MTC Utility Tunnel Design
Final Report

Prepared for:

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April 2015

BYRON & ASSOCIATES

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EXECUTIVE SUMMARY

The Church of Jesus Christ of Latter-day Saints is currently expanding its Missionary Training Facilities. Critical to this expansion is the furnishing of utility services to the new buildings. In this report research and designs solutions are presented. Advantages, viability, cost, community impact, and risk for each alternative are considered as part of the analysis. The design has been divided into two major approaches: an open cut or a trenchless method.

A traditional open cut method includes excavating the project site, one half of the road at a time. A geotechnical report showed that the soil type is mostly gravel with silt and sand. Several shoring methods were researched. While sheet piles would be the most economical, over ten utility lines running parallel to the street would need to be rerouted. Soldier piling is another quick and versatile option for shoring the deep excavation. Both shoring methods are possible since the groundwater level is well below the excavation depth. An 8'x11' concrete tunnel would be constructed. Because of time constraints, cast-in-place concrete is not a viable option. Precast concrete sections would be lowered in place by crane. Waterproofing of joints would provide for watertight connections. After backfill and road repair, the same procedure would be repeated for the other half. One lane of traffic would remain open during the entire construction process, as specified in the RFP. Overall, this method is more traditional is most likely the cheaper of the two design methods. However, the impacts are great and may not be able to be completed within the six week period.

The trenchless approach was explored as a design alternative. Auger boring, often referred to as 'jack and bore', is a popular type of horizontal boring. This technique involves excavating two shafts or pits on either side of the street. Steel sections of the 10' tunnel would be lowered and thrust through the soil while simultaneously removing spoil. Although there is little risk raveling ground, settlement would be carefully monitored. Further, there would be no road removal/repair, no open cut trench, and traffic could continue undisrupted. While this approach may be more expensive, construction time is significantly reduced and impact is minimized. This method is ultimately Byron & Associates' recommendation and has been recently used on a similar nearby project.

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INTRODUCTION

The Missionary Training Center (MTC) in Provo, UT is the main location where young men and women from The Church of Jesus Christ of Latter-day Saints gather to prepare to serve worldwide service missions. The LDS Church has decided to expand the MTC facilities to accommodate the growing number of missionaries. The expansion will replace the existing laundry and mail facilities and parking areas, which will be demolished and relocated to the opposite side of the intersection. Consequently, utility services will be provided to the MTC extension area just west of the intersection of 900 East and University Parkway (see *Figure 1*). These utility services will be installed underneath University Parkway by way of a tunnel.

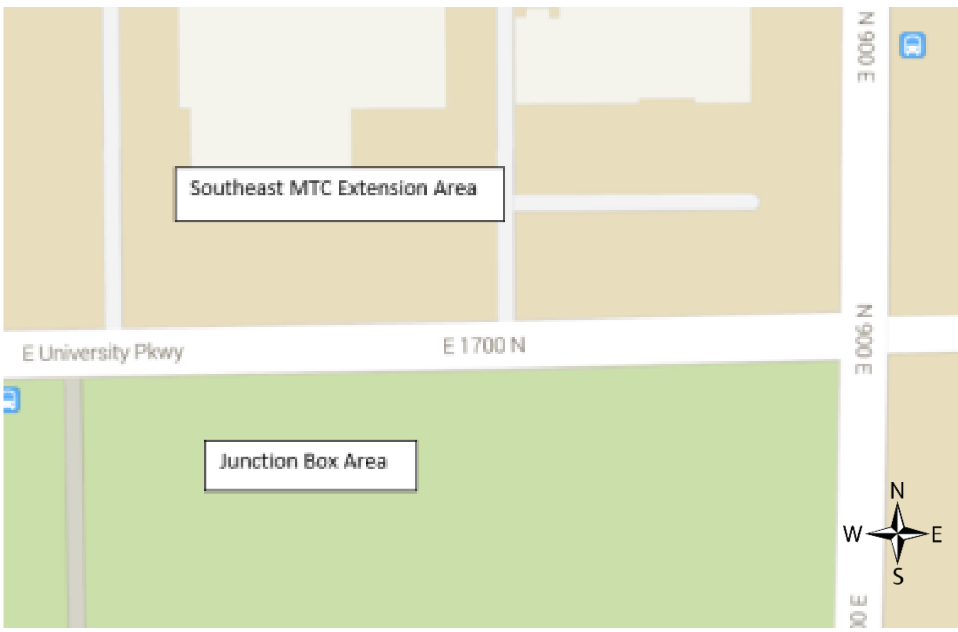


Figure 1: MTC Tunnel Location

The aim of this project is to connect utilities from the mechanical system junction box to the southeast MTC expansion area. This involves the design of an underground utility tunnel with foot access crossing under University Parkway (E 1700 N). As specified by the sponsor, the major constraints of this project are cost and time. Additionally, at least one lane of traffic will remain open each way. The construction of the project will be completed within six weeks (between July 4, 2015 and the start of education week August 17, 2015).

It was understood that scope of the project included tunnel design, shoring design, road repair design, and evaluation of social/environmental factors. It was assumed that the relocating and demolition of the existing facilities would be completed before the beginning of construction. Members of Byron & Associates were limited in their knowledge of engineering design components, construction experience, judgment, and cost estimating. Thus, the presented analysis and design may be incomplete and is subject to revision. However the purpose of the capstone project was achieved as team members worked together to research alternatives, contact professional consultants, and gain valuable design experience. All deliverables were completed and submitted by the required deadlines, as outlined in the contractual terms and conditions.

This report outlines the design options available to the client. While several alternatives were explored and researched, the two major design approaches include: 1) a traditional open cut and cover technique, and 2) a trenchless jack and bore method. Each design alternative includes preliminary cost estimates, drawings, and specifications. An analysis is presented with calculations for each design.

OPEN TRENCH DESIGN

EXCAVATION

The first approach discussed will be the open cut method. This involves excavation, shoring, tunnel placement, backfill and compaction, and road repair in two phases (one for each half of the road to keep one lane open each way). The anticipated excavation is 30' deep and 15' wide. The total length tunnel was determined to be 108'. Drawings from an engineer were obtained that included existing conditions and topography of the project area (see Appendix A). The location of the tunnel connection is known and the expansion area is expected to be clear and available. From the CAD drawings, it was discovered that several utilities run underground parallel to University Parkway. These utilities include various gas, water, and fiber optic lines that span the street at varying depths. *Figure 2* is a screenshot of a CAD drawing shown in the existing utilities.

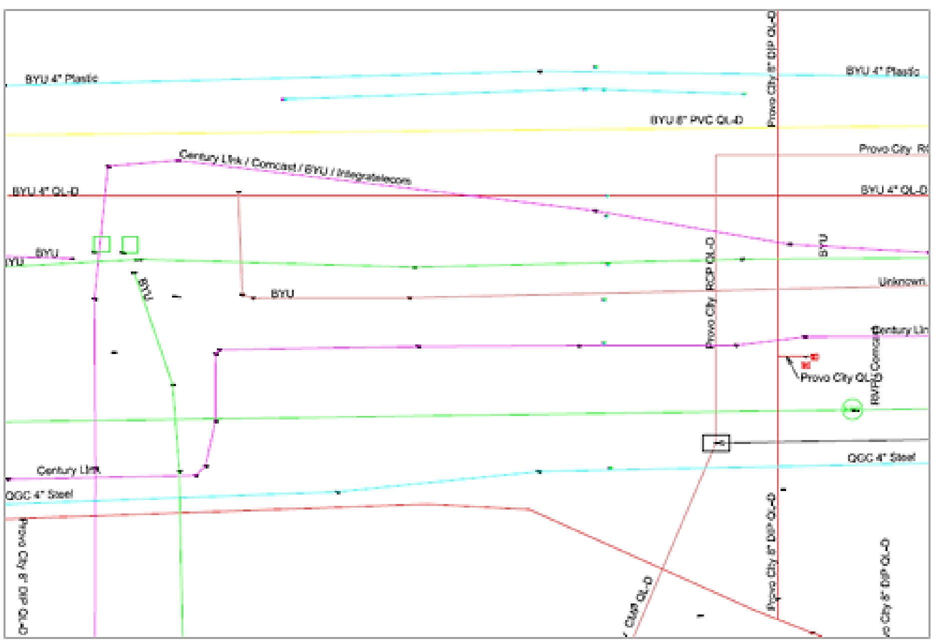


Figure 2: Existing utilities at the proposed road crossing

These utilities presented a large concern for excavation and shoring. This was the first major design obstacle of the project. About ten utilities of varying depths exist below surface (the deepest at 7') and are spaced several feet apart. Since 12' tunnel sections are unlikely to be maneuvered safely between utilities, it was assumed that the utilities would need to be rerouted around the project area. Considering the number and type of pipes and utility lines as well as the required distance to reroute them, it could be very expensive and time consuming to do so.

SHORING DESIGN

A geotechnical report of the location was obtained (see Appendix B). The report revealed that the soil is predominantly gravel with silt and sand. It also showed that the water table was at least 35 feet below the surface. Since the excavation depth is only 30 feet, pumping would not be an issue during excavation.

The two major options explored for deep shoring design were sheet piles and soldier piles. Sheet piles are common since they are cheap, minimize seepage, and eliminate potential caving or local shear failure. After consultation with geotechnical engineers it seemed that sheet piles were not a practical option unless the utility corridor beneath the roadway was rerouted. Calculations yielded a required section modulus of 2.3 in^3/ft and a recommended sheet pile using US Steel PMA-22 (see Appendix C). Vibrations from installing sheet piles may be a factor to sensitive neighbors in the nearby neighborhood.

Soldier piles were also considered in this design. The major advantages of soldier piles and lagging walls is versatility. Calculations showed that the apparent pressure for the design of braced excavation is 744 psf (see Appendix C). The tie backs would be spaced 8 feet vertically and 8 feet horizontally with 3 inch thick lagging. The expected moment (assuming good quality construction) is 38.1 kip-ft with a section modulus of 18.3 in^3. An HP 8x36 steel pile is recommended. Again, the utilities must be rerouted. Since sheet piles are typically cheaper than soldier piles, it is recommended that sheet piles be used in the deep shoring.

TUNNEL DESIGN

Two main methods for installing a concrete tunnel exist: cast-in-place and precast. The advantage of the cast-in-place method is fewer construction joints from monolithic construction. It is also easier to pour around and avoid utilities. The limiting factor for cast-in-place concrete is time. Seven days of cure time is required before the next stage can be poured to completion. In addition, the concrete can only be buried and loaded after a 28-day cure period in which the sections will gain 90% of their strength. This method would significantly extend the time for tunnel placement. It is estimated that a minimum of two pours per half of road and one 28-day cure period. Pouring half of the tunnel would take approximately five weeks minimum. Since the project must be completed in six weeks, cast-in-place is not a feasible option.

Instead, precast tunnel sections would be made off-site and then transported to the construction site when ready to install. Precast concrete tunnel sections would allow for the concrete to achieve cure strength off-site prior to construction. This method will reduce on-site construction time for the tunnel itself. One of the disadvantages of using a precast tunnel is waterproofing. Since there are more construction joints, more waterproofing would be required. Although the tunnel is above the water table, it is still necessary to ensure there will be no transmission of fluids in or out of the tunnel. Another disadvantage is the need for crane equipment to be on-site installing these precast sections. In most cases this is not a problem, but due to the placement of existing overhead power and phone lines it becomes more difficult and dangerous to workers.

Figure 3 is a CAD drawing showing the rectangular precast tunnel design proposed for this alternative method of tunnel construction. This tunnel design measures 8'-2" tall and 11' wide. Similar dimensions are shown by actual tunnel drawings in Appendix D. Nine sections at 12 feet each will total a tunnel length of 108 ft from the junction box connection. The vertical load on the tunnel is 45 kip-ft with a lateral earth pressure of 362 kip-ft. It was determined that the concrete sidewalls would be 18 inches thick and the ceiling and floor would be 11 inches thick. The precast sections would also be reinforced with steel rebar. This would be accomplished by #6 rebar framing around the perimeter of the structure tied into a grid with longitudinal bars running the length of each section. A 3-D representation of the rebar plan can be seen in *Figure 4*. The calculations used to determine these design values for the precast sections are shown in Appendix E.

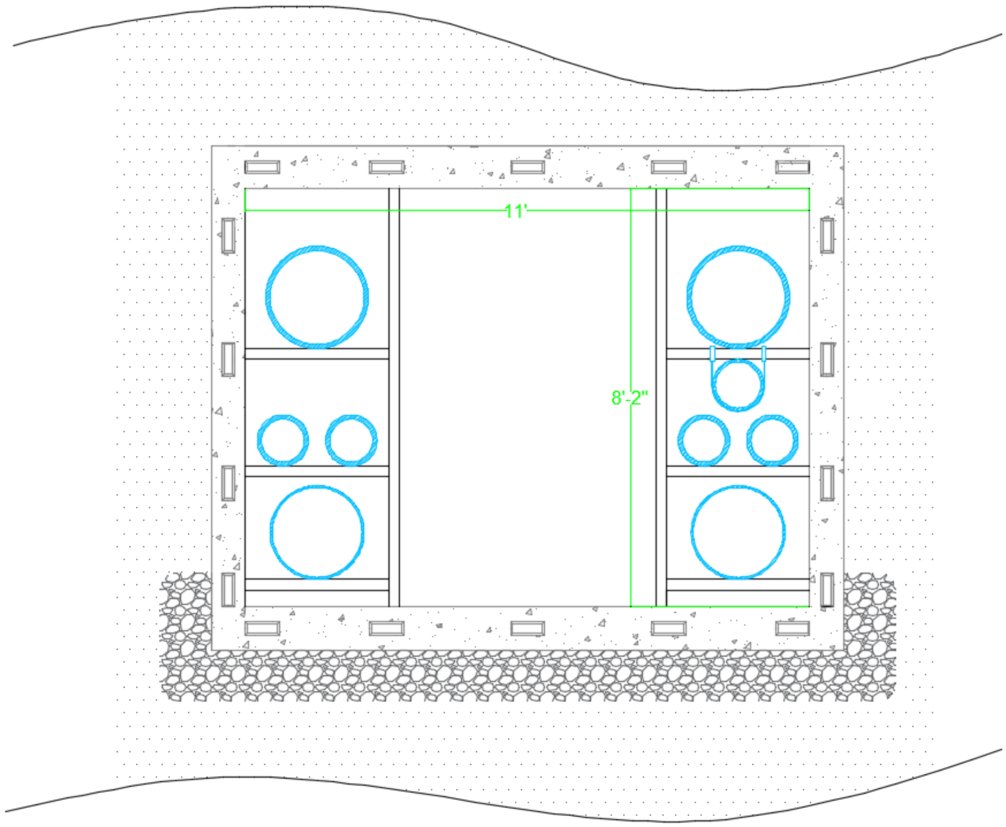


Figure 3: Cross sectional CAD drawing of precast concrete tunnel sections

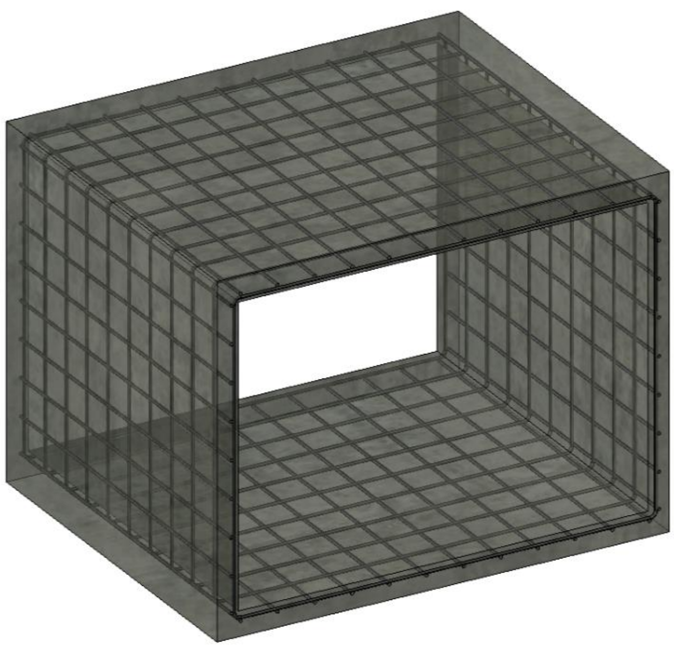


Figure 4: CAD drawing of rebar plan for precast reinforced sections

WATERPROOFING

Many common waterproofing solutions are available. If precast tunnel sections are used, sealant at the construction joints will be needed. Each technique is similar in principle but differs in execution and performance. The simplest solution for most projects is application of sealant on the outside and inside portion of the construction joints. Possible candidates to waterproof the joints are Koster and SikaSwell. After researching, the SikaSwell joint sealant best fits project requirements. A strip swells towards water exposure and will grow to fill cracks and void spaces. It is attached using a rubber sealant that is also waterproof.

TRAFFIC CONTROL

Traffic control will also be an important aspect of the project. After consulting a traffic engineer, it was determined that the traffic flow during construction will be at capacity regardless of signal phasing or attempts to minimize delays. Signal timing will remain unchanged during construction. It is likely that after the initial construction begins, volume will decrease as drivers avoid the area.

Since one lane must remain open in each direction during construction, preliminary sketches were drawn to illustrate the movement of traffic during the project. *Figure 5* shows the path of traffic flow during one phase. For each phase, half of University Parkway will be closed for excavation and tunnel placement. After road repair is complete, the process will be repeated for the other side. Traffic cones will most likely be the easiest way to direct traffic since the project is to be completed quickly and detours are temporary. Adequate warning signs and TCDs will ensure clear and safe traffic guidance. Also since there are two left-turn bays on the northern approach of 900 E at the intersection, one will be closed since only one westbound lane will be open on 1700 N.

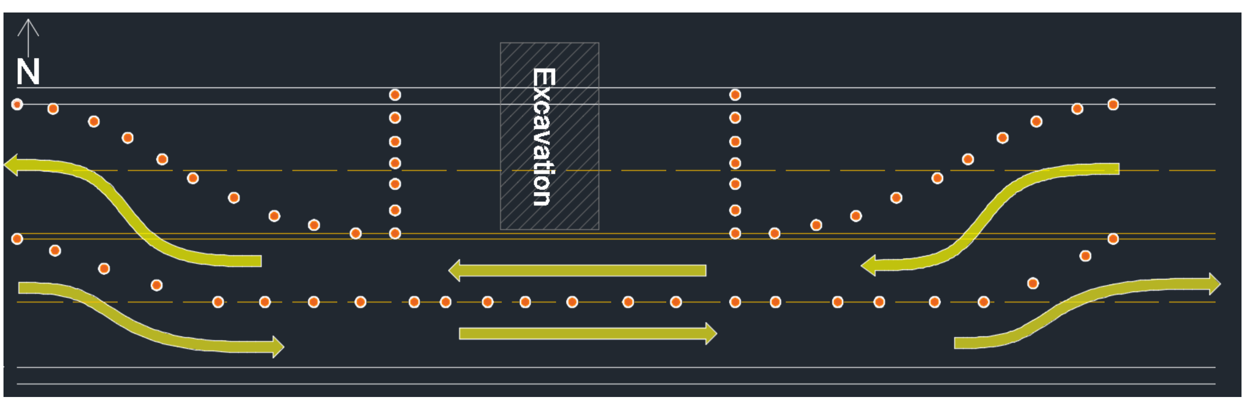


Figure 5: Sketch representing traffic cones and the flow of traffic during each phase of construction

ROAD REPAIR

After the tunnel has been placed, the trench will be backfilled and compacted. Repairs to the existing asphalt, sidewalks, and curb and gutter will need to be done to finish the project. There will be approximately 1,500 ft^2 of asphalt replaced that will be 4 inches thick. Dimensions of base material and pavement width will match current conditions. Additionally, 50 linear feet of both sidewalk as well as curb and gutter will also need to be replaced. Tests will be conducted on each product to ensure they meet the standards specified by Provo City engineers.

IMPACT

There is high impact with this approach since the utility corridor would need to be rerouted during construction. This may add substantial delays to construction. Also traffic delays would be significant. An open trench may pose danger to pedestrians. Construction zones will be fenced off and sound barriers used to reduce construction noise in nearby neighborhoods. All excavation will be performed in accordance with Provo City ordinances. Vibrations from installing sheet piles may be a factor to sensitive neighbors in the nearby neighborhood. A couple of matured trees will also need to be removed, which may cause some environmental concerns. Since the expansion area directly north of the road crossing is expected to be clear, a crane could be set up and operated from that lot. The overhead power lines may be able to operate despite power lines. Otherwise, they need to be rerouted so that tunnel sections can be easily lifted into place in a safe manner.

Permits would need to be obtained and associating fees paid to the Provo City Engineering Department. These fees would be minimal in contrast to the project estimates. Attempts were made to get pricing from the permit department but requests were not filled. Considering costs of excavation of 1750 yd^3 of soil, rerouting of ten or more utility lines, deep shoring using sheet piles, 8’x11’ precast concrete tunnel sections, SikaSwell waterproofing of joints, city fees for shutting down lanes of traffic, and road repair, Byron & Associates estimates that the total cost of this approach to be just over $715,000 (see Appendix F).

TRENCHLESS JACK AND BORE DESIGN

JACK AND BORE

Since the utility corridor was a major concern for excavation and shoring, another approach was explored. A professor referred us to a consultant who specializes in trenchless technologies. Auger boring, often referred to as jack and bore, is a popular type of horizontal boring. An illustration of the jack and bore operation is shown in *Figure 6.*

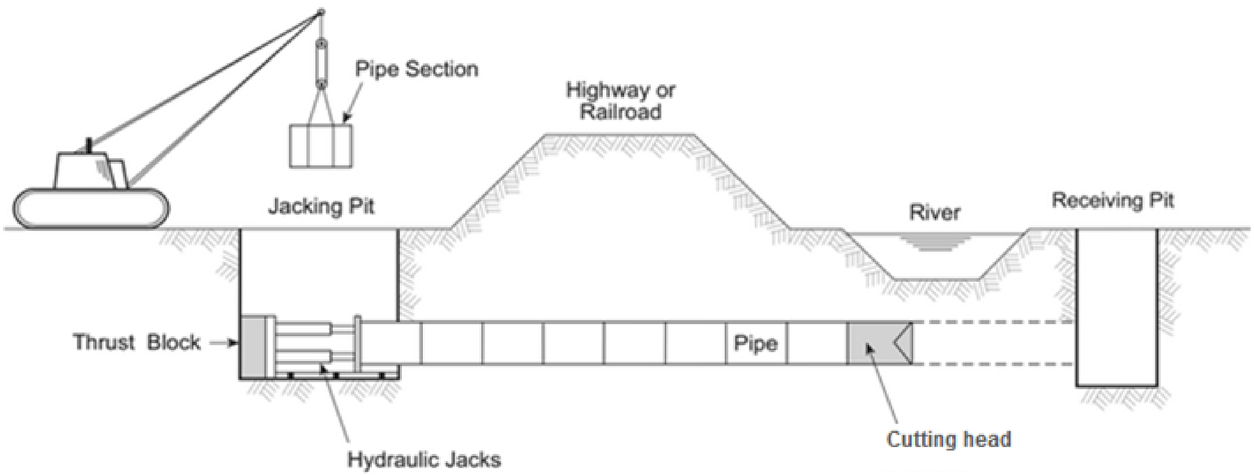


Figure 6: Jack and bore tunneling operation

The jack and bore procedure involves excavating two shafts, one on each side of University Parkway. One shaft, called the jacking pit, would contain the jacking machine and the other, known as the receiving pit, would be for removing the boring cutter head. The excavation for the jacking pit would be 25 feet long by 15 feet wide and would reach the designated depth of 30 feet. This would allow for the machine and ample room to insert each tunnel section. Shoring could be performed using sheet piles. Once the jacking machine is installed in the pit, the main jacks are retracted and steel tunnel sections are lowered into the pit. A helical auger 10' in diameter fit inside the pipe with a cutting head on the front of the leading section. As the jacks thrust the tunnel through the soil, the auger simultaneously removes spoil back to the jacking pit where it can be removed. Next, the jacks are retracted again and the next tunnel section is lowered into place. The two sections are welded together to provide waterproofing for the tunnel. The process is repeated until the tunnel reaches the receiving pit. The receiving pit would only need to be 10 feet long by 15 feet wide. The cutting head is removed and lifted out of the receiving pit and the auger is backed out and removed. Finally, with the tunnel in place, utilities needed for the MTC expansion area are ready to be installed.

TUNNEL DESIGN

It was determined that the design of this tunnel will include 10 ft inner diameter steel tunnel, since the maximum size auger for jack and bore is 10 feet and is circular in shape. Although not specified in the RFP, the circular design may be advantageous because of the structural strength that a circle provides in dissipating loads. The steel tunnel was determined to be 1/2 inch thick. This would provide adequate strength to support the load above the utility tunnel. After the tunnel is in place, grating will be installed through the entire tunnel to provide for foot access and maintenance in the tunnel. The grating will be attached through tack welding. According to the cost estimate, the steel tunnel would also be cheaper than the reinforced concrete (see Appendix F). A cross-section of the design is shown in *Figure 7*. A 3D rendering is shown in *Figure 8*.

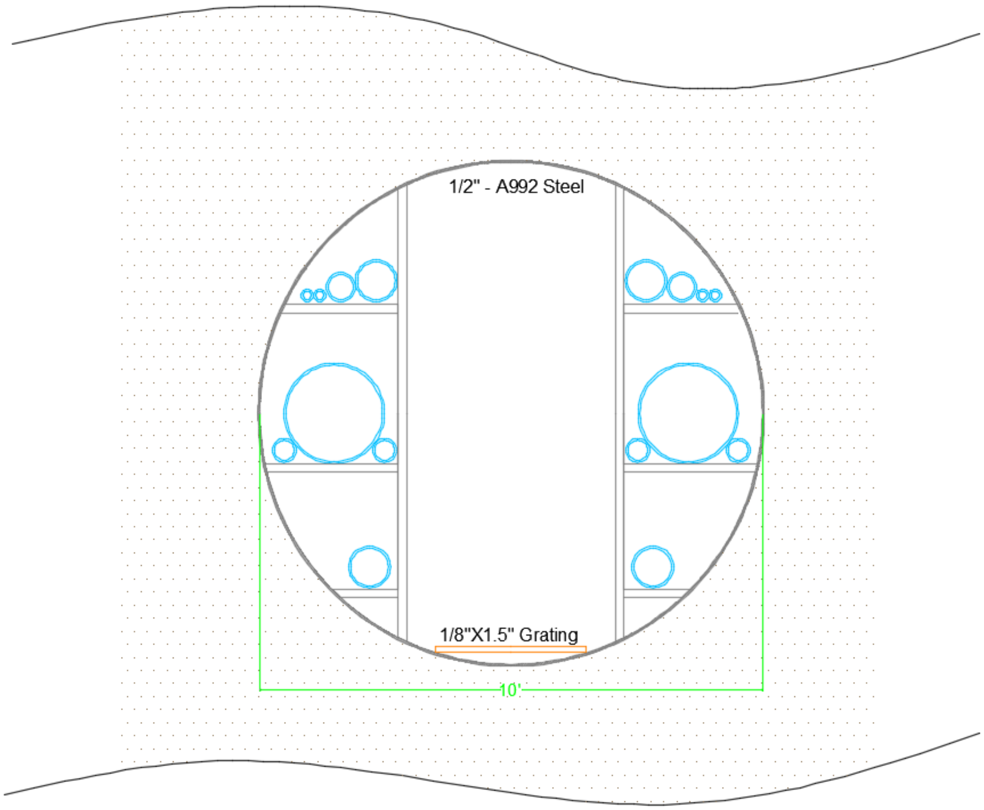


Figure 7: Cross sectional CAD drawing of steel tunnel sections

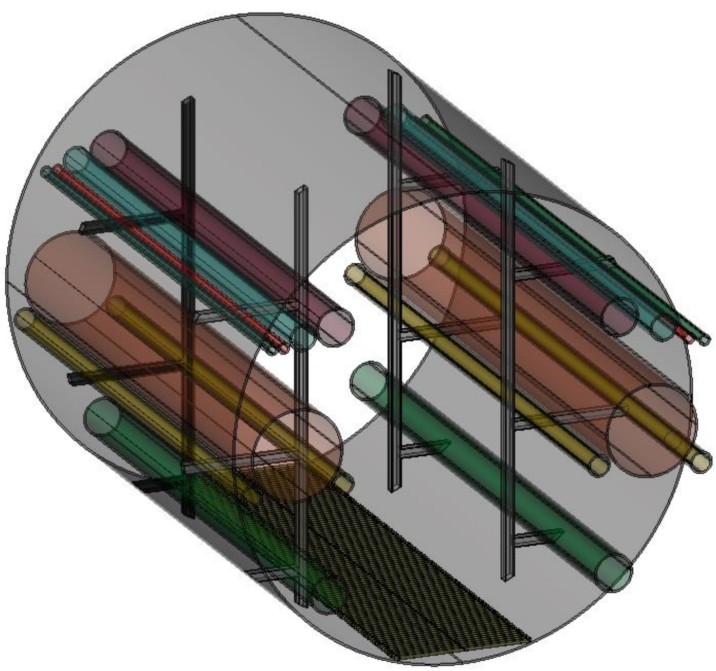


Figure 8: 3D rendering of steel tunnel design.

IMPACT

The trenchless design approach minimizes impact compared to the open trench design. The major advantage is reduced construction time. Since the project has time restrictions, the ability to expedite the process is valuable. The existing utilities would not need to be rerouted and road repair is unnecessary. It is estimated that construction could be completed within 4 weeks. The impacts on the surrounding neighborhood would be significantly less since there would be less excavation without an open trench across the roadway. Also, traffic flow would be able to continue undisrupted. There is some risk for settlement and raveling on the front end of the tunnel as it is being thrust through the soil. Based on the soil type, there is low risk. Equipment would carefully monitor settlement of the soil and road during the jack and bore process. It is possible that one to two inches of settlement may occur due to raveling, but this is negligible and would not affect the road. Overall, there are fewer components that could lead to problems and delays. It is a specialized but streamlined process.

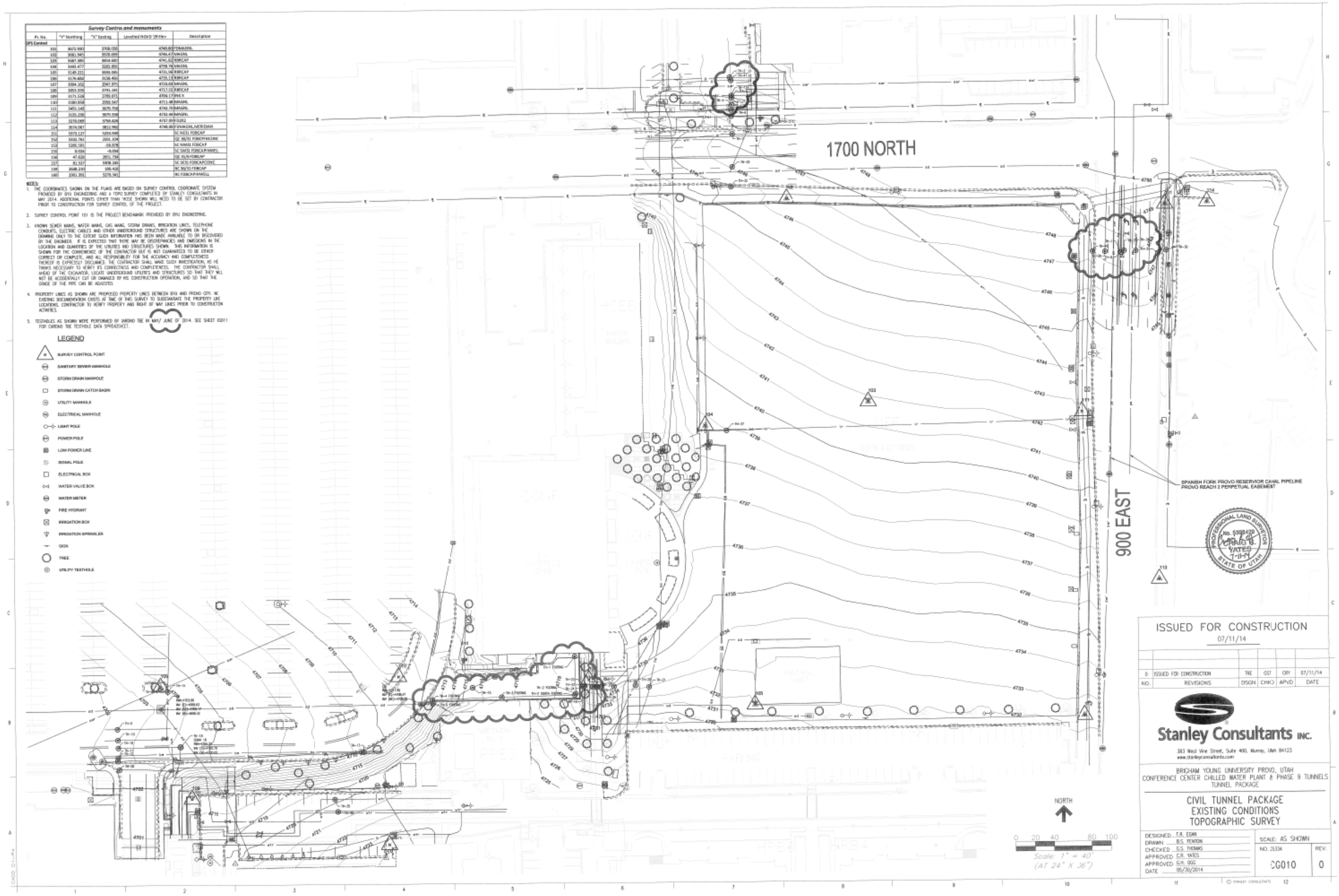
Considering costs of excavation of 583 yd^3 of soil for two pits, shoring using sheet piles, 10' steel tunnel sections, welding of joints, jack and bore set up and monitoring, Byron & Associates estimates that the total cost of this approach to be just under \$1.3 million (see Appendix F).

CONCLUSION

In summary, to provide utility services across University Parkway, several tunnel design alternatives are available to the client. Each design type has quantifiable advantages and disadvantages. Listed in this document are two design paths: an open trench and a trenchless design. Within the trenchless design, two subcategories exist. The first is a poured in place concrete tunnel. The second is a precast tunnel with twelve foot sections spanning the width of the road. In the designs proposed for this project, Byron & Associates has considered and fulfilled all RFP design requirements. The plans and cost estimations provided in this report represent the best effort of Byron & Associates to provide a safe and cost effective design. All deliverables were completed and submitted by the required deadlines, as outlined in the contractual terms and conditions. The deliverables were defined in the RFP and included tunnel design, shoring design, road repair design, and evaluation of social/environmental factors.

Based on the project limitations and research performed by Byron &Associates, we ultimately recommend the trenchless jack and bore tunnel design. This method is recommended because of the time constraints for the project, the ability to avoid existing utilities and the minimal impact on the surrounding area. Although the cost for the trenchless design is greater, the benefits seem to outweigh the cost.

APPENDIX A: Topography of Project Location



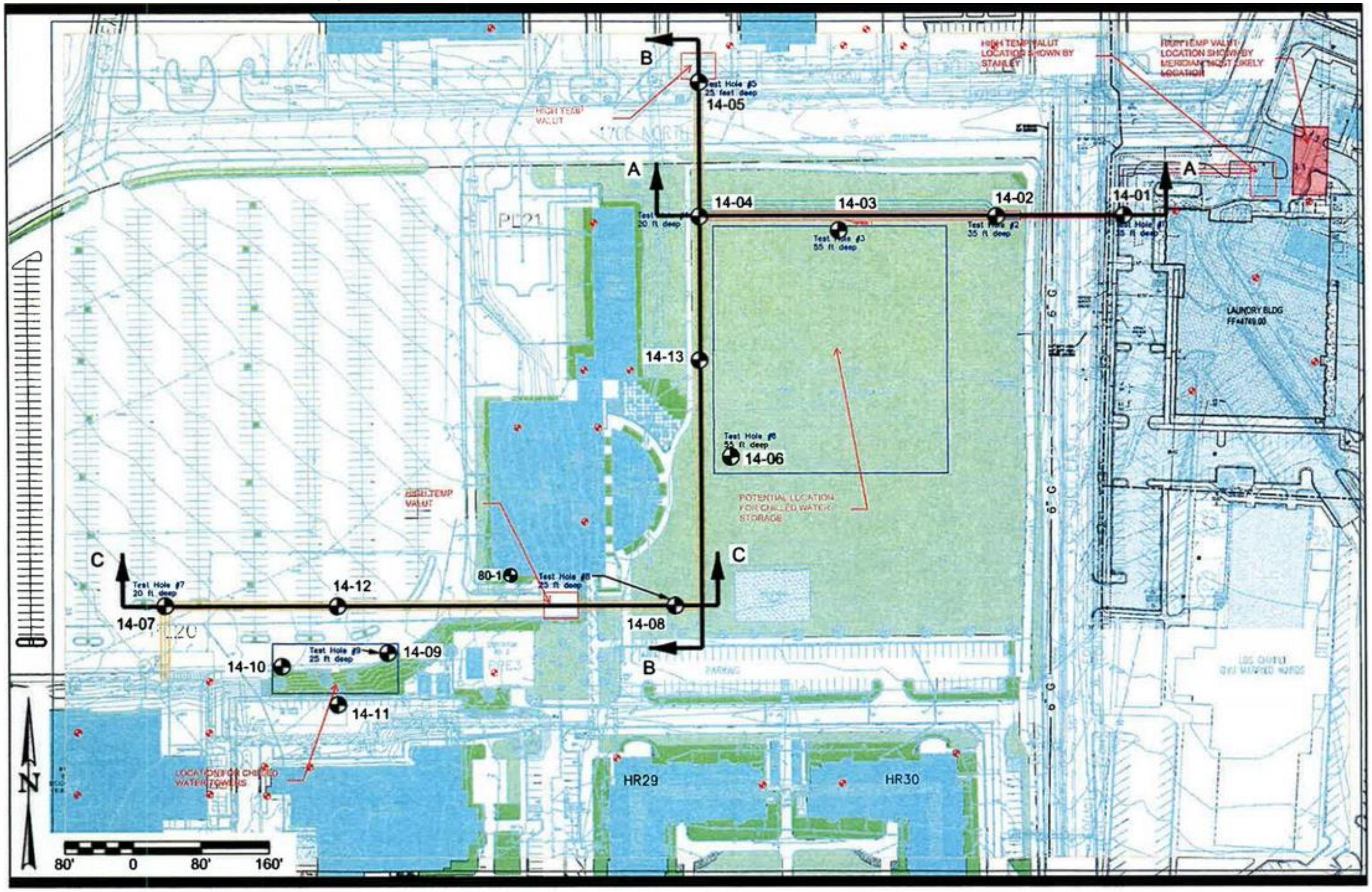


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Figure 2 SITE PLAN & TEST HOLE LOCATIONS

B.Y.U. - Conference Center Chilled Water Plant and Tunnels

Provo, Utah County, Utah

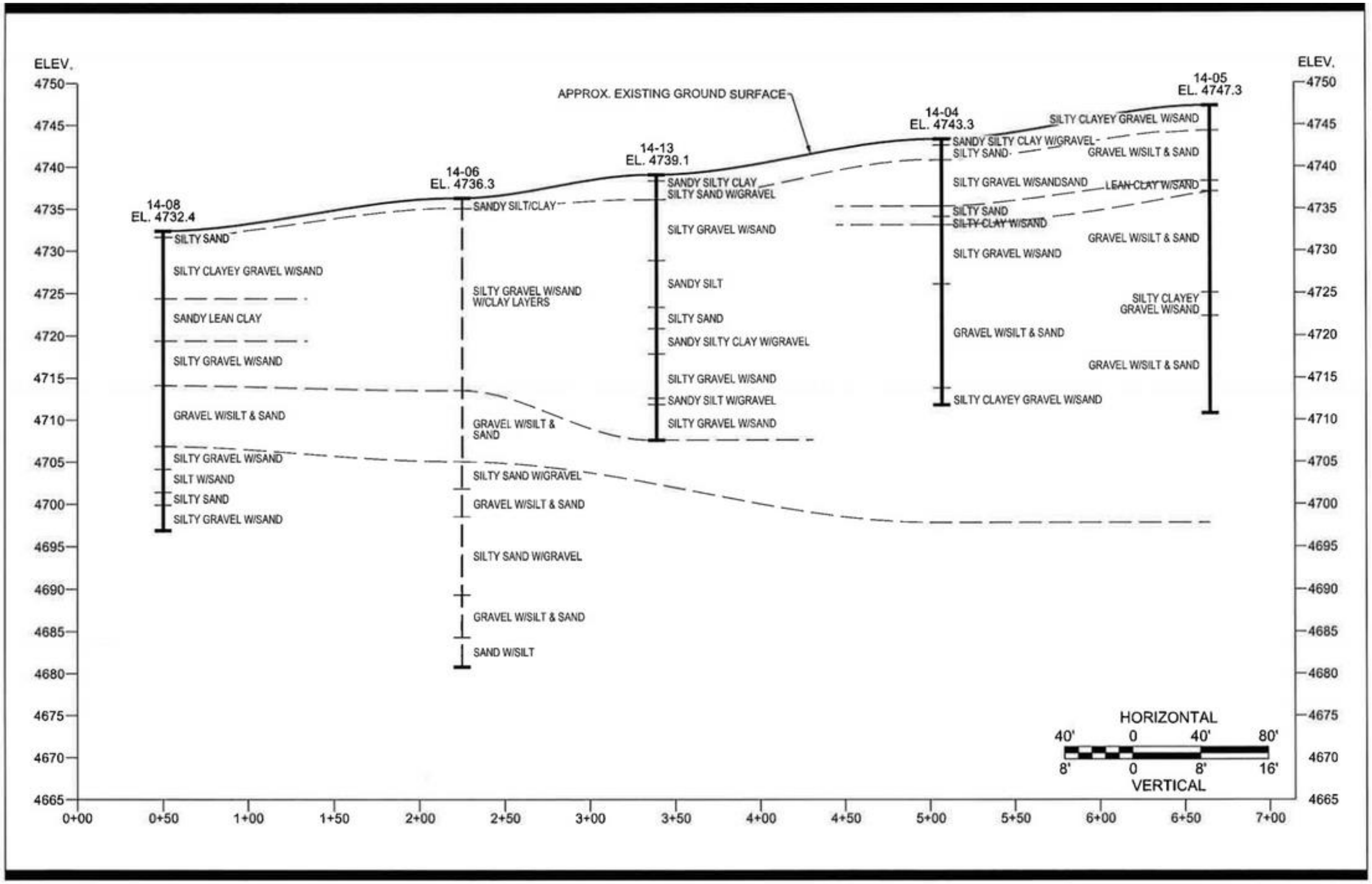

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Figure 4 CROSS SECTION B-B

B.Y.U. - Conference Center Chilled Water Plant and Tunnels

Provo, Utah County, Utah

DRILL HOLE LOG

BORING NO. 14-04

SHEET 1 OF 1

PROJECT: BYU - CONFERENCE CENTER CHILLED WATER PLANT AND TUNNELS
CLIENT: BRIGHAM YOUNG UNIVERSITY
LOCATION: N:3624 E:3295 (SEE SITE PLAN)
DRILLING METHOD: 08-CME-55 / N.W. CASING TO 27'
DRILLER: T. KERN, J. CHAVARIN
DEPTH TO WATER - INITIAL: ▽ DRY' **AFTER 24 HOURS:** ▼ N.M.

PROJECT NUMBER: 201401.009
DATE STARTED: 4/2/14
DATE COMPLETED: 4/2/14
GROUND ELEVATION: 4743.3'
LOGGED BY: C. SANBORN, J. BOONE

Elev. (ft)	Depth (ft)	Lithology	Sample: Type	Sample: Rec. (in)	Sample: See Legend	Sample: USCS (AASHTO)	Material Description		Dry Density (pcf)	Moisture Content (%)	Atter.: Liquid Limit	Atter.: Plast. Index	Gradation: Gravel (%)	Gradation: Sand (%)	Gradation: Silt/Clay (%)	Other Tests
				17	3,5,10,(32)	CL-ML	brown, moist	SANDY SILTY CLAY W/GRAVEL								
						SM	brown, moist	SILTY SAND								
4740																
								SILTY GRAVEL W/SAND plastic fines, sand layers, probable cobbles								
	5															
				11	25,40,35,(99+)	GM	brown-gray, moist, very dense			10.4			42	38	20	
4735								SILTY SAND (driller's observation)								
	10				T 0.43	CL-ML	brown, moist, firm	SILTY CLAY W/SAND								
				11	4,17,26,(74)	GM	brown-gray, moist, dense									
4730								SILTY GRAVEL W/SAND plastic fines, probable cobbles								
	15															
				14	47,78,50/3"	GM	brown-gray, moist, very dense			7.1			51	34	15	
4725				7	29,63/4"	GP-GM	brown-gray, moist, very dense									
	20							GRAVEL W/SILT & SAND probable cobbles								
				9	48,59,31,(99+)	GP-GM	brown, moist, very dense			7.6		NP	61	28	11	
4720																
				13	30,45,42,(93)	GP-GM	brown-gray, moist, very dense			7.0			52	36	12	
	25															
								GRAVEL W/SILT & SAND slightly plastic fines, probable cobbles								
				14	48,48,35,(84)	GP-GM	brown, moist, very dense									
4715																
	30							SILTY CLAYEY GRAVEL W/SAND								
				10	25,15,16,(30)	GC-GM	brown, moist, med. dense	possible cobbles								
								BOH								
4710																

DH_LOGV1AA BYU_HARMONTUN.GPJ US EVAL.GDT 5/5/14

LEGEND:

DISTURBED SAMPLE
2,3,2,(6) ← Blow Count per 6" ; (N1)60 Value
T 0.45 ← Torvane (tsf)
PP 0.90 ← Pocket Penetrometer (tsf)

UNDISTURBED SAMPLE
Pushed
T 0.45 ← Torvane (tsf)
PP 0.90 ← Pocket Penetrometer (tsf)

OTHER TESTS
UC = Unconfined Compression
CT = Consolidation
DS = Direct Shear
UU = Unconsolidated, Undrained
CU = Consolidated, Undrained
Chem. = pH, Resistivity, Sulfate, Chloride
Hyd. = Hydrometer

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DRILL HOLE LOG

BORING NO. 14-05

SHEET 1 OF 1

PROJECT: BYU - CONFERENCE CENTER CHILLED WATER PLANT AND TUNNELS
CLIENT: BRIGHAM YOUNG UNIVERSITY
LOCATION: N:3814 E:3294 (SEE SITE PLAN)
DRILLING METHOD: 08-CME-55 / N.W. CASING TO 34.3'
DRILLER: S. CHAFFIN, J. CHAVARIN
DEPTH TO WATER - INITIAL: ▽ DRY' **AFTER 24 HOURS:** ▼ N.M.

PROJECT NUMBER: 201401.009
DATE STARTED: 4/7/14
DATE COMPLETED: 4/7/14
GROUND ELEVATION: 4747.3'
LOGGED BY: C. SANBORN, J. BOONE

Elev. (ft)	Depth (ft)	Lithology	Sample				Material Description		Dry Density (pcf)	Moisture Content (%)	Atter.		Gradation			Other Tests
			Type	Rec. (in)	See Legend	USCS (AASHTO)					Liquid Limit	Plast. Index	Gravel (%)	Sand (%)	Silt/Clay (%)	
						SM	brown, moist	4" ASPHALT 5" ROAD BASE (SILTY SAND W/GRAVEL)								
				9	12,10,8,(38)	GC-GM	dk. brown, moist, med. dense	SILTY CLAYEY GRAVEL W/SAND possible cobbles								
4745																
	5			9	34,56,38,(99+)	GP-GM	brown, moist, very dense	GRAVEL W/SILT & SAND slightly plastic fines, probable cobbles		6.8			61	27	12	
4740																
	10				T 0.40	CL	brown, moist, firm	LEAN CLAY W/SAND								
				12	6,15,22,(59)	GP-GM	brown, moist, dense									
4735																
	15			11	28,40,40,(99+)	GP-GM	brown, moist, very dense	GRAVEL W/SILT & SAND slightly plastic fines, probable cobbles		6.9			61	29	10	
4730																
	20			7	6,12,15,(32)	GP-GM	brown, moist, med. dense									
4725																
				3	4,4,27,(34)	GC-GM	brown, moist, med. dense	SILTY CLAYEY GRAVEL W/SAND possible cobbles								
	25															
				4	12,16,19,(36)	GP-GM	brown, moist, med. dense									
4720																
	30			10	23,33,35,(66)	GP-GM	brown, moist, dense	GRAVEL W/SILT & SAND slightly plastic fines, probable cobbles		9.0			61	28	11	
4715				10	36,38,68/5"	GP-GM	brown, moist, very dense									
	35			13	20,25,22,(42)	GP-GM	brown-gray, moist, med. dense									
								BOH								
4710																

RB&G ENGINEERING, INC.

LEGEND:

DISTURBED SAMPLE: 2,3,2,(6) — Blow Count per 6"; (N1)60 Value; T 0.45 — Torvane (tsf); PP 0.90 — Pocket Penetrometer (tsf)

UNDISTURBED SAMPLE: Pushed; T 0.45 — Torvane (tsf); PP 0.90 — Pocket Penetrometer (tsf)

OTHER TESTS
UC = Unconfined Compression
CT = Consolidation
DS = Direct Shear
UU = Unconsolidated, Undrained
CU = Consolidated, Undrained
Chem. = pH, Resistivity, Sulfate, Chloride
Hyd. = Hydrometer

APPENDIX C: Shoring Calculations

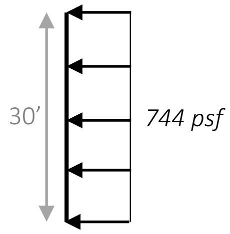
Soldier Piles

- The apparent pressure for design of the braced excavation is 744 psf.

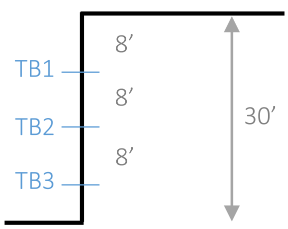
An average soil unit weight (γ) of 135 pcf was assumed from the geotechnical report. Since the soil type is predominantly gravel with silt and sand, a friction angle (φ) of 34° was also assumed.

$K_a = tan^2(45 - {}^{\varphi}/_2) = tan^2(45 - {}^{34}/_2) = 0.283$

$P = 0.65\, K_a\, \gamma\, H = 0.65(0.283)(135\, pcf)(30\, feet) = 744\, psf$



- The tie backs are to be spaced 8 feet vertically and 8 feet horizontally.



Using a tributary approach, all tie backs have the same load (F).

$F = (8\, ft)(8\, ft)(744\, psf) = 47616\, lb = 47.6\, kip$

Typically, a factor of safety between 1.33 and 1.5 is used in designing the tie back length. This relatively low value can be used because each anchor is proof loaded during construction.

$\therefore Design\ tie\ back\ force\ for\ 1.33(47.6\, kip) \approx 64\, kips$

- The required tie back lengths:

Tie Back	*Depth (ft)*	*Length (ft)*
1	8	40.5
2	16	24.5
3	24	16.5

- The expected moment (assuming good quality construction) is 38.1 kip-ft with section modulus of 18.3 in^3. (An allowable tensile stress of 25,000 psi was assumed.)

$$M_{max} = \frac{(744\ psf)(8\ ft)(8\ ft)^2}{10} = 38.1\ kip \cdot ft$$

$$S_x = \frac{M_{max}}{f_s} = \frac{(38.1\ kip \cdot ft)(12\ in/ft)}{25\ ksi} = 18.3\ in^3$$ >> Use steel pile *HP 8x36* (S_x = 29.8 in^3)

- Lagging requirement:

  For 8 ft c-c spacing (2.44 m), use 3 inch thick lagging based on FHWA RD-75-130 (1976).

- Expected settlement and wall movement is 1.1 inches and 1.6 inches, respectively.

  Based on O'Rourke (1992):

  $(\delta_V)_{max} = 0.003\ H = 0.002(30ft)(12\ in/ft) = 1.1\ inches$ at wall face

  Settlement varies linearly with distance from wall face to a value of zero at 100 ft from wall.

  $(\delta_H)_{max} = 1.5\ (\delta_V)_{max} = 1.5\ (1.08) = 1.6\ in$

Sheet Piles

- Required section modulus is 2.3 in^3/ft.

$$M_{max} = 38.1 \text{ kip-ft for 8 ft spacing of soldier piles}$$

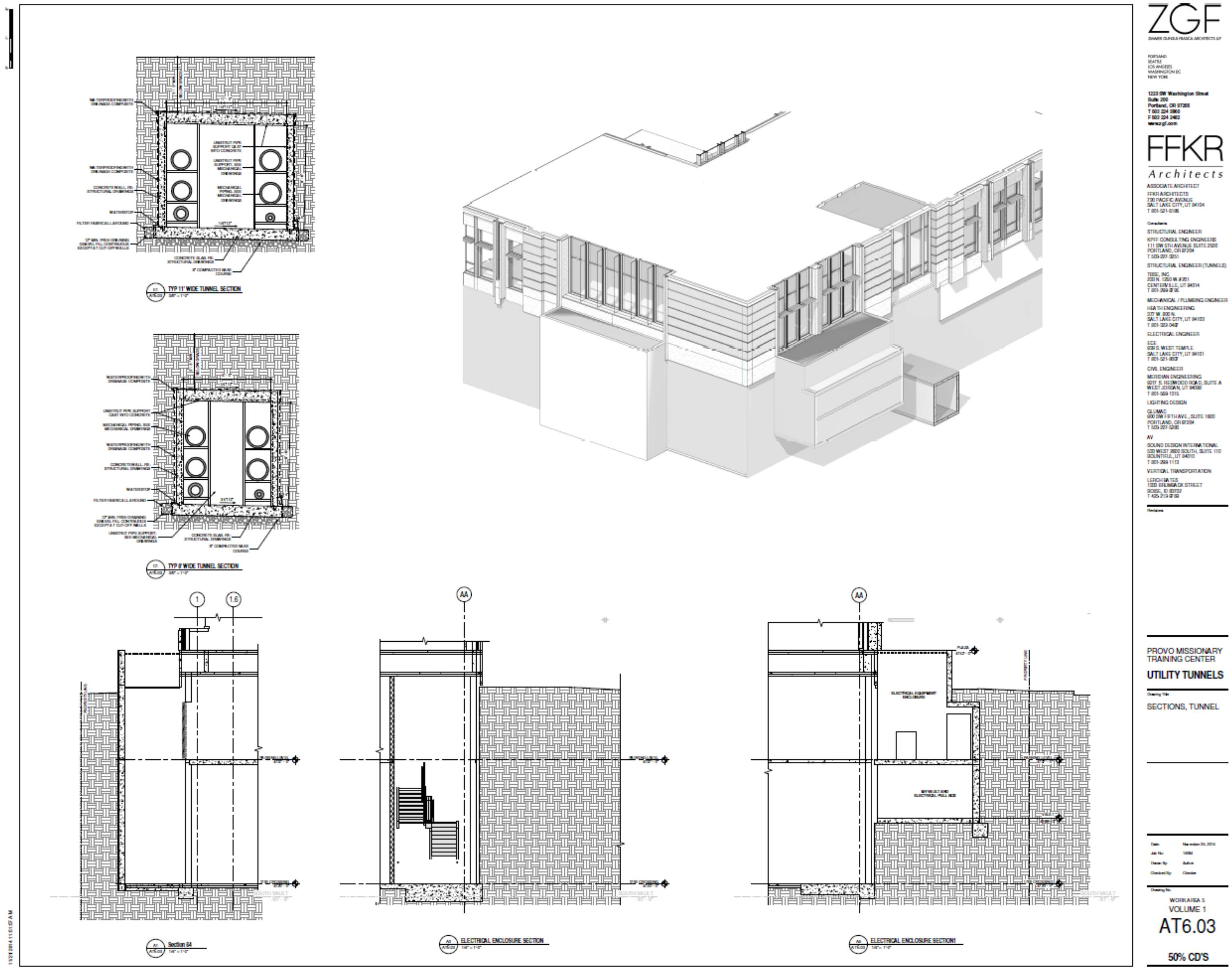
$$M_{max} = \frac{38.1\ kip \cdot ft}{8} = 4.76\ kip \cdot ft = 57.2\ kip \cdot in \quad for\ sheet\ pile$$

$$S_x = \frac{M_{max}}{f_s} = \frac{(57.2\ kip \cdot in)}{25\ ksi} = 2.3\ in^3/ft\ \ of\ wall$$

Possible sheet piles would include:

US Steel: *PMA-22* (S_x = 5.4 in^3/ft)
Canadian Rolling Mills: *L34* (S_x = 2.77 in^3/ft)
Arbed: *BU6* (S_x = 11.2 in^3/ft)

APPENDIX D: Tunnel Drawings



APPENDIX E: Tunnel Calculations

$Tunnel_{Roof} := 22ft$

$Height_{Outside} := 8ft$ $\qquad$ $Length := 1ft$

$Width := 11ft$

Assumed

$\gamma_{soil} := 135\frac{lbf}{ft^3}$

this number was used in part of the geotechnical report. To be conservative the same value was used in these calculations.

Top of Tunnel

$W_{soil} := \gamma_{soil} \cdot Tunnel_{Roof} \cdot Length = 2.97\frac{kip}{ft}$

Max Shear

$Point_{Load} := W_{soil} \cdot Width = 32.67kip$

$$R_1 := \frac{Point_{Load}}{2} = 16.335kip$$

$R_2 := R_1 = 16.335kip$

Max Moment=(WL^2)/8

$$M_1 := \frac{\left[W_{soil} \cdot (Width)^2\right]}{8} = 44.921kip \cdot ft$$

$$V_1 := \frac{\left[W_{soil} \cdot (Width)\right]}{2} = 16.335kip$$

Lateral Earth Pressure

P=(1/2)γ kH^2

In the notes that were provided to us it said to use the following values for the equation shown above.

$\gamma_1 := 135pcf$

$k_{active} := .2$ $\qquad$ if walls are free to move during backfill and using granular soil

$k_{atrest} := .4$ $\qquad$ In case of walls being backfilled with granular soil and walls are restrained

$k_{passive} := 3.$ $\qquad$ wall moves toward backfill

$$H_{333} := \left(30 - \frac{8}{3}\right)ft = 27.333ft$$

$$P_{lateral} := .5 \cdot \gamma_1 \cdot k_{active} \cdot H_{333}^2 = 14.12klf$$

Moment on the side wall

solve for the slope of the line and use calc. of rectangular distribution and triangular distribution.

$$F_1 := .5\gamma_1 \cdot k_{active} \cdot (22ft)^2 = 9.148klf$$

$$F_2 := .5\gamma_1 \cdot k_{active} \cdot (30ft)^2 = 17.01klf$$

$$F_3 := F_2 - F_1 = 7.862klf$$

$$M_r := (F_1 \cdot 4ft) + \left[F_3 \cdot \left(\frac{16}{3} ft\right)\right] = 78.523kip$$

$$y_{component} := \frac{M_r}{F_1 + F_3} = 4.616ft$$

$$M_{wall} := M_r \cdot y_{component} = 362.486kip \cdot ft$$

Solving for the thickness of the concrete. Considered per foot of tunnel

$$M_u := M_1 = 44.921kip \cdot ft$$

$$M_u = 5.391 \times 10^5 \cdot lbf \cdot in$$

$\phi := .9$ $\rho := .02$ $b := 12in$ $f_y := 60000psi$ $f_{primec} := 10000psi$

$$Mu := \phi \cdot \rho \cdot b \cdot d^2 \cdot f_y \cdot \left[1 - \frac{(\rho \cdot f_y)}{(1.7 f_{primec})}\right]$$

d in this equal to the depth of the concrete.

Solve for d:

$$d_{squared} := \frac{(M_u)}{\phi \cdot \rho \cdot b \cdot f_y \cdot \left[1 - \frac{(\rho \cdot f_y)}{1.7 f_{primec}}\right]} = 44.753in^2$$

$$d_1 := d_{squared}^{\frac{1}{2}} = 6.69in$$

$$A_s := \rho \cdot b \cdot d_1 = 1.606in^2$$

$$A_{smin} := \frac{\left[3 \cdot \left(\sqrt{f_{primec}}\right) \cdot b \cdot d_1\right] \cdot (1psi)^{.5}}{f_y} = 0.401in^2$$

This is an empirical equation units should be in square inches. In order to get this to work out appropriately in this program I multiplied the answer by 1psi^.5, this made the units work out.

$$a := \frac{(A_s \cdot f_y)}{0.85 f_{primec} \cdot b} = 0.944\,in$$

$$\varepsilon_1 := \frac{\left(d_1 - \frac{a}{0.8}\right)}{\frac{a}{.08}} \cdot .003 = 1.4\times 10^{-3}$$

equation used Mu=ϕ *As*fy(Dchosen-(As*fy/1.7*fc*b)) iterations necessary to find appropriate As value

Pathagorean eqution is used.

Equation turns to 0=-(Dchosen*ϕ *As*fy)+(As^2*fy^2*ϕ /1.7*fc*b)+Mu

since solving for As

$$d_{chosen} := 11\,in$$

$$b_c := d_{chosen} \cdot \phi \cdot f_y = 7.128\times 10^6 \frac{1}{ft} \cdot lbf$$

$$a_c := \frac{\left(f_y{}^2 \cdot \phi\right)}{(1.7 f_{primec} \cdot b)} = 2.744\times 10^7 \cdot \frac{lbf}{ft^3}$$

$$c_c := M_u = 4.492\times 10^4 \cdot ft\,lbf$$

$$A_{sc} := \frac{\left[b_c + \left[b_c{}^2 - (4 \cdot a_c \cdot c_c)\right]^{(.5)}\right]}{2 \cdot a_c} = 36.469\,in^2$$

$$S_{quareroot} := \sqrt{A_{sc}} = 6.039\,in$$

$$A_{sc2} := \frac{\left[b_c - \left[b_c{}^2 - (4 \cdot a_c \cdot c_c)\right]^{(.5)}\right]}{2 \cdot a_c} = 0.931\,in^2$$

$$a_{new} := \frac{(A_{sc2} \cdot f_y)}{.85 f_{primec} \cdot b} = 0.547\,in$$

this makes ε >=.005

$$\varepsilon_{new} := \left[\frac{\left[d_{chosen} - \left(\frac{a_{new}}{.8}\right)\right]}{\frac{a_{new}}{0.8}}\right] \cdot .003 = 0.045$$

$$Spacing_{rebarceiling} := \frac{(.44in^2)}{\left(\frac{A_{sc2}}{b}\right)} = 5.673in$$

In this calculation # 6 rebar was used and is placed every 6 inches. For easiness using a more simple measurement such as 12 inches is going to be much easier.

Thickness of walls

$f_{ywall} := 75000psi$ $\quad\quad \rho_{wall} := .03$

$$d_{squaredwalls} := \frac{(M_{wall})}{\phi \cdot \rho_{wall} \cdot b \cdot f_{ywall} \cdot \left[1 - \frac{(\rho_{wall} \cdot f_{ywall})}{1.7f_{primec}}\right]} = 181.452in^2$$

$$d_{wall} := \sqrt{d_{squaredwalls}} = 13.47in$$

$$A_{swall} := \rho_{wall} \cdot b \cdot d_{wall} = 5.658in^2$$

$$A_{swallmin} := \frac{\left[3 \cdot \left(\sqrt{f_{primec}}\right) \cdot b \cdot d_{wall}\right] \cdot (1psi)^{.5}}{f_{ywall}}$$

This is an empirical equation units should be in square inches. In order to get this to work out appropriately in this program I multiplied the answer by 1psi^.5, this made the units work out.

$$A_{swallmin} = 0.647in^2$$

$$a_{walls} := \frac{(A_{swall} \cdot f_{ywall})}{.85f_{primec} \cdot b} = 4.16in$$

$$\varepsilon_{walls} := \frac{\left(d_{wall} - \frac{a_{walls}}{.8}\right) \cdot .003}{\frac{a_{walls}}{.8}} = 4.771 \times 10^{-3}$$

Summary

The thickness of the roof of the tunnel and the floor needs to be 11 inches thick with 16 inches thick walls. The rebar used for this project was #6

.

$$d_{wchosen} := 18in$$

$$b_w := d_{wchosen} \cdot \phi \cdot f_{ywall} = 1.458 \times 10^7 \frac{1}{ft} \cdot lbf$$

$$a_w := \frac{\left(f_{ywall}{}^2 \cdot \phi\right)}{(1.7f_{primec} \cdot b)} = 4.288 \times 10^7 \cdot \frac{lbf}{ft^3}$$

$$c_w := M_{wall} = 3.625 \times 10^5 \cdot ft\ lbf$$

$$A_{sw1} := \frac{\left[b_w + \left[b_w^2 - (4 \cdot a_w \cdot c_w)\right]^{(.5)}\right]}{2 \cdot a_w} = 45.071 in^2$$

$$A_{sw2} := \frac{\left[b_w - \left[b_w^2 - (4 \cdot a_w \cdot c_w)\right]^{(.5)}\right]}{2 \cdot a_w} = 3.889 in^2$$

Using number 6 rebar

$$spacing := \frac{\left(2.25 in^2\right)}{\left(\frac{A_{sw2}}{b}\right)} = 6.943 in$$

$$a_{neww} := \frac{\left(A_{sw2} \cdot f_{ywall}\right)}{.85 f_{primec} \cdot b} = 2.86 in$$

$$\varepsilon_{neww} := \left[\frac{\left[d_{wchosen} - \left(\frac{a_{neww}}{.8}\right)\right]}{\frac{a_{neww}}{0.8}}\right] \cdot .003 = 0.012$$

this makes ε >=.005

$$Spacing_{wrebarceiling} := \frac{\left(2.25 in^2\right)}{\left(\frac{A_{sw2}}{b}\right)} = 6.943 in$$

APPENDIX F: Cost Estimation

Excavation & Backfill Estimate

OPEN CUT

Excavation		
Exc Length	105	FT
Exc Width	15	FT
Exc Depth	30	FT
Exc Volume	1750	CY
COST backhoe	$ 10	per CY
	$ 17,500	**excavation**
Backfill & Compaction		
Tunnel diameter	10	Fft
Tunnel Cross-Sect Area	78.5	SF
Tunnel Volume Displ.	305.4	CY
Backfill Volume	1444.6	CY
COST backfill	$ 15	per CY
	$ 21,669	**backfill & compaction**
	$ 39,169	**TOTAL**

TRENCHLESS

Excavation		
Shaft Depth	30	FT
Shaft Width	15	FT
Shore Length (Jacking Shaft)	25	FT
Shore Length (Receiving Shaft)	10	FT
Total Shaft Vol Exc	583	CY
Depth backhoe excv	15	FT
Depth clamshell excv	15	FT
Vol backhoe excv	292	CY
Vol clamshell excv	292	CY
COST backhoe excv	$ 10	per CY
COST clamshell excv	$ 30	per CY
	$ 11,667	**excavation**
Backfill & Compaction		
Tunnel outer diameter	10.1	FT
Tunnel Cross-Sect Area	79.9	SF
Tunnel Volume Displaced	310.5	CY
Backfill Volume	272.8	CY
COST backfill	$ 15	per CY
	$ 4,092	**backfill & compaction**
	$ 15,759	**TOTAL**

Shoring Estimate

SOLDIER PILES

Open Cut		
Shore Length	105	FT
Shore Width	15	FT
Shore Depth	30	FT
Shore Area	7200	SF
COST Soldier	$ 90	per SF
	$ 648,000	**Soldier piles**
	$ 648,000	**TOTAL**

SHEET PILES

Open Cut		
Shore Length	105	FT
Shore Width	15	FT
Shore Depth	30	FT
Shore Area	7200.0	SF
COST Sheet	$ 50	per SF
	$ 360,000	**Sheet piles**
Num. Utility Lines	10	
Num. Fiber Optics	1	
Distance rerouted	300	FT
COST Reroute (average)	$ 70	per LF
COST Reroute (fiber optic)	$ 150	per LF
	$ 255,000	**TOTAL**
	$ 615,000	**TOTAL**
Trenchless Shafts		
Shore Depth	30	FT
Shore Width	15	FT
Shore Length (Jacking Shaft)	25	FT
Shore Length (Receiving Shaft)	10	FT
Shore Area	3900	SF
COST Sheet Piles	$ 50	per SF
	$ 195,000	**Sheet piles**
	$ 195,015	**TOTAL**

Tunnel Estimate

RECTANGULAR TUNNEL		
Material: Concrete		
Side Wall Thickness	14	IN
Side Wall Length	11	FT
Floor Thickness	10	IN
Floor Length	8	FT
Unit Length	1	FT
Unit Volume Walls	0.95	CY per LF
Unit Volume Floors	0.49	CY per LF
Length Tunnel	105	FT
COST Concrete	$ 200	per CY
	$ 30,333	**Concrete**
Rebar Reinforcement		
Unit Reinforcement	1000	FT per section
Num Sections	9	
COST Reinforcement	$ 1	per FT
	$ 9,000	**Reinforcement**
	$ 39,333	**TOTAL**

ROUND TUNNEL		
Material: Steel		
Thickness	0.5	IN
Inner diameter	10	FT
Outer diameter	10.1	FT
Unit length	1	FT
Unit Volume of Steel	1.31	CF
Density of Steel	490	PCF
Unit Weight of Steel	644.1	LB per FT
Length Tunnel	105	FT
COST Steel	$ 0.50	per LB
	$ 33,814	**Steel**
Floor Grating		
Length tunnel	105	FT
Width	3	FT
COST grating	$ 6.92	per SF (3' width)
	$ 2,179.80	**Floor grating**
	$ 35,994	**TOTAL**

Connections Estimate

CONCRETE WATERPROOFING		
Tunnel Connections		
Tunnel Perimeter	42.0	FT
Num. Segments	9	
1 strip / 2 strip?	2	
Total Waterproof	756	FT
Num Req'd Tubes	42	
COST SikaSwell S-2 Polyurethane [20 oz.]	$ 42	per LF (yields 18 ft)
COST SikaSwell - P (strips)	$ 2	per LF
	$ 3,276	**Waterproofing**
	$ 3,276	**TOTAL**

STEEL WELDING		
Tunnel Connections		
Outer Tunnel Diameter	10.1	FT
Circumfremce	31.7	FT
Num. Segments	9	
Total Weld	285	FT
COST Welding	$ 75	per LF
	$ 21,382.46	**Welding**
Floor Grate		
Length of tunnel	105	FT
COST Tack Weld	$ 10	per LF
	$ 1,050.00	**Tack weld floor grate**
	$ 21,382	**TOTAL**

Jack and Bore Estimate

AUGER BORING			
Bore diameter	10	FT	
Bore length	105	FT	assuming no dewatering
COST Jack and Bore	$ 10,000	per LF for 10' auger	includes setup, monitoring, equipment maintenance, steel pipe, etc
	$ 1,050,000	**Jack and Bore**	
	$ 1,050,000	**TOTAL**	

Road Repair Estimate

ASPHALT			
Apsh Depth		4	IN
Asph Length		60	FT
Asph Width		20	FT
Asph Area		1200	SF
COST Asphalt	$	6	per SF
	$	**7,200**	**asphalt**
SIDEWALKS			
Side Length		20	FT
Num. Side		2	
Total Length		40	FT
COST Sidewalk (4" thick)	$	3.50	per FT
	$	**140**	**sidewalks**
CURB & GUTTER			
Side Length		20	FT
Num. Side		2	
Total Length		40	FT
COST curb/gutter	$	15	per FT
	$	**600**	**curb and gutter**
	$	**7,940**	**TOTAL**

Road Repair Estimate

ASPHALT			
Apsh Depth		4	IN
Asph Length		60	FT
Asph Width		25	FT
Asph Area		1500	SF
COST Asphalt	$	6	per SF
	$	**9,000**	**asphalt**
SIDEWALKS			
Side Length		25	FT
Num. Side		2	
Total Length		50	FT
COST Sidewalk (4" thick)	$	3.50	per LF
	$	**175**	**sidewalks**
CURB & GUTTER			
Side Length		25	FT
Num. Side		2	
Total Length		50	FT
COST curb/gutter	$	18	per LF
	$	**900**	**curb and gutter**
	$	**10,075**	**TOTAL**

City Fees Estimate

ROAD CLOSURE			
Time		42	days
COST city fee	$	100	per day
	$	**4,200**	**road/traffic**
PERMITS			
Num. Permits		4	
COST city fee	$	1,000	
	$	**4,000**	**permits**
	$	**8,200**	**TOTAL**

Cost Estimate Summary by Alternative

	Open Trench Design			Trenchless Design		
	Method	Cost		Method	Cost	
Excavation	Open Cut	$	39,169	Trenchless	$	15,759
Shoring	Sheet Piles	$	360,000	Sheet Piles	$	195,015
Reroute Utilities?	Yes	$	255,000	No	$	-
Tunnel Material	Concrete	$	39,333	Steel	*$*	*35,994*
Tunnel Shape	Rectangular			Round		
Waterproofing	SikaSwell	$	3,276	Weld	$	21,382
Jack and Bore?	No	$	-	Yes	$	1,050,000
Road Repair?	Yes	$	10,075	No	$	-
City Fees	Yes	$	8,200	Yes	$	-
ESTIMATED COST		**$**	**715,053**		**$**	**1,282,156**