Last Chance Grade Permanent Restoration Project

Advanced Planning Study Memorandum Alternative F Tunnel

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Caltrans

LAST CHANCE GRADE

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Acronyms and Abbreviations

2D, 3D	Two and three dimensional, respectively
ADT	Average Daily Traffic
APS	Advanced Planning Study
Caltrans	California Department of Transportation
CIP	Cast-in-place concrete
CSZ	Cascadia Subduction Zone
EDAS	Engineered Deformation Absorption System
EF	Large Earthflow Complex
EV	Electric vehicle
FLC	Flammable liquid cargo
HGV	Heavy goods vehicle
HPGA	Horizontal peak ground acceleration
ITS	Intelligent Transportation System
JF	Jet fan
LCG	Last Chance Grade
NFPA	National Fire Protection Association
NLCG	North Last Chance Grade Complex
PM	Post mile
Project	Last Chance Grade Permanent Restoration Project
SEM	Sequential excavation method
SPGR	Structure Preliminary Geotechnical Report
SLCG	South Last Chance Grade Complex
U.S. 101	U.S. Highway 101
Vs30	Average shear wave velocity upper 30 meters
WC	Wilson Creek Complex

1. Introduction

1.1. Purpose of the Memorandum

The purpose of this *Advanced Planning Study (APS) Memorandum - Alternative F Tunnel* is to present a tunnel design approach that addresses the geologic and geotechnical conditions that exist along the subject stretch of U.S. Highway 101 that also meets required highway design standards. Challenging geotechnical conditions along the alignment dictate the design of the structural elements required to accomplish the Last Chance Grade (LCG) Alternative F tunnel.

The Consultant-prepared APS Checklist is included in Appendix B.

2. Project Description

The Last Chance Grade (LCG) Permanent Restoration Project (Project) is located on a section of U.S. 101 known as Last Chance Grade in southern Del Norte County, California, approximately 10 miles south of Crescent City.

The purpose of the Project is to develop a long-term solution to the slope instability and potential roadway failure at LCG. The Project would consider alternatives that provide a more reliable connection, reduce maintenance costs, and protect the economy, natural resources, and cultural landscapes.

A long-term sustainable solution at LCG is needed to address:

- Economic ramifications of a long-term failure and closure
- Risk of delay/detour to traveling public
- Increase in maintenance and emergency project costs
- Increase in frequency and severity of large storm events caused by climate change

LCG is an area of geologic instability; there is a landslide complex that is approximately 3 miles long with over 30 active landslides. This instability has required significant expenditures of tax dollars on emergency construction projects and maintenance activities to keep the highway open and safe. Between 1997 and 2021, landslide mitigation efforts, including retaining walls, drainage improvements, and roadway repairs have cost more than $85 million. There is no foreseeable end to such expenditures, and effects of climate change may exacerbate conditions.

Other than U.S. 101, there are no viable routes between Crescent City and Klamath. Klamath is a community just south of LCG; many people routinely travel to and from Crescent City for work, school, or personal business. The LCG segment of U.S. 101 had an average annual daily traffic volume of 4,200 vehicles per day, with 640 vehicles in the peak hour (Caltrans 2016a). Typically, a one-way journey between the two cities would be about 22 miles, taking approximately 30-40 minutes. However, in the event of closure, a 449-mile detour would be required, which would take approximately 8 hours.

Potential economic consequences of an emergency 1-year closure of LCG include the loss of approximately 3,800 jobs and the reduction of business output by nearly half a billion dollars ($456 million) (Caltrans District 1, 2018). Such a closure would also lead to an estimated $236 million in travel costs, to be collectively borne by individuals, businesses, and government institutions.

A map of the project area is shown in Appendix A.

3. Alignment Description

3.1. Alternative Alignment Description

There are three alternatives for this Project, which include two build alternatives — X and F — that were developed to meet the purpose and need of the Project, as well as a No-Build Alternative. Both build alternatives would require geotechnical investigations. **Alternative X** would involve reengineering a 1.6-mile-long portion of the existing roadway. This alternative would include a series of retaining walls, underground drainage features, and strategic eastward retreats to minimize the risk of landslides.

Alternative F includes an approximately 6,000 foot-long two-lane, single-bore tunnel. The alignment connects to U.S. 101 on the south through an approximate 500-foot-long southern approach to the portal and reconnects to U.S. 101 on the north via a bridge section outside the north portal. The alignment includes a 150-foot-long bridge spanning a wetland area. The entire new highway alignment length is approximately 6,500 feet. The tunnel will diverge from existing U.S. 101 at approximate post mile (PM) 14.33 and merge back at approximate PM 15.62.

Details of the structures are outlined in Section 6.1. The APS for the bridge structure is presented in a separate document.

For the **No-Build Alternative**, no work would be done to the existing highway. Existing conditions would persist, including the continuation of emergency repairs and enhanced maintenance.

This memorandum focuses on Alternative F, Tunnel Alternative only.

The tunnel alignment is primarily situated beneath the Redwood National Forest with the exception at the South and North Portal areas and the northern approach bridge. Drawings in Appendix E show the limits of the proposed surface encroachment at the portals. There are no proposed intervening surface structures between the portals.

3.2. Clearances

The tunnel is sized to accommodate two, 12-foot-wide vehicle lanes, two 8-foot to 10-foot-wide shoulders, and pressurized emergency egress corridors. The tunnel height is sized to provide at least 16-feet 6-inches of clearance for the vehicle lanes and shoulders. Evacuation and service corridors will be provided on both sides of the tunnel. These enclosed corridor structures will provide safe egress passage in case of fire.

4. Geologic Conditions

4.1. Geologic Units

The project structures traverse three broad Ground Class Groups (Note: For more detailed descriptions refer to the *Structure Preliminary Geotechnical Report* [SPGR] in Appendix F).

4.1.1. Fill/Colluvium/Alluvium

These materials exhibit typical soil behavior, and the range of their engineering properties can be bounded from interpretations of both field and laboratory test results.

4.1.2. Franciscan Complex Formations

Mélanges

In the project area, Mélanges are interpreted as being derived from large submarine landslides (olistostrome). They consist of isolated, rootless rock blocks entrained within a highly sheared, dark gray siltstone or argillite matrix. The material appears to exhibit "block-in-matrix" texture that is typical of Mélanges elsewhere in the Franciscan Complex. Rock blocks (olistoliths) vary in size, lithology, and location, and larger blocks are mappable in scale. Due to the weak nature of the sheared Mélange matrix, these areas have a high susceptibility to earthflows and erosion and form a distinct hummocky, low gradient topography.

Broken Formation Rocks

In the project area, Broken Formation rocks consist mainly of thickly bedded, gray sandstone with lesser siltstone and shale interbeds. The material occurs as relatively intact blocks of varying sizes bounded by shear zones; therefore, bedding is discontinuous. Due to the preponderance of sandstone, Broken Formation areas are relatively resistant to erosion such that drainage paths are well established, and the surface topography is more stable than the mélanges and is suitable for old growth forest conditions to develop. The sandstone component of the Broken Formation is characteristically jointed, forming a blocky, broken texture with a general lack of cohesion between individual blocks.

4.2. Anticipated Ground Conditions

The southern approach (Reach 1) will penetrate two ground classes, the surficial colluvium/alluvium, and the upper mélange (earth flow) materials. The lower portions of the secant piles will penetrate and be found in the Mélange materials below the Large Earthflow Complex (EF) boundary. The highway tunnel (Reach 2) starts at the northern end of the south approach where it will penetrate the Mélange materials approximately 25 feet below the estimated EF shear zone. As the tunnel progresses north, it remains below the EF and in the Mélange for approximately 850 feet, at which point the tunnel should encounter the contact between the Mélange and the Broken Formation. From this contact to the North Portal, the tunnel (Reach 3), and North Portal (Reach 4) are in the Broken Formation and situated east of the LCG Slide Complexes. A summary of the engineering properties used for this study appear in the following table.

Geologic Unit	Lithology	Total Unit Weight (pcf)	Internal Friction Angle (ϕ) Degrees	Cohesion (c) psf
Alluvium	Mixed Gravel/Clay	-	-	-
Colluvium	Mixed Gravel/Clay	120 to 125	25 to 26	50
Earth Flow (Melange)	Argillite with SandStone Clasts	130 to 140	26	250
Rock/Debris Slides	Sandstone/Argillite	140	36-45	1000 to 3000
Earth Flow Basal Failure Zone	Sheared Sandstone/Argillite	140 to 145	18 to 30	0
Rock/Debris Basal Failue Zone	Sheared Argillite	140 to 145	32-34	0
Melange	Argillite	140 to 145	26	500

Note: For a more comprehensive discussion on properties, refer to the SPGR in Appendix F.

4.3. Landslide Types and Activity in the Tunnel's Vicinity

Landslide movement and the interpretation of potential failure surfaces is primarily derived from slope inclinometer data and slope geometry. Available slope inclinometer data and cross-sectional analysis suggests movement along basal failure surfaces/zones approaching depths of approximately 80 to 100 feet within the Northern Last Chance Grade (NLCG) complex, approximately 260 feet within the Southern Last Chance Grade (SLCG) complex, and approximately 270 feet within the Wilson Creek Complex (WC). However, as nested landslide complexes, inclinometers in these areas show movement across a wide range of depths, sometimes on multiple slide surfaces within the same slide mass and within the same measurement interval. Inclinometer data and cross-sectional analyses within the EF indicate movement along non-uniform, basal failure surfaces/zones varying from 45 feet to as deep as 100± feet.

4.4. Tunnel Alignment Relative to Slide Masses and Potential Movements

Alignment F is east of the NLCG, SLCG, and WC failure surfaces. With respect to the EF, Alignment F is positioned such that the tunnel(s) are approximately 25 feet below the base of the EF shear zone within the underlying mélange, which largely consists of decomposed argillite. The EF does intersect the tunnel approach structure. The upper approximately 75 feet of the approach structure headwall and sides will be subjected to EF loads. Section 6.0 of the memorandum discusses an innovative approach as to how these loads can be moderated and countered by the south approach structure.

4.5. Groundwater Conditions Along Tunnel Alignments

In the southernmost portion of the tunnel alignment, close to Route 101, piezometer data indicate that artesian pressures reach above the ground surface. Elsewhere, available data suggest variable groundwater conditions. High groundwater inflows are not anticipated in the mélange due to its state of weathering, which will effectively reduce most fracture flow. However, there is a possibility that some open fractures are present, and these could locally produce significant inflows. Such flows could be sustained under pressure. For much of the remaining tunnel alignment, groundwater levels are 150 to 250 feet below ground surface. At the south tunnel portal, the groundwater level appears to be approximately 40 to 45 feet above the crown of the tunnel, whilst groundwater levels decrease as the tunnel progresses north and the alignment rises in elevation. Additional piezometric data are needed along the alignment to better establish the hydrostatic conditions along the tunnel.

4.6. Hazardous Materials

Based on currently available data, potentially hazardous subsurface gases are not anticipated to be encountered in the excavation of Alternative F. Should hazardous subsurface gases be suspected, tunnel construction will be classified as gassy or potentially gassy. Underground equipment will be explosion proof, and appropriate Occupational Safety and Health Administration (OSHA) safety protocols will be incorporated in specifications. There are no other known hazardous materials along Alignment F.

4.7. Seismic Setting

The site area is characterized as a region of high seismic potential. The area south of the project study area, near the Mendocino triple junction, is perhaps the most seismically active area in the contiguous United States. The Cascadia Subduction Zone (CSZ) is capable of generating great earthquakes of high magnitude (>M8.5) and should a full-length rupture of the entire CSZ occur, an earthquake exceeding magnitude M9 is highly likely. The surface trace of the CSZ is located about 55 miles west of the site (measured from Google Earth Pro), while the fault surface dips eastward about 10 to 15 degrees. beneath the region. Therefore, the CSZ detachment fault boundary is located from 9-½ to 14 miles beneath the site. Between 37 and 60 miles south of the project area, there are a series of northwest-trending thrust faults, which include the Mad River fault zone, Table Bluff fault, and Little Salmon fault. These likely represent the nearest known Holocene-active surface faults to the project site. A series of suspected older, poorly defined bedrock faults occur north of Big Lagoon and generally south of the Klamath River, located 4-½ to 10 miles to the south and southeast of the project area.

Evidence for this fault was not observed in the field during previous LCG-related geologic investigations.

The preliminary horizontal peak ground acceleration (HPGA) values for the above-ground structures and tunnel portals are nearly identical, varying from 0.85g to 0.87g. While for the mid-tunnel site, the HPGA is 0.65g, due to a higher Vs30 (shear wave velocity at a depth of 30 meters) value. The HPGA values are based on the seismic parameters shown in the table.

4.7.1. Preliminary Site Seismic Parameters

Structure(s)	RW 1 R/L	Tunnel/ South Portal	Tunnel/ Middle	Tunnel/ North Portal	RW 2 R/L	Bridge
V_{S30} (m/s)	305	305	1,149 (3)	330	330	330

Note: For a more comprehensive discussion on seismic conditions, refer to the SPGR in Appendix F.

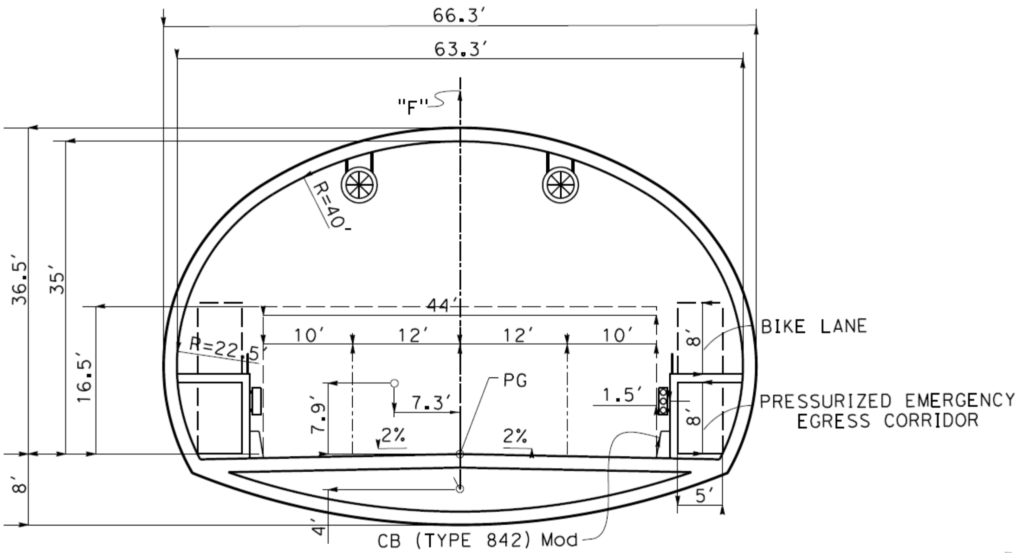
5. Tunnel Type, Construction, and Dimensions

5.1. Tunnel

5.1.1. Tunnel Dimensions

Figure 1 presents the general configuration of the tunnel and the key features and dimensions.

Figure 1. Two-Lane Tunnel



5.1.2. Tunnel Alignment and Slide Surfaces

The Alternative F alignment has been established to commence as far north along U.S. 101 as possible, but also to not intersect any of the coastal slope failure surfaces. This alignment positions the tunnel east of the coastal slope failure surfaces, shown in Figure 2, and is aligned vertically at the South Portal to pass approximately 25 feet below the base of the EF, as shown in Figure 3. This alignment does require the construction of an approach structure within the EF and the design requirements for this structure are discussed in Section 6.1.

At the southern portal, the tunnel passes through the Mélange for approximately 850 feet. At that point, the tunnel enters the Broken Formation and progresses northward for an additional 4,950 feet to the north portal.

Figure 2. Landslide Complexes

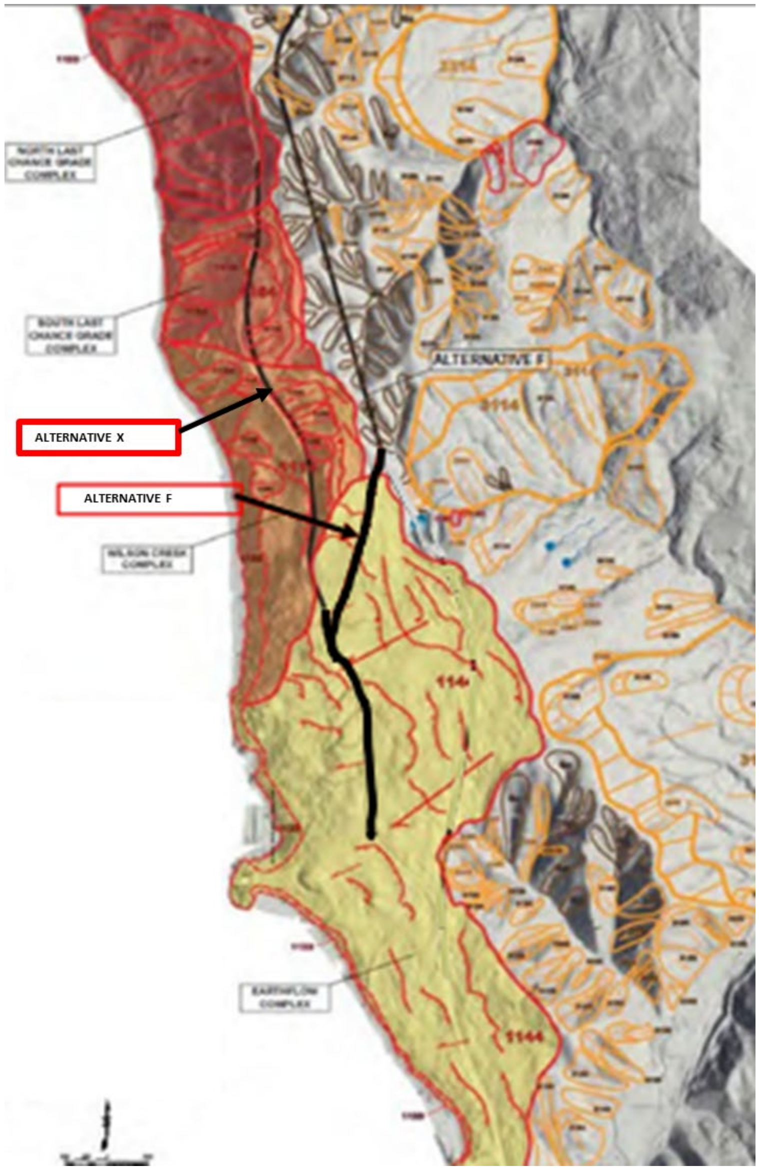
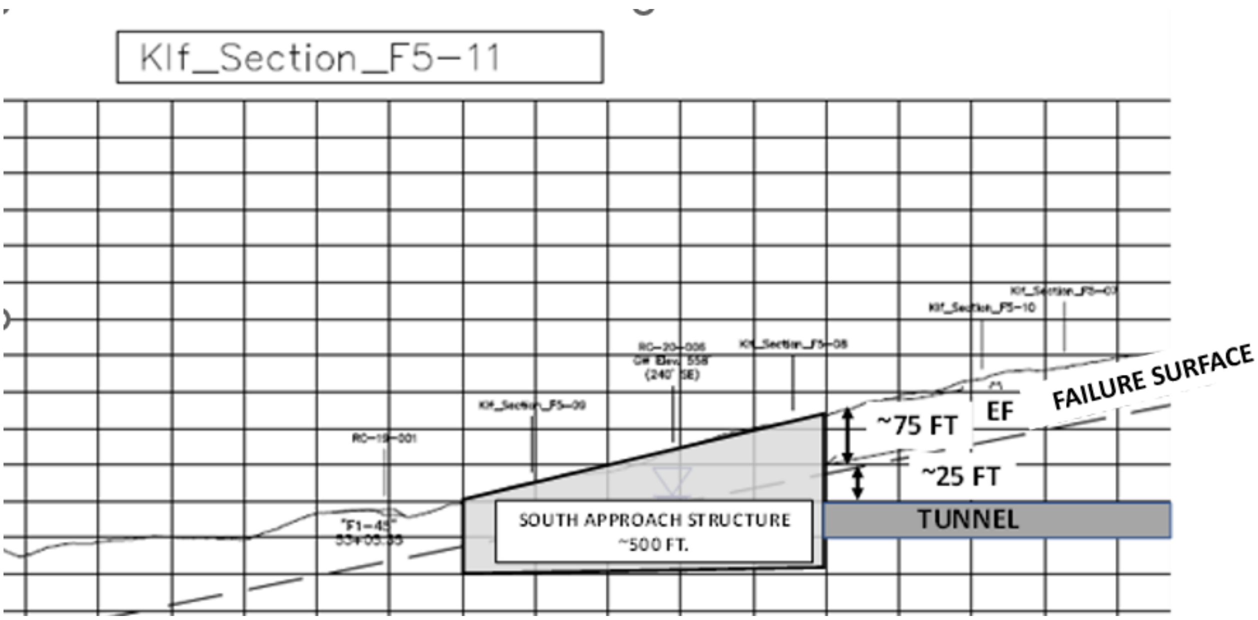


Figure 3. Tunnel and Earth Flow Failure Surface



5.1.3. Sequential Excavation Method (SEM) Tunnel Construction

General

The F alignment offers a significant reduction in length compared to the previously proposed F-4 alignment. This reduction makes it feasible to employ a simpler SEM for construction, eliminating the need for tunnel boring machines (TBM). SEM tunneling leverages the inherent strength of the ground, combined with relatively thin initial lining sections, to create a self-supporting ring and facilitate load distribution around the tunnel.

In SEM tunneling, the tunnel cross-section is divided into smaller headings (as shown in Figure 4), which are excavated sequentially. The size of each heading is determined by factors such as allowable ground deformation and the duration the ground can remain unsupported to allow for the placement of initial ground support. The staggered advancement (excavation) of headings along the tunnel's length is strategically designed to control the extent of unsupported ground arching, ensuring acceptable ground stability.

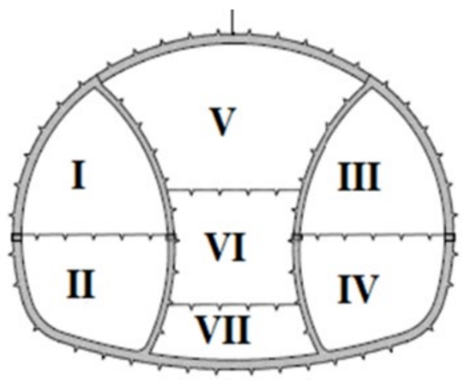
The initial ground support categories, which dictate the length of each heading excavation, the spacing of rock bolts, and the thickness of shotcrete lining, are designed to accommodate a range of expected ground conditions. These support categories will be assessed in the field, collaboratively by field engineering representatives and the contractor, for each excavation sequence. The assessment will be based on the observed ground conditions and the performance of previous segments.

The Mélange's soil-like nature and the fractured characteristics of the bedrock make roadheaders a suitable choice for excavation. The installation of the waterproofing system and final lining will occur after the entire tunnel has been excavated, and initial ground supports have been put in place.

LCG Specific

The Mélange, characterized by its soil-like nature, will necessitate a segmented approach to mining. Multiple heading segments, as depicted in Figure 4, will be employed for excavation. However, the SEM process in the Mélange may require the implementation of ceiling pre-support measures to manage the potential for roof raveling. The extent and specific requirements for ceiling pre-support will depend on further subsurface investigations and findings in the Mélange material. These measures will be designed to ensure the safety and stability of the tunneling process in this specific ground condition.

Figure 4. Sequential Excavation



SEM mining in the Broken Formation will similarly involve the use of multiple heading segments, although likely fewer than in the Mélange due to the differences in ground conditions. Given the fractured nature of the rock and the substantial width of the two-lane tunnel, a substantial number of rock bolts will be necessary to establish a continuous rock arch over the tunnel excavation. This rock bolting strategy is crucial for ensuring the stability and safety of the tunnel in these conditions.

Up to this point, the groundwater data collected has not indicated the presence of high-water pressure conditions along the alignment. However, it is important to note that these conditions will require further investigation in the subsequent phase of subsurface exploration. A comprehensive study of groundwater conditions will be necessary to ensure that the tunnel construction plans adequately account for any potential water-related challenges that may arise during excavation and tunneling activities.

Mining in the Broken Formation using SEM will indeed involve multiple heading segments, likely fewer than in the Mélange due to the differing ground conditions. Given the fractured nature of the rock and the substantial width of the two-lane tunnel, a substantial quantity of rock bolts will be necessary to establish a continuous rock arch over the tunnel excavation. This extensive rock bolting strategy is essential for ensuring the stability and safety of the tunnel in the presence of fractured rock conditions.

Initial Lining

The initial lining strategy for the SEM tunnel will involve several components, including flashcrete, rock bolts, lattice girders, and shotcrete. Each of these elements plays a crucial role in ensuring the stability and safety of the tunnel construction process, especially given the highly fractured nature of the bedrock.

Flashcrete: Flashcrete will be employed to provide temporary cohesion for the exposed tunnel walls while the area is being cleared (mucked) and rock bolts are installed. This initial application helps prevent any immediate instability of the tunnel walls.

Rock Bolts: Due to the fractured bedrock conditions, rock bolts will be a key element of the initial lining. Rock bolts provide structural support by anchoring the surrounding rock mass and stabilizing it. They are essential for maintaining the integrity of the tunnel.

Lattice Girders: Considering the highly fractured nature of the bedrock, it is likely that lattice girders will be necessary before placing the initial shotcrete lining, as depicted in Figure 5. Lattice girders are structural elements that provide additional reinforcement and distribute loads effectively in unstable or fractured rock conditions.

Shotcrete: The final component of the initial lining is shotcrete, which is applied over the lattice girders and serves as a protective layer for the tunnel walls. It provides long-term stability and helps mitigate potential rockfall hazards.

Given that the initial lining support will be in place for approximately a year, it is essential for it to be robust enough to withstand the stresses and pressures associated with tunnel construction and to support the ground effectively throughout this period. This approach ensures the safety and durability of the tunnel while construction activities progress.

Figure 5. Initial Lining

Waterproofing

Given the variability and uncertainty of the groundwater levels and pressures along the tunnel alignment, it would be prudent to install a comprehensive waterproof membrane system throughout the tunnel, as illustrated in Figure 6. This waterproofing membrane serves several critical purposes:

Leakage Prevention: The primary function of the waterproof membrane is to prevent any water from infiltrating the tunnel. Even if current groundwater levels are not a concern, unforeseen circumstances, or changes in groundwater conditions during construction or over time could lead to water seepage. The waterproof membrane acts as a protective barrier to keep the tunnel interior dry.

Groundwater Table Stability: In areas within or adjacent to national or state parklands, maintaining the stability of the groundwater table is of paramount importance. Alterations to the natural groundwater table can have ecological and environmental consequences. The waterproof membrane ensures that the tunnel construction activities do not disturb or alter the groundwater levels in these sensitive areas.

By incorporating a full-round waterproof membrane, the project not only ensures the structural integrity and longevity of the tunnel but also demonstrates a commitment to environmental preservation in national or state parklands. This proactive approach is essential to minimize potential impacts on the surrounding ecosystem.

Figure 6. Membrane Waterproofing

Although water samples have not detected deleterious chemicals in the groundwater an inert, flexible membrane material will be used to waterproof the tunnel. The membrane will envelope the entire tunnel perimeter and all joints sealed to ensure continuity between final lining pours.

<u>Final Lining</u>

The final lining of the tunnel will consist of cast-in-place (CIP) concrete, which is a robust choice for long-term durability and structural support. Here are the key considerations for the final lining:

Reinforced and Designed for Ground Loads and Pressures: The CIP concrete will be reinforced and structurally designed to withstand not only long-term ground loads but also groundwater pressures.

Additional Fire Survivability: To enhance fire survivability, an extra 3 inches of concrete cover will be provided in the final lining. This additional layer acts as a protective barrier, reducing the risk of damage due to high temperatures in case of a fire incident.

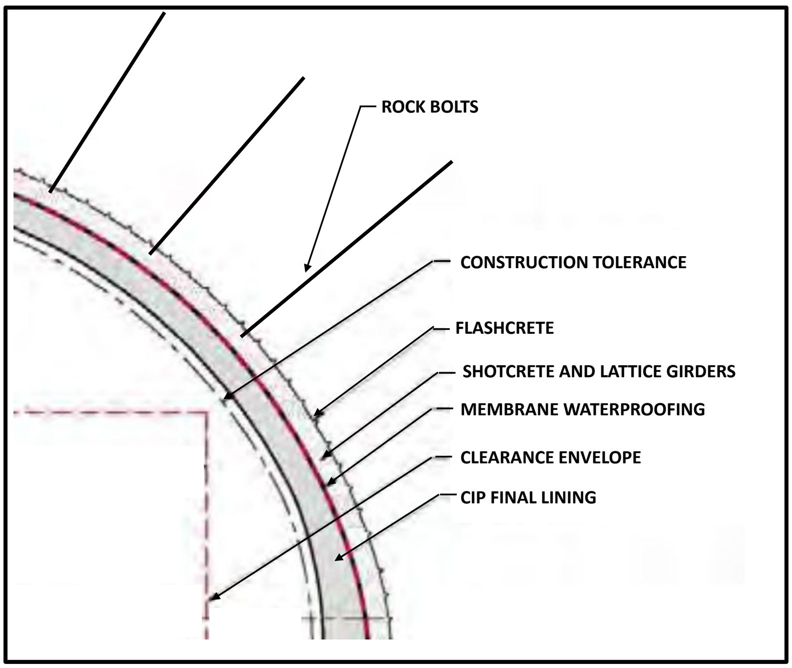
Seismic Design: The lining will be sized and reinforced to accommodate the strains associated with the design seismic event. This is crucial for ensuring the tunnel's resilience during seismic activity, which can exert significant strains and forces on the structure.

Polypropene Fibers for Spalling Reduction: In case subsequent fire scenario analyses determine a need for additional durability, polypropene fibers can be added to the concrete. These fibers reduce the potential for explosive spalling of the concrete when exposed to high temperatures during a fire.

Additionally, a preliminary analysis has been conducted to validate the satisfactory performance of the SEM lining during the design seismic event. The analysis indicates that the 24-inch-thick lining can effectively tolerate the strains associated with ovaling deformation resulting from extreme ground shaking.

Figure 7 provides a visual representation of the various components that constitute a typical SEM lining, illustrating the comprehensive approach taken to ensure the tunnel's long-term integrity and resilience in diverse conditions.

Figure 7. Lining Components SEM Tunnel



Ground Improvement

Ground improvement is usually provided outboard of tunnel headwalls to prevent excessive soil material inflow during commencement of tunneling. In the case of Alternative F, the South Portal headwall, where excavation would commence into the Mélange, will require some ground improvement outboard of the headwall. This ground improvement could consist of unreinforced secant piles or jet grouting. The selection of the ground improvement method would be based on compatibility with existing ground conditions as well as a preference for the least disruptive method on existing site conditions.

Drainage

The tunnel profile slopes upwards from south to north. This slope will result in all tunnel drainage flowing out the South Portal. The tunnel will have an invert drain to collect water that might be generated by vehicles or leakage in the tunnels, as well as water that may derived from firefighting. The size and capacity of the drainage structures and the collection system will be determined during subsequent stages of design based on the latest site investigation data.

6. Portals

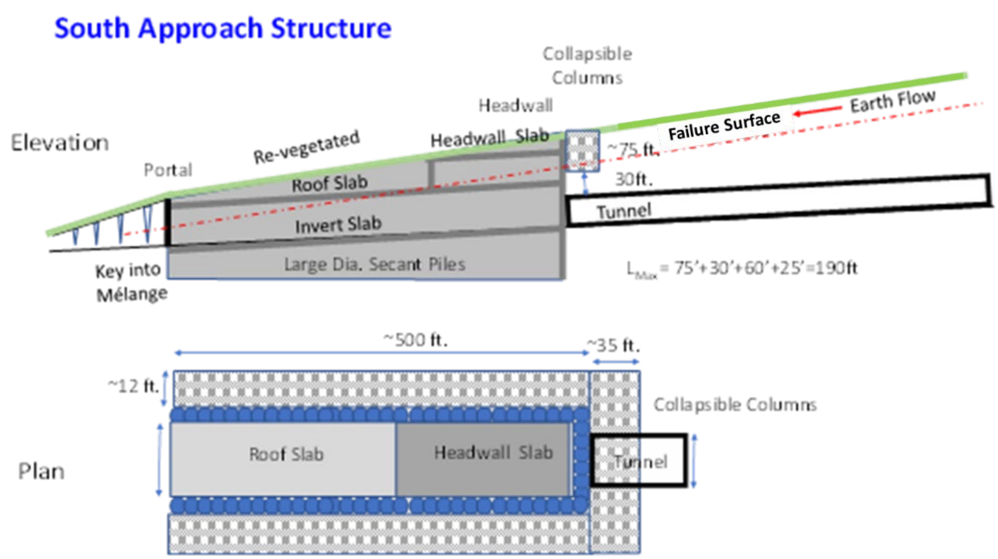
6.1. South Portal Design

6.1.1. Approach Structure

The south approach structure will be a significant structure and will serve to not only retain the adjoining ground materials, but also to resist on-going EF movement. The design concept uses large diameter secant piles and collapsible concrete columns to absorb the EF ground movements. The secant piles will be socketed into the Mélange well below the EF slide surface. While the collapsible columns would extend through the zone of EF movement and their strengths engineered slightly exceed the existing earth pressures in the EF.

The areal extent of the collapsible columns will be established to absorb the downslope movements of the EF. These include the currently observed downslope creep as well as the lateral spreading anticipated to occur as a result of the design seismic event. Lateral support of the approach structure walls will be provided by interior slabs within the approach structure, Figure 8.

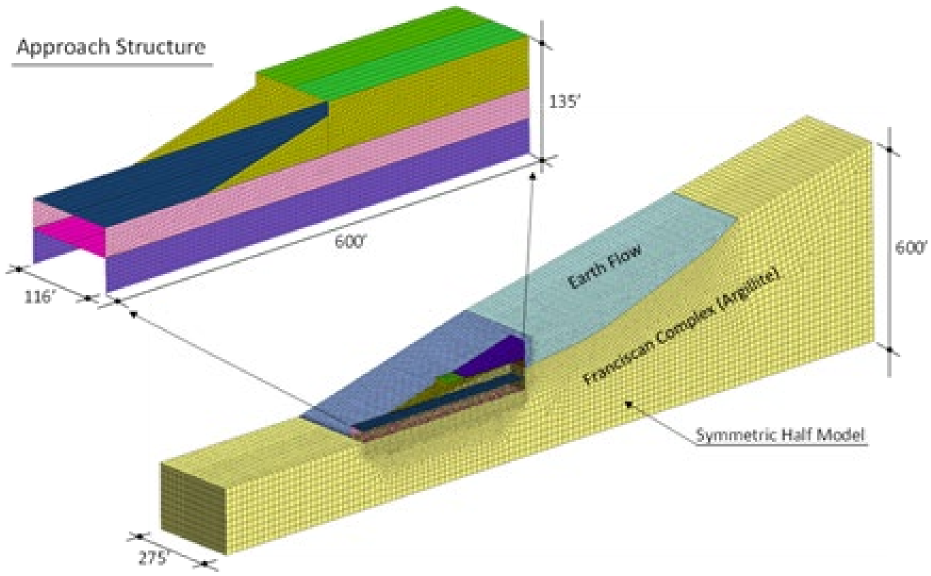
Figure 8. South Approach



6.1.2. Structural Design

This structural concept has been modeled using MIDAS GT^{tm} and cross checked with hand calculations. The results indicate that the loads imposed on the structure can be prescribed and effectively transmitted to the portions of the secant piles embedded (keyed) in the Mélange. In addition, the stress levels in the Mélange and the corresponding deflections are well within acceptable limits. Figure 9 is a half-section cut away of the Midas model.

Figure 9. MIDAS GT Model

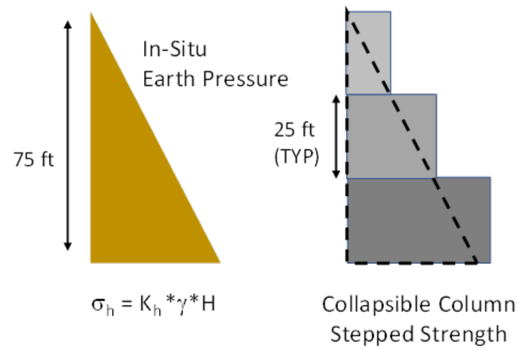


6.1.3. Earth Flow Accommodation

The EF will bear on the approach structure headwall. The upper approximate 75 feet of the headwall will be subjected to this load. Since this load is displacement derived, (e.g., EF downslope creep), the design approach will be to absorb this deflection using collapsible concrete columns. The strength collapse of the collapse columns will be the limiting loads on the approach structure. Because the approach structure is not perfectly aligned with the downslope movement collapsible columns will also be provided along the sides of the structure to limit those loads as well.

The strength of the collapsible concrete will be formulated to be slightly stronger than the existing soils. This is necessary to not diminish the current stability of the EF mass. Classical soil mechanics calculations suggest the corresponding earth pressure coefficient should be approximately 0.74, based on a Coulomb analysis. In-situ pressuremeter tests taken in the EF indicate earth pressure coefficients in the range of 0.7 to 0.85. This close correlation between theory and practice provides confirmation and a reasonable level of confidence in the selection of the column strength criteria. For the purposes of this study an earth pressure coefficient of 0.8 has been used and a stepped strength profile as shown in Figure 10 was used for modeling.

Figure 10. Stepped Strength Profile



The width of the collapsible column treatment zone is dependent upon the projected downslope movement of the EF over the life of the structure. This movement has been established by using an estimated yearly down slope movement extended over the service life of the tunnel and the estimated lateral spreading anticipated to occur due to the design seismic event. For the ongoing downslope creep, a rate of 2 inches per year for a 75-year service life has been assumed. This translates into a deflection of 12.5 feet. In addition to this deflection, an additional downslope movement of 22.8 feet will be accommodated for the seismic lateral spreading. Estimates of lateral spreading are empirically derived and depending on what method is used the results differ significantly. Figure 11 shows the range of these estimated deflections, which range from 4 to 22.8 feet. Considering these two modes of EF movement, a collapsible width of 35 feet has been selected. More in-depth analyses should be performed in subsequent stages of the design.

Figure 11. Lateral Spreading Estimates

Earth Flow Lateral Spreading Estimates (M=8.8, PGA 0.88g, a_{yield}=0.1g)	
Method	**Displacement - ft**
Bray and and Travasarou (2007)	4
Rathje and Saygili (2009)	22.8
Jibson (2007)	6.5

(Note: For more detailed descriptions refer to the Geotechnical Studies to Evaluate Feasibility of Alternative F-Short, May 2022 in Appendix H).

Peer Review of the Engineered Deformation Absorption System (EDAS)

The application of innovative designs, such as the EDAS system, necessitates a thorough and prudent engineering analysis, sound judgment, and a comprehensive peer review. While the individual components of the EDAS system are well-established and have been used in other applications, their use in the proposed configuration and under the extreme site conditions justifies a rigorous, independent evaluation.

To ensure the reliability and effectiveness of the EDAS system, the formation of a peer review panel consisting of independent subject matter experts is highly recommended. The panel should encompass various disciplines, including:

Soil Mechanics: Expert in soil mechanics will provide insights into how the EDAS system would behave considering the specific soil and EF conditions at the project site.

Landslides: Expert in landslides and general ground movement will provide insights into how the EF should behave under both static and dynamic conditions.

Cellular Concrete: Specialist in cellular concrete can offer valuable assessments of the material properties, fabrication, and its proposed application.

Seismic Ground Response: Given the seismic considerations, an expert in seismic ground response will evaluate how the EDAS system responds to potential seismic induced ground movements.

Drilled Shaft Construction: Expert in drilled shaft construction will assess the practical aspects of installing the EDAS system.

Soil/Structure Interaction Modeling: Expert to assess the soil/structure interaction modeling used to establish EDAS column strength, behavior under sustained and rapid loading and ultimately the load imposed on the south approach structure.

The peer review team's role will be to provide an independent and comprehensive evaluation of the EDAS system. This evaluation may include recommendations for additional materials and in-situ testing to validate the system's performance. Model testing, possibly using a centrifuge to simulate extreme conditions, can also be considered to further assess the system's behavior under different scenarios.

The input and recommendations from this peer review panel will be invaluable in ensuring the safety, effectiveness, and reliability of the EDAS system in the context of this specific project, particularly under extreme site conditions.

6.2. North Portal Design

6.2.1. Head Wall

The North Portal headwall, situated in a northern sloping rock face, presents specific construction challenges and safety considerations. Below is an overview of the construction and safety measures that will be required for this area:

For Initial Construction:

Clearing and Grubbing: The construction process begins with the clearing and grubbing of the impacted rock face, preparing the area for excavation.

Portal Excavation: Once the rock face is exposed, the portal excavation commences. Given the high degree of fracturing in the rock face, temporary stabilization measures will be essential to ensure safety during excavation.

Temporary Stabilization: Temporary stabilization will be achieved through a combination of rock bolts and shotcrete. Rock bolts anchor the fractured rock, while shotcrete provides added support and structural integrity. This stabilization will remain in place until the final portal structure is completed.

For The Final Portal Structure:

Cast-In-Place Concrete: The final portal structure will be constructed using CIP concrete. To blend with the existing geology and surroundings, the concrete is likely to be tinted and textured, creating a harmonious appearance with the natural rock.

Rockfall Protection Features: Given the potential for rockfall from the surrounding slopes, additional safety measures are essential. These may include the installation of a canopy portal extension or other protective structures designed to mitigate the impact of falling rocks and enhance safety for both construction personnel and future tunnel users.

By combining temporary stabilization methods during construction with the construction of a robust and contextually integrated final portal structure (Figure 12), the North Portal will be both safe and aesthetically pleasing. These measures should ensure the structural integrity of the portal while safeguarding against potential rockfall hazards in this challenging geological setting.

Figure 12. Contextually Designed Portal

6.2.2. Slope Stabilization

The north portal site's current conditions are not yet known in sufficient detail to precisely determine the slope stabilization measures that will be necessary. However, given the existing slope characteristics and the poor quality of the bedrock, it has been assumed that measures will be required to stabilize the slopes above and adjacent to the portal area. These measures may include:

Removal of Loose Rock Materials: Clearing and removing loose or unstable rock materials from the slopes is a fundamental step to enhance stability and safety in the area.

Regrading: Adjusting the slope gradient through regrading to mitigate the risk of slope instability. Re-grading the slopes to provide a more stable and controlled terrain.

Rock Bolting: In cases where unstable rock wedges or sections are identified, rock bolting can be employed to anchor and secure these areas. Rock bolts provide structural support and prevent the dislodging of potentially hazardous rock masses.

Revegetation: To further enhance slope stability and minimize erosion, revegetation will be implemented. Planting native vegetation can help bind the soil and rock materials, contributing to slope reinforcement.

It is important to note that additional subsurface investigations will be necessary to determine the exact extent and nature of the required slope stabilization measures. These investigations will provide the necessary data to make informed decisions and develop a comprehensive slope stabilization plan that ensures the long-term safety and stability of the portal site in the context of its specific geological conditions.

6.2.3. Slope Drainage

Given the relatively steep slope of the ground above the portal and the region's high rainfall, managing runoff effectively is crucial to prevent erosion and ensure the safety and integrity of the portal area. The means to direct this flow can vary depending on the specific conditions, and two potential options are:

Swales: Swales are shallow, vegetated channels designed to carry and manage stormwater runoff. They can effectively direct runoff to a designated discharge point while also providing some level of water filtration and sediment removal. Swales are a sustainable and environmentally friendly option for managing water flow.

Paved Channels: In cases where the quantities and velocities of runoff are high, especially in areas prone to heavy rainfall, paved channels may be a more suitable choice. Paved channels provide a more controlled pathway for runoff and can handle larger volumes of water. They are also effective in preventing erosion in high-flow scenarios.

The choice between swales and paved channels will depend on factors such as the expected volume and velocity of runoff, site-specific conditions, environmental considerations, and cost. Once the final poral configurations is established, a further assessment that considers the specific characteristics of the portal site and the anticipated rainfall patterns, will determine the most appropriate solution to manage runoff safely and effectively.

6.2.4. Run-off Control During Construction at Portals

Construction of both the South and North Portals in an area with high rainfall and potential for soil erosion demands effective erosion control measures to protect the exposed slopes. Soil erosion can be managed using:

Erosion Control Materials:

- **Hay Bales:** Hay bales can be strategically placed on slopes to slow down water flow and trap sediment. They are a simple and effective means of reducing erosion during construction.
- **Geotextile Fabrics:** Geotextile fabrics can be used to stabilize the soil, prevent erosion, and promote vegetation growth. They can be installed to cover and protect exposed slopes.
- **Sedimentation Basins:** Sedimentation basins allow runoff to settle, enabling suspended solids to settle out before the water is discharged.

The combination of erosion control materials, sedimentation basins, and, if necessary, flocculants ensures that Portal construction sites can manage rainfall effectively while minimizing soil erosion and the discharge of sediment-laden runoff into the environment.

7. Construction Considerations (Access, Equipment and Services)

Since the project site is situated in areas of multiple jurisdictions, any fieldwork will require multiple access agreements and entry permits. SEM tunnel construction utilizes predominantly self-powered construction equipment, the exception being hydraulically driven drills and or roadheaders. These may be either powered by generators or hydraulic pumps. Access for the construction of the tunnel can be provided from both the North and South portals, and thus there is no need for an intermediate shaft to the surface. A bridge will be required to span a low area near the north portal, while the South Portal structure will have to be largely completed to provide access from the south. The equipment that will be used in the tunnel construction will include front end loaders, drills, roadheaders, shotcrete mixers and sprayers, excavators, haul trucks and concrete trucks. The services required will include generators, temporary tunnel ventilation systems, water treatment facilities for construction generated water, fuel storage tanker, and clean water storage tank.

The construction at the north and South Portals will expose bare ground to rainfall. The high rainfall regime of the site will require that these areas be immediately covered with erosion control materials, such as hay bales and geotextile fabrics. For any sediment laden run-off that does occur, a sedimentation basin will be provided to allow suspended solids to settle out before discharge.

8. Geotechnical Considerations

The geotechnical challenges associated with this project, including active landslides, the Mélange, fractured bedrock, and the EF, indeed require rigorous investigation and analysis to ensure the successful design and execution of the project.

Subsurface and Surface Investigations: To address these challenges, extensive subsurface and surface investigations are crucial. These investigations are necessary to validate and refine the design concepts, particularly for the SEM tunnel excavation. They will provide essential data on soil and rock properties, groundwater conditions, and geotechnical characteristics critical for the design and construction phases.

Mélange Properties: Additional engineering properties related to the Mélange are essential to develop a thorough understanding of this material. These properties are particularly important for planning the sequencing of the SEM tunnel excavation. The Mélange's behavior during excavation and its response to ground support measures must be well-understood.

Elevation and Orientation of EF Failure Surface: The most critical piece of information required for this project is the accurate elevation and orientation of the EF failure surface. As the current interpretation is based on limited data, it is imperative that this data is validated, supplemented, and further investigated. Precise knowledge of the EF failure surface is vital for the design and implementation of the collapsible column concept, which is intended to counteract the effects of the EF.

In summary, comprehensive geotechnical investigations are the basis for addressing the project's complex challenges. This data will inform the design, construction, and safety measures required to ensure the success of the project, particularly in dealing with the unique geotechnical features and conditions at the site.

9. Special Structural Requirements

The south approach structure walls will need to function as both as earth retaining structures and as shear walls to counteract the EF loads. This structure will require a series of comprehensive 2D and 3D analysis to test its behavior under a range of potential ground properties. These analyses should entail both more traditional scale modeling and larger scale modeling to understand the behavior of the approach structure as an element in the body of the larger EF.

The bedrock quality and cover along the tunnel needs to be investigated further with additional borings and testing, as the width of the tunnel is large and sufficient good quality rock cover will be required to provide a stable arch. Should these conditions not be met, additional ground support and ground improvement will be required to make up for the lower rock quality.

10. Important or Unusual Design Assumptions or Structure Features

The estimate of the EF loads will require further study. Currently, it is assumed that these loads will be limited to the maximum strength of the collapsible columns. For a final design, additional analyses and model testing, as determined from the Peer Review effort, as described in Section 6.1.3, will need to be performed to validate the various design assumptions. In addition, more detailed modeling of the secant pile/Mélange interface behavior is needed to establish the required pile embedment with a higher degree of confidence. The 3D effects of the EF movement, which may not be perpendicular to the headwall, must be assessed to determine if these effects result in higher and/or torsional loads to the approach structure.

The final design will take into account seismic analysis of the various tunnel structures. Preliminary ovaling analyses indicate that the two-lane SEM tunnel in the Mélange will perform well during the design seismic event. Similar analyses need to be performed along the entire length of the tunnel to validate this finding for the various other ground and cover conditions.

The extreme ground shaking anticipated for the project site requires that all slope failure surfaces be located with respect to the tunnel alignment. New borings along the alignment should be fitted with inclinometers to detect subsurface movement, a clear indication of an active failure surface.

11. Aesthetics

The visual aesthetics of the Alternative F tunnel will be dominated by the perceptions of the south and north approaches and portals. Within the tunnel proper, it is advisable to keep it utilitarian so as not to cause distraction and reduce safety in the confined environment.

The aesthetics of the approaches and portals should be designed to conform to the natural surroundings. This can be accomplished with tinted and textured concrete as well as natural motifs embedded in retaining walls.

12. Construction Considerations (Staged Construction)

12.1. Limited Site Accessibility and Seasonal Work

The project site is somewhat remote with limited access along U.S. 101. The delivery of material and equipment will be by truck, as will muck removal. The total volume of muck to be hauled from the site totals approximately 1.1 million cubic yards. This translates into approximately 62 truckloads per day from each of the portals. For the APS cost estimate, it has been assumed that a disposal site can be located within 70 or 200 miles roundtrip from each portal.

There are no seasonal construction limitations, although special considerations should be given to erosion and run-off mitigation during the rainier seasons.

12.2. Constructability Review

- Both the north and South Portal structures will be considerable in size and will require aesthetic treatment to be contact sensitive to their surroundings.
- Since the Broken Formation is more stable than the EF materials, the alignment should be adjusted to exit the EF and enter the Broken Formation as soon as practical.
- Construction staging areas suitable for material and muck is limited, thus the tunneling contractor will have to secure more remote laydown areas both north and south of the project site.

12.2.1. Project Risk List

- Further subsurface investigations reveal conditions not anticipated in this study.
- New slope inclinometer data reveal considerable lateral movements at a depth below the current tunnel alignment.
- The rock quality and cover over the entire length of the tunnel needs to be established.

13. Muck Volumes, Hauling, and Disposal

An important factor to consider in tunnel construction is the bulking of the material that is excavated. Mining breaks the rock down into smaller granular particles and in doing so it increases the void ratio of the material. This bulking or swelling of the material determines the final volume of material that needs to be transported and disposed of. For the rough order magnitude (ROM) cost estimate, a range of bulking factors has been used based on the method of excavation and materials excavated. These will have to be validated after further investigation of the site's soil and rock materials.

The volume of muck (excavated materials) generated from Alternative F will total approximately one million cubic yards. The SEM tunneling will produce approximately 0.75 million cubic yards of muck, assuming a bulking factor of 1.5. The excavation associated with the construction of the portals will produce approximately 0.28 million cubic yards of muck, assuming a bulking factor of 1.3. The muck produced by the tunnel construction will be hauled from both the North and South Portals. The muck produced at the two portals will be hauled from their respective locations. Disposal sites have not been identified as of this time; however, cost estimates assume that these sites will be within 70 or 200 miles roundtrip of the project site. In later planning phases, efforts will be made to find beneficial reuses for the muck.

As of writing this report, there have been no identifiable contaminates along the tunnel alignment, either natural or manmade, in either the bedrock or soil along the alignment. At the OMC, hexavalent chromium (CS-6), lead based paint or aerial deposited lead were detected. Refer to the Environmental Impact Report/Environmental Impact Statement (DED) for more details. Water leaching from any disposal site will require treatment to reduce suspended solids to below regulatory limits.

14. Tunnel Roadway Drainage

Tunnel drainage water must be collected and treated prior to discharge. Since the tunnel slopes upward continuously to the north portal, the drainage water is naturally collected at the low point near the South Portal. The drainage system must be designed for a possible spill of an FLC and to limit the extent of a flammable liquid fire, and to account for firefighting water and wastewater from tunnel washing. For that, a slotted drainage duct with regular compartmentalization is required. All drainage components will be fabricated of non-flammable materials. All drainage water must be collected into a detention tank, which must be adequately sized to contain extinguishing water that may impose an environmental hazard. Drain inlets and piping must keep the roadway within the tunnel free of ponding water.

15. Operations and Maintenance Center (OMC)

A dedicated facility to support the required maintenance and operations for the LCG tunnel alternate is proposed on the east side of the highway approximately 2,000 feet south of the South Portal. The facility design concept includes a secure yard and building with space for support vehicles, equipment, and staff to support normal and emergency operations. The building incorporates program elements required to support 24/7 staffing of an operations control center. One design was developed for the OMC building and yard. It was configured to minimize disruption to the site and integrate visual screening from the highway. The yard is located on the downslope site of the OMC site and the building is positioned against the retaining walls at the rear of the site with the retaining wall abutting the rear wall of the building. Building functions are all accommodated within a single story, including equipment storage space.

15.1. Site Civil

The OMC site includes an open paved yard area that will support maintenance vehicle access and storage needs. The paved area will be permeable pavement stripped with parking spaces for staff use. The building and yard will be secured by fencing with access control at the entry gate.

15.1.1. Landscape Buffer

A 40-foot landscape buffer is proposed along the west side of OMC site between the new roadway alignment and the OMC yard, respectively, to provide visual screening of the site.

15.1.2. Storm Drainage

Drainage inlets will be placed along the shoulders of the new roadway alignments and the OMC to collect surface flows. These flows will be conveyed to a bioswale located downstream before being discharged to the ocean.

15.1.3. Power and Site Lighting

Utility power to the facility will be provided by PacifiCorp. Discussions with PacifiCorp have led to the present design concept of a utility substation near the OMC as well as generators and a step-up transformer for the tunnel. The tunnel is supplied with medium voltage rather than 480V, drastically reducing the size of wiring and switchgear. The high prices for copper in recent years leads to a significant cost savings potential in using a higher voltage in the tunnel.

Electrical power for site lighting of the OMC maintenance yard will be provided from the South Portal electrical equipment enclosure and stepped down for lighting distribution. Per National

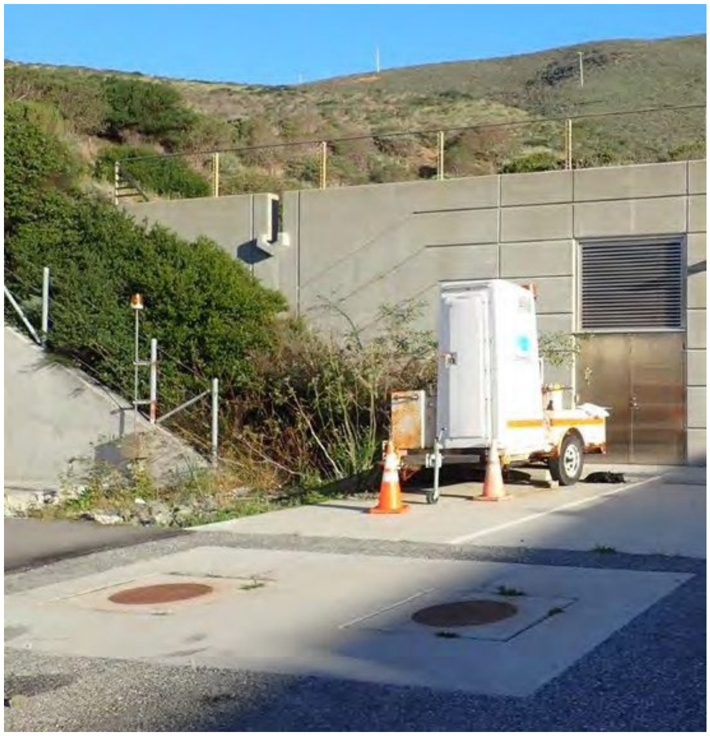
Electrical Code (NEC) emergency power requirements, a combination of the generator station at the South Portal electrical equipment yard along with Uninterruptable Power Supplies (UPS) will be used for emergency site lighting, and they will provide the required illumination automatically in the event of an interruption. Site lighting will be provided in accordance with Backlight, Uplight, and Glare (BUG) requirements and be primarily downward lighting on poles mounted around the perimeter of the yard. Lighting of the yard will have an occupied and non-occupied mode, which will further reduce lighting levels around the building when the facility is not being occupied.

15.1.4. Water and Sewer Tanks

The remote location of this facility does not allow for a municipal water supply, such as a city domestic water or sanitary sewer system. Initial research did not identify any available ground water sources near the tunnel site. Additional exploration for ground water that may be pumped should be considered in future project phases. A 15,000-gallon on-site water holding tank will be provided for domestic water use at the OMC. The on-site water tank will be equipped with a level monitor that will notify the operations control center when the tank needs refilling. A water filtration system will be provided within the building mechanical space to treat stored water for domestic water use. The building water supply will be pressurized by a domestic water booster pump and piped to a hydropneumatic holding tank. The hot water system will be run off a liquid propane gas (LPG) instantaneous hot water heater that will serve hot water fixtures separately. The hot water supply will be sized for the building demand, including staff showers.

The building sanitary sewer system will follow traditional plumbing methods but will discharge to a 3,000-gallon holding tank. Site grades support gravity flows for the sanitary piping from the building to the tank. The holding tank will have a level monitor that will notify the operations control center when the system is reaching capacity and a vacuum truck will be required to pump out the tank. Tank notification will include a supervisory control and data acquisition (SCADA) message sent to the operator and a local alarm light (shown in Figure 13) adjacent to the tank manhole covers.

Figure 13. Sanitary Collection Tank Level Indicator



15.1.5. Electrical Power Supply

PacifiCorp will provide electrical power service for the tunnel and OMC. Because the area where the tunnel is located is served by a radial transmission line (only one source from one end), the electrical service will be backed up by engine generators to meet NEC and NFPA 502 emergency power requirements. These generators will be located in an electrical equipment yard within the OMC parking lot. External fuel tanks (grade mounted and double wall with leak detection) will support normal and emergency operations of both standby generators. Both emergency generators will have access to the entire fuel store on site and are sized to provide full redundancy for emergency operations (when emergency fans and equipment are not running).

15.2. Structures and Retaining Walls

Retaining walls with top-mounted safety fencing will be located around the OMC building and yard for security purposes and to provide a grade break that allows the OMC facilities to be placed below the existing ground surface. The site retaining walls are proposed to be constructed of reinforced concrete with heights up to 20 feet. Caltrans standard retaining walls cannot be used at this site due to the high seismic peak ground accelerations that are expected to exceed 0.7g.

Since retaining walls will be large elements that will potentially be visible from off site, it is recommended that they have integrally colored concrete that is textured with a naturalistic pattern and that harmonizes with the forested surroundings.

15.2.1. Building Architecture

The OMC building and yard are configured to minimize their footprint and disruption to the site. In each of the three layout options, the yard is located on the downslope site of the OMC site and the building up against the retaining walls at the rear of the site with the retaining wall abutting the rear wall of the building. Building functions are all accommodated within a single story. The building height is sufficient for storing maintenance vehicles roof, and the exterior treatment will employ materials, such as CIP concrete, for walls to resist vehicle impacts and the effects of the damp marine environment. A green roof is incorporated into the design. Further details will be developed during the design phase.

Type 316 stainless steel will be used for doors, locksets, plates, and other hardware exposed on the exterior. Standing seam copper roofs with copper gutters, roof accessories, and downspouts are recommended as they can withstand exposure to the area's humid, salt-laden air from the ocean. The roof can be given weak acid treatment to accelerate formation of a protective and aesthetically pleasing green patina, blending it into the surrounding.

Storage

Rooms for specific material categories shown on the building plans correspond to the building needs that were evaluated. It is anticipated that as the project program and interior layout is further refined, the discrete storage rooms may be merged as appropriate where it is determined that there is no need to segregate materials by room. For example, Small Parts Storage and Electronics Storage may eventually be merged.

Specific materials being stored, such as road flares, may be of sufficient quantity to trigger the need for a Hazardous ("H") Occupancy for their storeroom. To minimize the amount of wall areas shared with the non-Hazardous ("B") Occupancy of the rest of the OMC building, the optimal placement of H Occupancy spaces is at one end of the building with doors facing the yard without connection to the rest of the building.

Workshops

Workshops include service bays for heavy equipment servicing as well as smaller, specialized workshops for the servicing and repair of components and equipment. Heavy vehicle repair will be done off site. The three heavy equipment bays are high enough to accommodate dump-truck-sized maintenance vehicles. The bay depth can accommodate work benches at the back wall, opposite the large roll-up doors that open onto the yard. Bays are wide enough to provide workspace for mechanics and their equipment between bays and to allow for drop-down exhaust reels and hose reels for lubrication, compressed air, 110 volt (V) electric power, and other services.

Equipment Storage

The heavy equipment bays may double as storage bays for large vehicles. This will extend the life of specialized vehicles by limiting exposure to the harsh marine environment.

Offices

Office space is provided for personnel who monitor tunnel operations, administration, and meetings. Meeting rooms may also support safety and security use by the California Highway Patrol or other stakeholders.

Ancillary Spaces

Ancillary spaces include a server room, an electrical room, a data and communications closet, a mechanical room, and a materials recycling enclosure.

15.2.2. Building Mechanical

Mechanical heating, ventilation, and air conditioning (HVAC) systems will be provided to meet building comfort criteria for occupants in winter and summer conditions. HVAC systems will be sized to ensure adequate cooling is provided for internal equipment spaces, electronics, and computer rooms. High efficiency mini-split equipment may be used to minimize duct routing and provide control flexibility. Demand controlled ventilation may be considered to reduce ventilation demand. Indoor package units should be considered for equipment rooms with high internal head gain. The building layout limits available space for outdoor condensers to be installed near the building. Package roof mounted equipment is not considered for the building due to visual considerations.

15.2.3. Building Electrical and Lighting

OMC building electrical and lighting power will be provided from the South Portal electrical equipment enclosure and stepped down for lighting and low voltage distribution within the building. Illumination levels and minimum controls will be provided to meet the requirements appropriate to the tasks performed. Emergency lighting and power will be provided by a combination of the generator station at the electrical equipment area along with UPS. Emergency lighting and power will be arranged to provide the required service automatically in the event of interruption.

16. Tunnel Fire Life Safety

Alternative F has many similarities to the Devils Slide Tunnel (Tom Lantos Tunnel) constructed in Caltrans District 4 along Route 1 near Pacifica that was completed in 2013 and has unidirectional traffic. However, the proposed Alternative F tunnel is bidirectional, comparable to several remote road tunnels in Europe with similar length and traffic volumes. This section describes the fire risk assessment, tunnel ventilation, egress, and fire protection systems for the Alternative F tunnel.

16.1. Fire Risk Assessment

The LCG tunnel is comparable to many remote road tunnels in Europe with similar length and bidirectional traffic, which have low accident rates and very rare fire incidents.

The proposed alignment provides an acceptable level of safety based on:

- Low traffic volumes
- Wide roadway with 12-foot-wide traffic lane + 10-foot-wide emergency lane

An unfavorable factor is the significant tunnel grade, which may slow down heavy vehicles driving uphill or lead to overheated brakes and subsequent uncontrolled speed in the downhill direction.

In case of a fast-developing large fire, for instance from an FLC truck, fire buoyancy may become a determining factor that drives the smoke quickly towards the north. Therefore, rapid incident detection and reaction time of safety equipment, particularly ventilation and traffic management, is required.

The emergency egress corridor to the North Portal leads to a point of safety. This should be considered for the evacuation concept.

Regardless of the tunnel design, it must be evaluated whether FLC trucks need to be escorted by vehicles in an adequate distance to avoid accidents with other traffic and to minimize the danger to other tunnel occupants in the case of a fire.

16.2. Tunnel Ventilation Design Parameters

16.2.1. Traffic Data and Tunnel Use

Based on available data traffic projections are:

- Average daily traffic (ADT) of 4,410 vehicles in 2031 (8% heavy goods vehicles [HGV], peak hour 670 vehicles with 60% in one direction)
- ADT 4,670 vehicles in 2051
- Bidirectional traffic in the SEM tunnel.
- Accommodate vehicle speeds of at least 45 mph within the tunnel. Maximum posted speed is 55 mph (60 mph design) within the tunnel. Additional safety measures must be considered during the preliminary design phase to support bi-directional tunnel traffic speeds over 40mph.
- HGVs will be allowed in the tunnel. Escort and/or temporary tunnel closures are likely to be required for the transport of flammable liquids based on a future quantitative risk analysis.
- The Project includes tunnel access by pedestrians and bicyclists. Project risk and egress analyses will be advanced during the next design phase.

Additional operation analyses should confirm how to support bidirectional traffic in case of closure of one lane. For the calculation of the number of vehicles standing in the tunnel in a fire incident, it is assumed that half of the vehicles driving in the tunnel are blocked by the fire, and additional vehicles are driving into the tunnel until the fire is detected and tunnel access is closed. As the fire incident develops, it is supposed that blocked vehicles and people may be on both sides of the incident location. Therefore, limiting smoke spread and retaining smoke stratification is the fire ventilation goal.

Note: During the Preliminary Engineering phase, an engineering analysis of the effect of moving traffic on dynamic fire scenarios under different boundary conditions must be considered.

16.2.2. Meteorology

Based on preliminary tunnel portal design data the following altitudes are defined:

- South Portal altitude: 104 meters/340 feet above sea level (a.s.l)
- North Portal altitude: 264 meters/867 feet a.s.l
- Mean: 184 meters/604 feet a.s.l

Meteorological boundary conditions may significantly affect the airflow in the tunnel and the spread of smoke in case of a fire. Current U.S. codes do not explicitly define the authoritative meteorological boundary conditions. For the APS design stage, they are estimated based on the following assumptions.

- Wind pressure on portals: 20 Pascal (Pa) from the south, 10 Pa from the north
- Barometric pressure difference: 18 Pa (10 Pa/km)
- Natural buoyancy: temperature difference inside tunnel – ambient temperature: 5 Kelvin (K)

In support of preliminary engineering, the extent of meteorological boundary conditions must be clearly defined (e.g., 90th percentile) and based on available data near the project site. The nearest weather station is Crescent City, Jack McNamara Field Airport (KCEC) NOAA weather station.

Preferably, installation of temporary weather stations with temperature and wind measurements at the foreseen tunnel portal locations should be considered to provide the most accurate meteorological data.

16.2.3. Design Fire

The emergency tunnel ventilation and fire life safety system design and operation depend on many factors. The tunnel fire scenarios are based on a design fire with established parameters, including peak heat release rate, fire growth/decay, and smoke generation rates. The design fire is based on the type of vehicles and cargos that are expected to use the tunnel now and in the future.

The preliminary design fire size proposed is 50 megawatts (MW), which corresponds to an HGV fire. During preliminary engineering, a sensitivity analysis must be completed to finalize the design fire basis that considers the type of vehicle (cars, buses, HGV, flammable liquid cargo [FLC] tankers). Based on the projected 75-year design life of the tunnel, additional considerations for fuel cell and electric vehicle (EV) fires must be considered in the final design fire determination.

The critical velocity is calculated according to the formula derived from the memorial tunnel tests (as described in the National Fire Protection Association [NFPA] 502 appendix). The fire resistance and fire buoyancy are calculated with a practical engineering approach.

16.2.4. Fire Safety Approach

Based on the list of factors outlined in NFPA 502, an engineering analysis will continue to be conducted to ensure that applicable variables have been accounted for in the overall fire safety approach. Key factors for the proposed tunnel include: tunnel users, rural facility location, traffic congestion, emergency response time and capacity, vehicle access points, prevailing wind, future vehicle use, and bidirectional and reversible traffic operation.

The preliminary fire safety concept is based on the following assumptions:

- Reliable incident/smoke detection systems installed.
- Automatic reaction of safety systems, with positive alarm sequence (tunnel operator can abort in case of false alarm).
- Intelligent Traffic Systems (ITS) to stop traffic ahead of the tunnel at both portals and empty tunnel on lanes downstream of fire. Due to the bridge at the northern portal,

traffic should be stopped ahead of the bridge.

- Smoke control by longitudinal ventilation provides tenable conditions for self-rescue and emergency service access.
- Egress of people away from the incident location towards the portals and through emergency exit doors to the egress corridor
- Access to emergency services preferably from the clean portal.
- Fire fighters must be able to operate in a smoke-filled environment with self-contained breathing apparatuses (SCBA)

Fire fighter and emergency services are expected to be dispatched from the following locations:

- From the north: Crescent City (travel time approximately 20 minutes)
- From the south: Clam Beach (travel time approximately 60 minutes); California Redwood Coast-Humboldt County Airport may support emergency medic helicopter access.

Due to the expected long response times of fire departments and emergency responders, it is important that tunnel safety systems, such as incident detection, traffic management/tunnel closure, and emergency ventilation start immediately upon confirmed fire alarm to provide tenable conditions for self-rescue.

Stakeholder meetings with the State Fire Marshal and the Redwood national and state parks will be required during the preliminary design phase. Tunnel operations schemes must be fully automatic for remote tunnel facilities.

16.3. Tunnel Ventilation Design and Operation

Based on operational experience from similar tunnels, forced or mechanical ventilation will not be required during normal operations. Natural ventilation is expected to be sufficient to ensure that allowable limits of visibility and noxious emissions from vehicles are not exceeded, more so when considering the increasing percentage of EVs projected into the future.

Therefore, the ventilation system is designed for emergency fire ventilation.

A longitudinal ventilation system with jet fans (JF) is proposed. The described operational concept is the basis of design. The ventilation design is determined by steady state pressure balance calculations for cold air density. Fire effects are considered by empirical factors.

Design requirements for the bi-directional tunnel section according to NFPA 502 are below:

> **11.2.3** In tunnels with bidirectional traffic where motorists can be on both sides of the fire site, the following objectives shall be met:
>
> (1) Smoke stratification shall not be disturbed.
> (2) Longitudinal air velocity shall be kept at low magnitudes.

Smoke flow will be driven by the moving traffic and meteorological conditions in the initial stage before the fire is detected and emergency systems are started. On confirmed detection, system priority should be the immediate start of the ventilation, together with the tunnel closure at both portals.

Since people may be exposed to smoke on both sides of the fire location, the following principles are followed to achieve the goals as described in NFPA 502.

1. Avoid flow reversal.
2. Stabilize the flow at defined flow velocity (ca. 1 – 1.5 meters/second [m/s]).
3. Do not activate fans close to the fire location to avoid disruption of the smoke layer.
4. Operate JFs as far as possible from the fire location.
5. Operate JFs preferably upstream.

Figure 14 shows smoke stratification under controlled flow conditions in a bidirectional road tunnel that is similar to LCG.

Figure 14. Smoke Stratification Under Controlled Flow Conditions in a Bidirectional Road Tunnel

16.3.1. Feedback Flow Control System

To achieve the fire ventilation goals in a bi-directional tunnel, a feedback flow control provides additional smoke control, based on accurate, reliable measurement of in-tunnel flow velocity. Careful consideration of system equipment selection during the design phase is required to ensure adequate redundancy and availability. Typical systems require at least 3 anemometers that are distributed along the length of the tunnel. The ventilation direction is determined by the measured state of flow at the moment of detection.

Jet Fans Preliminary Selection

The concept design JFs are fully reversible with symmetrical blades and with the following specifications:

- Nominal (impeller) diameter (millimeters): 125 mm/49 inches
- Motor rating (horsepower): 100 HP 480V 3phase
- Nominal thrust (Newtons): 2025 N forward/2025 N reverse
- Outer diameter (millimeters): 1500 mm
- Length (millimeters): 5200 mm
- Protection screens for intake of birds and bats

For flow control, JFs are equipped with variable frequency drives (VFD) starters.

Tunnel ventilation system design calculations will be developed in the preliminary engineering phase to determine the critical velocity required to avoid smoke backlayering. The jet fans should be sized to achieve critical velocity in the bidirectional tunnel which may be applied under specific circumstances and after the evacuation phase upon request by the State Fire Marshal. A detailed dynamic analysis is required during preliminary engineering to validate the quantity of JFs required to achieve the flow control requirement.

Figure 15 shows a typical JF installation with motor controls mounted to the ceiling within the tunnel. Provisions for maintenance and environmental protection must be considered in the design. Controllers, motors, cables, and filters must be harmonized with one another.

Figure 15. Jet Fans with In-tunnel Controllers (shown without screens)

16.3.2. Tunnel Ventilation Layout

JFs are typically placed in groups of two in the tunnel ceiling. The JFs are equipped with screens on the inlet. Power is supplied by the substations at the OMC. The minimum distance between jet fan groups and portals and obstructions, such as signal beams in the tunnel ceiling, is 250 feet.

16.4. Emergency Egress

NFPA 502 requires emergency exits from the tunnels in distances of a maximum of 1,000 feet. For that, an egress corridor beside the roadway is foreseen, which is also to be used as a service tunnel for cable ducts, pipes, equipment, and maintenance access.

Emergency exit doors into the egress corridor are foreseen in regular distances. To allow for spatial restrictions and enable reliable door opening under different pressure scenarios, sliding doors are proposed, as shown in Figure 16.

Figure 16. Tunnel Emergency Exit with Sliding Door (example with recessed door shown)

Spacing between emergency exits is proposed to be approx. 290 feet, leading to 19 emergency exit doors, providing improved means of egress than required by the code.

The egress corridor will be equipped with a separate, appropriately designed pressurization ventilation system to prevent smoke migration into the egress corridor through open doors.

16.5. Fire Protection

16.5.1. Standpipe

The fire protection standpipe will be a Class I automatic charged wet standpipe system mounted to the interior of the tunnel wall. Dual 8 inch ductile iron headers will run parallel throughout the tunnel section. Fire hose valves (FHV) to be spaced at 200 feet maximum along the entire tunnel. Fire hose valves will include automatic pressure reducing capability for safe hose operating pressures.

16.5.2. Fire Pumps and Fire Water Storage Tank

The tunnel standpipe system will be charged with dual-split case horizontal fire pumps per NFPA 20, providing system redundancy. Each pump will have a dedicated suction pipe into the water holding tank. A jockey pump will maintain pressure in the system per code.

Due to the remote location, an on-site water tank will be required to supply water for the fire standpipe system. A 70,000 gallon CIP water holding tank will be set below grade with hatch access in the pull-out area outside the North Portal. A 2-1/2 inch fill pipe will run from the water holding tank beneath the tunnel roadway to the North Portal to a secured fill valve for water trucks to fill after each system flush or fire event.

16.5.3. Construction Safety Systems

Temporary safety measures will support a safe environment for workers and mitigate the risk of fire or other dangerous conditions during construction. A temporary standpipe is required with fire department connections supplied by an approved water source and extended as construction progresses. Temporary ventilation fans are required in underground areas that provide sufficient fresh air to ensure compliant air quality and that are capable of continuous operation in accordance with an approved ventilation plan. Temporary standpipe and ventilation systems must remain in service until permanent systems are commissioned.

17. Tunnel Electrical, Control, and Communications

17.1. Electric Utility Service

Power lines are not routed along the exiting highway near the proposed tunnel. There is an existing overhead transmission line in the forested area to the east of the tunnel site. The most feasible approach appears to be a single utility service at the South Portal. Overall electrical demand for the tunnel during maximum load conditions will be 5 to 10MW. The electric utility interface and main switchgear at the South Portal will include metering per PacifiCorp requirements and 12.47kV distribution equipment.

In urban areas, this is usually provided by using two diverse electrical sources from the serving electric utility. In this case, the tunnel is located along a long radial-feed transmission line. This means that only one source is available from the utility. Therefore, local power backup must be included in the Project.

An electrical substation that is built and maintained by the electric utility will be constructed south of the South Portal, and it will provide electric service during construction and later for permanent tunnel operation.

17.2. Backup Power Supply and Generator

NFPA guidance documents for tunnels require NEC emergency power, which contains several restrictions on the system configuration, speed of switchover to backup, and system reliability. A combination approach of a generator for large loads along with UPS will be used to meet the requirements.

The generator station is comprised of two parallel generator sets, paralleling switchgear, and a step-up transformer will supply backup power for tunnel loads including fans and pumps. The generator station will be located at the South Portal in the OMC parking lot. The backup power generation systems will be supplied by a fuel source that is preliminarily sized at 10,000 gallons of diesel fuel storage.

17.3. Motor Controllers

Tunnel motor loads will include the tunnel fans, fire pumps, pumping for storm water, wastewater, potable water, and pressurization fans for spaces that lead to both tunnels. Small motor loads of less than 150 hp will be served at 480 V. If present, large motors over 150 hp may be served by 480 V or 4,160 V. While the higher voltage requires less current allowing smaller conductors, equipment can be larger and more expensive.

17.4. Tunnel Lighting

All tunnel lighting systems will utilize LED lights with automatic controls. For the tunnel transition sections, a networked lighting controller system capable of dimming the LED lights in response to ambient light conditions will be used to match portal luminance with outdoor conditions and transition drivers to the main tunnel section. The main tunnel section will have non-dimmed lighting.

LED floor guidance lights are foreseen to help drivers stay in the lane and to serve as wayfinding lighting in case of a fire, see Figure 15.

17.5. Local Control Center/SCADA

A SCADA system comprised of networked controllers will provide the backbone monitoring and control for tunnel systems, automation, and control of ITS elements. Typically, networked controllers are off-the-shelf PLCs used in the process control automation industry. Proprietary controller systems designed for tunnel operations are available and could also be considered.

CCTV, fire detection, and other systems integrated by the SCADA system will allow an operator to monitor and manually control tunnel elements if required. A remote interface with the same capabilities as the local control interface can also be implemented by adding communication to a remote operations center.

17.6. Communication Systems

At this preliminary stage, several systems are grouped under the blanket title of Communication Systems. These include:

- Data networks used for SCADA, CCTV, phones, and network controls. A set of networks run over fiber optic cable will provide communications between all tunnel facilities.
- Interface to external networks at one of the portals allows for off-site alarm delivery and monitoring.
- Emergency service radio system.

17.7. Fire Alarm System

- Fire detection and alarm system that includes both manual pull stations and fire or smoke detectors in associated facilities, and a linear heat detection cable and smoke detectors in the tunnel.
- First responder fire control/command center located at portals or maintenance facilities.

17.8. Intelligent Transportation Systems

The tunnel will include ITS elements that provide automated or remote-activated traffic control and monitoring features including the following:

- CCTV system will include automated video recording of security and fire events as well as remote visibility into the tunnel and associated facilities
- Traffic Management Controller

- Traffic speed sensors
- Variable message signs
- Lane travel indicators (red/green lights)
- Gates used to automatically close the tunnel during emergencies

18. Cost Estimate and Construction Schedule

18.1. Construction Cost Estimate

A summary of relative construction costs is provided in Appendix C. Significant time may occur between construction stages given the sensitive nature of the Project's environs. Project costs, including structure costs, should be re-evaluated and revised when the complete construction schedule is determined. Currently, the construction cost estimate, to mid-point of construction (2033), is $2.2 Billion.

18.2. Construction Schedule Summary

A construction schedule is included in Appendix D. Construction is assumed to begin with Contractor Notice to Proceed (NTP) on 1/2/2031, and it is expected to take approximately six years to complete. It assumes the contractor will excavate from both the south and north portals using SEM mining methods. In addition, the schedule assumes no seasonal restrictions on the work and that muck hauling is not restricted. These assumptions should be re-evaluated as environmental mitigation requirements are established.

18.3. Assumptions

- Base costs are in 2023 dollars.
- Escalation is based on varying rates to reflect the current inflationary cycle.
- NTP for construction issued on 1/2/2031.
- Construction schedule (NTP to substantial completion) is six years.
- SEM advance rate is 20 feet/day total, 10 feet/day for north and south headings.
- Roadways are two 12-foot-wide traffic lanes with two 10-foot-wide shoulders on both sides.
- Roadways and shoulders shall have 16 feet-6 inches height clearance.
- No seasonal restrictions on the work, and muck hauling is not significantly restricted.
- Muck disposal sites will be within 70 or 200 miles roundtrip of the site.
- Tunnels will be designed to be watertight, thus full hydrostatic loading.
- Tunnels will have a drainage system with gravity drainage to the South Portal.
- Tunnels will be constructed using SEM construction.
- Tunnel alignments are situated below or beyond detected rockslide surfaces and there are no active slides below this level.
- The tunnels traverse the EF area sufficiently below the flow slide surface to prevent any earthflow loading or displacement.

- Mean Earthquake Moment Magnitude (M) based on the 2014 United States Geological Survey (USGS) hazard deaggregation analysis for the HPGA scenario. The evaluated values for all sites are also quite close, varying from M8.65 to M8.66.
- Seismic deformations, ovaling, and racking will result in minimal to no lining damage.
- Rock conditions at the North Portal consist of the Broken Rock formation and are not an active or inactive flow slide.