Jefferson Lab Electron Ion Collider

Bored Tunnel Feasibility Study

Jefferson Sciences LLC

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1. Introduction

Jefferson Lab is proposing to build a new Electron Ion Collider (JLEIC) located in the in the north-eastern portion of the current property in Newport News, Virginia. The new JLEIC is laid out in a “figure-eight” pattern, covering approximately 94 acres, to be constructed beneath undeveloped wooded and grass land. The purpose of this study is to evaluate the alternative of a deep bored tunnel for the new JLEIC in the same general location and configuration as the cut and cover tunnel in the initial proposal. The level of detail is at a schematic level to develop a comparable cost of the tunnel only. The conventional facilities are excluded as are other costs which would be similar in either case. The cost data for the figure-eight cut and cover tunnel will be the baseline cost data prepared by the JLAB staff. The cost data for the figure-eight deep bored tunnel will be derived from the current cost data.

1.1. Existing tunnel

The existing oval shaped CEBAF tunnel foot-print constructed in 1987 - 1991 is approximately 4,175 feet long and was constructed by the cut and cover technology. The tunnel cross section is 10’ x 13.5’ (inside height and width) with an approximately 2’ thick bottom and top slab and 1.75’ walls. The concrete structure is waterproof and constructed on a mud slab with a finished floor elevation of approximately 11.2’ based on the Jefferson Lab datum. The structure is covered by approximately 14’ of earth, and when combined with the 1’4” concrete walls, radiation protection is provided. The bottom of the trench is situated geologically over the Yorktown Formation.

1.2. Proposed cut and cover collider tunnel

The proposed JLEIC tunnel has been configured in a figure-eight shape as shown on Figure 1-1. The baseline cost estimate develop by JLAB staff was for a cut and cover construction with a reinforced concrete box. The length of the figure-eight collider tunnel (measured along the approximate centreline) is 7,079 feet and is constructed primarily on the Yorktown Formation and further supported by concrete piles.

1.3. Alternative bored tunnel

The alternative bored tunnel, also configured in a figure-eight shape, would be constructed approximately 83 feet deep from the surface and within the Yorktown Formation, using a tunnel boring machine. The bored tunnel is lined with segmental concrete linear blocks and has an inside diameter of 25’ to encompass the cut and covered tunnel cross section inside dimensions.

1.4. Cost comparison elements

For the purposes of this study, only the construction of the figure-eight tunnel using the cut cover method versus a bored tunnel method is considered.

The conclusion of the evaluation will be the comparative cost of the bored tunnel versus the cut and cover method of construction with a general discussion of the impact on the cost and other implications of the other differentiators.

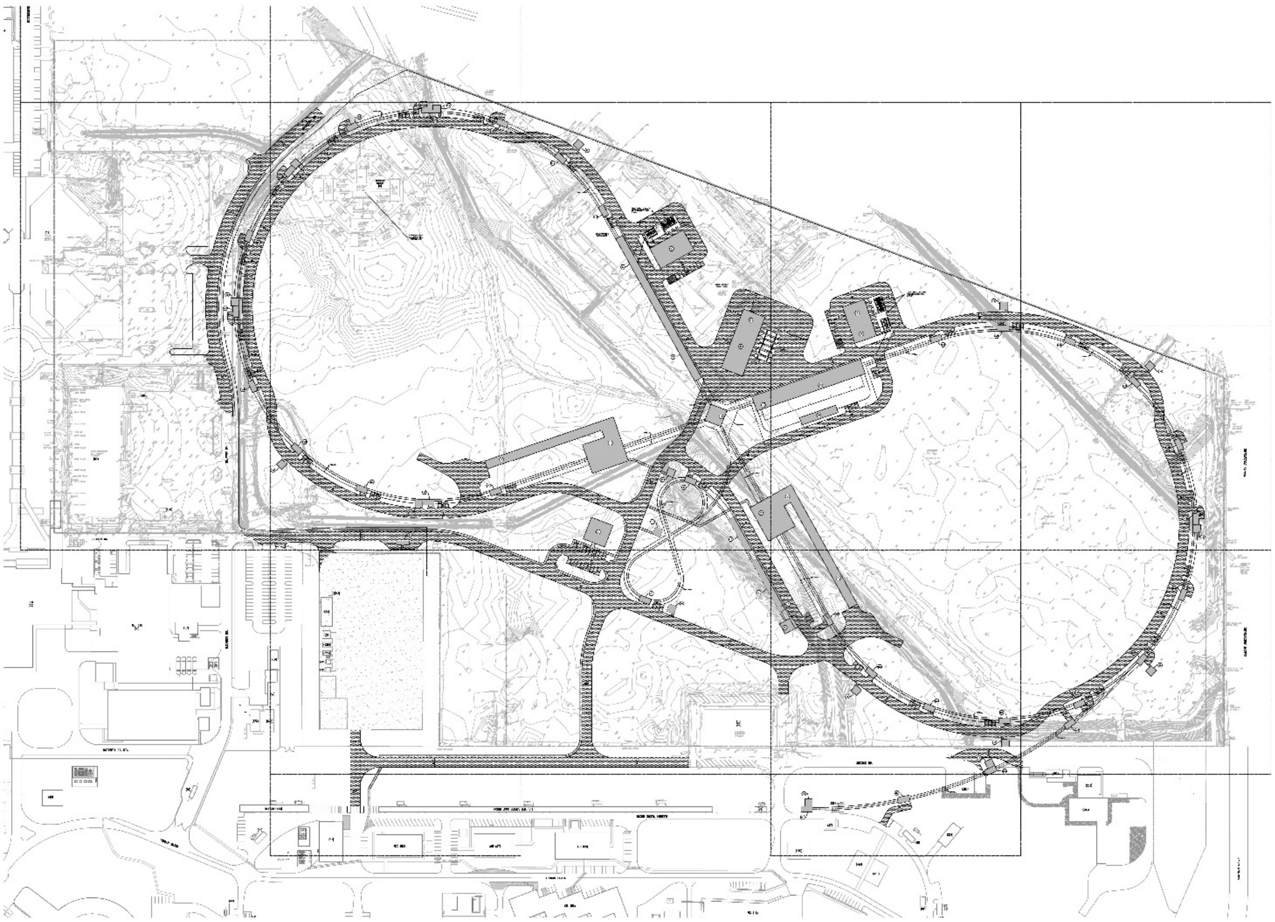


Figure 1-1 Proposed JLEIC tunnel configuration

2. Geotechnical conditions

The following sections provide a summary of applicable information from the geotechnical report (Wheeler, et.al, 2016) and other available information (Peebles, et.al, 1984).

2.1. Regional geology

The project site is located within the Atlantic Coastal Plain physiographic province. Bedrock of the Late Mesozoic age is present at depths of greater than 2,000 feet, and is overlain by Lower and Upper Cretaceous, Tertiary, Pleistocene, and recent sediments.

A bored tunnel alternative for this project would be sited within the Yorktown Formation, which is considered to be from the early to middle Pliocene Epoch of the Tertiary Period. Within south-eastern Virginia, the Yorktown Formation consists of fossiliferous marine silty fine sand and crossbedded, biofragmental sand. Locally, the Yorktown Formation underlies the Chowan River, Shirley, and Tabb formations.

Above the Yorktown Formation is the middle Pleistocene Shirley Formation, which is composed of fluvial and estuarine sand, clay, organic soil, and peat. At the base of the Shirley formation (and immediately overlying the Yorktown Formation) there is a discontinuous pebbly to boulder sand. The pebbles, cobbles and boulders range from well-rounded to angular and were derived from rocks of the Piedmont, Blue Ridge, and Valley and Ridge provinces. The largest clasts in these deposits are 5 feet in diameter. Planar and cross-stratified, well sorted, gray to light brown, fine to pebbly, coarse sand overlies the basal part of the formation. Locally, the sand is cemented by iron and manganese oxides. Layers of peat and other organic materials including tree stumps are also found in some locations in the Shirley Formation.

2.2. Site conditions

The geologic stratigraphy generally consists of recent sediments and man-placed Fill underlain by marine deposited Sands, Silts and Clays of the Shirley Formation underlain by the Yorktown Formation extending to a significant depth. Table 2-1 is a summary of the geotechnical conditions from the Geotechnical Report.

The position of the groundwater table was measured at multiple locations and was encountered at depths below the ground surface ranging from about five (5) to eight (8) feet corresponding to Elevations 25 to 37 feet.

Table 2-1 Summary of geotechnical conditions

Average Depth (ft)	Designation/ Formation	Description	Uncorrected SPT Blow Counts
0 - 4	Fill	Topsoil; Erratic deposits of disturbed or man-placed materials	n/a
4 - 30	Shirley Formation	Red, Orange, Brown and Tan, Sandy CLAY (CL) with varying amounts of Silt and trace fibrous organics.	3 – 13
		Brown and Gray SAND (SP-SM, SM, SC) with varying amounts of Silt and Clay.	1 – 19
		Intermediate layers of Soft, Gray, Silty and Sandy CLAY (CL, CH); Brown and Black Organic Materials and Peat (Pt)*	2 – 8
30 – 75 (full depth of borings)	Yorktown Formation	Gray and Brown SAND (SM, SC) with varying amounts of Silt, Clay, Gravel, and marine shell fragments; Gray Sandy, Clayey SILT (ML) with varying amounts of marine shell fragments.	3 – 17

*(Peebles, et.al., 1984) notes a discontinuous pebbly to boulder sand at the base of the Shirley formation.

3. Proposed cut and cover tunnel

This section will address the cost of the cut and cover tunnel as originally proposed by the JLAB staff.

3.1. Layout

The layout of the cut and cover tunnel is the figure-eight configuration shown on Figure 1-1. The tunnel will have a finished floor elevation of approximately 11.2’. The existing ground surface ranges from approximately elevation 30’ to elevation 40’ (the average ground elevation of 34’ was used in this study). The bottom of the excavation of the tunnel will be approximately 30’ in depth. All elevations given are based on a datum established during the original construction. The figure-eight configuration consists of the arc sections and straight sections. The cross section for the straight section is shown Figure 3-1. The straight sections of the figure-eight configuration computed at the center line of the tunnel is 2,240.9 feet in total length. These straight cross sections are 21.0 feet in width and 11.2 feet in height on the inside.

The arc sections of the figure-eight configuration computed at the center line total 4,625.9. These sections are 12.1 feet in width and 8.5 feet in height on the inside. The radius of the arc section on the proposed tunnel center line is 510’.

The tunnel is constructed of reinforced concrete with wall thickness of 2’, the floor slab is 3’ deep and the top slab is 2.5’. The tunnel structure will sit on a 3” thick concrete mud slab extending 3” beyond the floor slab. The structure is supported by 18” square concrete piles driven 50’ deep and placed at an interval to provide one (1) pile for every 80 square feet of structure floor slab. A waterproofing membrane is provided on the walls and top slab.

3.2. Construction method

The construction method for this tunnel is standard cut and cover technology. This same method was used for the existing CEBAF tunnel. This method of construction is not unusual for the Hampton Roads area, so special construction technologies are not necessary. The proposed method assumes side slopes of excavation of a 1:2 ratio – one (1) foot horizontal to a 2' vertical. The trench has an average assumed depth of 30' with a bottom width of 16.1' in the arc sections and a bottom with of 25' in the straight sections. The baseline costs for this tunnel were prepared by JLAB staff and is provided in Appendix B.

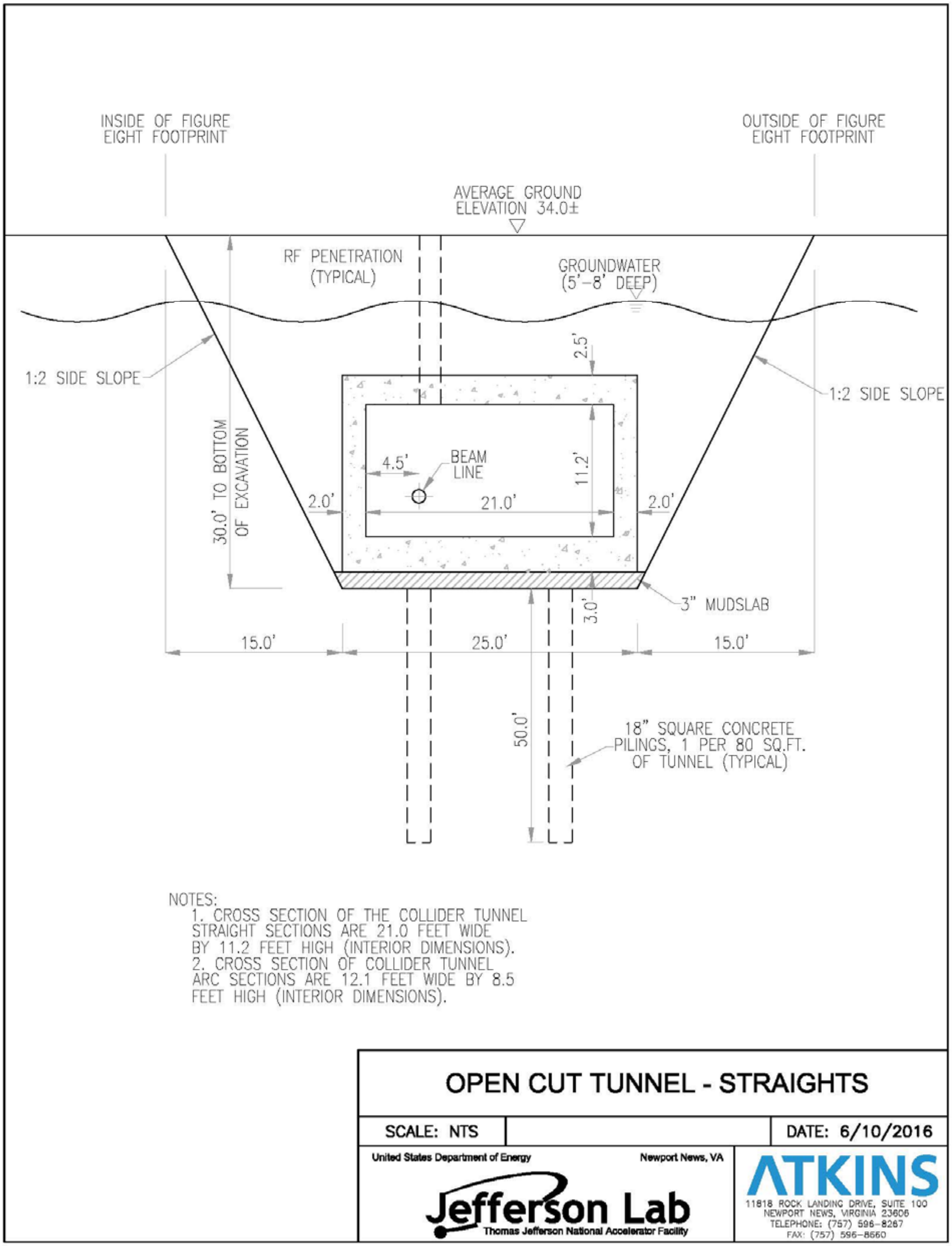


Figure 3-1 Open cut tunnel

3.2.1. Problems and risk

This section outlines briefly the problems and risks associated with the proposed cut and cover tunnel construction method. This study only addresses the construction cost impact positively or negatively in a general fashion.

3.2.1.1. Dewatering

The baseline cost developed by JLAB includes an allowance for dewatering. It was assumed two dewatering installations of 500'each would be installed in series in advance of the. These systems would be relocated progressively as the tunnel is constructed. The total time in place was 414 days for the straight sections and 629 days for the arc sections. The geotechnical report prepared by GET Solutions, Inc. recommends the dewatering be performed to lower the groundwater level no more than 5' below the proposed excavation depth. The costs, as proposed, are being used as being reasonable for this comparison.

3.2.1.2. Side slope assumptions

The cost estimate prepared by JLab, more specifically the section for the collider tunnel arcs, work breakdown structure 1.4.2.2.1.1 and collider tunnel straight section, work breakdown section 1.4.2.2.1.2, made the assumption that the excavation of the trench would allow side slopes of 1:2 (1 foot horizontal by 2' vertical). The geotechnical report prepared by GET Solutions, Inc., recommends a minimum side slope of 1.5:1. For the purposes of this report, it has been decided to compare cost based on the original assumption. However, it is recognized that this may be understated.

The proposed cost estimate also assumed that excavation support or shoring would be required for 578.2 feet of length in the arc section adjacent to existing structures. This assumption was used; however, closer examination indicates only half of this length may be needed.

3.2.1.3. Foundation analysis

It was assumed in the JLab cost estimate that the cut and cover tunnel would be constructed on a 3" concrete "mud slab" which is anticipated to be set directly upon the bottom of the excavated trench. The purpose of the 3" mud slab is primarily to provide a working foundation for construction. The JLab cost estimate anticipated pilings for additional structural support since the tunnel would not be bearing on the Yorktown Formation in its entirety. The cost estimate was based on using 18" square concrete piles 50' deep, with each pile supporting 80 square feet of the structure.

It was discovered during the GET Solutions, Inc geotechnical investigation that about two-thirds of the length of the proposed tunnel would be constructed directly on or within in the Yorktown Formation (based on a bottom of tunnel elevation of 8'). The remaining third of the tunnel length would be above the Yorktown Formation. The GET Solutions, Inc. geotechnical report recommended 2'-3' of structural fill in lieu of the piles and mudslab. Additionally, where the Yorktown Formation drops below the bottom elevation of the tunnel, over-excavation to the Yorktown Formation and backfill with structural fill would be necessary. Figure 3-2 shows the approximate top elevation of the Yorktown Formation.

Since the JLab cost estimate assumed pilings for the entire tunnel, that assumption and cost is being used for the purposes of this study. A further detailed analysis of the foundation approach would be necessary to determine the most cost effective method to be used, however, that analysis is beyond the scope of this study.

3.2.1.4. Disposal of excess material

The JLab cost estimate determined the volume of excess material as the quantity of total excavation of the cut and cover tunnel trench minus the volume of material occupied by the tunnel and the 3" mud slab. The original cost estimate assumed the depth of the excavation is 30' but it is actually less; however, the assumed 30’ was used for this study. It would be expected that the excavated material would be segregated for backfill as either suitable for structural fill or not suitable for structural fill.

Additionally, some surface layer material may be separated for reuse as the final vegetative cover material. At this point and for this comparison, the original assumption was used recognizing the volume may be reduced by consolidation and compacted when backfilling is accomplished.

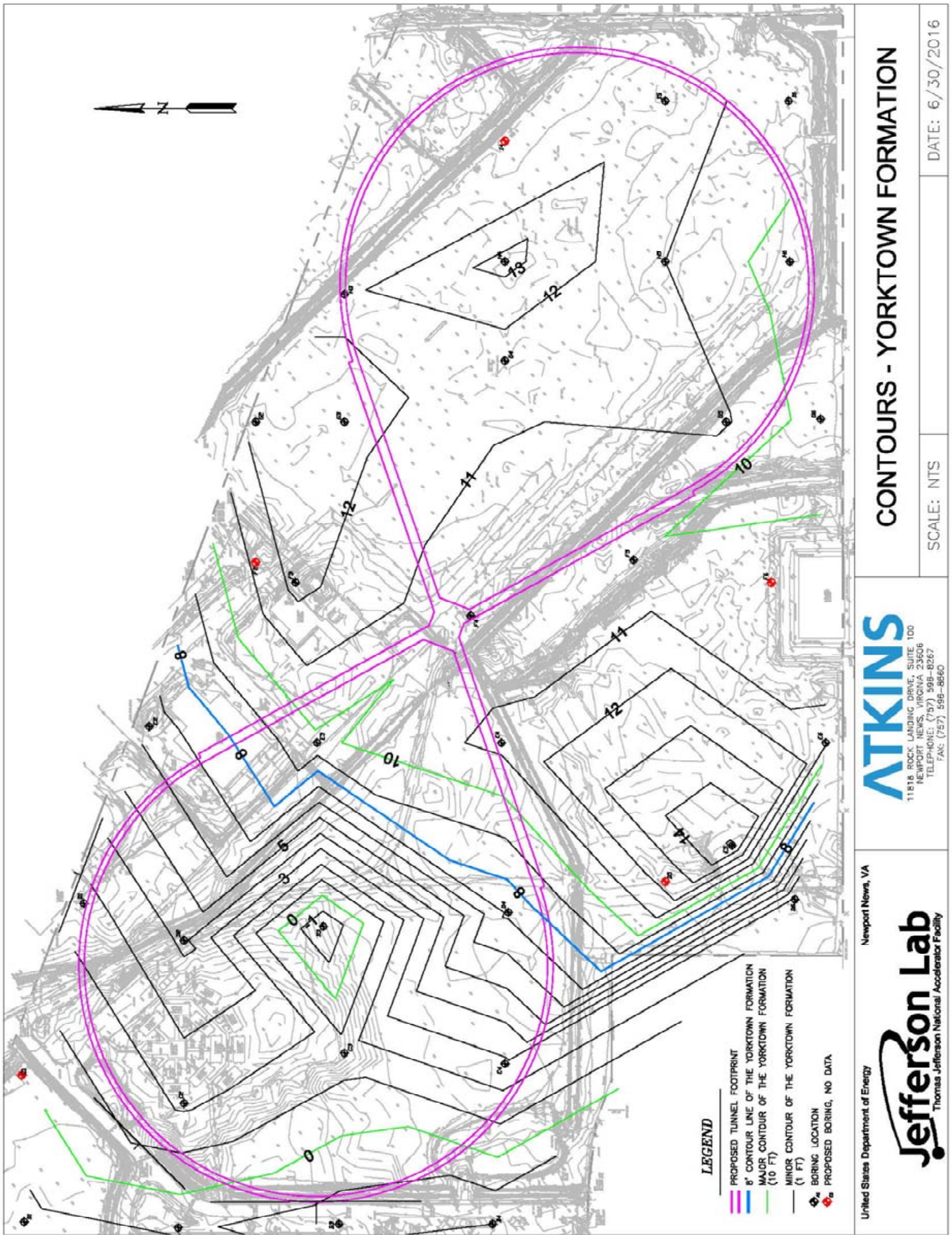


Figure 3-2 Yorktown Formation

3.2.1.5. Extreme weather events

Extreme weather events can have risk impacting both cost and schedule. No allowances have been made.

3.2.1.6. Contaminated groundwater or excavated soil disposal

No contaminated soil was noted during the soil borings. The JLab cost estimate assumed no treatment of the dewatering effluent for potential contaminated groundwater would be required at the time of construction.

3.3. Cut and cover tunnel alternative construction cost

The costs for the cut and cover tunnel presented in this section are from the JLab Work Breakdown Structure (WBS) cost estimate without any modification. The JLAB cost estimate was in 2014 dollars. A detailed cost estimate can be found in Appendix B.

Table 3-1 Collider tunnel arcs, WBS 1.4.2.2.1.1

Item	Description	Direct Cost
1	Excavation	$ 1,292,976
2	Excavation support	$ 429,448
3	Dewater	$ 2,076,409
4	Backfill with compaction	$ 841,432
5	Dispose of excess soil	$ 184,126
6	6" Perforated pipe foundation drain	$ 160,384
7	Concrete piles 18" square	$ 3,102,959
8	3" Mud slab	$ 136,621
9	Floor Slab	$ 2,438,817
10	Walls	$ 3,187,375
11	Roof slab	$ 4,493,286
12	Waterstop	$ 109,700
13	Waterstop with membrane	$ 485,602
14	Bentonite waterproofing	$ 256,443
15	Protection board	$ 410,723
16	Drain board	$ 141,842
	Arc total direct cost	**$ 19,748,143**

Table 3-2 Collider tunnel straight sections, WBS 1.4.2.2.1.2

Item	Description	Direct Cost	
1	Excavation	$	751,722
2	Excavation support	$	-
3	Dewater	$	1,366,511
4	Backfill with compaction	$	438,024
5	Dispose of excess soil	$	163,544
6	6” Perforated pipe foundation drain	$	78,217
7	Concrete piles 18” square	$	2,328,183
8	3” Mud slab	$	101,428
9	Floor Slab	$	1,829,870
10	Walls	$	2,032,719
11	Roof slab	$	3,371,359
12	Waterstop	$	53,499
13	Waterstop with membrane	$	312,059
14	Bentonite waterproofing (bottom & sab)	$	173,933
15	Protection board (wall)	$	263,940
16	Drain board	$	96,205
	Straight section total direct cost	**$**	**13,361,213**

Table 3-3 Total direct costs

Total direct costs			
Combined direct	Arc	$	19,748,143
	Straight	$	13,361,213
		$	**33,109,356**
20% Contractor overhead & profit (assumes tunnel contractor is sub to general contractor)		$	6,621,871
Construction cost cut & cover tunnel			
Based on 2014 datum (ENR Construction Cost Index – 9800)		$	39,731,227
Updated by ENR Construction Cost Index May 2016-10315		$	**41,836,982**

(This cost estimate does not include contingency, design and engineering costs, or construction management costs)

4. Access shaft and bored tunnel layout and preliminary design

The physical configuration of a modified figure eight to be tunnelled at a constant elevation essentially requires construction of a large shaft at the central convergence point of the figure eight layout. From this shaft, the tunnel would proceed around one loop of the figure eight and then break back into the shaft. The process would then be repeated for the second loop of the figure eight. Thus, four penetrations would be required in the shaft.

4.1. Shaft

Sizing the shaft diameter was based on the size of the required four penetrations and the fact that a reasonable pillar of concrete is needed between penetrations to transfer the loads around the openings. Based on initial design calculations and the four penetrations, a 60-ft inside diameter shaft is a reasonable size (See Figures A-1 through A-3 in Appendix A). Factors in selecting the likely shaft construction method for evaluation included the tunnel depth based on provision of about two diameters of ground cover above the tunnel, the required shaft diameter, and the high groundwater table. The most reasonable choice for shaft construction method is the slurry trench construction method in which fluid supported trenches are dug for emplacement of reinforcing steel and poured concrete panels to form the shaft. A depth of approximately 83 feet is required to the top of the shaft bottom slab (see tunnel discussion below).

Initial design calculations and other construction considerations indicate a probable panel thickness of four feet and a width of approximately 12 feet (intersecting about one foot on each end of the adjacent panels), as shown in Appendix A, Figure A-2.

The general construction sequence is shown schematically in Figure 4.1 and described as follows.

- Concrete guide walls are constructed to define the shaft footprint and to guide the panel excavation.
- The initial set of panels (likely every other panel) are excavated using specialized excavation equipment such as clamshell buckets or hydromills and the trench supported with a slurry mixture to maintain the trench stability.
- A rebar cage is then inserted into the excavated panel and concrete is placed by tremie pipe while the displaced slurry is removed and captured on site for re-use and eventual disposal.
- The secondary panels are then excavated to intersect the primary panels at each end.
- The same procedure is repeated until the shaft perimeter is completed.
- Once all of the panels are completed, the material inside the shaft is excavated with a clamshell bucket under water or slurry to prevent boiling and other soil instabilities due to the high groundwater table.
- A concrete plug is placed in the bottom of the shaft using tremie methods. The plug will be doweled and/or physically keyed into the shaft wall by means of pre-formed blockouts to provide a shear connection.
- Water or slurry within the shaft is pumped out.

Initial calculations estimate that the shaft plug/bottom slab would need to be 18 feet thick to prevent shaft uplift due to buoyancy forces.

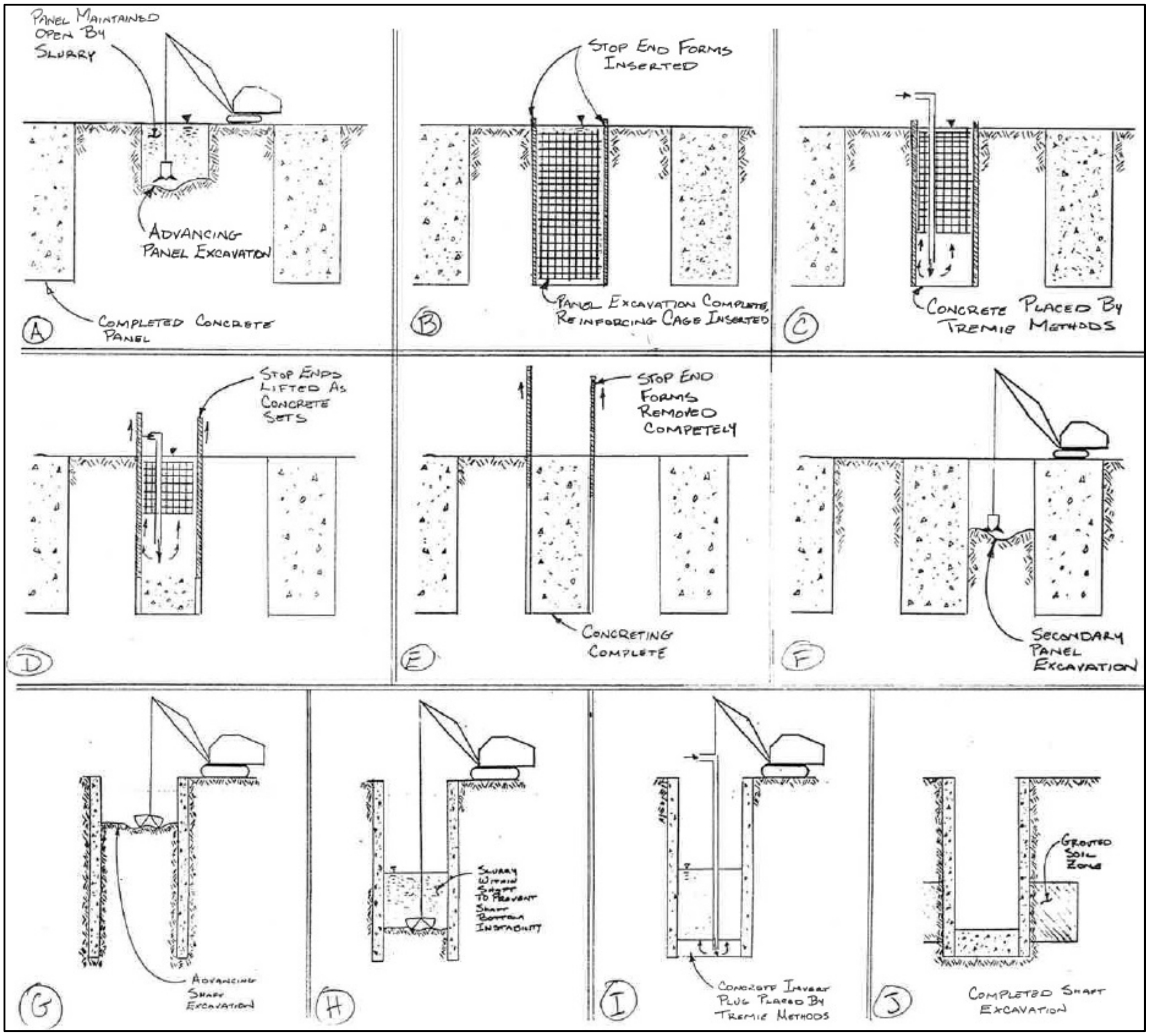


Figure 4-1 Concrete slurry wall construction sequence

A series of figures is provided in Appendix A to illustrate the main details of the slurry wall shaft. See Figures A-1 through A-3, Appendix A. Other details are shown in Figures A-4 and A-5, Appendix A.

An additional significant detail required for tunneling out of a shaft in soil below the groundwater table which is susceptible to flowing behavior under groundwater pressure gradients is a zone of stabilized soil at each of the tunnel penetrations to the shaft. This prevents inflow of soil and groundwater to the shaft during breakout by the Tunnel Boring Machine (TBM) and placement of the initial sections of tunnel liner. In the soils present at the site, jet grouting is an effective means of creating these stabilized zones and is not radically different in costs from other methods, so it was used as the basis for the cost estimate. At each tunnel penetration to the shaft, a zone of stabilized soil known as “Soilcrete” would be created by drilling and injection of a cement slurry while cutting the soil with a water jet to form a column of solidified soil. Columns are spaced to provide for intersection of adjoining columns and thereby creating a solidified soil mass. These jet grout blocks would be 38 ft by 38 ft in cross section, centered on the tunnel axis, and would extend 65 ft from the shaft wall, each having a volume of about 3,476 cubic yards.

4.2. Tunnel

We understand that the tunnel must provide a clear 21-ft wide by 11.2-ft high operating envelope, which requires an absolute minimum inside diameter of 23.8 ft. For planning purposes, we have considered this to be centered within a 25-ft minimum inside diameter tunnel, providing approximately 7 inches of additional clearance around the entire perimeter. See Figure A-6. It should be understood that a new TBM would likely not be ordered and fabricated for a project of this magnitude. Contractors would likely refurbish and modify a current TBM (either owned or purchased). It is recommended that a minimum diameter be specified and that larger diameters up to some maximum be allowed. This will permit taking advantage of a greater number of potential used TBM's and contribute toward receiving the most favorable bid price. Therefore, actual inside, outside, and excavated diameters may be different than outlined and assumed in this study.

For this feasibility study, a ground cover of approximately two tunnel diameters (55 feet) was considered between the tunnel crown and ground surface. The majority of the site has a surface elevation between 32 to 40 feet meaning the tunnel envelope would span approximately -23 to -51 feet in elevation. The Geotechnical Report states that the upper limits of the Yorktown Formation appear to be between elevation +12 to -8 indicating that the tunnel would be entirely contained with the Yorktown Formation.

The mixed soils of the Yorktown Formation below the groundwater table (and thereby saturated) require that tunneling be performed using a pressurized-face tunnel boring machine (TBM), either an EPB or slurry TBM to balance soil and groundwater pressures. The relatively low cohesion and plasticity and the silt and sand grain size of the soils would be considered by some to favor a slurry machine, but either machine type can work, and this decision is best left to the contractor.

Initial tunnel support would be gasketed precast concrete segmental liner. This is the best choice considering required construction methodology (TBM), tunnel curvature, groundwater table position and ground loadings. Initial calculations considering thrust and handling loads, which normally govern segment design, indicate the segments would be 15 inches thick. Rebar reinforcement would consist of 2 ea - #6 bars every 6" of tunnel length radially and 2 ea - #4 bars every 6" around the circumference of the tunnel longitudinally, and could be supplemented with steel or polymer fibers for toughness and improved resistance to handling damage. Each ring of segments would be 4 feet wide due to the tight radius of curvature (see further discussion below), and would be tapered at the edges to permit construction of the required curvature. See Figures A-6 and A-7, Appendix A for more schematic details on precast concrete segmental liner thickness and assembly.

Tunneling with a TBM requires sizing the diameter of the cutterhead to provide an overcut affording some clearance for passage of the TBM shield. As the tunnel segmental liner is pushed out the rear of the TBM shield, the annular space between the segment external surface and the overcut is filled with annular backfill grout to fill the space and mitigate the tendency for settlement that will occur if this space is not filled promptly. This grouting can be performed through grout ports on the external portion of the TBM tail shield or through segment grout ports that are provided during fabrication of the segments.

The layout of the bored tunnel alternative for the Electron Ion Collider would require approximately 7,004 LF of bored tunnel, of which, 4,684 LF would have a horizontal radius of curvature of 510 feet. The constant diameter of the bored tunnels as compared to the variable width of the cut-and-cover tunnel and aligning the tunnels across the shaft resulted in a length increase of 45 feet (7,124 vs. 7,079). Deduction for the shaft (2 times 60 ft diameter) subtracted from the 7,124 leaves 7,004 LF.

This is a very tight curve for a TBM tunnel of this diameter and unusual in that the curvature is continuous for long distances. The general consensus of TBM manufacturers and contractors is that it can be done, but special consideration must be given to the following:

- A larger allowable variance (inches of departure from design position) than the typical value of three inches per 100 feet of tunnel in horizontal alignment should be considered during design due to the required large taper in the segments throwing the alignment off.
- The tunnel section may often tend to be slightly more egg-shaped due to the tail shield in the inner part of the curve area interfering with the erection of the segments in a perfect circle. This could affect the level of reinforcement provided during actual segment design.
- Segment durability – the concrete segments will be potentially be subject to somewhat variable thrust loads that can cause cracking. Steel of polymer fibers can be added to segment concrete to help mitigate this. The schedule will need to allow for time to repair segments and spalls.
- The TBM will require an articulation joint in the shield, not an uncommon requirement.
- Production rates on curved sections may be up to 65% slower than for straight portions of the alignment.
- Narrower segment ring widths will be necessary to allow tunneling continuously at the required radius. We considered 4-ft wide segments for this evaluation, when it would be more typical to use a segment ring width of 5 feet or more for a tunnel of this diameter.

4.3. Cost estimate

A feasibility-level construction cost estimate was prepared for the shaft and tunnel configuration described in this report using the HCSS HeavyBid 2016 software.

All material costs were estimated from costs derived for similar projects. No material quotes were solicited or received from suppliers or otherwise. Some material and other construction costs were estimated using RSMeans Heavy Construction Cost Data 2015. All data obtained from RSMeans was multiplied by the Newport News, VA Location Factor of 0.861. Sales tax at a rate of 6.0% was applied to all material costs.

The equipment internal rent (ownership) and operating costs were estimated with the EquipmentWatch custom cost evaluator online portal (www.equipmentwatch.com). For each piece of equipment the applicable gas or diesel price was adjusted to correlate with approximate current local prices, and for off-highway equipment the federal and state taxes were subtracted (assuming those could be deducted by the contractor). The mechanic wage rate input was also adjusted to correlate with the local prevailing wage rate.

Labor rates were estimated using the Davis Bacon Wage Decision Number VA160053 Heavy Construction prevailing wage rates published for the independent City of Newport News, VA. Estimates for foreman, superintendents, shifters, and indirect labor (project managers, engineers, safety personnel, etc.) were made using knowledge of the prevailing wages and experience with similar projects. Burden on labor rates considered were Social Security, Medicare, Federal Unemployment Tax and State Unemployment Tax and any fringe benefits required by Davis Bacon.

The tunneling production rate was estimated to average 10 LF per 8-hour shift or 30 LF per day (assuming three 8-hour shifts per day) in the straight portions of the tunnel and 8 LF per shift (24 LF per day) in the curved portion. A short portion to “shake-out” the TBM and another 360 LF of slower production due to “learning-curve” were assumed to account for these real factors that influence overall tunnel production rates. These overall advance rates would account for normal work stoppages and interventions.

Table 4.1 provides a summary of the major cost items documenting our overall estimate of $129.3 million for the central shaft and figure eight tunnel configuration. This estimate includes all applicable mobilization, taxes, burden, mark-ups, and indirect costs. The HeavyBid cost summary sheets are provided in Appendix B.

Table 4-1 Cost estimate summary

Bid Item	Direct Cost	Indirect Cost	Subtotal	Markup	Total Cost
Mobilization	**$4,835,286**	**$1,722,089**	**$6,557,375**	**$991,996**	**$7,549,371**
Site Prep (s/c)	**$355,166**	**$123,578**	**$478,744**	**$24,288**	**$503,032**
Construction Shaft (s/c)	**$2,487,138**	**$865,846**	**$3,352,984**	**$177,752**	**$3,530,736**
Jet Grout Tunnel Eyes (s/c)	**$3,942,068**	**$1,371,620**	**$5,313,688**	**$269,582**	**$5,583,275**
Tunnel East Loop	**$36,195,715**	**$12,891,121**	**$49,086,835**	**$7,425,828**	**$56,512,650**
Tunnel West Loop	**$33,183,225**	**$11,818,221**	**$45,001,446**	**$6,807,793**	**$51,809,253**
Demobilization	**$2,417,643**	**$861,045**	**$3,278,688**	**$495,998**	**$3,774,686**
Total					**$129,263,003**

Cost estimate notes:

1. Direct Cost includes direct labor, permanent material, construction material, and equipment rental.
2. Construction Material includes equipment insurance, TBM power cables, soil/tunnel muck conditioners (bentonite and polymers), other cable, slurry piping, push frames for TBM launch, etc.
3. Indirect Costs include:
   - Indirect labor – PM; tunnel, equipment, and electrical superintendents; foremen; engineering and survey; safety, office personnel, QA/QC, and warehousemen
   - Temporary office facilities, storage and shop buildings, fencing, walls, noise protection
   - Temporary utilities – water, sewer and sanitation, heat electricity, generators, fuel
4. Markup – Subcontracts – 5.1-5.3%; Self performed items – 15.1%. These costs assume that the tunnel contractor is the prime. If the tunnel contractor was a subcontractor to a GC with an overall contract for the work, there could be an additional 5% markup added to these costs.
5. Incremental Cost for Additional Tunnel Length – Should the tunnel length be increased by up to 20-25 percent, a rough cost per foot for the additional length of tunnel would be $14,794/foot, the unit cost for the West Loop Tunnel. The West Loop was selected because a factor for the learning curve at the beginning of the project was applied to the East Loop resulting in a higher unit cost for tunneling. This incremental cost is appropriate for use in screening and feasibility studies and only for length increase of up to 25 percent. A greater change in configuration for much greater length should be subject to a new tunnel cost estimate.

The following items are excluded from the estimate provided in this study:

1. The estimate was prepared based on 2016 dollars with no accounting for escalation.
2. There is no contingency contained in this estimate. This would be considered a “Class 5” estimate based on International Recommended Practice No. 17R-97 of the American Association of Cost Engineers (2003). Descriptors that accompany this classification are “very preliminary,” “conceptual,” and recommended to be used for feasibility studies, comparison of initial alternatives, and concept screening. Recommended contingency range for this estimate class is 30 to 75 percent. We recommend adding 30 to 50 percent to the estimate as a contingency to account for uncertainties and lack of development at the feasibility level.
3. The estimate is also excludes design and construction management costs. This should be addressed in the overall study, adding design and construction management costs for the entire scope of the project.

4.4. Other comments and considerations

4.4.1. Radiation

The potential effects of radiation on the planned gaskets for sealing the precast concrete segmental tunnel liner rings was expressed as a potential issue during the kick-off conference call for this study. We contacted Datwyler, a prominent Swiss supplier of tunnel gaskets, who, some time ago, acquired Phoenix, a German supplier. Phoenix supplied the gaskets used in the tunnel constructed for the HERA accelerator at DESY in Hamburg, Germany.

The Datwyler representative provided a letter documenting that the gaskets for the HERA tunnel were manufactured from a specially developed and patented EPDM (ethylene propylene diene monomer) compound designed as 3300/971. This particular product was developed to provide greater long term ray protection, and would be available if required for this project. Provided test results on gasket materials indicated that exposure to gamma radiation did decrease tensile strength and increased Shore Hardness, but had a relatively minor decrease in compression set, which would be the most important property for efficacy in sealing.

Should the tunnel alternative be selected, it would be prudent to have some tests performed to evaluate radiation resistance to guide material selection for final design. However, it appears that this issue can be addressed with some testing and proper design attention. The gasket suppliers are very sophisticated and should be able to confirm the suitability of a gasket material for this application during detailed design.

4.4.2. Seismic

The project is located within a region with some seismic activity. The preliminary geotechnical report (Wheeler, et.al, 2016) indicates that in accordance with the guidelines presented in Section 1613 of the International Building Code (IBC) the site should be classified as “Site Class ‘D’” based on the shear wave velocity measurements obtained from CPT soundings and other evaluation.

The main seismic issue for the proposed shaft and tunnel lies in the relatively stiff properties of the deeply imbedded and reinforced shaft and shaft-to-tunnel junctions in comparison to the more “free-floating” tunnel in the soil medium. This can lead to large strains at the tunnel/shaft connection. These strains for the design earthquake and proposed actual design and the resulting loads would need to be evaluated and the connections designed accordingly. A secondary consideration is the tensile strength capacity of the segment connections along the length of the tunnel when exposed to a bending pattern caused by ground waves during a seismic event. Multiple types of longitudinal reinforcement methods can be employed to increase this strength capacity including locking dowels, threaded bolts, and post-tensioned rods that span across multiple sets of segments.

4.4.3. Vibrations

Research on vibrations associated with tunnel boring operations has shown that besides vibrations from rotating cutterheads as they excavate the ground, vibrations can also be caused by running supply trains into the tunnel on jointed tracks. However, the greatest indicator of expected vibration level is ground type rather than bore diameter or excavation method. The soils expected in construction of this project should generate relatively smaller vibrations than would be associated with tunneling in harder soils or in rock. A very rough indication from some published data is that the vibrations could tend to be about 0.003 – 0.004 in/sec or less at distances between 30 and 100 ft from the tunnel face. For comparison, measured vibrations at 8 sites on a rock tunneling project in Massachusetts ranged from 0.002 to 0.008, with an average of 0.0046 in/sec.

Theoretical predictions of vibrations levels for individual tunnels are relatively unreliable at this time. Mitigating measures exist for vibration due to track joints in trackage for supply trains, and administrative controls can be placed on excavation to address certain problems with vibration. Should the bored tunnel alternative be selected, it is suggested that limiting vibration levels be identified by Jefferson Labs for any sensitive measuring equipment in use at buildings near to the proposed construction area. The use of such equipment should also be characterized as to whether measurements are taken continuously or only during particular experiments. This should aid the design and construction planning entities in framing the contract documents to fully address this issue as required prior to construction.

4.5. Tunnel study limitations

We based the analyses and recommendations submitted in this report on the information currently available to us. This includes the geotechnical report which contained the subsurface exploration and laboratory testing program. However, conditions on the site may vary between the discrete locations observed at the time of our subsurface exploration. The nature and extent of variations between borings may not become evident until during construction.

This report has been prepared to aid in the evaluation of the bored tunnel alternative and to assist in the design of the project. It is intended for use concerning this specific project. We based our recommendations on information on the site and proposed construction as described in this report.

We have endeavoured to complete the services identified herein in a manner consistent with that level of care and skill ordinarily exercised by members of the profession currently practicing in the same locality and under similar conditions as this project. No other representation, express or implied, is included or intended, and no warranty or guarantee is included or intended in this report, or other instrument of service.

4.6. New Austrian Tunneling Method

Commentary on the applicability of the New Austrian Tunneling Method (NATM) was requested. The NATM method is most often used in rock but is seeing increasing use in soft ground. For an opening of this size, it would require the excavation of multiple sections, referred to as “headings” or “drifts,” whose sequence would be planned and executed to follow NATM design principles. A circular configuration would not be most efficient for this type of sequential excavation, and the design would most likely have an ovoid shape resembling a horseshoe with legs curved inward for greater efficiency in carrying compression loadings. The primary characteristics of NATM include the following:

- Mobilization of the inherent strength of the ground.
- Shotcrete protection against loosening and excessive deformation.
- Sophisticated and extensive measurement information embedded in the lining, the ground, and boreholes, which must be monitored and analyzed in real time throughout construction to permit adjustment of the construction process in accordance with observed deformations.
- Flexible support – because of the mobilization of the inherent ground strength, the primary lining is relatively thin. A separate final lining of concrete is normally required.
- The invert (bottom section) of the lining has to be closed quickly to create a compression ring to mobilize the ground’s inherent strength. For an ovoid shape that would be likely for this tunnel, a concrete invert would have to be placed to complete this closure and would then need to harden before it could support construction equipment loading to excavate the following increment.

For NATM to be applied, the tunnel face and a short distance behind the tunnel face need to be capable of standing unsupported until the mined section can be supported up to the tunnel face. In the soils at the Jefferson Lab site, the combination of being deep below the water table and being of sandy and silty nature mean that they will not have the required stability naturally. For them to be of sufficient stability to permit application of this method would require stabilization of soil encompassing the entire volume of soil demarcated by the excavated diameter of the tunnel, plus an estimated 6-ft thick zone around this diameter (roughly a 40-ft diameter circle). For the 7,000-ft length of the tunnel, this would be nearly 326,000 cubic yards of soils that would have to be stabilized by dewatering, jet grouting, ground freezing, or a combination. This is anticipated to be cost-prohibitive.

Application of NATM is generally significantly more expensive on a per-foot of tunnel basis than use of a TBM unless the tunnel is so short that the mobilization cost of the TBM overshadows its lower tunnel excavation cost. At 7,000 ft in length, this would be a very long NATM tunnel, which would have a lower production rate that TBM tunneling. It is also of sufficient length to effectively amortize the mobilization cost of the TBM over enough tunnel footage so as not to unduly influence the cost, and so the scale factor in this case favors TBM tunneling. In addition, shotcrete is more expensive that cast concrete, is highly dependent on the qualifications and skill of the nozzleman, and requires considerable field QA/QC. TBM tunneling with precast concrete segments requires QA/QC as well, but it can be done in the controlled environment of a casting plant.

A more typical application of NATM tunneling at this depth and in this soil type would be if two parallel transportation tunnels were constructed for highway or mass transit, and cross passages between them were required at intervals. Such tunnels might be in the range of 30 to 100 feet in length, and would have a smaller cross section than the main tunnels. It would be fairly common to use NATM for construction of such tunnels in conjunction with ground freezing, because the volume of soil requiring freezing would be relatively small.

NATM tunneling would provide an initial lining, not a final lining. NATM tunnels are typically finished with cast concrete linings. In this case, waterproofing would be necessary considering the use of the space to be created by tunneling, and a cast-in-place concrete liner would be required inside the waterproofing. This two-pass approach would definitely exceed the cost of the one-pass TBM method for a tunnel of this length. NATM tunneling also carries greater risks which are present daily and require constant attention to changes in ground conditions.

Overall, it is our considered opinion that NATM tunneling is more expensive and more risky than TBM tunneling for the proposed configuration

5. Alternative comparisons

5.1. Construction cost

The purpose of this report is to evaluate the traditional cut and cover tunnel construction method as used on the existing CEBAF Tunnel against a bored tunnel construction method. The comparison is limited to the construction of the tunnel itself without including any of the other conventional facilities. The cut and cover tunnel construction is taken directly from the 2014 JLab cost estimate (ENR Construction Cost Index of 9800) and updated to May 2016 (ENR Construction Cost Index of 10315).

The bored tunnel cost estimate was developed by Lachel for May 2016 for comparison.

Cut & Cover	$41,836,982
Bored Tunnel	$129,263,003

5.2. Other considerations

This comparison was developed to produce a comparative cost based on a schematic level of analysis. Other factors impacting the cost were discussed in a relative fashion with the understanding that the cost would be comparatively small and not a differentiation.

5.2.1. Contingency

As stated in Section 4.3 these costs are very preliminary or conceptual. Contingency has not been accounted for in the costs provided for either the cut & cover method or the bored tunnel method. However, the level of confidence for the cut & cover method costs shown is believed to be higher than the bored tunnel costs shown.

5.2.2. Other conventional facility considerations

There are additional conventional facility considerations required for the bored tunnel alternative that would need to be further evaluated, such as:

- RF facilities
- Vehicle access ramps
- Detector Hall construction
- The small figure-eight tunnel connection and depth
- Connection to the existing CEBAF tunnel
- Radiation / ground water contamination
- Egress facilities
- Tunnel access
- Service buildings
- Utility services (water, sewer, LCW, cryogenics, power, communications, mechanical, HVAC, ventilation)

All of these items would result in a probable increase to the bored tunnel alternative construction cost; which would favor the cut and cover method.

Appendices

Appendix A. Access shaft and bored tunnel layout and preliminary design

A.1. Plan – Shaft

A.2. Elevation – Shaft

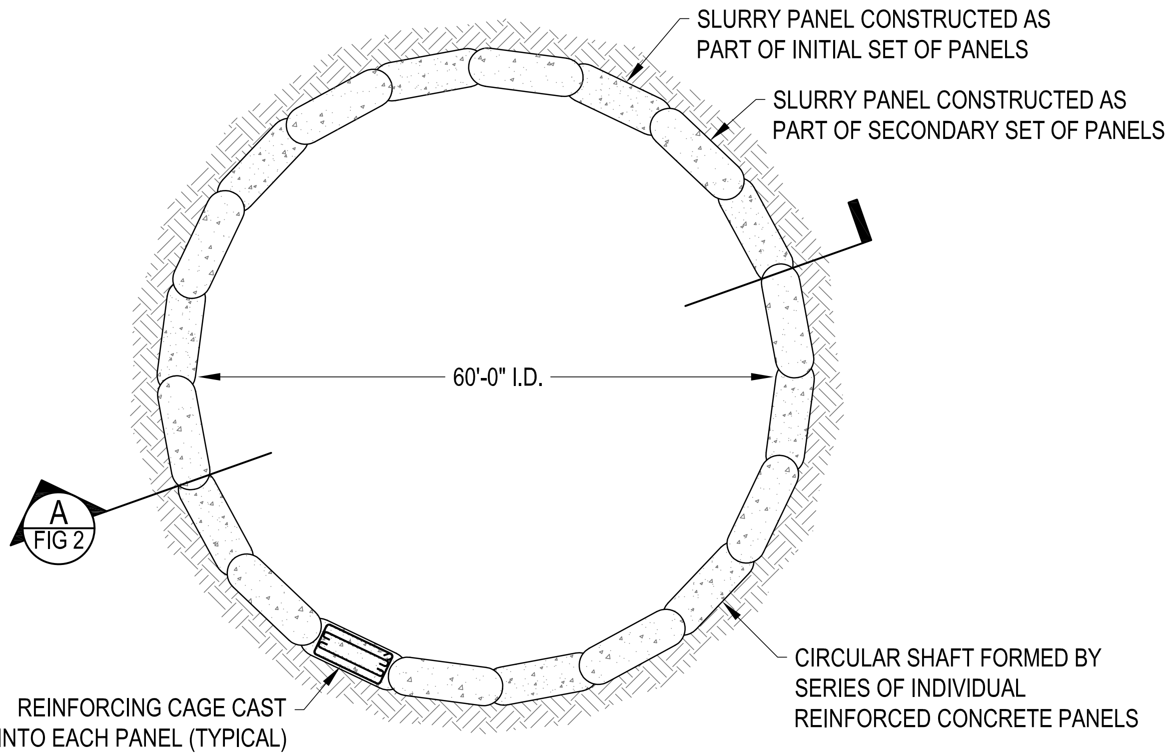
A.3. Plan – Shaft at tunnels

A.4. Elevation – Support collar

A.5. Support collar detail

A.6. Elevation – Tunnel

A.7. Isometric – Tunnel lining



PLAN VIEW - SLURRY WALL SHAFT

SCALE: 1" = 20'

FIG. A-1 PLAN - SHAFT

SCALE: NTS	PROJECT NO: P100047423	DATE: 6/09/2016

United States Department of Energy

Newport News, VA

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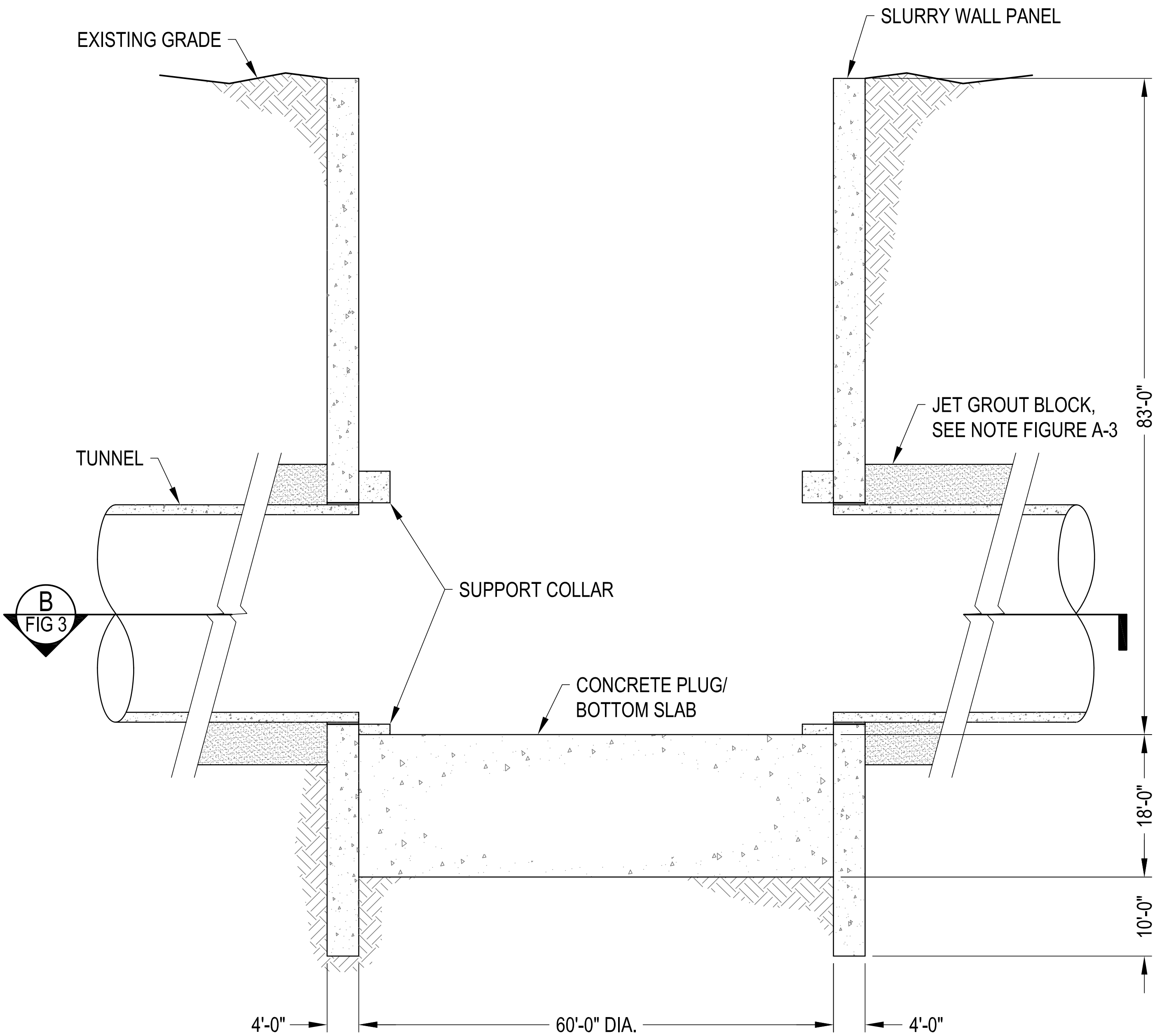

CROSS-SECTION A-A
SLURRY WALL SHAFT
SCALE: 1" = 20'

FIG. A-2 ELEVATION - SHAFT

SCALE: NTS	PROJECT NO: P100047423	DATE: 6/09/2016

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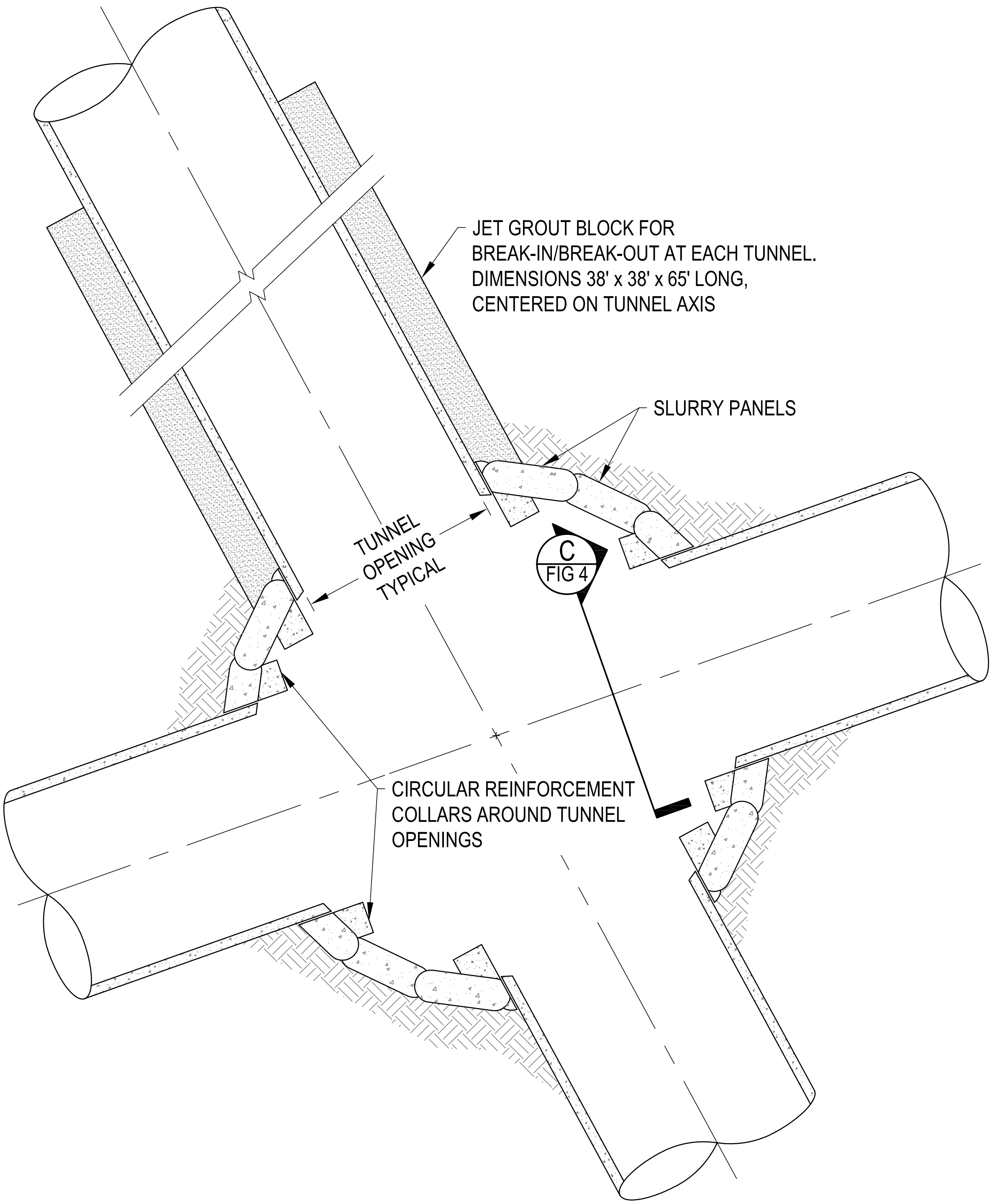

SECTION B-B - PLAN OF SHAFT AT
TUNNEL SPRINGLINE

SCALE: 1" = 20'

FIG. A-3 PLAN - SHAFT AT TUNNELS

SCALE: NTS	PROJECT NO: P100047423	DATE: 6/09/2016

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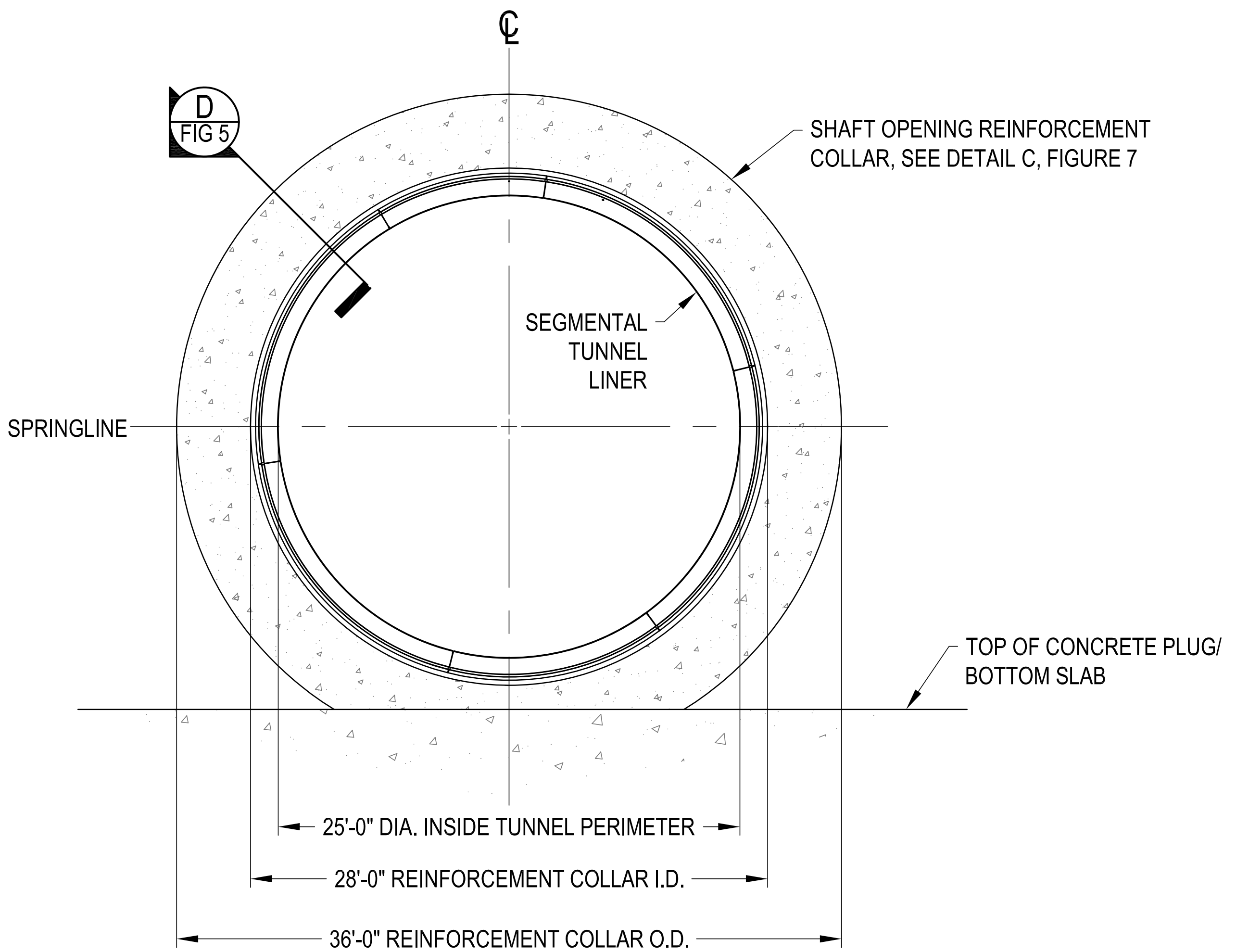

SECTION C-C - FROM SHAFT LOOKING AT TUNNEL OPENING

SCALE: 1" = 10'

FIG. A-4 ELEVATION - SUPPORT COLLAR

SCALE: NTS	PROJECT NO: P100047423	DATE: 6/09/2016

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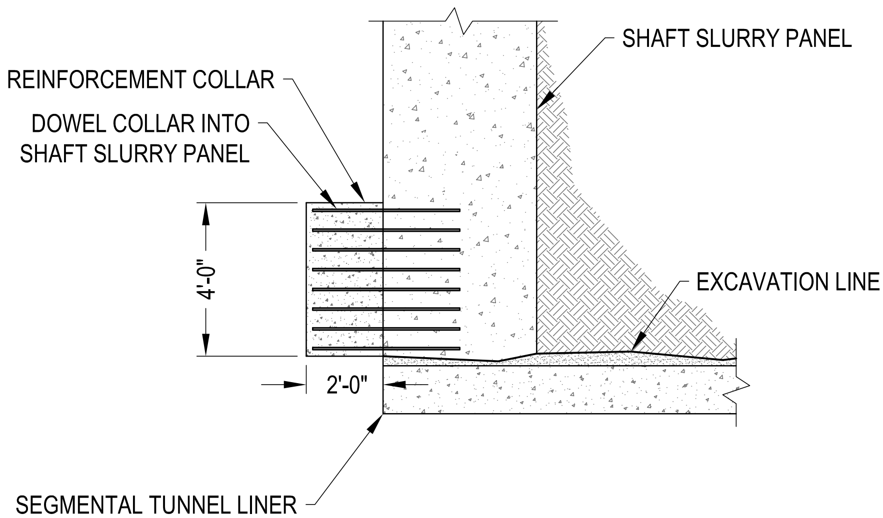

SECTION D-D - REINFORCEMENT COLLAR CONNECTION TO SLURRY PANELS

SCALE: 1" = 5'

NOTE: COLLAR DIMENSIONS ARE APPROXIMATE, SHOWN FOR ILLUSTRATIVE PURPOSES ONLY

FIG. A-5 SUPPORT COLLAR DETAIL

SCALE: NTS	PROJECT NO: P100047423	DATE: 6/09/2016

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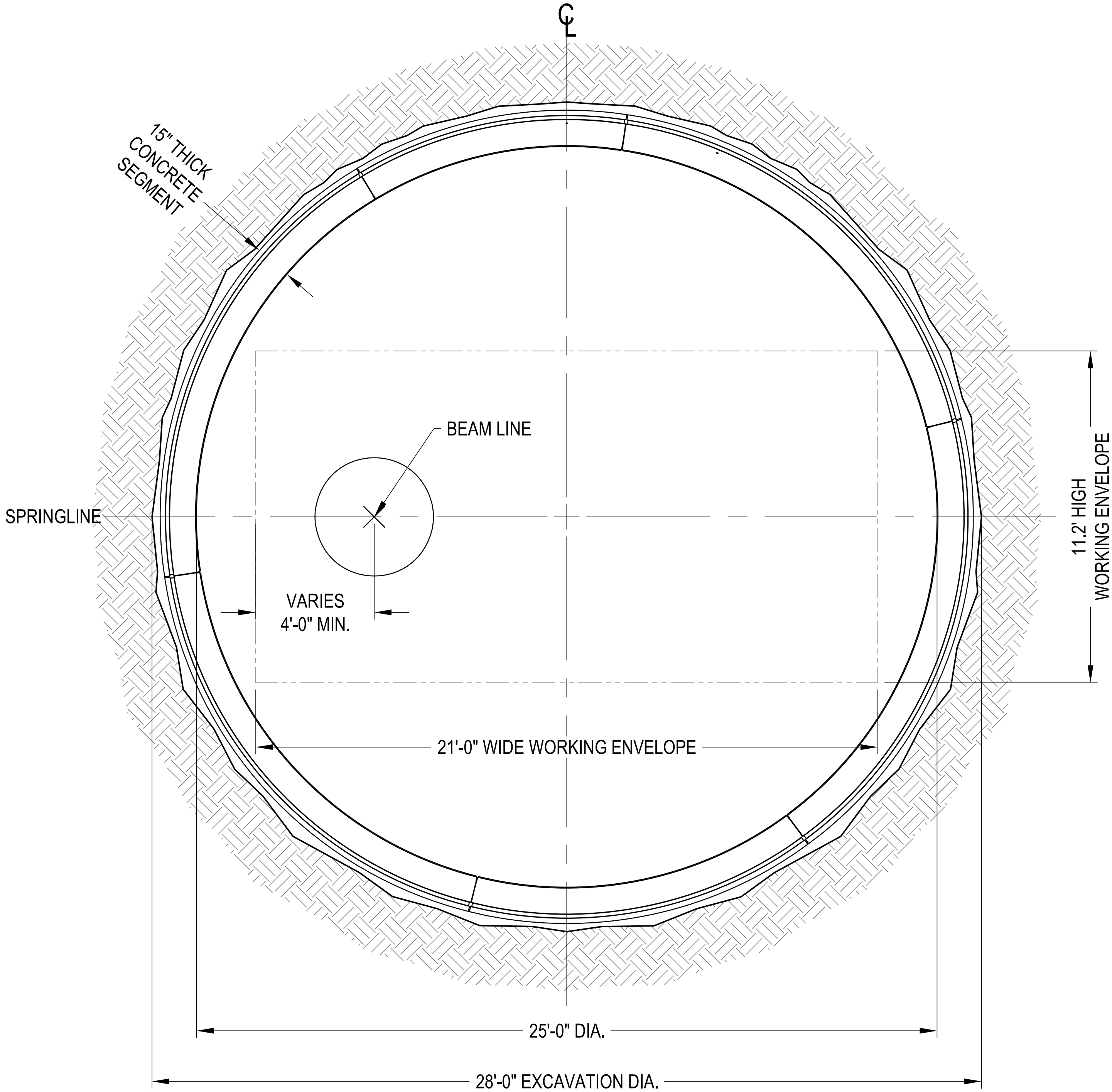

CROSS SECTION

SEGMENTAL TUNNEL LINER

SCALE: 1" = 5'

FIG. A-6 ELEVATION - TUNNEL

SCALE: NTS	PROJECT NO: P100047423	DATE: 6/09/2016

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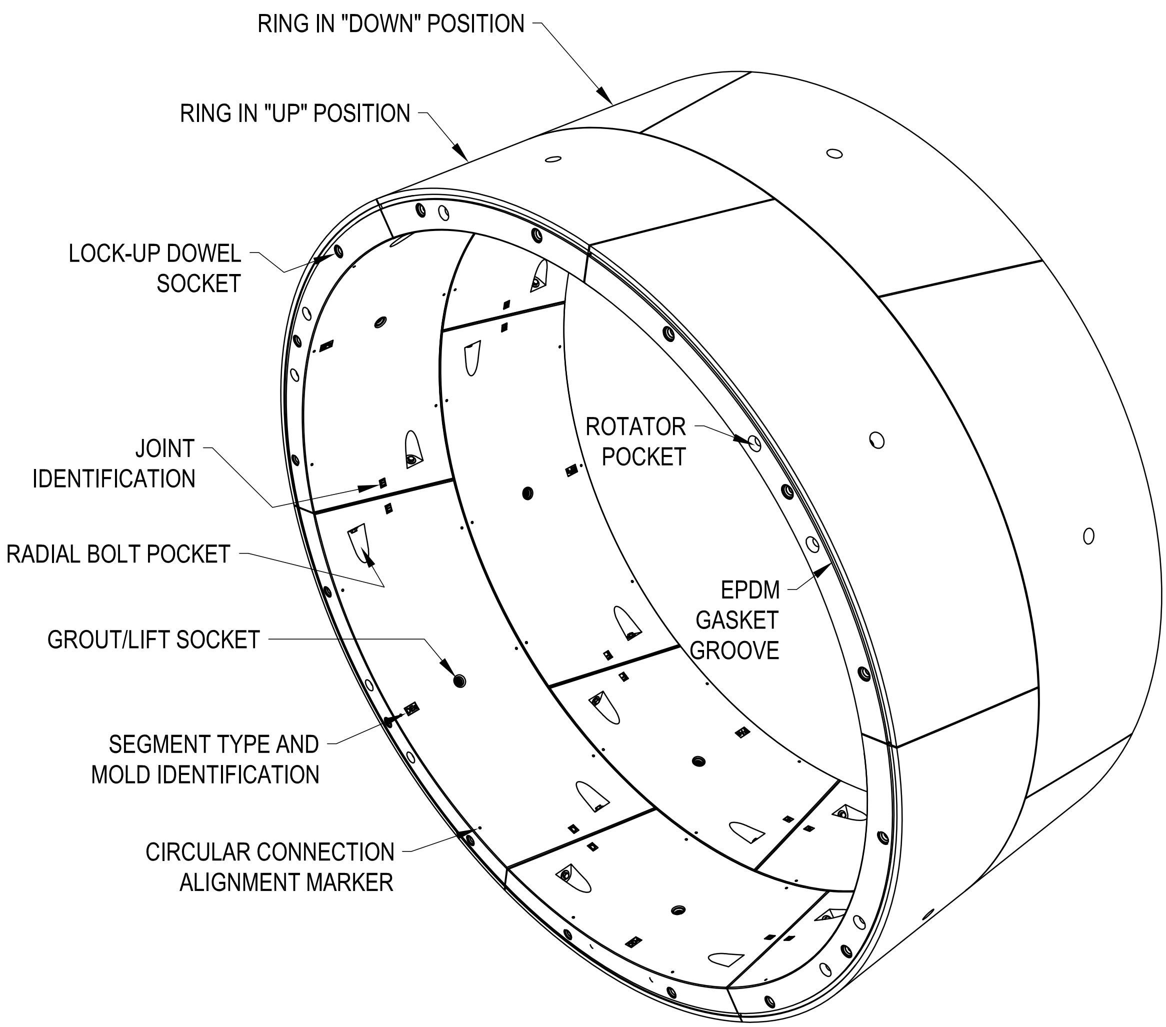

25'-0" ID X 27'-6" OD X 4'-0" SEGMENTAL RINGS

2 RINGS SHOWN IN STRAIGHT DRIVE ORIENTATION

NTS

NOTE: SEGMENTS ARE FABRICATED WITH TAPERED EDGES TO PERMIT CONSTRUCTION OF CURVES BY PLACING SEGMENTS IN ROTATED ORIENTATION.

FIG. A-7 ISOMETRIC - TUNNEL LINING

SCALE: NTS	PROJECT NO: P100047423	DATE: 6/09/2016

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Appendix B. Cost estimate summary

ESTIMATE SUMMARY - COSTS & BID PRICES

Bid#	Client# Bid Description	Quantity	Unit	Manhours	Direct Labor	Perm Matl	Constr Matl	Equip-Ment	Sub-Contr	Direct Total	Indirect Charge	Total Cost	Total Cost Unit Price	Markup	------Balanced Bid------ Total	Unit Price	Bid Price	Bid Total
150005		1.00	LS				4,835,286			4,835,286	1,722,089	6,557,375	6,557,375.41	991,996	7,549,371	7,549,371.37	7,549,371.37	7,549,371.37
MOBILIZATION														15.1 %				
150010		1.00	LS						355,166	355,166	123,578	478,744	478,743.97	24,288	503,032	503,032.31	503,032.31	503,032.31
SITE PREPARATION														5.1 %				
150011		101.00	VF				56,058		2,431,080	2,487,138	865,846	3,352,984	33,197.86	177,752	3,530,736	34,957.78	34,957.78	3,530,735.78
CONSTRUCTION SHAFT														5.3 %				
150012		13,905.00	CY						3,942,068	3,942,068	1,371,620	5,313,688	382.14	269,582	5,583,270	401.53	401.53	5,583,274.65
JET GROUT TUNNEL EYES														5.1 %				
150014		3,502.00	LF	103,073	3,637,335	11,566,964	9,677,821	11,313,595		36,195,715	12,891,121	49,086,835	14,016.80	7,425,828	56,512,663	16,137.25	16,137.25	56,512,649.50
TUNNEL EAST LOOP				29.43										15.1 %				
150015		3,502.00	LF	88,500	3,147,642	11,566,964	8,884,836	9,583,784		33,183,225	11,818,221	45,001,446	12,850.21	6,807,793	51,809,238	14,794.19	14,794.19	51,809,253.38
TUNNEL WEST LOOP				25.27										15.1 %				
150020		1.00	LS				2,417,643			2,417,643	861,045	3,278,688	3,278,687.70	495,998	3,774,686	3,774,685.67	3,774,685.67	3,774,685.67
DEMOBILIZATION														15.1 %				
Totals:				191,572	6,784,976	23,133,927	25,871,643	20,897,378	6,728,313	83,416,239	29,653,519	113,069,759		16,193,236	129,262,996			129,263,002.66
												[113,069,760]						[14.3 %]

Code between Balanced Bid & Bid Price: U=Unbalanced, F=Frozen, C=Closing Biditem (item to absorb unbalancing differences).
[bracketed numbers represent adjusted quantities]
** in front of the Biditem indicates a Non-Additive item

Markup % is shown as a percentage of cost

				Manhours	Direct Labor	Perm Matl	Constr Matl	Equip-Ment	Sub-Contr	Direct Total	Indirect Charge	Total Cost	Total Cost Unit Price	Markup	Balanced Bid Total	Unit Price	Bid Price	Bid Total
90000701	INDIRECT LABOR - SALARIE				2,985,495					2,985,495				447,824				
90000702	INDIRECT LABOR - HOURLY			16,358	391,943					391,943				58,792				
90000703	INDIRECT LABOR - SETUP/T						159,000			159,000				23,850				
90000704	MOBE/DEMOBE INVOICES						284,080			284,080				42,612				
90000805	P & E RENT/PURCHASE/FREI						291,500	21,575,000		21,866,500				3,279,975				
90000810	TIME RELATED EXPENSES						605,923	160,301		766,223				114,934				
90000830	NON-TIME RELATED EXPEN						424,000			424,000				63,600				
90000840	CONTINGENCIES & OUTSID						263,000			263,000				39,450				
90000850	TAXES AND INSURANCE						1,883,974			1,883,974				282,596				
CONTINGENCY @ ??% TOTAL C	% of ++																	
Bond from Summary Table											629,304							
INDIRECT TOTALS ==>				16,358	3,377,438		3,911,476	21,735,301		29,024,215	629,304				<= Subtotal			
Markup on Resource Costs														16,193,236				
********* TOTAL	JOB =====>			207,930	10,162,414	23,133,927	29,783,119	42,632,679	6,728,313	112,440,454	629,304	113,069,759		16,193,236	129,262,996			129,263,002.66

ESTIMATE SUMMARY - COSTS & BID PRICES

Bid#	Client# / Bid Description	Quantity	Unit	Manhours	Direct Labor	Perm Matl	Constr Matl	Equip-Ment	Sub-Contr	Direct Total	Indirect Charge	Total Cost	Total Cost Unit Price	Markup	------Balanced Bid------ Total	Unit Price	Bid Price	Bid Total

Spread Indirects On TOTAL COST Spread Markups On Markup% Spread Addons&Bonds On TotalLessSub

Bond Calculations

Selected Bond Table: B1 **Description: Performance Bond**

	Contract Amount	Rate per 1000	Bond Amount
First:	$ 100,000	15.00	$ 1,500.00
Next:	$ 400,000	10.00	$ 4,000.00
Next:	$ 2,000,000	7.00	$ 14,000.00
Next:	$ 2,500,000	5.50	$ 13,750.00
Next:	$ 2,500,000	5.00	$ 12,500.00
Remainder:		4.50	$ 547,933.48
		Subtotal:	$ 593,683.48
Time Threshold 1: 12	**Extended Time Rate 1:**	1.0000 %	$ 35,621.01
Time Threshold 2: 0	**Extended Time Rate 2:**	0.0000 %	$ 0.00
Length of Job: 18		**Total Bond Amount:**	$ 629,304.49

-----Estimate Notes-----

Bid Date: 06/01/2016 Owner: Engineering Firm:

Estimator in Charge: MLR

Desired Bid (if specified)= 0.00 Sort: Hold Acct: N Subitem: N NonAdd: N

Last Summary on 06/10/2016 at 8:17 AM.

Last Spread on 06/10/2016 at 8:17 AM.

WBS	Description	Interior Height, meters	Interior Width, meters	Length, meters
1.4.2.2.1.1	Collider Tunnel arcs	2.6	3.7	1410
	Underground tunnel houses the beam electron and ion beam lines at Elev 11 feet; Const depth 30'			
	Personnel & equipment access are part of the building cost estimates			
	Dimensions in Feet	8.5	12.1	4625.9

Jefferson Lab - Facilities Management										
Item No.	**Description**	**Height, Feet**	**Width, Feet**	**Length, Feet**	**Quantity**	**Units**	**Unit Cost**	**Direct Cost**	**Dewtr WD**	**Comments**
1	Excavation	30	46.1	4655.9	238,689	CY	5.42	1,292,976	181	No shoring or dewatering, 1:2 Slope
2	Excavation Support	30		578.2	17,347	SF	24.76	429,448		Adjacent to existing structures, Assume 1/8 of tunnel length
3	Dewatering				629	Day	3300.00	2,076,409		Prorate for calender days, no VOC treatment, 500 LF sections of tunnel, Two dewatering systems
4	Backfill w/ compaction				199,203	CY	4.22	841,432	163	Excavation minus disposed
5	Dispose of Excess Soil	14.3	16.1	4625.9	39,486	CY	4.66	184,126		Volume of tunnel & mud slab
6	6" Perforated Pipe Foundation Drain			9276.1	18,552	LF	8.65	160,384		Concurrent w/ other work
7	Concrete piles, 18" square		16.1	4625.9	46,661	VLF	66.50	3,102,959	11	50' pile per 80 SF of tunnel
8	3" Mud Slab Concrete	0.25	16.6	4626.4	713	CY	191.68	136,621	2	3" beyond floor slab
9	Floor Slab	3.0	16.1	4625.9	8,295	CY	294.00	2,438,817	18	Walls sit on floor slab
10	Walls	8.5	2.0	9276.1	5,861	CY	543.81	3,187,375	10	2' thick walls
11	Roof Slab	2.5	16.1	4625.9	6,913	CY	650.00	4,493,286	31	2.5' thick roof slab
12	Waterstop			9276.1	18,552	LF	5.91	109,700		Walls at roof & floor
13	Waterproofing Membrane	13.5	16.1	4625.9	199,836	SF	2.43	485,602	13	Walls & Roof
14	Bentonite Waterproofing	3.0	16.1	4625.9	102,413	SF	2.50	256,443	6	Under slab
15	Protection Board	13.5	16.1	4625.9	199,836	SF	2.06	410,723	14	With Membrane
16	Drain Board	3.0	16.1	4625.9	102,413	SF	1.39	141,842	2	With Bentonite
17	Firestopping		12.1	4625.9	56,154	SF	0.92	51,762		
18	Sealants		12.1	4625.9	56,154	SF	1.73	97,291		

WBS	Description	Interior Height, meters	Interior Width, meters	Length, meters	
1.4.2.2.1.2	Collider Tunnel Straight Sections	3.4	6.4	683.0	Straight section minus Detector Halls length
	Underground tunnel houses the beam electron and ion beam lines at Elev 11 feet; Const depth 30'				
	Personnel & equipment access are part of the building cost estimates				
	Dimensions in Feet	11.2	21.0	2240.9	

Item No.	Description	Height, Feet	Width, Feet	Length, Feet	Quantity	Units	Unit Cost	Direct Cost	Dewtr WD	Comments
	Jefferson Lab - Facilities Management									
1	Excavation	30	55.0	2270.9	138,771	CY	5.42	751,722	105	No shoring or dewatering, 1:2 Slope
2	Excavation Support				-	SF	24.76	-		No existing structures near by. No shoring included.
3	Dewatering				414	Day	3300	1,366,511		Prorate for calender days, no VOC treatment, 500 LF sections of tunnel, Two dewatering systems
4	Backfill w/ compaction				103,699	CY	4.22	438,024	85	Excavation minus disposed
5	Dispose of Excess Soil	16.9	25.0	2240.9	35,072	CY	4.66	163,544		Volume of tunnel & mud slab
6	6" Perforated Pipe Foundation Drain			4523.8	9,048	LF	8.65	78,217		Concurrent w/ other work
7	Concrete piles, 18" square		25.0	2240.9	35,010	VLF	66.50	2,328,183	11	50' pile per 80 SF of tunnel
8	3" Mud Slab Concrete	0.25	25.5	2241.4	529	CY	191.68	101,428	2	3" beyond floor slab
9	Floor Slab	3.0	25.0	2240.9	6,224	CY	294.00	1,829,870	18	Walls sit on floor slab
10	Walls	11.2	2.0	4523.8	3,738	CY	543.81	2,032,719	10	2' thick walls
11	Roof Slab	2.5	25.0	2240.9	5,187	CY	650.00	3,371,359	31	2.5' thick roof slab
12	Waterstop			4523.8	9,048	LF	5.91	53,499		Walls at roof & floor
13	Waterproofing Membrane	16.2	25.0	2240.9	128,419	SF	2.43	312,059	13	Walls & Roof
14	Bentonite Waterproofing	3.0	25.0	2240.9	69,462	SF	2.50	173,933	6	Under slab
15	Protection Board	16.2	25.0	2240.9	128,419	SF	2.06	263,940	14	With Membrane
16	Drain Board	3.0	25.0	2240.9	69,462	SF	1.39	96,205	2	With Bentonite
17	Firestopping		21.0	2240.9	47,053	SF	0.92	43,373		
18	Sealants		21.0	2240.9	47,053	SF	1.73	81,523		

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