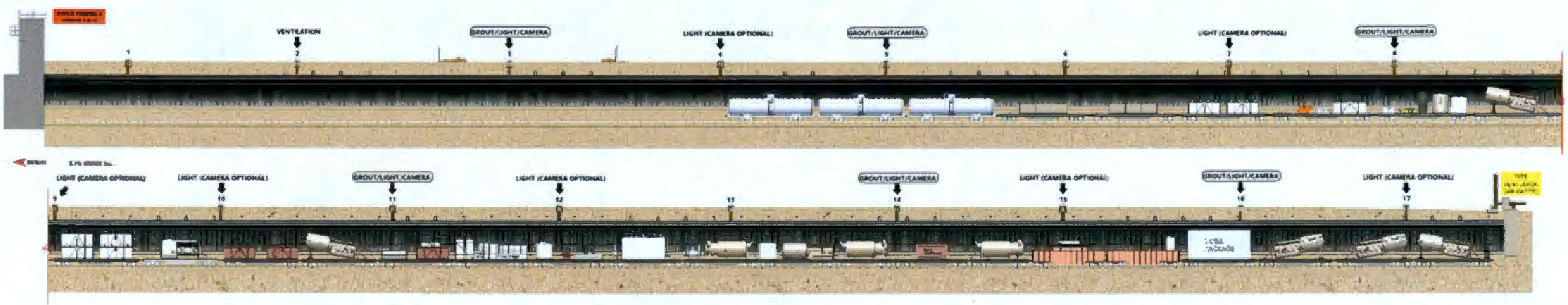

Figure 11.11. Location of Risers and Equipment for Grouting Tunnel Number 2

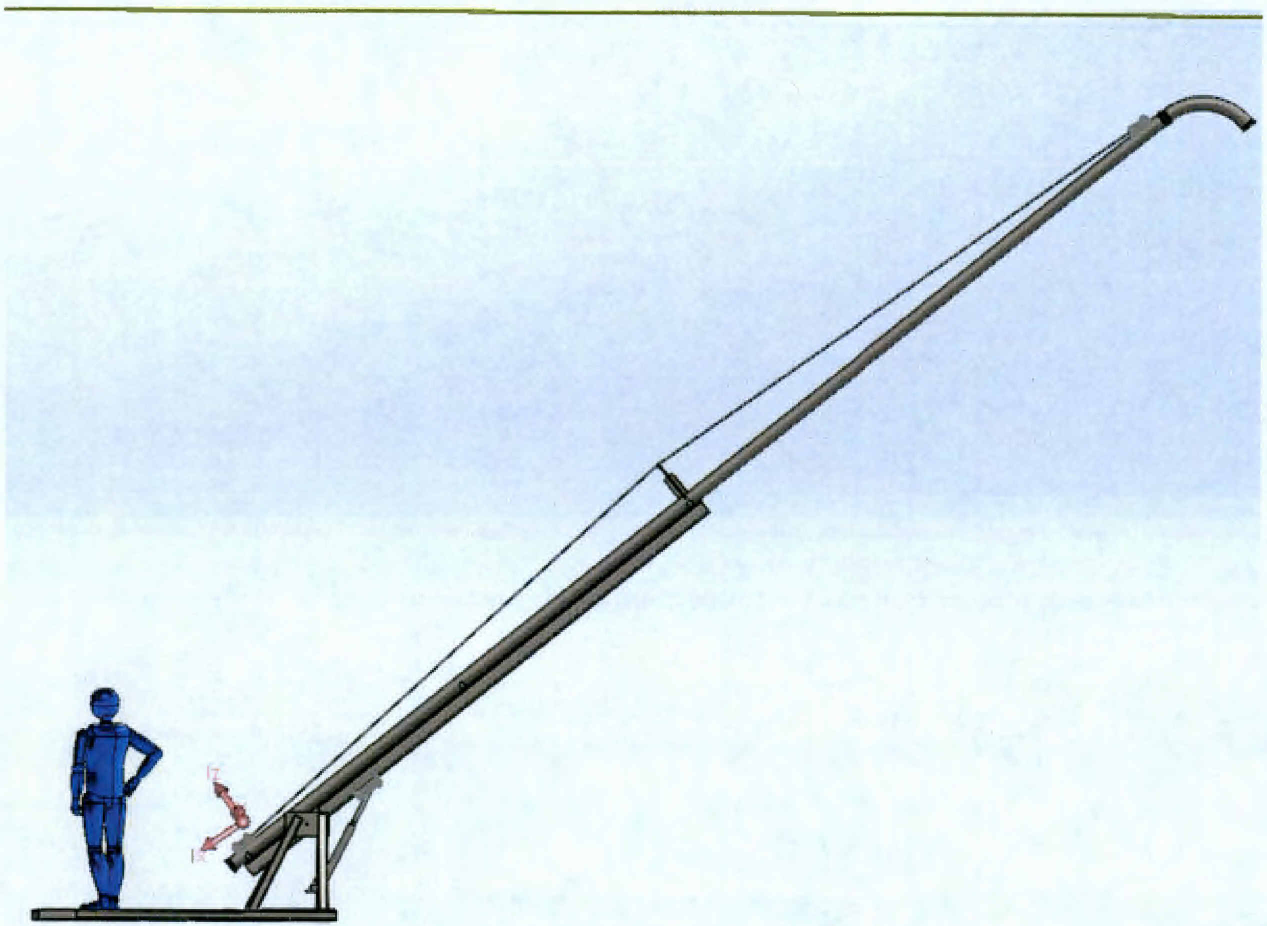

Figure 11.12. Goose-neck grout delivery piping for Tunnel Number 2

PUREX STORAGE TUNNELS
ADDENDUM F
PREPAREDNESS AND PREVENTION
CHANGE CONTROL LOG

Change Control Logs ensure that changes to this unit are performed in a methodical, controlled, coordinated, and transparent manner. Each unit addendum will have its own change control log with a modification history table. The "**Modification Number**" represents Ecology's method for tracking the different versions of the permit. This log will serve as an up to date record of modifications and version history of the unit.

Modification History Table

Modification Date	Modification Number
09/30/2010	

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ADDENDUM F
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ADDENDUM F
PREPAREDNESS AND PREVENTION

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F. PREPAREDNESS AND PREVENTION

F.1 Preparedness and Prevention Requirements

This addendum discusses preparedness and prevention measures for the Plutonium Uranium Extraction Facility (PUREX) Storage Tunnels. The PUREX Storage Tunnels are permitted as miscellaneous units under Washington Administrative Code (WAC) 173-303-680 and comprise Closing Unit Group 19.

On May 9, 2017 workers discovered a portion of Tunnel Number 1 had collapsed, prompting an immediate response action to protect workers and the environment. A structural evaluation revealed the threat of further failure of Tunnel Number 1. An interim stabilization measure to fill Tunnel Number 1 with engineered grout was taken under Section J.4.5 of the PUREX Tunnels Contingency Plan and Permit Condition III.2.A.1 of the Hanford Facility RCRA Permit. Grouting in Tunnel Number 1 was completed in November 2017. Filling the tunnel void spaces with grout improved tunnel stability, provided additional radiological protection, and increased durability while not precluding final closure actions.

A structural evaluation also revealed the threat of future failure of Tunnel Number 2. To protect stored waste containers from potential damage caused by a tunnel failure event (e.g., puncture of a container by a falling structural member) and to prevent any associated release of dangerous waste constituents to the environment, an interim closure action to cover the stored waste and fill Tunnel Number 2 void spaces around the waste with engineered grout is being taken. Until grouting is completed, enhanced surveillance and monitoring measures have been implemented using video equipment to provide daily observation of the tunnel surface.

F.1.1 Equipment Requirements

The following sections describe the internal and external communications systems and emergency equipment required.

F.1.1.1 Internal Communications

PUREX Storage Tunnel Number 1 is filled with grout and personnel entry is not possible. Because of the threat of structural failure, personnel entry into Tunnel Number 2 is prohibited. When grouting is completed in Tunnel Number 2, the tunnel will be filled and personnel entry will not be possible. No internal communications equipment is required.

F.1.1.2 External Communications

External communications equipment for summoning emergency assistance from the Hanford Fire Department and/or emergency response teams are provided by two-way portable radios or other devices during normal surveillance activities and during interim closure activities (grouting).

F.1.1.3 Emergency Equipment

Equipment included in the emergency plan for the PUREX Storage Tunnels is provided in Addendum J.

F.1.1.4 Water for Fire Control

The fire hazard associated with the operation of the PUREX Storage Tunnels was considered to be very low because of the minimal amount of combustibles stored within the tunnels and the lack of an ignition source. Filling the tunnels with grout during the response action for Tunnel Number 1 and interim closure for Tunnel Number 2 further isolates the waste from ignition sources and essentially eliminates the air supply required to sustain a fire inside the tunnels. During the grout curing period following placement, some heat of hydration is generated as a result of the curing process. However, because of the lack of available air, a fire inside the dangerous waste storage area would not be sustainable.

In the unlikely event it is determined there is a fire in the storage area of the tunnels, the contingency plan will be activated. Because of the potential of the mixed waste stored within the tunnels to leach, the use of water for fire control will be avoided if possible. Should the fire continue to propagate, heavy equipment and cranes will be called to the scene to cover burning segments of the tunnel.

Heavy equipment and cranes are readily available on the Hanford Facility at all times and generally are available for deployment to the scene of an emergency within 1 hour.

F.1.2 Aisle Space Requirement

Requirements for aisle space are not considered appropriate for the safe operation of the PUREX Storage Tunnels and were not included in design documents.

F.2 Preventive Procedures, Structures, and Equipment

The following sections describe preventive procedures, structures, and equipment.

F.2.1 Unloading Operations

Operation of the PUREX Storage Tunnels does not involve the loading or unloading of dangerous waste. No additional waste will be received into the tunnels. Therefore, the requirements of WAC 173-303-806(4)(a)(viii)(A) are not applicable to the PUREX Storage Tunnels.

F.2.2 Runoff/Run-On

The design of the PUREX Storage Tunnels included consideration and provisions for the control of runoff and run-on. Construction of both tunnels included the application of a moisture barrier before placement of the soil overburden. On Tunnel Number 1, 40.8-kilogram mineral surface roofing was applied to the external surfaces of the structural timbers (top and sides). The roofing material was nailed in place with an overlap of approximately 10 centimeters at all joints and seams. All interior and exterior steel surfaces of Tunnel Number 2 were coated with at least a 0.9-millimeter bituminous, solvent coal tar base, coating compound. The coating was applied using a two coat system, with each coat not less than 0.45 millimeters, ensuring a total dry film thickness of not less than 0.9 millimeter.

The soil overburden covering the PUREX Storage Tunnels also is contoured to provide a side slope of 2 (horizontal) to 1 (vertical). This construction serves to divert any seasonal or unanticipated run-on away from the storage area of the PUREX Storage Tunnels. Equipment used to support grouting of Tunnel Number 2 is designed to ensure that run-on is diverted away from the tunnel storage area. Grouting is not expected to impact the exterior contouring of either tunnel; however, when grouting is completed, visual observations of the side slopes will be conducted to confirm the contours remain in a condition to ensure proper runoff and to divert run-on away from the tunnel storage area.

Run-on at the PUREX Storage Tunnels is controlled by the design features of the exterior of the tunnels that serve to divert run-on away from the interior of the tunnels. Additionally, all waste within the tunnels is stored well above the floor level on railcars. The potential for run-on contacting the waste is further reduced after grouting because the grout encapsulates the waste to present another physical barrier between the source of potential run-on (generally precipitation outside the tunnel) and the waste. The control of run-on combined with the storage of all waste above the floor elevation and grout encapsulation provides adequate assurance that runoff will not occur at the PUREX Storage Tunnels and the potential for release of dangerous waste as a result of run-on is negligible. Groundwater at the PUREX Storage Tunnels is approximately 400 feet (120 meters) below ground surface.

For potential situations where a natural catastrophic event occurs, inspections as required by the Contingency Plan will be conducted to ensure the contours remain in a condition that ensures proper runoff and continues to divert run-on away from the tunnel storage areas.

F.2.3 Water Supplies

Water was supplied to the PUREX Storage Tunnels from the PUREX Plant. This water was used for the sole purpose of filling the water-fillable doors should it have been determined necessary. There are no other sources or uses of water at the PUREX Storage Tunnels. The line that supplied water to the PUREX Storage Tunnels was blanked and emptied during deactivation activities. The doors will not be refilled.

F.2.4 Equipment and Power Failures

The procedures, structures, and equipment used to mitigate the effects of equipment failure and power outage are described in the following sections.

F.2.4.1 Mitigation of the Effects of Equipment Failure

Maintaining safe storage of materials in the PUREX Storage Tunnels is not contingent on continued operation of equipment. Waste in Tunnel Number 1 is encapsulated with grout and requires no operating equipment. When Tunnel Number 2 grouting is completed, waste will also be encapsulated with no operating equipment required. Prior to and during grouting operations, the only operating equipment associated with Tunnel Number 2 is for video surveillance and for grout injection. In-person observation of the tunnel surface can replace video surveillance until equipment can be repaired or replaced. If equipment used in the grouting process fails, grouting can be temporarily halted without impact to safe storage of waste until the equipment is repaired or replaced.

F.2.4.2 Mitigation of the Effects of Power Failure

Maintaining safe storage of materials in the PUREX Storage Tunnels is not contingent on continued supply of electrical power. Waste in Tunnel Number 1 is encapsulated with grout and safe storage requires no electrical power. When Tunnel Number 2 grouting is completed, waste will also be encapsulated with no electrical power required. Prior to and during grouting operations, the only powered equipment associated with Tunnel Number 2 is for video surveillance and for grout injection. Equipment is powered using portable generators and batteries. If necessary, in-person observation of the tunnel surface can replace video surveillance and grouting can be temporarily halted without impact to safe storage of waste until power can be restored.

F.2.5 Personnel Protection Equipment

PUREX Storage Tunnel Number 1 is filled with grout, and personnel entry is not possible. Because of the threat of structural failure, personnel entry into Tunnel Number 2 is prohibited. After grouting is completed in Tunnel Number 2, the tunnel will be filled and personnel entry will not be possible. As a result, no special protective clothing or respiratory protection is required to protect personnel from the stored waste.

During grouting operations, personnel protection equipment will be determined by work control documents. Personnel are trained and qualified in using protective equipment.

F.3 Prevention of Reaction of Ignitable, Reactive, and/or Incompatible Waste

There is no reactive or incompatible waste stored in the PUREX Storage Tunnels. The only ignitable waste stored within the tunnels is silver nitrate, an oxidizer. The silver nitrate is present within the silver reactors (deposited on unglazed ceramic packing) stored in Tunnel Number 2.

Although silver nitrate exhibits the characteristic of ignitability, it is contained within stainless steel vessels, stored on railcars above the floor level, and isolated from combustible materials and other dangerous waste. Grout fill added to Tunnel Number 2 will be compatible with the ignitable waste although it is unlikely to directly contact the waste because the silver nitrate is contained within stainless steel vessels. Additional measures to prevent reaction of the ignitable waste are not considered necessary before, during, or after grouting.

F.4 Control of Releases to the Atmosphere

Releases to the atmosphere are not a concern from Tunnel Number 1 because the waste is encapsulated by the grout fill. When Tunnel Number 2 is grouted, the waste will be similarly encapsulated. During grouting operations at Tunnel Number 2, air expelled from the tunnel will pass through high-efficiency particulate air (HEPA) filters as described in Chapter 11 to ensure that releases to the atmosphere are not a concern.

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PUREX STORAGE TUNNELS
ADDENDUM I
INSPECTION REQUIREMENTS
CHANGE CONTROL LOG

Change Control Logs ensure that changes to this unit are performed in a methodical, controlled, coordinated, and transparent manner. Each unit addendum will have its own change control log with a modification history table. The "**Modification Number**" represents Ecology's method for tracking the different versions of the permit. This log will serve as an up to date record of modifications and version history of the unit.

Modification History Table

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ADDENDUM I
INSPECTION REQUIREMENTS

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ADDENDUM I
INSPECTION REQUIREMENTS

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I. INSPECTION REQUIREMENTS

This addendum discusses the inspection requirements for dangerous waste management units within the Plutonium Uranium Extraction Facility (PUREX) Storage Tunnels. The PUREX Storage Tunnels are permitted as miscellaneous units under Washington Administrative Code (WAC) 173-303-680 and comprise Closing Unit Group 19.

I.1 PUREX Tunnel Number 1

PUREX Tunnel Number 1 has been filled with grout, and personnel entry is no longer possible. Inspection of the tunnel interior cannot be performed. External inspections of the tunnel will be performed annually. Annual inspections are sufficient because the waste is encapsulated with grout minimizing the potential for structural failure and release of dangerous waste constituents to the environment through normal aging of the structure. The identified inspection frequency is sufficient to detect the types of problems defined in Table I.1. The inspection schedule and records will be maintained in the Hanford Facility Operating Record, PUREX Tunnel Number 1 File for a minimum of 5 years.

Information from inspections will be recorded on inspection record forms. The forms are used to initiate corrective action if necessary. The elements inspected at Tunnel Number 1 are identified in Table I.1. Abnormal conditions are recorded, evaluated, and corrective action initiated as necessary. Abnormal conditions means changes from previous observations of the exterior conditions of the tunnel that have the potential to affect the safe storage of dangerous wastes.

Table I.1. Inspection Schedule for Tunnel Number 1

Requirement Description	Inspection Frequency	Types of Problems
Perform external surveillance of PUREX Storage Tunnel Number 1	Annual	External surfaces of PUREX Storage Tunnel Number 1 are observed for evidence of structural deterioration. Tunnel subsidence and erosion of the earth cover are of primary concern. The points of access to Tunnel Number 1 are inspected to ensure warning signs are in place, visible, and legible.

I.2 PUREX Tunnel Number 2

PUREX Tunnel Number 2 will be filled with grout during interim closure activities. The inspection requirements before and after grouting are described below.

Personnel access into Tunnel Number 2 is prohibited because of the threat of structural failure. During and after grouting, personnel entry will not be possible. Thus, inspection of the tunnel interior will not be performed. Video surveillances of the exterior of the tunnel are performed and documented and will continue daily until grouting is completed. External visual inspections of the tunnel will be performed annually. Annual inspections are sufficient because the waste will be encapsulated with grout minimizing the potential for structural failure and release of dangerous waste constituents to the environment through normal aging of the structure. The identified inspection frequency is sufficient to detect the types of problems defined in Table I.2. The inspection schedule and records will be maintained in the Hanford Facility Operating Record, PUREX Tunnel Number 2 File for a minimum of 5 years.

Information from inspections will be recorded on inspection record forms. The forms are used to initiate corrective action if necessary. The elements inspected at Tunnel Number 2 are identified in Table I.2. Abnormal conditions are recorded, evaluated, and corrective action initiated as necessary. Abnormal conditions means changes from previous observations of the exterior conditions of the tunnel that have the potential to affect the safe storage of dangerous wastes.

Table I.2. Inspection Schedule for Tunnel Number 2

Requirement Description	Inspection Frequency	Inspection Method	Types of Problems
Perform external surveillance of PUREX Tunnel Number 2	Annual	Visual	External surfaces of PUREX Tunnel Number 2 are observed for evidence of structural deterioration. Tunnel subsidence and erosion of earth cover are of primary concern. The points of access to Tunnel Number 2 are inspected to ensure warning signs are in place, visible, and legible.
Perform external surveillance of PUREX Tunnel Number 2	Daily until interim closure grouting activities are complete	Video	External surfaces of PUREX Tunnel Number 2 are observed for evidence of structural deterioration. Tunnel subsidence, erosion of earth cover, and vent stack damage are of primary concern.

ADDENDUM J
CONTINGENCY PLAN

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ADDENDUM J
CONTINGENCY PLAN

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FIGURE

TABLE

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J. CONTINGENCY PLAN

J.1 General Information

The Plutonium-Uranium Extraction 218-E-14 and 218-E-15 (PUREX Storage Tunnels) are located in the 200 East Area of the 1,450-square kilometer U.S. Department of Energy, Richland Operations Office (DOE-RL) operated Hanford Site in southeastern Washington State. The Hanford Site Emergency Preparedness Program is based upon the incident command system, which allows a graded approach for responses to emergency events. This plan contains a description of facility specific planning and response. It is used in conjunction with Permit Attachment 4, *Hanford Emergency Management Plan* (DOE/RL-94-02). Response to events is performed using facility specific and/or Site level emergency procedures.

J.1.1 Facility Name

U.S. Department of Energy
Hanford Site
PUREX Storage Tunnels

J.1.2 Facility Location

Benton County, Washington; within the 200 East Area. Structures covered by this plan are:

218-E-14 Tunnel Number 1

218-E-15 Tunnel Number 2

J.1.3 Owner

Doug S. Shoop, Manager
U.S. Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

J.1.4 Facility Manager

CH2MHill Plateau Remediation Company
P.O. Box 1600
Richland, Washington 99352-1600

J.1.5 Description of Facility and Operations

The PUREX Storage Tunnels consist of two structures, 218-E-14 (Tunnel Number 1) and 218-E-15 (Tunnel Number 2). The PUREX Storage Tunnels are permitted as miscellaneous units under Washington Administrative Code (WAC) 173-303-680 and comprise Closing Unit Group 19. The tunnels are used for the storage of material from the PUREX Plant and from other onsite sources. The material stored in the tunnels contains dangerous waste and varying amounts of mixed waste contamination; therefore, the stored material is managed as mixed waste. The tunnels are no longer in active operation.

In May 2017, workers discovered a portion of Tunnel Number 1 had collapsed, prompting an immediate response action to protect workers and the environment. A structural evaluation revealed the threat of further failure of Tunnel Number 1. An interim stabilization measure to fill Tunnel Number 1 with engineered grout was taken under Section J.4.5 of this contingency plan and Permit Condition III.2.A.1 of the Hanford Facility RCRA Permit. Grouting in Tunnel Number 1 was completed in November 2017. Filling the tunnel void spaces with grout improved tunnel stability, provided additional radiological protection, and increased durability while not precluding final closure actions. Tunnel Number 1 will receive no new waste and will continue to store the existing encapsulated waste until final closure.

At the same time, a structural evaluation also revealed the threat of future failure of Tunnel Number 2. To protect stored waste containers from potential damage caused by a tunnel failure event (e.g., puncture of a container by a falling structural member) and to prevent any associated release of dangerous waste constituents to the environment, an interim closure action to cover the stored waste and fill Tunnel Number 2 void spaces around the waste with engineered grout is being taken. No waste has been added to Tunnel Number 2 since 1996 and no waste will be added or removed, nor will personnel entry be permitted prior to grouting because of the threat of structural failure. Personnel entry will not be possible after grouting is completed.

J.1.6 Building Evacuation Route

The PUREX Storage Tunnels evacuation route is shown in Figure J.1.

J.2 Emergency Coordinators/Building Emergency Director (EC/BED)

Table J.1. Emergency Coordinator/Building Emergency Director[a]

Designation	Job title	Work location	Work phone
Primary	Facility Operations	MO-294	373-1355

[a]The names and home phone numbers of all Emergency Coordinators/Building Emergency Directors are maintained at the single point-of-contact (the Hanford Patrol Operations Center) telephone number 373-3800 in accordance with the Hanford Facility RCRA Permit Condition II.A.4.

Emergency response will be directed by the EC/BED until the Incident Commander arrives. The incident command structure and staff with supporting on-call personnel fulfill the responsibilities of the EC/BED as discussed in WAC 173-303-360.

During events, facility personnel perform response duties under the direction of the EC/BED. The Incident Command Post (ICP) is managed by either the senior Hanford Fire Department member present on the scene or senior Hanford Patrol member present on the scene (security events only). These individuals are designated as the Incident Commander (IC) and as such have the authority to request and obtain any resources necessary for protecting people and the environment. The EC/BED becomes a member of the ICP and functions under the direction of the IC. In this role, the EC/BED continues to manage and direct facility operations.

A listing of the primary and alternate EC/BEDs by title, work location and work telephone numbers is identified in the Table J.1. The EC/BED is on the premises or is available through an "on-call" list 24 hours a day.

J.3 Implementation of the Plan

In accordance with WAC 173-303-360(2)(b), the BED ensures that trained personnel identify the character, source, amount, and areal extent of the release, fire, or explosion to the extent possible. Identification of waste can be made by activities that can include, but are not limited to, visual inspection of involved containers, sampling activities in the field, reference to inventory records, or by consulting with facility personnel. Samples of materials involved in an emergency might be taken by qualified personnel and analyzed as appropriate. These activities must be performed with a sense of immediacy and shall include available information.

The BED shall use the following guidelines to determine if an event has met the requirements of WAC 173-303-360(2)(d):

1. The event involved an unplanned spill, release, fire, or explosion,

AND

2.a The unplanned spill or release involved a dangerous waste, or the material involved became a dangerous waste as a result of the event (e.g., product that is not recoverable), or

2.b The unplanned fire or explosion occurred at the PUREX Storage Tunnels or transportation activity subject to RCRA contingency planning requirements,

AND

3. Time-urgent response from an emergency services organization was required to mitigate the event, or a threat to human health or the environment exists.

As soon as possible, after stabilizing event conditions, the BED shall determine, in consultation with the Site contractor environmental single-point-of-contact, if notification to the Washington State Department of Ecology is needed to meet WAC-173-303-360(2)(d) reporting requirements. If all of the conditions under 1, 2, and 3 are met, notifications are to be made to Ecology. Additional information is found in Attachment 4, *Hanford Emergency Management Plan* (DOE/RL-94-02), Section 4.2.

If review of all available information does not yield a definitive assessment of the danger posed by the incident, a worst case condition will be presumed and appropriate protective actions and notifications will be initiated. The BED is responsible for initiating any protective actions based on their best judgment of the incident.

The BED must assess each incident to determine the response necessary to protect the personnel, facility, and the environment. If assistance from Hanford Patrol, Hanford Fire Department, or ambulance units is required, the Hanford Emergency Response Number (911 from offsite telephones or 373-0911 from cellular telephones) must be used to contact the POC and request the desired assistance. To request other resources or assistance from outside the Surveillance and Maintenance facilities, the POC business number is used (373-3800).

J.3.1 Dangerous and/or Mixed Waste

A seismic event, explosion, tornado, structural failure, or an aircraft crash could cause damage to the storage tunnels and could involve environmental exposure to mixed waste. These events are considered the only credible sources of a release as the PUREX Storage Tunnels are unoccupied structures and there are no continuous processes associated with waste storage. Following the failure of Tunnel Number 1 discovered in May 2017, the tunnel was filled with engineered grout. Tunnel Number 2 will undergo interim closure and be stabilized with engineered grout. The grout encapsulates the stored waste and reduces the potential for environmental exposure to mixed waste from the events described above to occur. Grouting also removes the potential for further structural failure of the tunnels because the grout totally encapsulates the waste and fills the tunnel to within a short distance from the interior roof. Grout filled Tunnel Number 1 to within approximately 6 inches from the roof timbers. Similar conditions will exist after grouting of Tunnel Number 2. In the event that damage to the exterior of either tunnel were to occur, the soil overburden would fill the remaining gap and preclude the release of dangerous or mixed waste to the environment.

Emergency responses for credible dangerous and/or mixed waste releases can be found in the following sections.

J.3.2 Fire or Explosion

The fire or explosion hazard associated with the PUREX Storage Tunnels is considered to be very low because of the minimal amount of combustibles stored within the tunnels and the lack of an ignition source.

- Because of the potential for mixed waste to leach, water is not the preferred choice for fire control. Filling the tunnels with grout during the response action for Tunnel Number 1 and interim closure for Tunnel Number 2 further isolates the waste from ignition sources and essentially eliminates the air supply required to sustain a fire inside the tunnels. Should the fire continue to spread, heavy equipment and cranes will be called to the scene to cover burning segments of the tunnels. In addition, the following actions are taken in the event of a fire or explosion:
  - The single point-of-contact (911 from site office phones or 373-0911 from cellular phones) is notified immediately.

  - The EC/BED proceeds directly to the ICP and sends a representative to meet the Hanford Fire Department.
  - The EC/BED obtains all necessary information pertaining to the incident
  - Depending on the severity of the event, the EC/BED or his/her designee may be required to provide notifications to the site contractor environmental single point of contact, which in turn notifies offsite agencies and/or the occurrence notification center informing them as to the extent of the emergency (including estimates of mixed waste quantities released to the environment) and any actions necessary to protect nearby buildings and/or structures.
  - Depending on the severity, the EC/BED requests activation of the affected area ICP to establish organizations to provide assistance from DOE-RL, other Hanford site contractors, and outside agencies (if 911 from site office phones or 373-0911 from cellular phones is called, the ICP will automatically be activated).
  - The Hanford Patrol establishes roadblocks within the area to route traffic away from the emergency scene.
  - If necessary, Hanford Fire Department medical personnel remove injured personnel to a safe location, apply first aid, and prepare the injured for transport to medical aid stations or to local hospitals.

- Depending on the magnitude of a natural phenomena event, fire, or an explosion, damage to the storage tunnels is possible. The hazards could involve personnel and environmental exposure to mixed waste. In the event of such an occurrence, a recovery plan will be developed.

J.3.3 Seismic Event/Tornado

Depending on the magnitude of the seismic event or tornado, damage to the storage tunnels is possible. The hazards could involve personnel and environmental exposure to mixed waste.

Emergency responses for seismic events and tornadoes would be the same as those for a fire or explosion. Refer to Section J.3.2.

J.3.4 Aircraft Crash

In addition to the potential for serious injuries or fatalities involved with an aircraft crash, damage to the storage tunnels is possible, which could result in a fire, explosion, or a mixed waste release. The hazards could involve personnel and environmental exposure to mixed waste.

Refer to Section J.3.2 for emergency responses for fires and explosions.

J.3.5 Bomb Threat/Explosive Device

Depending on the magnitude of an explosion, damage to the storage tunnels is possible. The hazards could involve personnel and environmental exposure to mixed waste. For emergency responses, refer to Section J.3.2 for explosions.

J.3.6 Damaged Dangerous and/or Mixed Waste Shipment

The PUREX Storage Tunnels no longer receive waste; therefore, no response to damaged shipments is required.

J.4 Unit/Building Emergency Response Procedures

The initial response to any emergency is to immediately protect the health and safety of persons in the area. Identification of released material is essential to determine appropriate protective actions. Containment, treatment, and disposal assessment are secondary responses.

Emergency action levels associated with event classifications applicable to the PUREX Storage Tunnels include the following. A Site Area Emergency can be declared for a hazardous material release resulting from a fire, explosion, operational accident involving a sufficient quantity of hazardous material, natural hazards (i.e., seismic event and/or tornado/high winds), aircraft crash, discovery or detonation of an explosive device, hostage situation or armed intruders, or catastrophic loss of confinement. An Alert can be declared for a fire, explosion, operational accident involving a sufficient quantity of hazardous material, natural hazards (i.e., seismic event and/or tornado/high winds), aircraft crash, or accident resulting in facility damage that threatens a confinement structure. The preceding sections describe the process for implementing basic protective actions as well as descriptions of response actions for events.

J.4.1 Notification

Notification will be made in accordance with the requirements of WAC 173-303-145 and WAC 173-303-360.

J.4.2 Identification of Released/Spilled Materials

Methods for identifying the character, source, amount, and areal extent of any materials when there has been a release or spill to the environment, a fire, or an explosion are outlined in, Attachment 4, *Hanford Emergency Management Plan* (DOE/RL-94-02), Section 4.2.

J.4.3 Prevention of Recurrence or Spread of Fires, Explosions, Releases

The EC/BED, as part of the incident command structure, takes the steps necessary to ensure that a secondary release, fire, or explosion does not occur. The following actions are taken:

- Isolate the area of the initial incident by shutting off power, closing off ventilation systems, if still operating, etc., to minimize the spread of a release and/or the potential for a fire or explosion
- Inspect surface of the tunnels for leaks, cracks, or other damage
- Contain and isolate residual mixed waste material
- Cover or otherwise stabilize areas where residual released mixed waste remains to prevent migration or spread from wind or precipitation run-off
- Install new structures, systems, or equipment to enable better management of mixed waste
- Reactivate adjacent operations in affected areas only after cleanup of residual mixed waste is achieved.

J.4.4 Termination of Event

For events where the Hanford Emergency Operations Center (Hanford-EOC) is activated, the RL Emergency Manager has the authority to declare event termination. This decision is based on input from the EC/BED, Incident Commander, and other emergency response organization members. For events where the Hanford-EOC is not activated, the Incident Command structure and staff will declare event termination.

J.4.5 Incident Recovery and Restart of Operations

A recovery plan is developed when necessary. A recovery plan is needed following an event where further risk could be introduced to personnel, the facility, or the environment through recovery action and/or to maximize the preservation of evidence. Depending on the magnitude of the event and the effort required to recover from it, recovery planning may involve personnel from RL and other contractors. If a recovery plan is required, it is reviewed by appropriate personnel and approved by a Recovery Manager before restart. Restart of operations is performed in accordance with the approved plan. While no active operations occur at the PUREX Storage Tunnels, approval may be required to restart activities in adjacent facilities.

If this plan was implemented for a WAC emergency (refer to Section J.3), the Washington State Department of Ecology must be notified before operations can resume. Attachment 4, *Hanford Emergency Management Plan* (DOE/RL-94-02), Section 5.1, discusses different reports to outside agencies. This notification is in addition to other required reports and must include information documenting the following conditions:

- There are no incompatibility issues with the waste and released materials from the incident.
- All the equipment has been clean, fit for its intended use, and placed back into service.

Additional information that Ecology requests regarding these restart conditions may be included in the required 15-day report identified in WAC 173-303-360(2)(k).

For emergencies not involving activation of the Hanford-EOC, the EC/BED ensures that conditions are restored to normal before operations are resumed. An onsite Recovery Manager could be appointed at the discretion of RL to restore conditions to normal. This process is detailed in Attachment 4, *Hanford Emergency Management Plan* (DOE/RL-94-02), Section 9.0. The makeup of this organization depends on the extent of the damage and its effects. The onsite recovery organization will be appointed by the appropriate contractor's management.

J.4.6 Incompatible Waste

After an event, the EC/BED or the onsite recovery organization ensures that no waste that might be incompatible with the released material is treated, stored, and/or disposed of until cleanup is completed. Cleanup actions are taken by facility personnel or other assigned personnel. Attachment 4, *Hanford Emergency Management Plan* (DOE/RL-94-02), Section 9.2.3, describes actions to be taken.

Waste from cleanup activities is designated and managed as newly generated waste. A field check for compatibility before storage is performed, as necessary. Incompatible wastes are not placed in the same container. Containers of waste are placed in storage areas appropriate for their compatibility class.

If incompatibility of waste was a factor in the incident, the EC/BED or the onsite recovery organization ensures that the cause is corrected.

J.4.7 Post Emergency Equipment Maintenance and Decontamination

All equipment used during an incident is decontaminated (if practicable) or disposed of as spill debris. Decontaminated equipment is checked for proper operation before storage for subsequent use. Consumables and disposed materials are restocked. Fire extinguishers are recharged or replaced.

The EC/BED ensures that all equipment is cleaned and fit for its intended use before operations are resumed. Depleted stocks of neutralizing and absorbing materials are replenished, self-contained breathing apparatus are cleaned and refilled, protective clothing is cleaned or disposed of and restocked, etc.

J.5 Emergency Equipment

Because no personnel entry is permitted into the storage tunnels, no permanent emergency equipment, communications equipment, warning systems, personal protective equipment, or spill control and containment supplies are located in the tunnels.

During an emergency response event, personnel use portable emergency equipment, which could include heavy equipment and cranes (Section J.3.2). Also, for such operations, work plans are followed and pre-job safety meetings take place.

J.6 Coordination Agreements

The DOE-RL has established a number of coordination agreements, or memoranda of understanding (MOU) with various agencies to ensure proper response resource availability for incidents involving the Hanford Site. A description of the agreements is contained in Attachment 4, *Hanford Emergency Management Plan* (DOE/RL-94-02), Table 3-1.

J.7 Required Reports

Post incident written reports are required for certain incidents on the Hanford Site in accordance with Attachment 4, *Hanford Emergency Management Plan* (DOE/RL-94-02), Section 5.1.

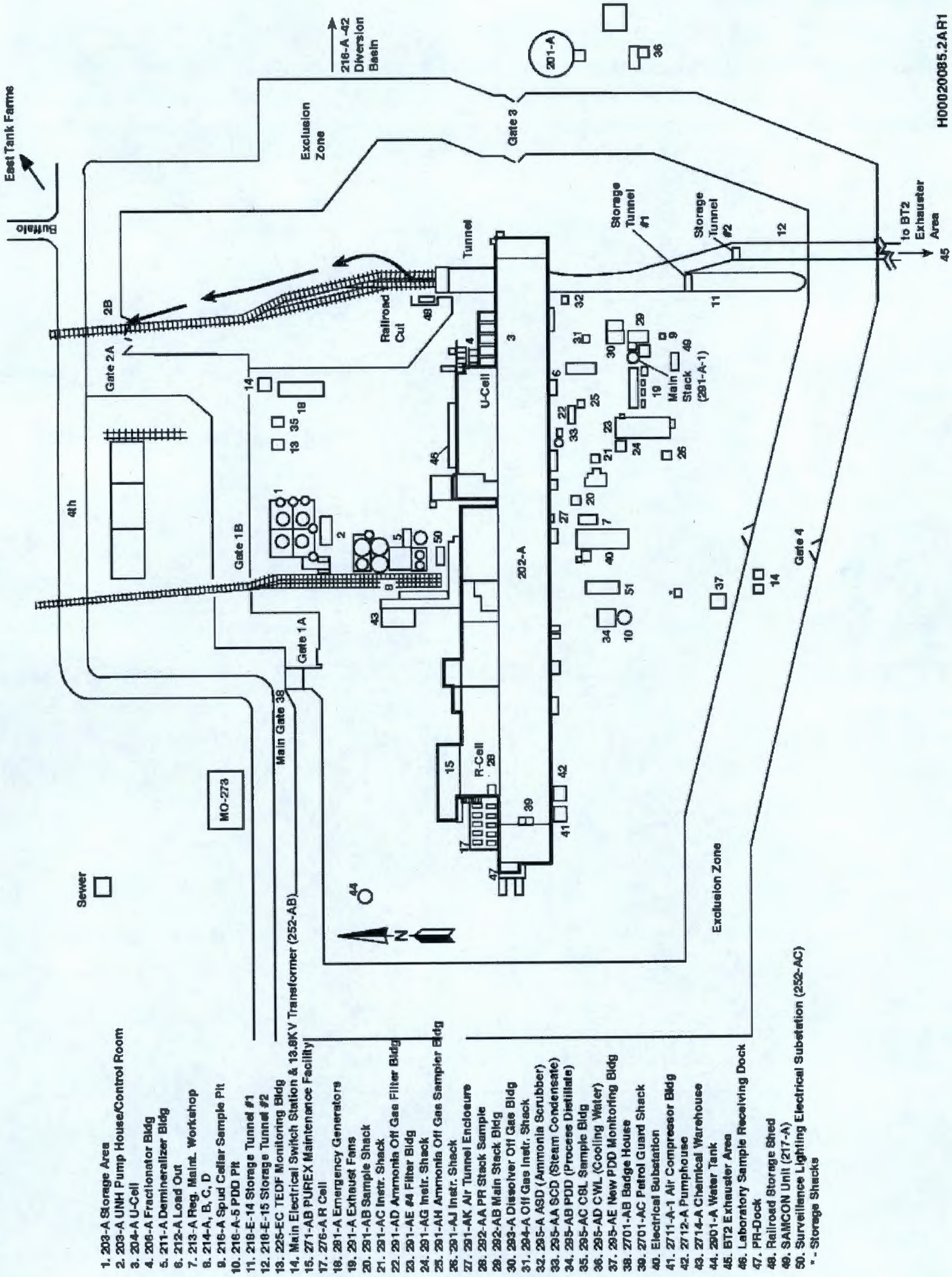

Figure J.1. PUREX Storage Tunnels Evacuation Route