Appendix C3. Tunneling Effects Assessment (Final Draft)

1. Introduction and Purpose

The purpose of this technical memorandum (TM) is to summarize the results of a preliminary settlement analysis for the Project along the Bethany Reservoir Alignment. The TM also discusses the preliminary analysis of TBM vibrations that can be expected along the tunnel alignment. The analysis involved estimating ground surface settlements along with the settlement of key infrastructure the tunnel crosses, which are reported herein. The settlement analysis is used to begin assessing the potential mitigation measures that may be needed for the existing structures, levees, utilities, and roadways resulting from the proposed tunnel excavation method. The evaluation presented in this TM for the purposes of the environmental impact report is based upon a 36-foot ID main tunnel which would be installed with at least two-tunnel diameters of cover. During final design phase, specific cover depths would be determined based upon site-specific geotechnical information and tunnel profile.

Surface settlements resulting from tunneling activities depend on the following considerations, among others:

- Geological conditions
- Tunnel excavation diameter
- Amount of groundcover
- Tunnel excavation method
- Ground support installed
- Backfill grouting of segmental lining
- Workmanship of the tunnel contractor

This TM addresses the key parameters required to estimate tunnel-induced settlement and provides preliminary settlement values at key Project locations (based solely on proposed construction activities). It does not address settlement due to liquefaction, consolidation, or other long-term considerations.

The information in this TM is based on conceptual engineering information at time of preparation. This TM considers a Project design flow capacity of 6,000 cubic feet per second (cfs). The internal diameter of the tunnel is anticipated to be36 feet as recommended in the Concept Engineering Report (CER) Appendix A2 *Hydraulic Analysis of Delta Conveyance Options.*

The elevations presented in the TM should be considered approximate. The vertical datum used for this project is the North American Vertical Datum of 1988 (NAVD 88). Once the final alignment, invert elevation (at the bottom of the tunnel), and tunnel diameter(s) are chosen, the results and discussion will require updates.

1.1 Organization

This TM is organized as follows:

- Introduction and Purpose
- Tunnel Conditions
- Settlement Approach
- Critical Settlement Analysis Locations
- Settlement Results

- Allowable Settlements
- Methods to Reduce Settlement Potential
- Vibrations Due to TBM Operations
- Sound Pressure Level Prediction at San Joaquin River Crossing
- Conclusions
- References
- Attachment 1 – Preliminary Tunnel Plan and Profiles
- Attachment 2 - Unmitigated Ground Settlement Results

2. Tunnel Conditions

2.1 Tunnel Corridor

The Delta Conveyance Project - Bethany Reservoir Alignment is presented in Figure 1. Attachment 1 provides the preliminary tunnel plan and profiles used for this TM.

2.2 Geological Conditions

Based on information provided in the *Conceptual Engineering Report* (CER) (DWR, 2018), it is anticipated that the tunnel would be excavated in saturated soft ground conditions. Based on the data previously collected within the tunnel alignment and the anticipated depth of the proposed tunnel, it is expected the soil deposits around the tunnel would consist of clays, silts, silty and clayey sands, and clean sands (DWR, 2018). The groundwater table is expected to be at depths less than 15 feet from existing ground surface. Additionally, some organic materials (primarily peat) could be encountered near the ground surface during shaft excavation. This information was based on a limited number of borings previously analyzed and would need be confirmed by future field investigations. It is expected that the geology would vary over the very long tunnel alignment.

2.3 Tunnel Excavation and Ground Support Assumptions

The settlement analysis assumes the tunnel would be excavated with a pressurized face tunnel boring machine (TBM) using either an earth pressure balance machine, a slurry shield, or a hybrid with a minimal overcut. The analysis further assumes the ground would be supported with bolted and gasketed precast concrete tunnel segments. The tunnel segments are assumed to be erected as close as possible within the tunnel tail shield, and the annular space outside the tunnel segments would be backfill grouted closely after segment erection.

3. Settlement Approach and Key Parameters

3.1 Settlement Approach

Settlement in soft ground caused by tunneling generally occurs in the form of a symmetrical trough, centered about the tunnel centerline. The settlement trough shape is approximated as an inverted Gaussian normal distribution curve (Figure 2). The total area under the curve represents the volume loss 2due to tunneling, typically expressed as a percentage of the total tunnel excavation volume.

The actual settlement along the tunnel alignment would vary and be governed by factors such as final TBM configuration, ground and groundwater conditions, depth of tunnel the operation of the TBM, and the construction methods.

Figure 1. Delta Conveyance Project- Bethany Reservoir Alignment

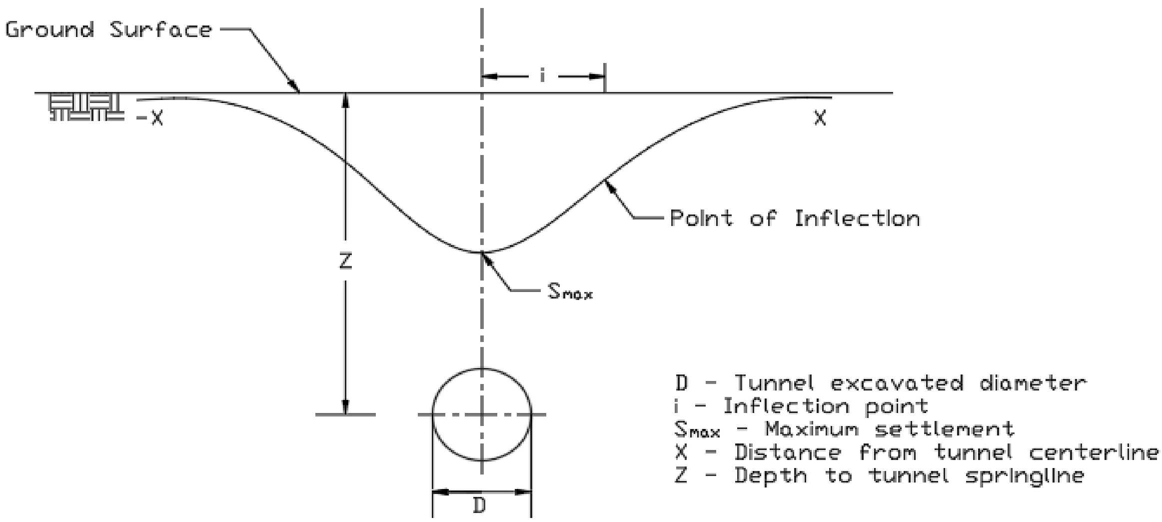


Figure 2. Generalized Settlement Trough due to Tunneling (Mair, 1998)

Along the Project Alignment, it appears that the tunnel would cross most structures and utilities in a generally perpendicular direction. Ground settlements for these utilities would take a shape similar to that shown on Figure 2. There do not appear to be significant utilities that run approximately parallel to the tunnel within the width of the settlement trough. However, there are some locations where the tunnel runs approximately parallel to canal levees. Utilities or levees that do run parallel to the tunnel alignment, would experience a settlement profile similar to what is shown on Figure 3.

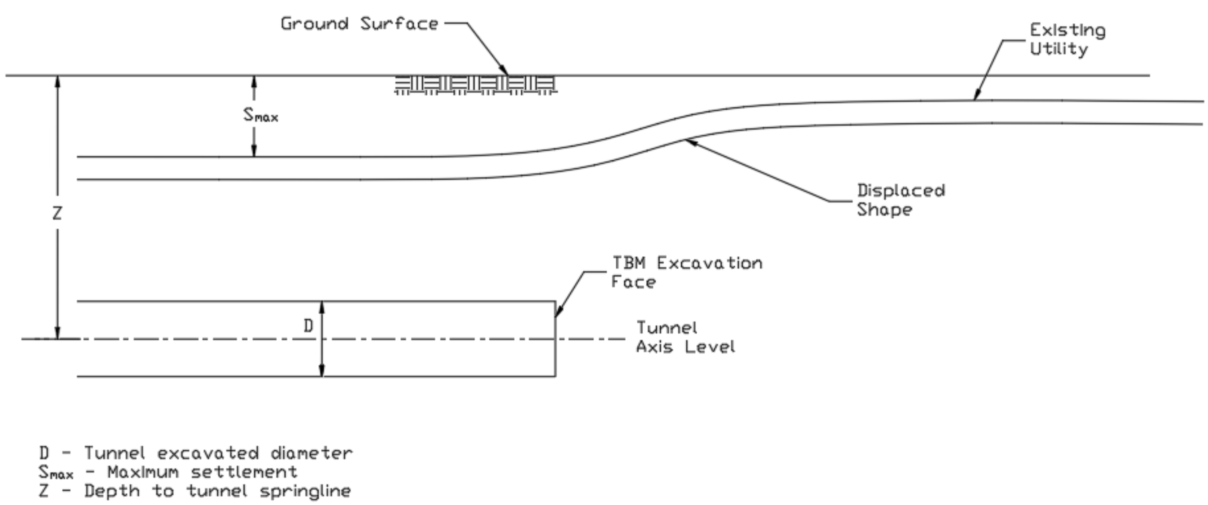


Figure 3. Settlement Trough for Utilities Parallel to the Tunnel (Mair, 1998)

3.2 Key Parameters

3.2.1 Tunnel Excavation Diameter

The excavation diameter is used, in part, to calculate the total soil volume loss that occurs during tunnel excavation. The excavated tunnel diameter is based on the tunnel's finished inside diameter, segment thickness, and overcut. The recommended inside diameter for a Project design capacity of 6,000 cfs was selected as 36-foot per the CER Appendix A2. The thickness of the segments depends on the finished inside diameter of the tunnel, as well as the structural design. To facilitate segment erection, steering tolerances and shield thickness the excavated diameter is slightly larger than the outside diameter of the precast segments. This over excavation is referred to as the overcut. A 36-foot inside diameter tunnel with an assumed segment thickness of 36 inches and an overcut of 7 inches results in an excavation diameter of 40.2 feet. Generally, all other factors remaining constant, a larger tunnel diameter would result in a larger maximum settlement value and wider settlement trough.

3.2.2 Tunnel Depth

For this preliminary settlement analysis presented in this TM, ground surface settlements were estimated for the current tunnel profile (Attachment 1), along with raising the tunnel by 10, 20, and 30 feet, respectively. Generally, as the tunnel depth decreases the maximum settlement value increases and the settlement trough width decreases.

3.2.3 Volume Loss

This settlement analysis assumes the tunnel would be excavated using a pressurized face TBM. Recent projects constructed around the world have reported volume losses between 0.15 percent and 1.5 percent for pressurized face tunnels, with most reporting volume losses between 0.25 percent and 0.5 percent (ITA, 2007). This typical range is representative of volume losses anticipated for this Project. Settlement values presented within this TM are based on a volume loss of 0.25 percent, as that value was estimated to provide the most realistic results. Settlement values for a volume loss of 0.5 percent are included in the tables presented in Attachment 2. Generally, the greater the volume loss, the larger the total settlement and the settlement trough width.

3.2.4 Trough Width Parameter

The transverse distance from the tunnel centerline to the inflection point, (i=Kz) is characterized by a trough width factor (K) and the depth to the tunnel springline (z). The trough width factor K is a function of ground type. The ranges of recommended K values are 0.2 to 0.3 for sands above the groundwater table, and 0.4 to 0.7 for hard to soft clays (O'Reilly and New, 1982). For sands below the groundwater level, the K factor ranges from 0.2 to 0.6, depending on the ratio of tunnel depth to tunnel diameter (Peck, 1969). As discussed, the ground conditions for this Project consist of layers of saturated clay, silt, silty and clayey sands, and clean sands. A trough width parameter of 0.5 was used to represent the clays. The trough width parameter for the sands below the water table was determined to be 0.5 based on the guidance provided by Peck (1969). A copy of the calculation to determine the trough width parameter for the sands is provided in Attachment 2. Typically, larger trough width parameters result in wider overall settlement troughs with lower maximum settlement values.

4. Critical Settlement Analysis Locations

Several locations along the tunnel alignment have been identified as critical related to settlement due to the presence of existing infrastructure. Settlements were estimated at locations along the tunnel alignment where the minimum and maximum tunnel depths would be encountered. The minimum tunnel depth generally results in the largest surface settlement along the tunnel alignment, while the maximum tunnel depth generally results in the widest settlement trough along the tunnel alignment.

4.1 Bethany Reservoir Alignment Tunnel

4.1.1 East Bay Municipal Utility District's Mokelumne Aqueducts

The tunnel would cross the Mokelumne Aqueducts at approximately tunnel Station 1926+00. At that location, all three aqueducts are above the ground surface and sitting on pipe saddles that are supported on piles. The piles at this location have a tip elevation of approximately -38 feet. The tunnel excavation crown at this location would be approximately Elevation -123 feet. This would result in approximately 85 feet of cover between the pile tips and the tunnel crown.

4.1.2 Stockton Deep Water Ship Canal

The tunnel would cross the Stockton Deep Water Ship Canal at approximately Station 1667+00. The bottom of the canal is at approximately Elevation -37 feet. The tunnel excavation crown would be located at approximately Elevation -120 feet. This would result in approximately 85 feet of clearance between the tunnel crown and the bottom of the canal. This separation would exceed the minimum clearance of 75 feet required by the Port of Stockton

4.1.3 Agricultural Canals

The tunnel would cross several agricultural canals. The canals consist of artificial levees, generally built up to between Elevation 10 feet and Elevation 20 feet with water flowing within the levees. The levees are constructed with fill material placed on the existing ground surface. The critical component of the canals are the foundations for the levees, which are assumed to be located at the surrounding ground level. Generally, the ground level around the levees is at approximately Elevation -10 feet. This would result in approximately 128 feet of cover between the tunnel springline and the levee foundations.

Between Lower Roberts Island and the BRPP, the tunnel would cross underneath several canals, including the West Canal and Victoria Canal\North Canal. The Victoria Canal\North Canal, at approximately Station 2170+00, has the least amount of ground cover. The ground level adjacent to this canal is at approximately Elevation -8 feet and this would result in approximately 134 feet of cover between the tunnel springline and the foundation.

4.1.4 Railroad Lines

4.1.5 Roadways

The tunnel would cross under two key well-traveled roadways: State Routes 4 and 12. The two roadways are supported on compacted native material. Table 1 summarizes the tunnel crossing beneath the roadways.

Table 1. Tunnel Roadway Crossings Summary

Roadway	Approximate Tunnel Station	Approximate Tunnel Crown Elevation	Approximate Ground Surface Elevation	Approximate Depth to Springline (ft)
State Route 4	2115+00	-125	-10	135
State Route 12	1220+00	-115	0	135

Note:

ft = foot (feet)

4.1.6 Natural Gas Pipelines

The tunnel would be located within an area of natural gas fields with hundreds of active and inactive wells. Currently, it is not anticipated that the tunnel will pass near any active wells where the surface equipment would be impacted by settlement. The gas lines are assumed to be near the surface, with invert depths of less than 10 feet and pipe diameters less than 24 inches. The tunnel excavation crown elevation near the gas lines would be approximately Elevation -115 feet. The cover between the tunnel springline and the bottom of the pipe would be approximately 125 feet.

4.1.7 Overhead High-voltage Electrical Transmission Line

The tunnel would cross multiple lines north of the Mokelumne River. The pole foundation types and depths are not known at this time; nor are the specific pole locations relative to the tunnel. For this TM, it was conservatively assumed that the towers are located along the tunnel centerline and supported on deep foundations extending 50 feet below grade. The ground surface elevation in these ranges varies between approximately Elevation 0 feet and 10 feet. Therefore, it is assumed that the base of the deep foundations is at Elevation -50 feet. The tunnel excavation crown would be located at approximately Elevation -112 feet; therefore, there would be approximately 82 feet of soil between the tunnel springline and the base of the foundation.

The tunnel would also cross a high-voltage electrical transmission line near Station 2380+20 just east of the CCF. The foundation type and depth are not known now, nor are the specific locations relative to the tunnel corridor. For this TM, it was conservatively assumed that the towers are located adjacent to the tunnel and supported on deep foundations extending 50 feet below ground surface. The ground surface elevation in this area is approximately Elevation 0 feet. Therefore, based on this assumption it is calculated that the base of the deep foundations is at Elevation -50 feet. The tunnel excavation crown would be located at approximately Elevation -125 feet; therefore, there would be approximately 95 feet of soil between the tunnel springline and the base of the foundation.

These settlement data are based on limited geotechnical information and conceptual engineering-level data. In addition, an allowable settlement criterion would need to be established for each structure identified. Also, if the calculated maximum settlements are not acceptable for a given structure/feature, then mitigation measures will be taken in advance of tunneling to reduce such settlements to acceptable levels.

4.1.8 Jones Penstocks Tunnel Crossing

The current plans show the tunnel underneath the Jones Penstocks with a ground cover of approximately of 20 feet. Based on the expected ground and groundwater conditions and excavation method, structure protection measures would need to be implemented to reduce potential impacts to the penstocks. In addition to instrumentation and monitoring, it is envisaged that ground improvement combined with under pinning could be required to protect the penstocks while the tunnels are being excavated. The response of the penstocks should be evaluated in subsequent design phases using numerical methods to determine the extent of the protective measures deemed necessary. As-built drawings and material properties for the penstocks, along with results from future geotechnical investigations, would also be needed to perform a detailed evaluation of this crossing.

4.1.9 Other Key Project Locations

Another consideration would be for the tunnel alignment near irrigation canals.

- The shallowest depth of cover over the tunnel crown outside of irrigation canals would be located at Station 930+00. At this location, the depth of cover would be approximately 125 feet to the tunnel springline. This location could represent the maximum settlement for near-surface utilities.

5. Settlement Results

This section presents the settlement results for the Project without any efforts to reduce the settlement potential. The results represent the maximum anticipated settlement values. Actual settlement values could be significantly less than those presented with implementation with good construction practices and ground improvement if required.

The tables provided do not include all parameter combinations. The values presented in the following table are based on a volume loss between 0.25 and 0.50 percent. Note, the calculated settlement trough widths do not include ground surface settlements less than 1/8-inch. Attachment 2 provides the complete results.

5.1 Bethany Reservoir Alignment

Tables 2 and 3 summarize the settlement results for the Bethany Reservoir Alignment tunnel. Table 2 shows the variability in the settlement and trough width for an 18-foot finished inside radius, while Table 3 shows the same for the multiple tunnel depths considered.

Table 2. Maximum Settlement for 18-foot Finished Inside Radius Tunnel Along Project

Existing Infrastructure and Tunnel Location[a]	Volume Loss (percent)	Depth to Springline[a] (ft)	Maximum Settlement (in)	Settlement Trough Width (ft)
EBMUD Mokelumne Aqueducts (Station 1926+00)	0.25	79.92	0.38	119.3
Stockton Deep Water Ship Canal (Station 1667+00)	0.25	104.92	0.29	136.1
Agricultural Canals (Multiple locations)	0.25	127.92	0.24	145.0
State Route 4 (Station 2115+00)	0.25	134.92	0.22	146.4
State Route 12 (Station 1220+00)	0.25	134.92	0.22	146.4
Victoria Canal\North Canal (Station 2170+00)	0.25	134	0.22	144

Existing Infrastructure and Tunnel Location[a]	Volume Loss (percent)	Depth to Springline[a] (ft)	Maximum Settlement (in)	Settlement Trough Width (ft)
Victoria Canal\North Canal (Station 2170+00)	0.50	134	0.44	213
Electrical Trans. Lines (Station 2380+20)	0.25	95	0.31	129
Electrical Trans. Lines (Station 2380+20)	0.50	95	0.63	171
Shallowest Depth of Cover (Station 930+00)	0.25	124.92	0.24	144.2

[a] Stations and tunnel springline depths are approximate. Depth to springline is fixed for each tunnel size.
Notes:
N/A indicates maximum settlements less than 1/8th of an inch which was used as the cutoff for settlement trough width
EBMUD = East Bay Municipal Utilities District
ft = foot (feet)
in = inch(es)

Table 3. Maximum Settlement for Different Tunnel Depths Along Bethany Reservoir Alignment

Existing Infrastructure and Tunnel Location[a]	Radius[a] (ft)	Depth to Springline[b] (ft)	Maximum Settlement (in)	Settlement Trough Width (ft)
EBMUD Mokelumne Aqueducts (Station 1926+00)	18	79.92	0.38	119.3
		69.92	0.43	110.5
		59.92	0.51	100.5
		49.92	0.61	89.0
Stockton Deep Water Ship Canal (Station 1667+00)	18	104.92	0.29	136.1
		94.92	0.32	130.3
		84.92	0.36	123.3
		74.92	0.40	115.1
`Agricultural Canals (Multiple locations)	18	127.92	0.24	145.0
		117.92	0.26	141.9
		107.92	0.28	137.6
		97.92	0.31	132.1

Existing Infrastructure and Tunnel Location[a]	Radius[a] (ft)	Depth to Springline[b] (ft)	Maximum Settlement (in)	Settlement Trough Width (ft)
State Route 4 (Station 2115+00)	18	134.92	0.22	146.4
		124.92	0.24	144.2
		114.92	0.26	140.7
		104.92	0.29	136.1
State Route 12 (Station 1220+00)	18	134.92	0.22	146.4
		124.92	0.24	144.2
		114.92	0.26	140.7
		104.92	0.29	136.1
Shallowest Depth of Cover (Station 930+00)	18	124.92	0.24	144.2
		114.92	0.26	140.7
		104.92	0.29	136.1
		94.92	0.32	130.3

[a] Radius shown are finished internal radii
[b] Stations and tunnel springline depths are approximate
Notes:
EBMUD = East Bay Municipal Utilities District
ft = foot (feet)
in = inch(es)

Settlement for the 36-foot diameter tunnel, as shown in Table 3, would range from 0.22 to 0.43 inches at the current depth. Settlement results for the 36-foot diameter tunnel would range from 0.29 to 0.61 inches if the tunnel depth was raised by 30 feet.

6. Allowable Settlements

The preliminary assessment includes the estimates of free-field settlements caused by the underground construction. The purpose of this preliminary analysis is to evaluate anticipated ground movements so that potential construction methods could be identified to minimize settlement. In this preliminary assessment, limits of the trough width are established, and any structures located outside this zone require no further future assessment. The stages that follow are usually structure-specific and would be performed in future when site specific geotechnical information becomes available and the maximum settlement criteria that would be acceptable by the owners of the various structures/features in question.

7. Methods to Reduce Settlement Potential

7.1 Settlement Monitoring

During construction, a robust settlement monitoring program should be developed to monitor ground movements as the tunnel advances. The information gained during the initial stages of this monitoring program could be used to refine TBM operational techniques, as well as future settlement predictions. The settlement monitoring program would likely consist of some combination of the following instruments.

- **Ground monitoring points** – Settlement monitoring point installed in the ground to detect ground movement. These can be located above utilities at shallow depths, directly adjacent to utilities and installed near the utility invert elevation, or at the foundation level of key infrastructure. Ground monitoring points typically consist of placing a steel rod inside a drilled hole that is cased and grouted. The steel rod is then monitored for movement. The spacing and frequency of these monitoring points typically depend on the ground conditions, and the surface and near-surface features.
- **Utility monitoring points** – Settlement monitoring point that is placed directly on top of a utility to specifically monitor movement in an individual utility. These monitoring points typically are similar to the ground monitoring points. For utilities running perpendicular to the tunnel, utility monitoring points can be placed across the utility at defined intervals within the anticipated settlement trough width to determine the extent of movement that occurred across the utility. Utilities that run perpendicular to the tunnel often have monitoring points spaced equally along the utility, as long as it is within the anticipated tunnel settlement trough. The actual spacing of utility monitoring points would depend on the existing condition of the utility, the importance of the utility, the estimated settlement, and the availability of surface access.
- **Extensometers** – Settlement monitoring anchor that measures displacement continuously via a reference head located at the ground surface. Extensometers are typically installed within a drilled hole and grouted in-place. Multiple extensometers can be installed within a borehole to measure displacements at multiple elevations.
- **Structure monitoring points** – Monitoring points can be placed directly on aboveground infrastructure to monitor them for movement. These monitoring points can be as simple as survey targets that are surveyed using traditional surveying techniques to liquid-leveling sensors that are strung along a structure that continually monitor and report movement. For this Project, it is anticipated that, at a minimum, the EBMUD Mokelumne Aqueducts, rail lines, and overhead transmission power lines would require structure monitoring points.

In addition to the settlement monitoring techniques described, the TBM and trailing gear can be designed to alert the operator when the conditions for ground settlement are occurring. For example, scales or lasers can be used to monitor the volume of material being removed by the conveyor belt on the TBM. If over excavation were to occur, a likely indication of future settlement, the operator would be notified and TBM performance could be altered. Regardless of the settlement monitoring means, the settlement monitoring data should be continuously monitored during construction, and TBM operations modified should unanticipated settlements occur.

7.2 Ground Improvement

Should unacceptable settlements of any utilities or structures be anticipated, the settlement risk could be reduced prior to tunnel excavation. There are several different methods that can be used to either reduce the potential settlement of a utility/structure or reduce the potential impact settlement would have on the utility. The final selection of the best options for each location will be determined following additional geotechnical investigations.

For this Project, the number of utilities and structures that the tunnel crosses are limited and widely spaced. As a result, the settlement of utilities along the tunnel could be reduced, if required, by grouting the ground between the tunnel crown and the invert of the utility and foundation before tunnel excavation and sometimes after tunneling if the actual ground losses are deemed to be excessive despite all efforts to minimize ground loss. Grouting effectively reduces settlement by strengthening the ground so the soil can support higher loads before deforming and by reducing the likelihood of over-excavation, which can lead to settlement. The following grouting methods are anticipated to be feasible for this Project:

- Jet grouting
- Compaction grouting
- Permeation grouting
- Compensation grouting

Jet grouting involves injecting grout into the ground under high pressure. Once the hole is drilled, the grout, which is typically cementitious, is injected in a circular motion as the drill string is slowly raised. The grout erodes and mixes in with the soil, creating a column of strengthened ground. Jet grouting is more effective in granular soils, because they are more erodible than cohesive soils.

Compaction grouting densifies the soil by injecting a stiff grout into the ground to compact and displace the existing soil. Compaction grout is injected under high pressure in a vertical or inclined hole, to create a spherical of compacted soil around the hole. Compaction grouting is typically performed in fine-grained soils with cementitious grouts.

Permeation grouting works by filling the pore space in granular soils with grout to create a strengthened soil mass. Therefore, it does not work well in soils with a large percentage of fine material. Using this method, the grout is injected at lower pressures to not disturb the soil. This method works well with both cementitious and chemical grouts.

Compensation grouting requires injecting cementitious grout under high pressures to create fractures in the soil matrix, which are filled with grout. The grout compacts the soil surrounding the fracture creating strengthened seams of soil. The grout injection locations are controlled by injecting the grout through sleeve port pipes. Compensation grouting is commonly used to mitigate settlements that have occurred since the ground heaves when the fractures are opened allowing infrastructure to be re-leveled. The primary advantage of compensation grouting is that it can be performed in almost any soil condition.

7.3 Utility Relocation and Rehabilitation

If a utility within the tunnel settlement trough can be relocated outside of the settlement trough, that is likely the easiest and most cost-effective method to reduce potential settlement. However, this is not always possible due to existing surface and near-surface features and the utility alignment.

Existing utilities that are susceptible to damage from settlement can be relined with a material that will allow greater movement. This is often performed on utilities that are deteriorating or were originally constructed of materials, such as brick or cast-iron, which do not allow much deflection before cracking or failing. There are multiple materials and techniques that can be used to re-line utilities. However, all methods reduce the effective of the pipeline cross section, thus potentially reducing its capacity.

8. Vibrations Due to TBM Operations

Ground vibrations are primarily a function of the excavation method and geologic conditions. Vibrations generated by TBM excavation are typically extremely low and rarely cause damage to surface structures. The peak particle velocity produced is a commonly used parameter to measure the potential risk for building damage from construction activities such as TBM operations. Typically, vibrations exceeding about 0.02 to 0.03 inches per second were found to be noticeable and potentially disturbing (Oriard, 1972). Previous studies indicate that humans can detect steady state vibrations as low as about 0.01 inches per second in terms of peak particle velocity (Flanagan, 1993; Siskind, D.E., et al., 1980).

For the conceptual design effort, an evaluation of the vibration was made based on attenuation curves developed for variety of types of construction equipment, as shown on Figure 4. One of the curves show the relationship between peak particle velocity and resultant distance from the TBM (soil). Based on the current tunnel profiles shown on the drawings a minimum ground cover of 110 feet (33.5 m) can be expected along the main tunnel alignment for the central and eastern alternatives. Based on the current minimum ground cover a peak particle velocity of 0.003 inches per second (0.07 mm/s) can be expected. Assuming that humans can detect vibrations equal to or greater than 0.01 inches per second, it appears unlikely there will be that noticeable vibrations will be generated along the main tunnel alignment. Further evaluations of the vibrations will be made during final design.

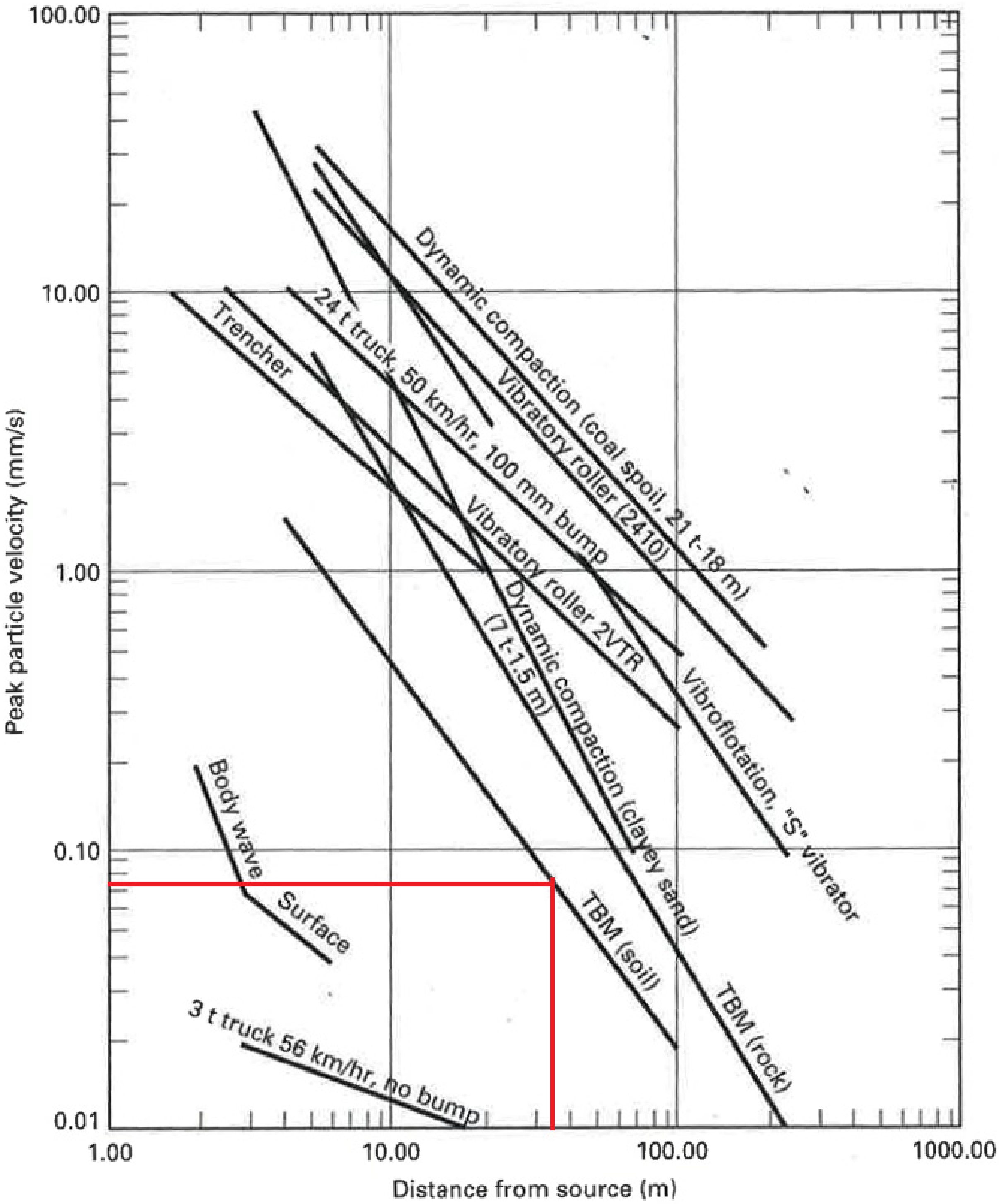


Figure 4. Attenuation of Peak Particle Velocity with Distance from Source for Variety of Construction Equipment (Dowding, 1996).

9. Sound Pressure Level Prediction at San Joaquin River Crossing

The groundborne vibration (GBV) in soil and sound pressure level (SPL) in water due to the operation of a tunnel boring machine (TBM) for the Project were predicted at the San Joaquin River crossing. The factors which influence the generation and propagation of groundborne vibration from TBMs are primarily the amount of energy required to cut the soil and the propagation characteristics of the soil. Rotational speed, cutter head type and face pressure have a much smaller effect. The energy requirement is a function of the tunnel diameter and the operating characteristics of the machine.

The prediction of groundborne vibration from TBMs begins with measured field data obtained on other TBM projects. For this evaluation, a recent California tunneling project, the Los Angeles (LA) Metro Red Line Section 2 (HMMH, 1993) was used in the computations for predicting the GBV and SPL. The geotechnical conditions at the Project tunnel depth are expected to consist of saturated soils comprising of clays, silts, silty and clayey sands, and clean sands based on the data previously collected and are similar to the LA Metro Red Line Section 2 ground conditions. A 21-foot shielded TBM was used to excavate the LA Metro Red Line tunnels and due to the smaller diameter, a correction factor was applied to account for the larger 40-foot diameter TBM that would be used on the Project. The LA Metro Red Line Tunnels were excavated 43 feet below ground surface at the location where the vibration measurements were recorded compared 68 feet below the analysis point for the San Joaquin River Crossing.

To predict TBM induced vibration levels, the 1993 LA Metro Red Line measured TBM reference levels at a known distance were extrapolated using the 2011/2016 measured attenuation profiles from borehole vibration propagation test performed in the area of the Westside Purple Line Extension- Section 3 tunnel alignment. Six borehole measurements performed by ATS Consulting in 2011 and 2016 (ATS Consulting 2011, 2016) were utilized to determine the effective attenuation rates of propagating waves along the alignment. The borehole vibration propagation tests followed the Detailed Assessment approach recommended in the Federal Transit Administration (FTA) guidance manual (FTA, 2018). The relationship shown below (WSP, 2020) was used to make the predictions for the RMS vibration velocity L_v at the bottom of the San Joaquin River Channel.

$$L_v = L_{vo} + \text{alpha x} \log_{10} (R/R_o) \qquad \textbf{[1]}$$

Where:

L_v	=	Predicted vibration level at the bottom of the San Joaquin River Channel
L_{vo}	=	1993 measured reference RMS velocity in dB re: 1 micro-inch/sec.
R_o	=	Source to vibration sensor distance for L_{vo} in feet
R	=	Source to receiver distance for predicted level L_v in feet
alpha x log10 (R/R_o)	=	2011/2016 measured composite attenuation rate

Underwater sound pressure levels (SPL) often are expressed in decibels (dB). The decibel is used for many different engineering applications, and it is commonly used to describe the magnitude of a sound pressure. It is a convenient way of expressing sound pressure level because the sound pressure is typically a result of a very wide range of pressures. The relationship shown below (Caltrans, 2020) was used to make the prediction for the SPL in water at the bottom of the San Joaquin River Channel.

$$SPL_{water} = SPL_{air} + 26 \text{ dB} \qquad \textbf{[2]}$$

The SPL predicted at the San Joaquin River Crossing is summarized below.

Top of Tunnel to River Channel Bottom	68 feet
Sound Pressure Level (SPL) in Soil	72 dB
Adjustment for 20 to 40-foot diameter TBM	6 dB
Adjusted Sound Pressure Level in Soil	78 dB
Caltrans Conversion from soil SPL to water SPL	26 dB
Adjusted SPL in Water	104 dB

10. Conclusion

The data presented in this TM are based on limited geotechnical information and conceptual engineering-level data. Once invert elevations are established and site-specific geotechnical conditions are determined at the key Project locations, this information will be updated to reflect ground conditions encountered during the geotechnical investigation program.

In a few locations, specific methods to reduce settlement potential are anticipated to be required, especially at the EBMUD Mokelumne Aqueducts crossing locations on the Bethany Reservoir Alignment.

An allowable settlement criterion would be established for each utility along the tunnel alignment, in partnership with the utility owner.

A Project-specific instrumentation monitoring program would be developed, considering the requirements of all the Project participants, the public, and third parties. The monitoring program would be used during construction to monitor the performance of the construction and adjust TBM operations to limit settlement.

Estimated sound pressure level in the water at the bottom of the river channel is not expected to exceed a SPL of 110 dB. The analysis should be revisited once more detailed geotechnical information becomes available at the San Joaquin River Crossing.

11. References

ATS Consulting, June 2011. Results of Borehole Vibration Propagation Test for Los Angeles Metro Westside Subway Extension.

ATS Consulting, July 2016. Los Angeles Metro Groundborne Vibration Assessment between Century Park West and Wilshire Boulevard.

California Department of Water Resources (DWR). 2018. Conceptual Engineering Report California WaterFix Byron Tract Forebay Option (WaterFix BTO).

The California Department of Transportation (Caltrans). 2020.Technical Guidance for the Assessment of Hydroacoustic Effects of Pile Driving on Fish.

Dowding, C.H. 2000. Construction Vibrations 2nd Edition, December 2000, pp.249.

East Bay Municipal Utility District (EBMUD). 1966. First, Second & Third Mokelumne Aqueducts Profile and Alignment STA 2130+00 to STA 2564+00.

East Bay Municipal Utility District (EBMUD). Undated. Third Mokelumne Aqueduct Mortar Lined & Coated Steel Pipe Above Ground Soil Boring Data, Pile Penetrations, & Location of Pipeline Supports Station P-2480+00 to P-2600+00.

Federal Transit Administration (FTA), September 2018. Transit Noise and Vibration Impact Assessment Manual.

Flanagan. 1993. Ground Vibrations from TBMs and Shields. Tunnels and Tunneling. October 1993, pp. 30-33.

Harris Miller Miller & Hanson (HMMH). 1993. Vibration from Los Angeles Metro Rail Tunneling Operations, HMMH Report No. 292330.

International Tunneling Association (ITA). 2007. "ITA/AITES Report 2006 on Settlements induced by tunneling in Soft Ground." Tunnelling and Underground Space Technology. Vol 22. Accessed April 27, 2020. https://about.ita-aites.org/publications/search-for-a-publication

Mair, R.J. 1998. Geotechnical Aspects of Design Criteria for Bored Tunnelling in Soft Ground.

O'Reilly, Myles and New, Barry. 1982. Settlements above tunnels in the United Kingdom – their magnitude and prediction. Institution of Mining and Metallurgy. Reprinted in May 2015 Tunnels and Tunnelling. Accessed June 16, 2020. http://www.tunnelsonline.info/news/settlements-above-tunnels-in-the-united-kingdom-their-magnitude-and-prediction-6733559.

Oriard, L.L. 1972. Blasting Operations in the Urban Environment. Bulletin of the Association of Engineering Geologists, Vol. IX, No. 1, pp. 27-46.

Siskind, D.E., et al. 1980. Structure Response and Damage Produced by Ground Vibration for Surface Mine Blasting. Report of Investigations 8507, U.S. Department of Interior, Bureau of Mines. Washington, D.C.

Watercare Services Limited. 2018. Settlement Assessment of Grey Lynn Tunnel and Mawariki Street Shafts (Draft Revision No. 3).

WSP. 2020. Los Angeles Metro Westside Purple Line Extension Section 3 - Underground Construction Vibration Assessment.

Attachment 1
Preliminary Tunnel Plan and Profiles

PLAN

1"=7000'

GENNERAL TUNNEL NOTES:

1. SITE PLAN FOR AQUEDUCT SECTION FROM BETHANY RESERVOIR PUMPING PLANT TO THE BETHANY RESERVOIR NOT SHOWN. SEE BETHANY RESERVOIR AQUEDUCT DRAWINGS FOR DETAILS.
2. ALL ELEVATIONS ARE FROM THE USGS NATIONAL ELEVATION DATASET (NED) AND ARE SUBJECT TO CHANGE BASED ON PROJECT SPECIFIC SURVEYS AND DATUM SELECTION.

TUNNELS AND SHAFTS

VERIFY SCALE
BAR IS ONE INCH ON ORIGINAL DRAWING.
0 1"

REV	DATE	DESCRIPTION	SUB.	APPD
	SEP 2024	DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT		

DESIGNED: M ELLIS
DRAWN: A O'DONNELL
CHECKED: S DUBNEWYCH
APPROVAL RECOMMENDED:
APPROVAL BY: A MURDOCK

CONCEPT PLANNING DOCUMENT

NOT FOR CONSTRUCTION

DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

Figure 1

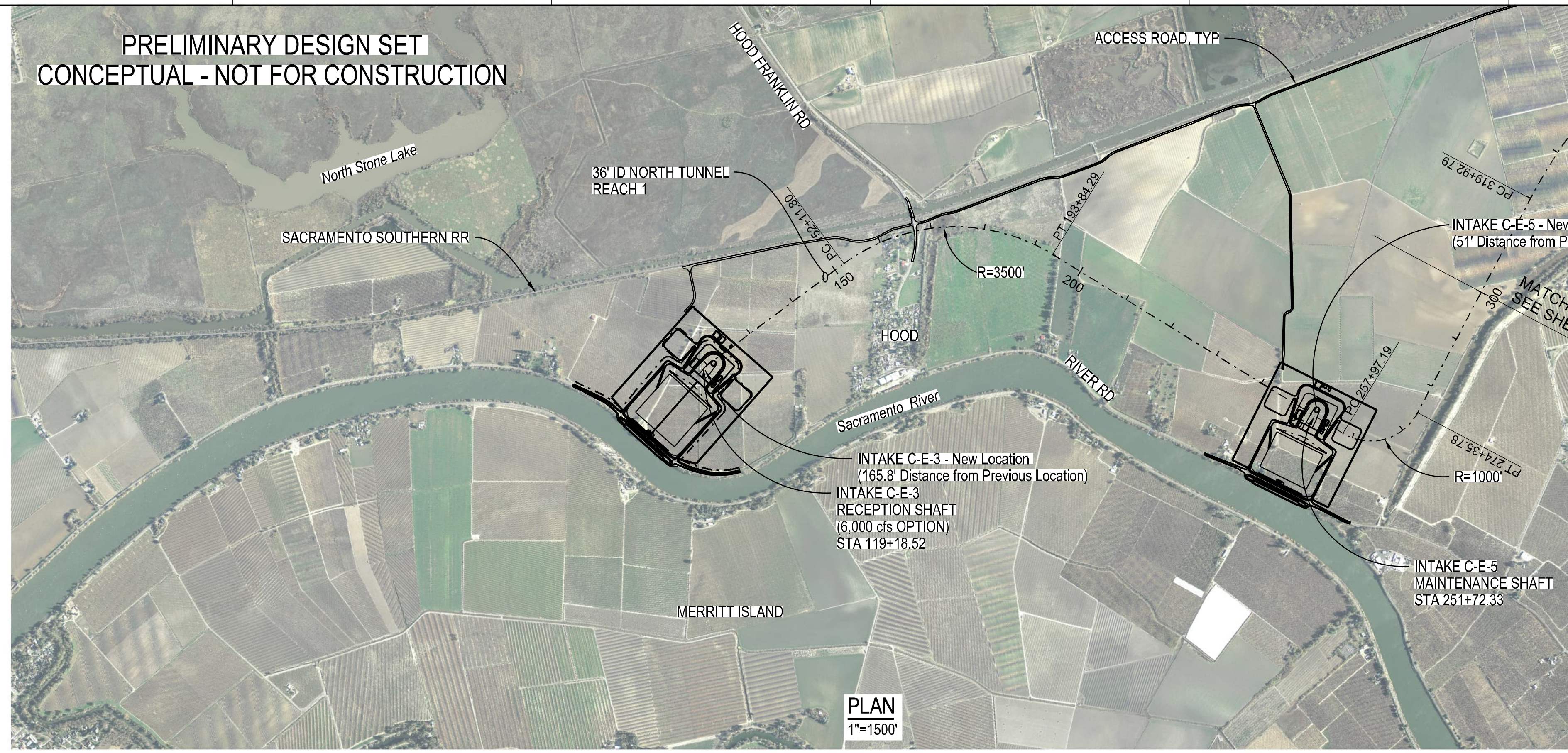
DELTA CONVEYANCE PROJECT
CONCEPT ENGINEERING REPORT

OVERALL SITE MAP

PROJECT NO. W8X97000
SHEET NO. PPE-G-0010TN
REV
SEQUENCE NO. 49

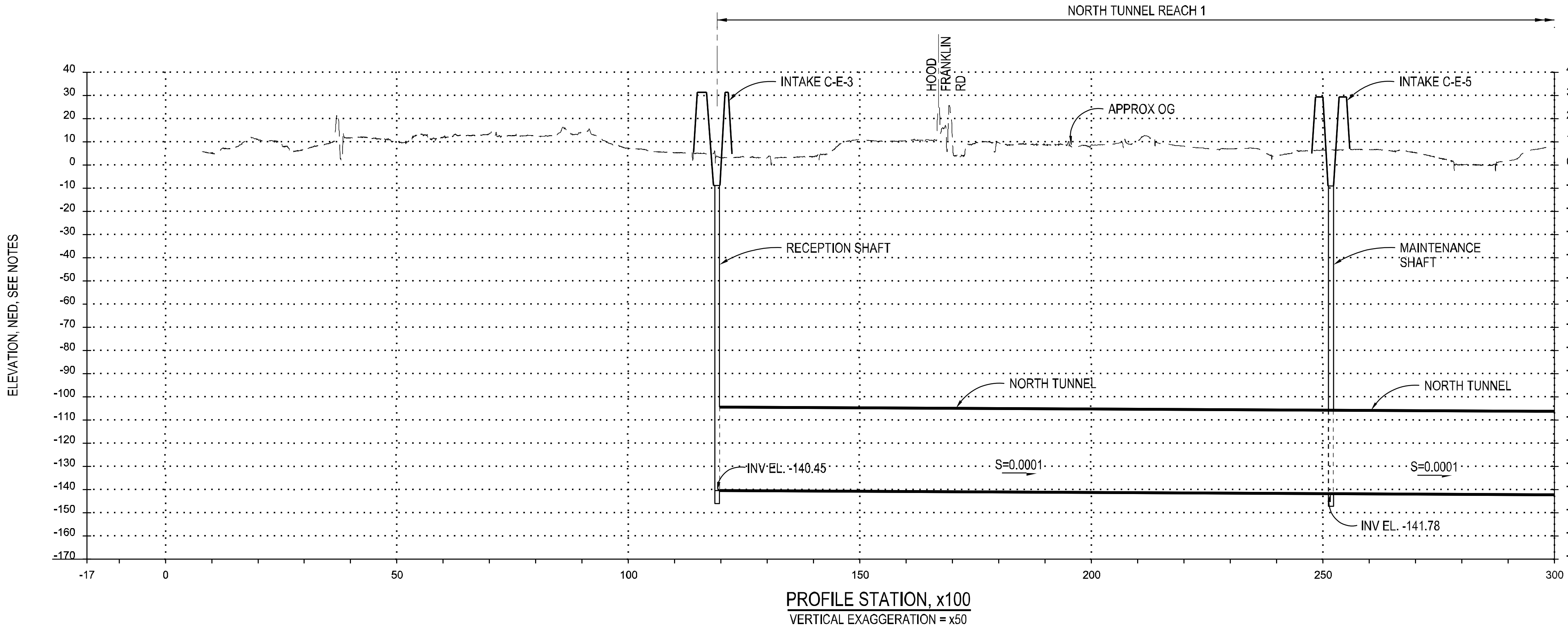
PPE-G-0010TN_W8X97000.dgn

PLOT DATE:9/27/2024 PLOT TIME:2:08:14 PM



NOTES:

1. ALT 36' ID TUNNEL SHOWN FOR 6,000 cfs.
2. TOPOGRAPHY DATA IS BASED ON USGS NATIONAL ELEVATION DATASET (NED). DATA IS FOR CONCEPTUAL USE ONLY.
3. SEE SHAFT SITE PLANS FOR DISTURBANCE LIMITS.



TUNNELS AND SHAFTS

VERIFY SCALE
BAR IS ONE INCH ON ORIGINAL DRAWING.
0 1"

DESIGNED	APPROVAL RECOMMENDED
M ELLIS	
DRAWN: R WYNN	APPROVAL BY: A MURDOCK
CHECKED: S DUBNEWYCH	

REV	DATE	DESCRIPTION	SUB.	APPD
	SEP 2024	DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT		

CONCEPT PLANNING DOCUMENT

NOT FOR CONSTRUCTION

DCA
DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

Figure 2 DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT

NORTH TUNNEL
PLAN AND PROFILE - SHEET 1 OF 2

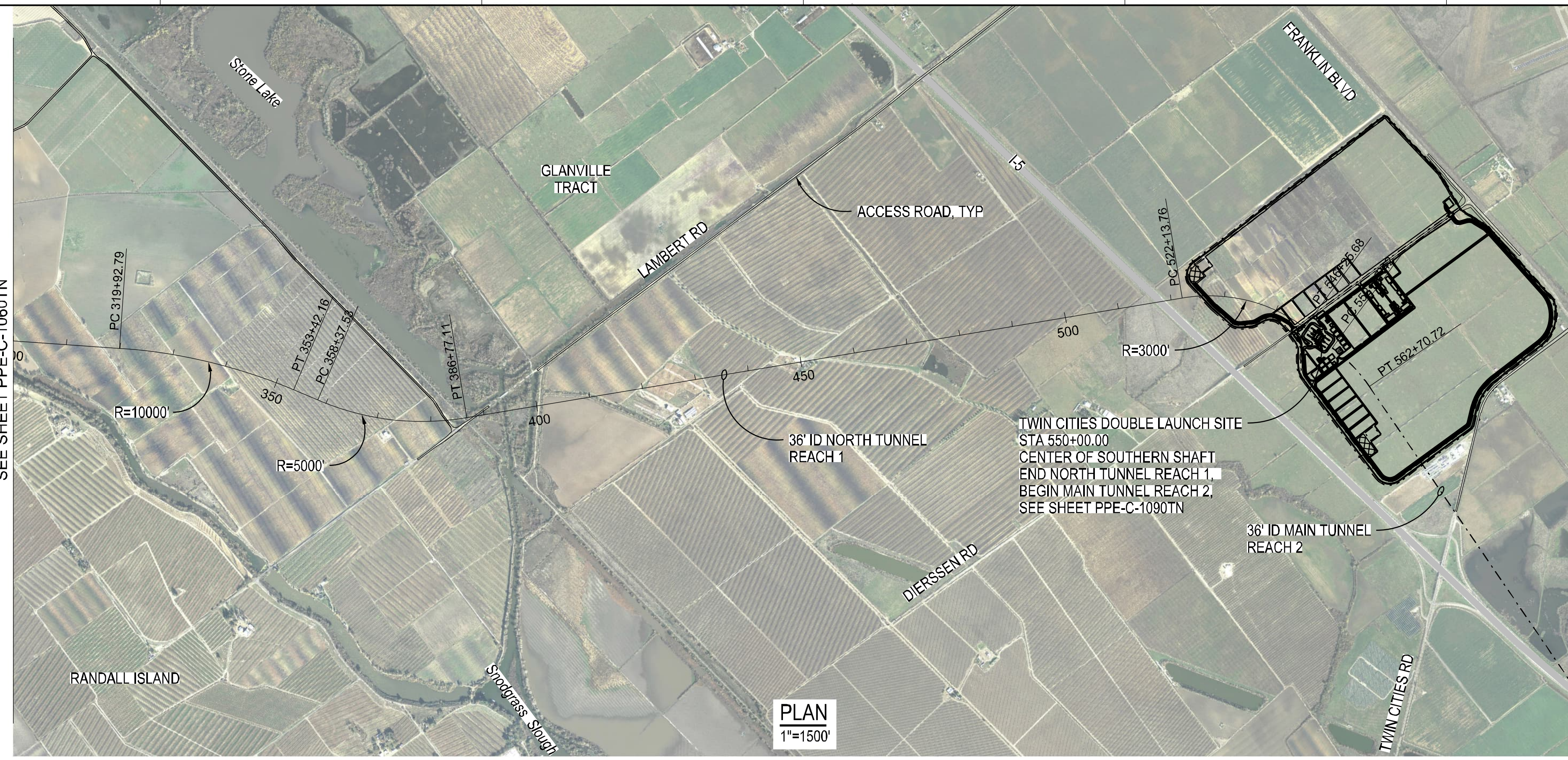
PROJECT NO. W8X97000
SHEET NO. PPE-C-1060TN
REV | SEQUENCE NO. 50

PPE-C-1060TN_W8X97000.dgn

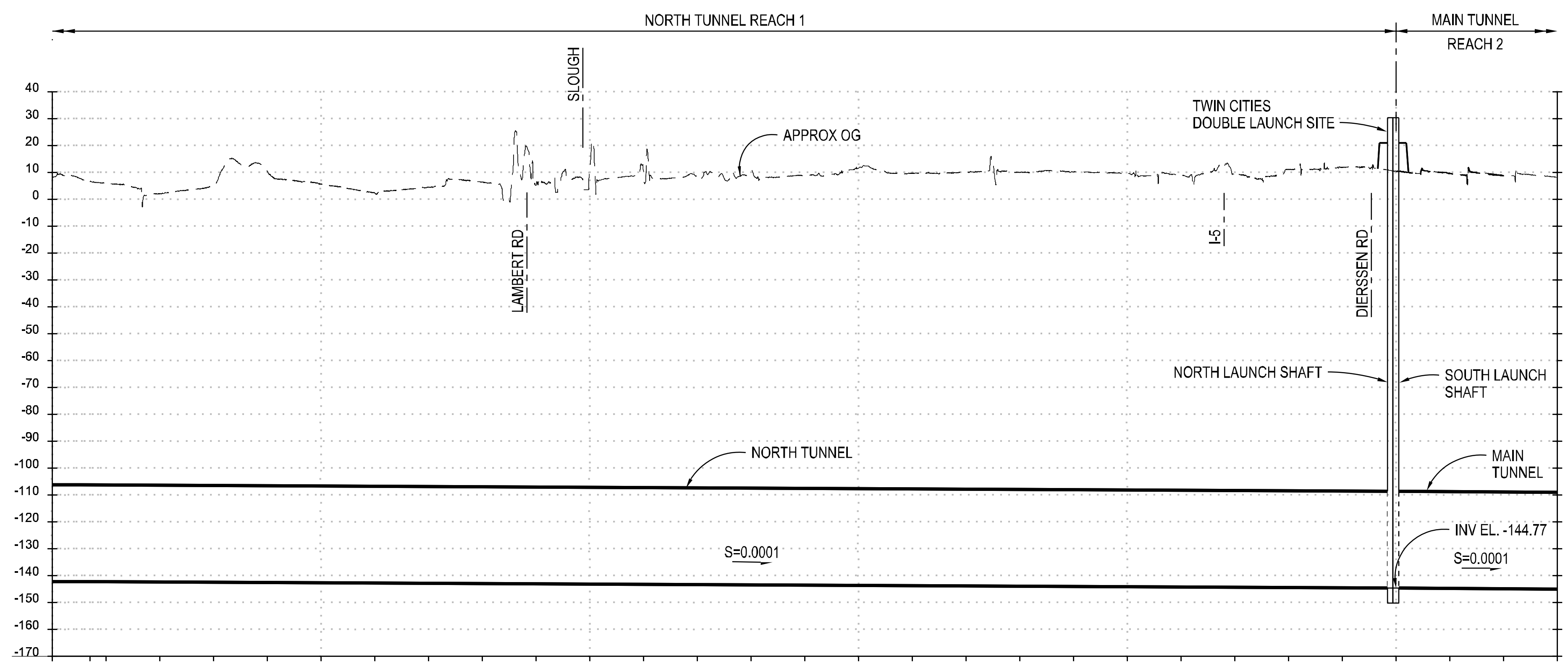
PLOT DATE:9/27/2024 PLOT TIME:2:10:18 PM

A B C D E F G H

0 1500 3000
SCALE IN FEET



PLAN
1"=1500'



PROFILE STATION, x100
VERTICAL EXAGGERATION = x50

NOTES:

1. ALT 36' ID TUNNEL SHOWN FOR 6,000 cfs.
2. TOPOGRAPHY DATA IS BASED ON USGS NATIONAL ELEVATION DATASET (NED). DATA IS FOR CONCEPTUAL USE ONLY.
3. SEE SHAFT SITE PLANS FOR DISTURBANCE LIMITS.

TUNNELS AND SHAFTS

VERIFY SCALE
BAR IS ONE INCH ON ORIGINAL DRAWING.
0 1"

REV	DATE	DESCRIPTION	SUB.	APPD
	SEP 2024	DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT		

DESIGNED: M ELLIS
DRAWN: R WYNN
CHECKED: S DUBNEWYCH
APPROVAL RECOMMENDED:
APPROVAL BY: A MURDOCK

CONCEPT PLANNING DOCUMENT

NOT FOR CONSTRUCTION

DCA
DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

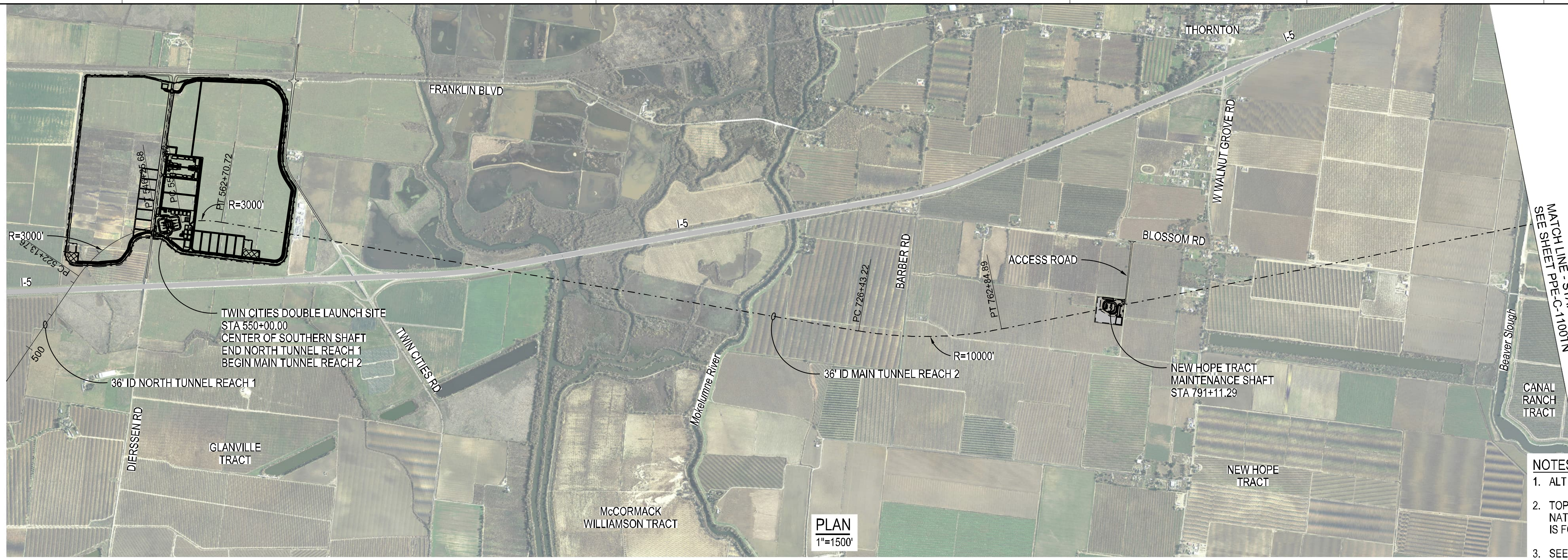
Figure 3
DELTA CONVEYANCE PROJECT
CONCEPT ENGINEERING REPORT

NORTH TUNNEL
PLAN AND PROFILE - SHEET 2 OF 2

PROJECT NO. W8X97000
SHEET NO. PPE-C-1070TN
REV
SEQUENCE NO. 51

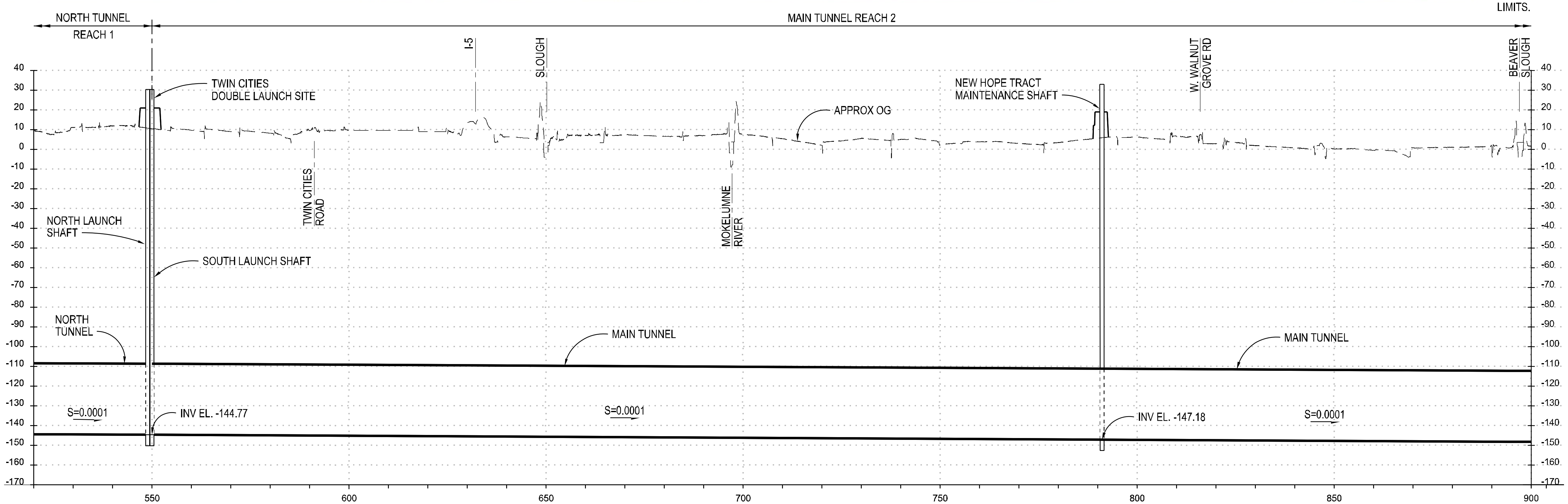
PPE-C-1070TN_W8X97000.dgn

PLOT DATE:9/27/2024 PLOT TIME:2:09:33 PM



NOTES:

1. ALT 36' ID TUNNEL SHOWN FOR 6,000 cfs.
2. TOPOGRAPHY DATA IS BASED ON USGS NATIONAL ELEVATION DATASET (NED). DATA IS FOR CONCEPTUAL USE ONLY.
3. SEE SHAFT SITE PLANS FOR DISTURBANCE LIMITS.



VERIFY SCALE
BAR IS ONE INCH ON ORIGINAL DRAWING.
0 1"

TUNNELS AND SHAFTS

REV	DATE	DESCRIPTION	SUB.	APPD
	SEP 2024	DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT		

DESIGNED	M ELLIS
DRAWN	R WYNN
CHECKED	S DUBNEWYCH
APPROVAL RECOMMENDED	
APPROVAL BY	A MURDOCK

CONCEPT PLANNING DOCUMENT

NOT FOR CONSTRUCTION

DCA
DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

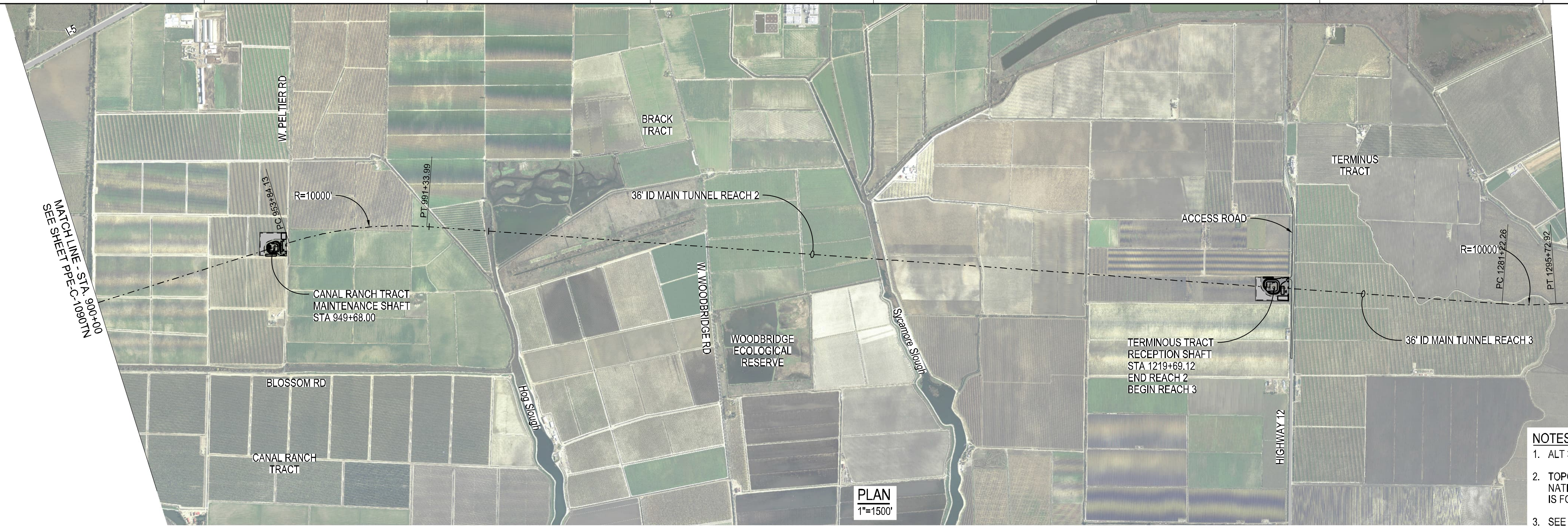
Figure 4 DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT

MAIN TUNNEL PLAN AND PROFILE SHEET 1 OF 5

PROJECT NO. W8X97000
SHEET NO. PPE-C-1090TN
REV
SEQUENCE NO. 52

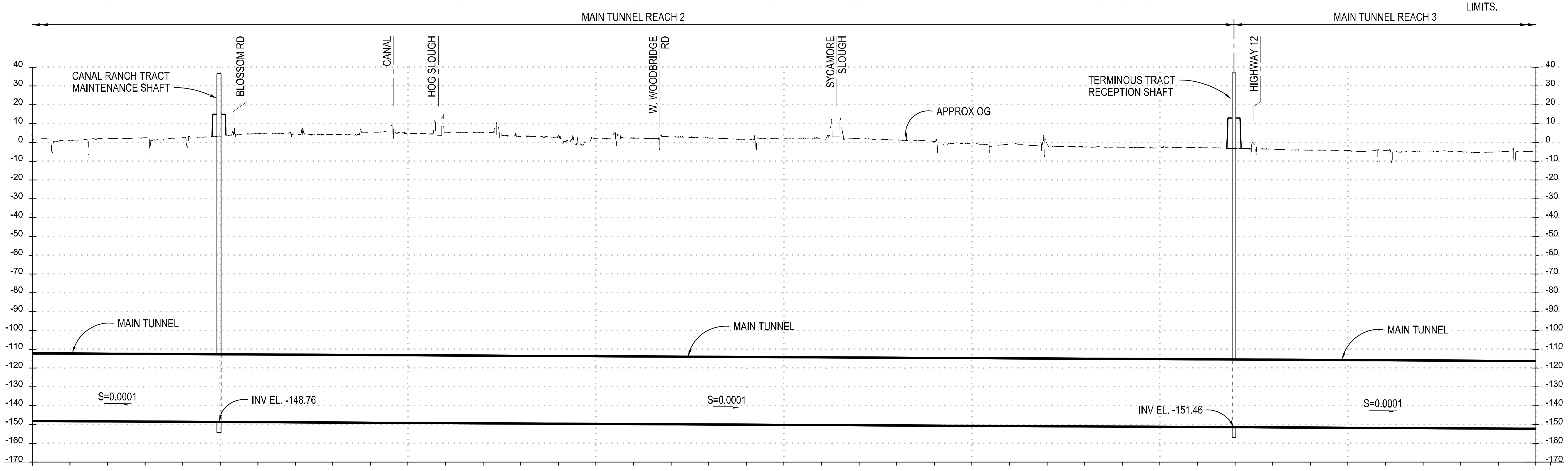
PPE-C-1090TN_W8X97000.dgn

PLOT DATE:9/27/2024 PLOT TIME:2:11:32 PM



PLAN
1"=1500'

NOTES:
1. ALT 36' ID TUNNEL SHOWN FOR 6,000 cfs.
2. TOPOGRAPHY DATA IS BASED ON USGS NATIONAL ELEVATION DATASET (NED). DATA IS FOR CONCEPTUAL USE ONLY.
3. SEE SHAFT SITE PLANS FOR DISTURBANCE LIMITS.



PROFILE STATION, x100
VERTICAL EXAGGERATION = x50

TUNNELS AND SHAFTS

REV	DATE	DESCRIPTION	SUB.	APPD
	SEP 2024	DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT		

DESIGNED: M ELLIS
DRAWN: R WYNN
CHECKED: S DUBNEWYCH
APPROVAL RECOMMENDED:
APPROVAL BY: A MURDOCK

CONCEPT PLANNING DOCUMENT

NOT FOR CONSTRUCTION

DCA
DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

Figure 5 DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT

MAIN TUNNEL PLAN AND PROFILE
SHEET 2 OF 5

VERIFY SCALE
BAR IS ONE INCH ON ORIGINAL DRAWING.

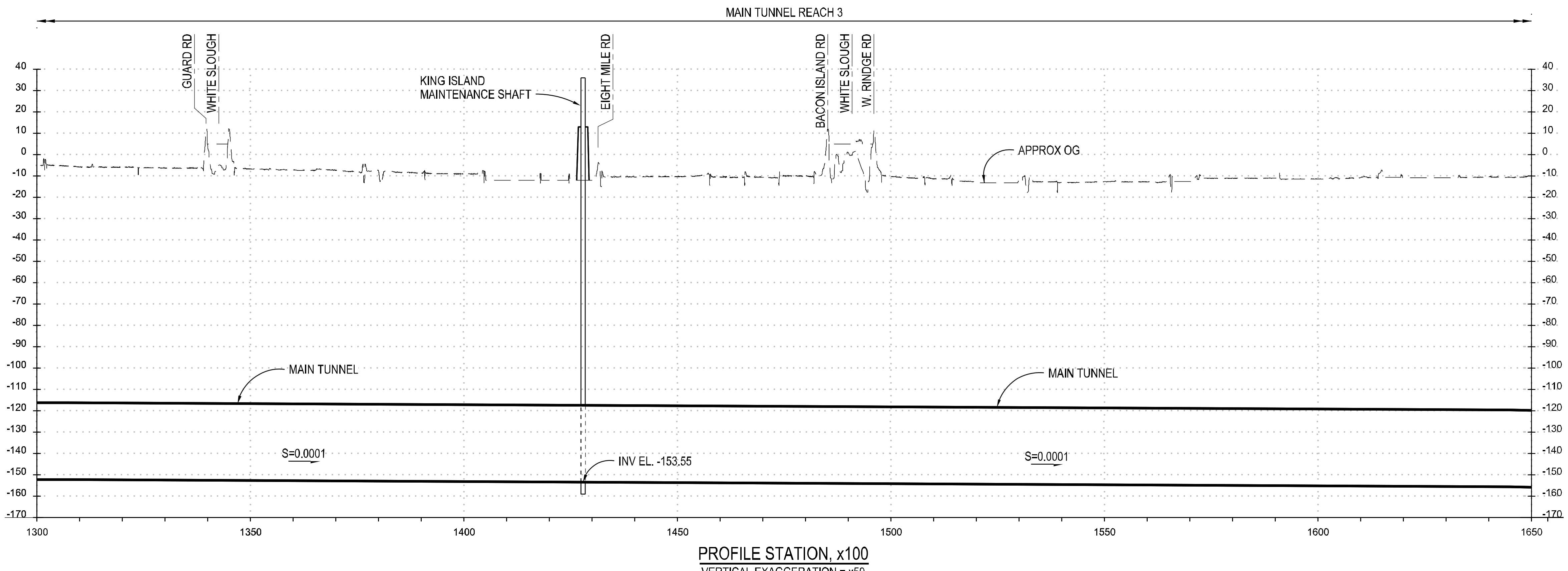
PROJECT NO. W8X97000
SHEET NO. PPE-C-1100TN
REV
SEQUENCE NO. 53

PPE-C-1100TN_W8X97000.dgn

PLOT DATE:9/27/2024 PLOT TIME:2:12:49 PM

NOTES:

1. ALT 36' ID TUNNEL SHOWN FOR 6,000 cfs.
2. TOPOGRAPHY DATA IS BASED ON USGS NATIONAL ELEVATION DATASET (NED). DATA IS FOR CONCEPTUAL USE ONLY.
3. SEE SHAFT SITE PLANS FOR DISTURBANCE LIMITS.



TUNNELS AND SHAFTS

VERIFY SCALE
BAR IS ONE INCH ON ORIGINAL DRAWING.
0 1"

REV	DATE	DESCRIPTION	SUB.	APPD
	SEP 2024	DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT		

DESIGNED: M ELLIS
DRAWN: R WYNN
CHECKED: STEVE DUBNEWYCH
APPROVAL RECOMMENDED:
APPROVAL BY: A MURDOCK

CONCEPT PLANNING DOCUMENT

NOT FOR CONSTRUCTION

DCA
DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

Figure 6 DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT

MAIN TUNNEL PLAN AND PROFILE
SHEET 3 OF 5

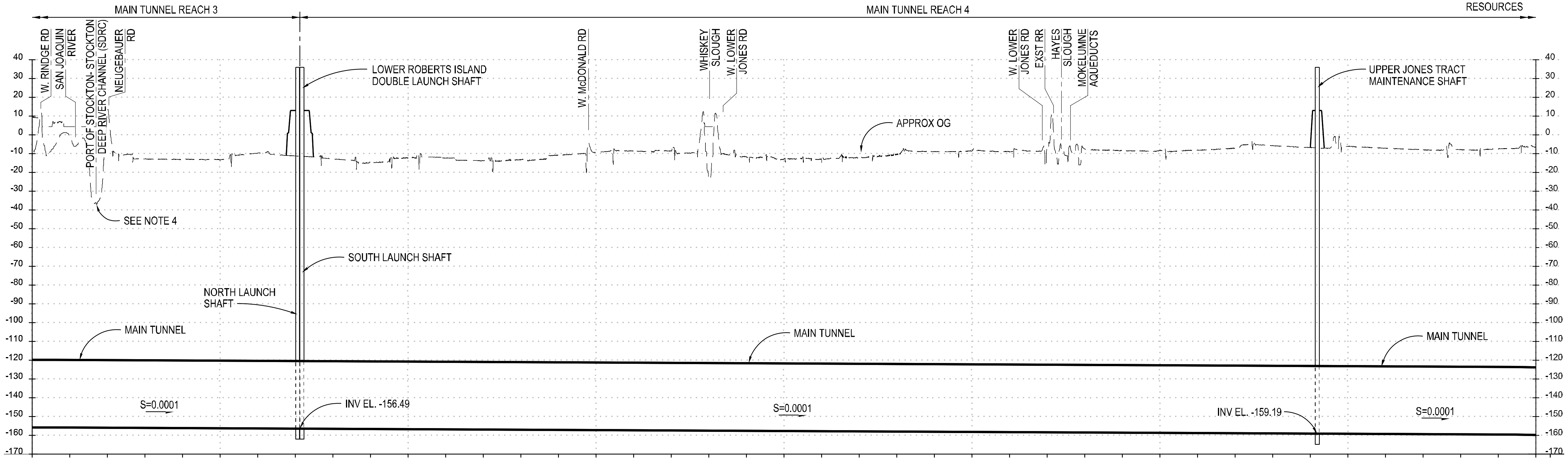
PROJECT NO. W8X97000
SHEET NO. PPE-C-1110TN
REV
SEQUENCE NO. 54

PPE-C-1110TN_W8X97000.dgn

PLOT DATE:9/27/2024 PLOT TIME:2:11:16 PM

PLAN
1"=1500'

NOTES:
1. ALT 36' ID TUNNEL SHOWN FOR 6,000 cfs.
2. TOPOGRAPHY DATA IS BASED ON USGS NATIONAL ELEVATION DATASET (NED). DATA IS FOR CONCEPTUAL USE ONLY.
3. SEE SHAFT SITE PLANS FOR DISTURBANCE LIMITS.
4. BATHYMETRY DATA FROM STA:1664+52 TO STA:1669+42 WAS PROVIDED BY THE CALIFORNIA DEPARTMENT OF WATER RESOURCES



PROFILE STATION, x100
VERTICAL EXAGGERATION = x50

TUNNELS AND SHAFTS

VERIFY SCALE
BAR IS ONE INCH ON ORIGINAL DRAWING.
0 1"

REV	DATE	DESCRIPTION	SUB.	APPD
	SEP 2024	DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT		

DESIGNED: M ELLIS
DRAWN: R WYNN
CHECKED: STEVE DUBNEWYCH
APPROVAL RECOMMENDED:
APPROVAL BY: A MURDOCK

CONCEPT PLANNING DOCUMENT
NOT FOR CONSTRUCTION

DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

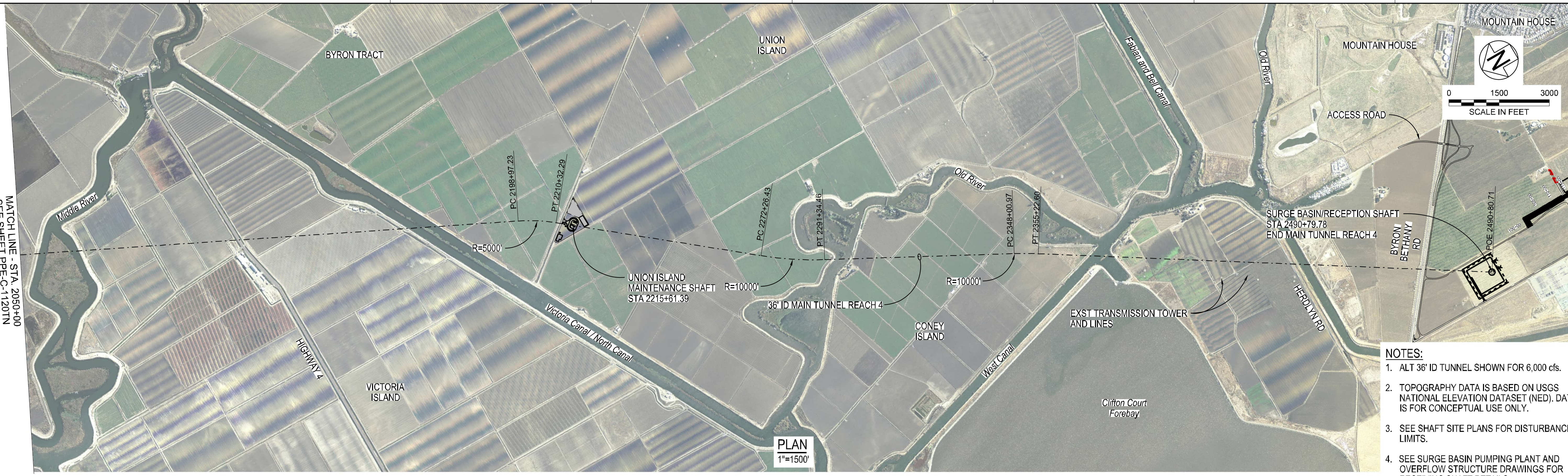
Figure 7 DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT

MAIN TUNNEL PLAN AND PROFILE
SHEET 4 OF 5

PROJECT NO. W8X97000
SHEET NO. PPE-C-1120TN
REV
SEQUENCE NO. 55

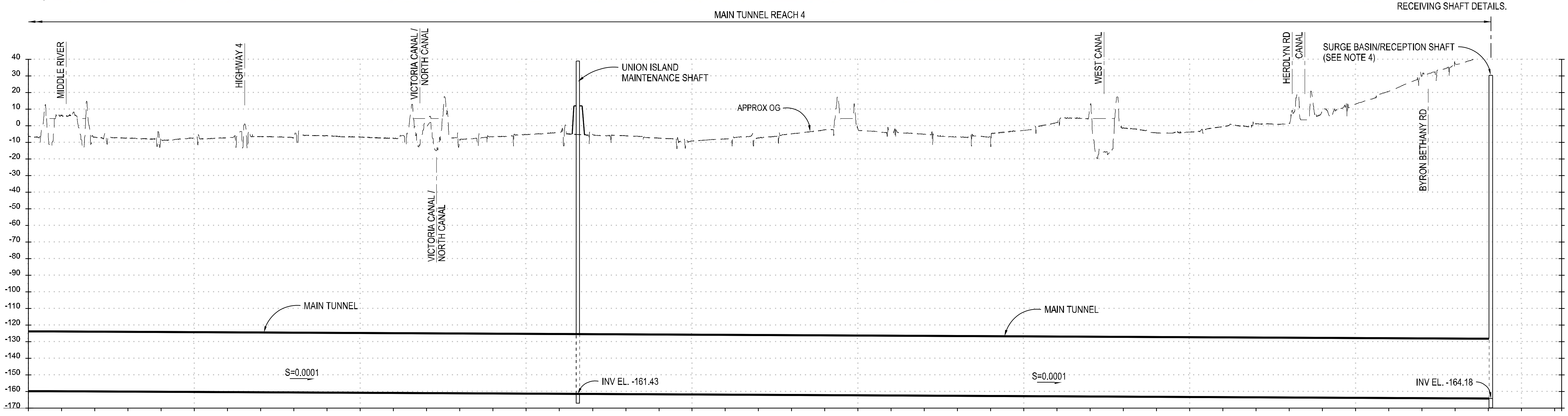
PPE-C-1120TN_W8X97000.dgn

PLOT DATE:9/27/2024 PLOT TIME:2:11:32 PM



NOTES:

1. ALT 36' ID TUNNEL SHOWN FOR 6,000 cfs.
2. TOPOGRAPHY DATA IS BASED ON USGS NATIONAL ELEVATION DATASET (NED). DATA IS FOR CONCEPTUAL USE ONLY.
3. SEE SHAFT SITE PLANS FOR DISTURBANCE LIMITS.
4. SEE SURGE BASIN PUMPING PLANT AND OVERFLOW STRUCTURE DRAWINGS FOR RECEIVING SHAFT DETAILS.



PROFILE STATION, x100
VERTICAL EXAGGERATION = x50

VERIFY SCALE
BAR IS ONE INCH ON ORIGINAL DRAWING.
0 1"

TUNNELS AND SHAFTS

REV	DATE	DESCRIPTION	SUB.	APPD
	SEP 2024	DELTA CONVEYANCE PROJECT CONCEPT ENGINEERING REPORT		

DESIGNED: M ELLIS
DRAWN: R WYNN
CHECKED: STEVE DUBNEWYCH
APPROVAL RECOMMENDED:
APPROVAL BY: A MURDOCK

CONCEPT PLANNING DOCUMENT

NOT FOR CONSTRUCTION

DCA
DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

Figure 8
DELTA CONVEYANCE PROJECT
CONCEPT ENGINEERING REPORT

MAIN TUNNEL PLAN AND PROFILE
SHEET 5 OF 5

PROJECT NO. W8X97000
SHEET NO. PPE-C-1130TN
REV
SEQUENCE NO. 56

PPE-C-1130TN_W8X97000.dgn

PLOT DATE:9/27/2024 PLOT TIME:2:13:11 PM

Attachment 2
Unmitigated Ground Settlement Results

Note: The term "Eastern Corridor" or "East Corridor" and utilities described on the following pages represent locations which are within the vicinity of the Project.

By: CPS
Checked By: SF

Project Name: Delta Conveyance

Location: East corridor EBMUD Mokelumne Aqueducts

Approx Station: 1900+00

Purpose: To estimate the settlement caused by tunnel excavation

References:
Aoyagi, T. (1995) Representing Settlement for Soft Ground Tunneling
California Waterfix (2018) Conceptual Engineering Report Byron Tract Forebay Option
O'Reilly and New (1982) Settlements above tunnels in the United Kingdom - their magnitude and prediction
Peck, R.B. (1969) Deep Excavations and Tunneling in Soft Ground

Assumption(s):
Calculated settlement is from construction activities only
Ground conditions are similar to those in the Conceptual Engineering Report

Equations

Maximum Settlement $$S_{max} = \frac{\sqrt{2} \cdot V_s}{2 \cdot \sqrt{\pi} \cdot i}$$

Settlement Trough Inflection Distance $$i = K \cdot Z$$

Total Settlement Volume $$V_s = V_L \cdot \pi \cdot R^2$$

Settlement at Distance x from Tunnel Centerline $$S = S_{max} \cdot e^{\left(\frac{-x^2}{2 \cdot i^2}\right)}$$

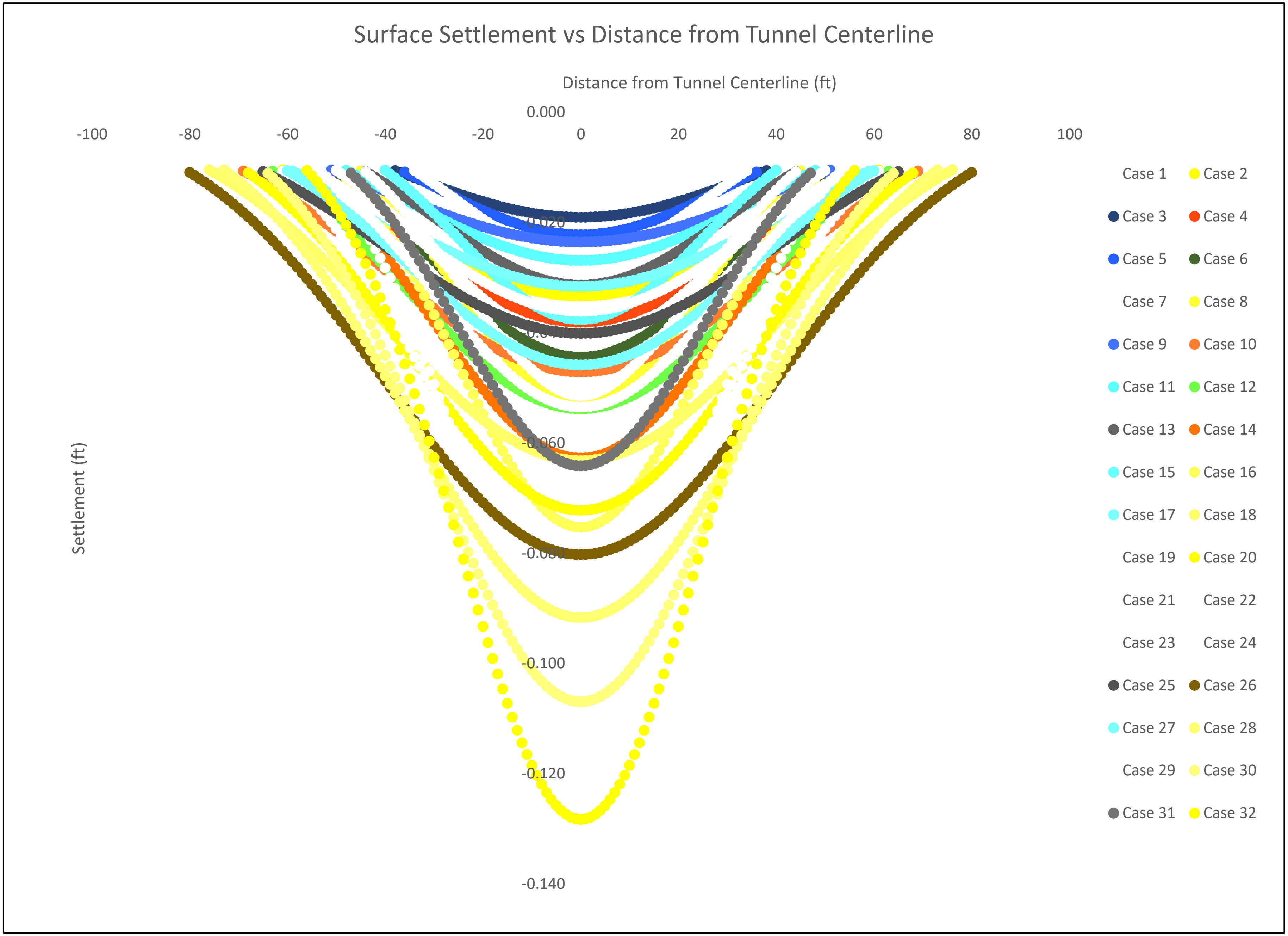
Input Parameter	Symbol	Value	Unit	Notes
Excavated Tunnel Radius	R_1	14.60	ft	26 ft inside diameter plus segments and excavation overcut
	R_2	17.35	ft	31 ft inside diameter plus segments and excavation overcut
	R_3	20.10	ft	36 ft inside diameter plus segments and excavation overcut
	R_4	22.65	ft	40 ft inside diameter plus segments and excavation overcut
Depth to Excavation Springline	Z_1	80.10	ft	Depth to springline on plan and profile from pile tip elev (EL -60)
	Z_2	70.1	ft	Raise tunnel 10 feet
	Z_3	60.1	ft	Raise tunnel 20 feet
	Z_4	50.1	ft	Raise tunnel 30 feet
Trough Width Parameter	K	0.5	NA	Cohesive soil (O'Reilly and New, 1982) and cohesionless soil below groundwater table (Peck, 1969)
Ground Loss Percent	V_{L1}	0.25%	%	Assumed average value based on recent projects
	V_{L2}	0.50%	%	Assumed max value based on recent projects

By: _CPS_____
Checked By: _SF______

East Corridor EBMUD Mokelumne Aqueduct Crossings

Case	Parameter Combination				Maximum Settlement		Settlement Trough
	R (ft)	Z (ft)	K	V_L	ft	in	ft
1	14.6	80.1	0.5	0.25%	0.02	0.20	77.7
2	14.6	80.1	0.5	0.50%	0.03	0.40	122.2
3	14.6	70.1	0.5	0.25%	0.02	0.23	77.0
4	14.6	70.1	0.5	0.50%	0.04	0.46	112.9
5	14.6	60.1	0.5	0.25%	0.02	0.27	74.0
6	14.6	60.1	0.5	0.50%	0.04	0.53	102.4
7	14.6	50.1	0.5	0.25%	0.03	0.32	68.7
8	14.6	50.1	0.5	0.50%	0.05	0.64	90.5
9	17.35	80.1	0.5	0.25%	0.02	0.28	102.3
10	17.35	80.1	0.5	0.50%	0.05	0.57	139.1
11	17.35	70.1	0.5	0.25%	0.03	0.32	96.6
12	17.35	70.1	0.5	0.50%	0.05	0.65	127.0
13	17.35	60.1	0.5	0.25%	0.03	0.38	89.3
14	17.35	60.1	0.5	0.50%	0.06	0.75	113.9
15	17.35	50.1	0.5	0.25%	0.04	0.45	80.3
16	17.35	50.1	0.5	0.50%	0.08	0.90	99.7
17	20.1	80.1	0.5	0.25%	0.03	0.38	119.3
18	20.1	80.1	0.5	0.50%	0.06	0.76	152.1
19	20.1	70.1	0.5	0.25%	0.04	0.43	110.5
20	20.1	70.1	0.5	0.50%	0.07	0.87	138.0
21	20.1	60.1	0.5	0.25%	0.04	0.51	100.5
22	20.1	60.1	0.5	0.50%	0.08	1.01	122.9
23	20.1	50.1	0.5	0.25%	0.05	0.61	89.0
24	20.1	50.1	0.5	0.50%	0.10	1.21	106.8
25	22.65	80.1	0.5	0.25%	0.04	0.48	131.6
26	22.65	80.1	0.5	0.50%	0.08	0.96	161.9
27	22.65	70.1	0.5	0.25%	0.05	0.55	120.7
28	22.65	70.1	0.5	0.50%	0.09	1.10	146.2
29	22.65	60.1	0.5	0.25%	0.05	0.64	108.7
30	22.65	60.1	0.5	0.50%	0.11	1.28	129.7
31	22.65	50.1	0.5	0.25%	0.06	0.77	95.5
32	22.65	50.1	0.5	0.50%	0.13	1.54	112.3

By: CPS
Checked By: SF



By: CPS
Checked By: SF

Project Name: Delta Conveyance

Location: East corridor Stockton Deep Water Ship Canal crossing

Approx Station: 1612+00

Purpose: To estimate the settlement caused by tunnel excavation

References:
Aoyagi, T. (1995) Representing Settlement for Soft Ground Tunneling
California Waterfix (2018) Conceptual Engineering Report Byron Tract Forebay Option
O'Reilly and New (1982) Settlements above tunnels in the United Kingdom - their magnitude and prediction
Peck, R.B. (1969) Deep Excavations and Tunneling in Soft Ground

Assumption(s):
Calculated settlement is from construction activities only
Ground conditions are similar to those in the Conceptual Engineering Report

Equations

Maximum Settlement $$S_{max} = \frac{\sqrt{2} \cdot V_s}{2 \cdot \sqrt{\pi} \cdot i}$$

Settlement Trough Inflection Distance $$i = K \cdot Z$$

Total Settlement Volume $$V_s = V_L \cdot \pi \cdot R^2$$

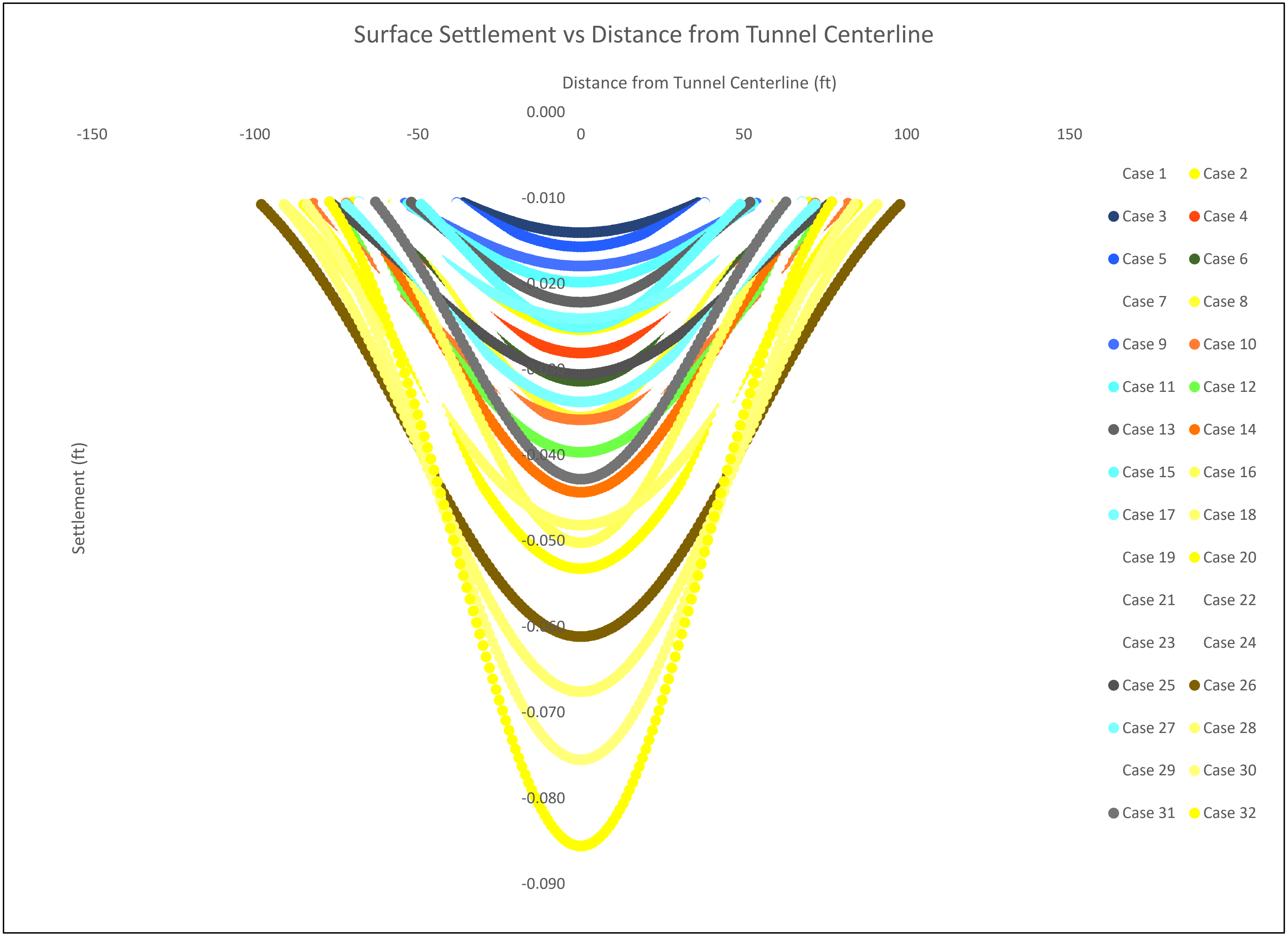
Settlement at Distance x from Tunnel Centerline $$S = S_{max} \cdot e^{\left(\frac{-x^2}{2 \cdot i^2}\right)}$$

Input Parameter	Symbol	Value	Unit	Notes
Excavated Tunnel Radius	R_1	14.60	ft	26 ft inside diameter plus segments and excavation overcut
	R_2	17.35	ft	31 ft inside diameter plus segments and excavation overcut
	R_3	20.10	ft	36 ft inside diameter plus segments and excavation overcut
	R_4	22.65	ft	40 ft inside diameter plus segments and excavation overcut
Depth to Excavation Springline	Z_1	105.10	ft	Depth to springline on plan and profile from canal bed (EL -35)
	Z_2	95.1	ft	Raise tunnel 10 feet
	Z_3	85.1	ft	Raise tunnel 20 feet
	Z_4	75.1	ft	Raise tunnel 30 feet
Trough Width Parameter	K	0.5	NA	Cohesive soil (O'Reilly and New, 1982) and cohesionless soil below groundwater table (Peck, 1969)
Ground Loss Percent	V_{L1}	0.25%	%	Assumed average value based on recent projects
	V_{L2}	0.50%	%	Assumed max value based on recent projects

East Corridor Stockton Deep Water Ship Canal Crossing

Case	Parameter Combination				Maximum Settlement		Settlement Trough
	R (ft)	Z (ft)	K	V_L	ft	in	ft
1	14.6	105.1	0.5	0.25%	0.01	0.15	66.3
2	14.6	105.1	0.5	0.50%	0.03	0.31	140.4
3	14.6	95.1	0.5	0.25%	0.01	0.17	73.5
4	14.6	95.1	0.5	0.50%	0.03	0.34	134.0
5	14.6	85.1	0.5	0.25%	0.02	0.19	77.1
6	14.6	85.1	0.5	0.50%	0.03	0.38	126.4
7	14.6	75.1	0.5	0.25%	0.02	0.21	77.7
8	14.6	75.1	0.5	0.50%	0.04	0.43	117.7
9	17.35	105.1	0.5	0.25%	0.02	0.22	109.6
10	17.35	105.1	0.5	0.50%	0.04	0.43	165.3
11	17.35	95.1	0.5	0.25%	0.02	0.24	107.9
12	17.35	95.1	0.5	0.50%	0.04	0.48	155.5
13	17.35	85.1	0.5	0.25%	0.02	0.27	104.6
14	17.35	85.1	0.5	0.50%	0.04	0.53	144.8
15	17.35	75.1	0.5	0.25%	0.03	0.30	99.6
16	17.35	75.1	0.5	0.50%	0.05	0.60	133.2
17	20.1	105.1	0.5	0.25%	0.02	0.29	136.1
18	20.1	105.1	0.5	0.50%	0.05	0.58	183.9
19	20.1	95.1	0.5	0.25%	0.03	0.32	130.3
20	20.1	95.1	0.5	0.50%	0.05	0.64	171.8
21	20.1	85.1	0.5	0.25%	0.03	0.36	123.3
22	20.1	85.1	0.5	0.50%	0.06	0.71	158.9
23	20.1	75.1	0.5	0.25%	0.03	0.40	115.1
24	20.1	75.1	0.5	0.50%	0.07	0.81	145.1
25	22.65	105.1	0.5	0.25%	0.03	0.37	154.3
26	22.65	105.1	0.5	0.50%	0.06	0.73	197.8
27	22.65	95.1	0.5	0.25%	0.03	0.41	145.9
28	22.65	95.1	0.5	0.50%	0.07	0.81	183.9
29	22.65	85.1	0.5	0.25%	0.04	0.45	136.6
30	22.65	85.1	0.5	0.50%	0.08	0.91	169.4
31	22.65	75.1	0.5	0.25%	0.04	0.51	126.3
32	22.65	75.1	0.5	0.50%	0.09	1.03	154.1

By: CPS
Checked By: SF



By: CPS
Checked By: SF

Project Name: Delta Conveyance

Location: East corridor agricultural canal crossings

Approx Station: 1430+00

Purpose: To estimate the settlement caused by tunnel excavation

References:
Aoyagi, T. (1995) Representing Settlement for Soft Ground Tunneling
California Waterfix (2018) Conceptual Engineering Report Byron Tract Forebay Option
O'Reilly and New (1982) Settlements above tunnels in the United Kingdom - their magnitude and prediction
Peck, R.B. (1969) Deep Excavations and Tunneling in Soft Ground

Assumption(s):
Calculated settlement is from construction activities only
Ground conditions are similar to those in the Conceptual Engineering Report

Equations

Maximum Settlement $$S_{max} = \frac{\sqrt{2} \cdot V_s}{2 \cdot \sqrt{\pi} \cdot i}$$

Settlement Trough Inflection Distance $$i = K \cdot Z$$

Total Settlement Volume $$V_s = V_L \cdot \pi \cdot R^2$$

Settlement at Distance x from Tunnel Centerline $$S = S_{max} \cdot e^{\left(\frac{-x^2}{2 \cdot i^2}\right)}$$

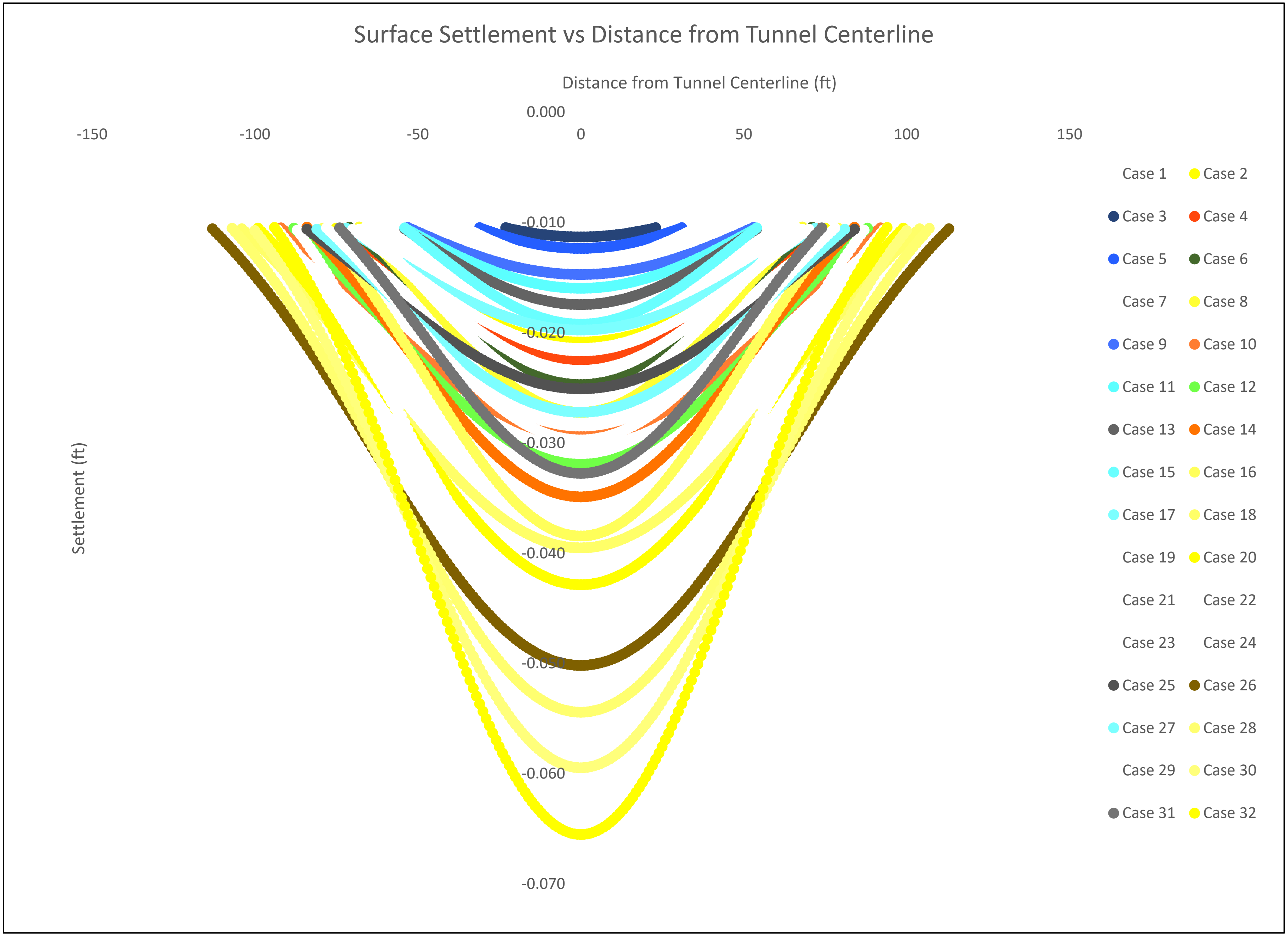
Input Parameter	Symbol	Value	Unit	Notes
Excavated Tunnel Radius	R_1	14.60	ft	26 ft inside diameter plus segments and excavation overcut
	R_2	17.35	ft	31 ft inside diameter plus segments and excavation overcut
	R_3	20.10	ft	36 ft inside diameter plus segments and excavation overcut
	R_4	22.65	ft	40 ft inside diameter plus segments and excavation overcut
Depth to Excavation Springline	Z_1	128.10	ft	Depth to springline on plan and profile from levee base
	Z_2	118.1	ft	Raise tunnel 10 feet
	Z_3	108.1	ft	Raise tunnel 20 feet
	Z_4	98.1	ft	Raise tunnel 30 feet
Trough Width Parameter	K	0.5	NA	Cohesive soil (O'Reilly and New, 1982) and cohesionless soil below groundwater table (Peck, 1969)
Ground Loss Percent	V_{L1}	0.25%	%	Assumed average value based on recent projects
	V_{L2}	0.50%	%	Assumed max value based on recent projects

By: CPS
Checked By: SF

East Corridor Agricultural Canal Crossings

Case	Parameter Combination				Maximum Settlement		Settlement Trough
	R (ft)	Z (ft)	K	V_L	ft	in	ft
1	14.6	128.1	0.5	0.25%	0.01	0.13	5.9
2	14.6	128.1	0.5	0.50%	0.02	0.25	150.9
3	14.6	118.1	0.5	0.25%	0.01	0.14	47.9
4	14.6	118.1	0.5	0.50%	0.02	0.27	147.1
5	14.6	108.1	0.5	0.25%	0.01	0.15	63.2
6	14.6	108.1	0.5	0.50%	0.02	0.30	142.1
7	14.6	98.1	0.5	0.25%	0.01	0.16	71.8
8	14.6	98.1	0.5	0.50%	0.03	0.33	136.0
9	17.35	128.1	0.5	0.25%	0.01	0.18	106.6
10	17.35	128.1	0.5	0.50%	0.03	0.35	184.7
11	17.35	118.1	0.5	0.25%	0.02	0.19	109.2
12	17.35	118.1	0.5	0.50%	0.03	0.38	176.8
13	17.35	108.1	0.5	0.25%	0.02	0.21	109.8
14	17.35	108.1	0.5	0.50%	0.03	0.42	168.1
15	17.35	98.1	0.5	0.25%	0.02	0.23	108.6
16	17.35	98.1	0.5	0.50%	0.04	0.46	158.6
17	20.1	128.1	0.5	0.25%	0.02	0.24	145.0
18	20.1	128.1	0.5	0.50%	0.04	0.47	209.2
19	20.1	118.1	0.5	0.25%	0.02	0.26	141.9
20	20.1	118.1	0.5	0.50%	0.04	0.51	198.7
21	20.1	108.1	0.5	0.25%	0.02	0.28	137.6
22	20.1	108.1	0.5	0.50%	0.05	0.56	187.4
23	20.1	98.1	0.5	0.25%	0.03	0.31	132.1
24	20.1	98.1	0.5	0.50%	0.05	0.62	175.5
25	22.65	128.1	0.5	0.25%	0.03	0.30	169.9
26	22.65	128.1	0.5	0.50%	0.05	0.60	227.2
27	22.65	118.1	0.5	0.25%	0.03	0.33	163.7
28	22.65	118.1	0.5	0.50%	0.05	0.65	214.8
29	22.65	108.1	0.5	0.25%	0.03	0.36	156.6
30	22.65	108.1	0.5	0.50%	0.06	0.71	201.8
31	22.65	98.1	0.5	0.25%	0.03	0.39	148.5
32	22.65	98.1	0.5	0.50%	0.07	0.79	188.2

By: CPS
Checked By: SF



By: CPS
Checked By: SF

Project Name: Delta Conveyance

Location: East corridor rail road crossing

Approx Station: 1900+00

Purpose: To estimate the settlement caused by tunnel excavation

References:
Aoyagi, T. (1995) Representing Settlement for Soft Ground Tunneling
California Waterfix (2018) Conceptual Engineering Report Byron Tract Forebay Option
O'Reilly and New (1982) Settlements above tunnels in the United Kingdom - their magnitude and prediction
Peck, R.B. (1969) Deep Excavations and Tunneling in Soft Ground

Assumption(s):
Calculated settlement is from construction activities only
Ground conditions are similar to those in the Conceptual Engineering Report

Equations

Maximum Settlement $$S_{max} = \frac{\sqrt{2} \cdot V_s}{2 \cdot \sqrt{\pi} \cdot i}$$

Settlement Trough Inflection Distance $$i = K \cdot Z$$

Total Settlement Volume $$V_s = V_L \cdot \pi \cdot R^2$$

Settlement at Distance x from Tunnel Centerline $$S = S_{max} \cdot e^{\left(\frac{-x^2}{2 \cdot i^2}\right)}$$

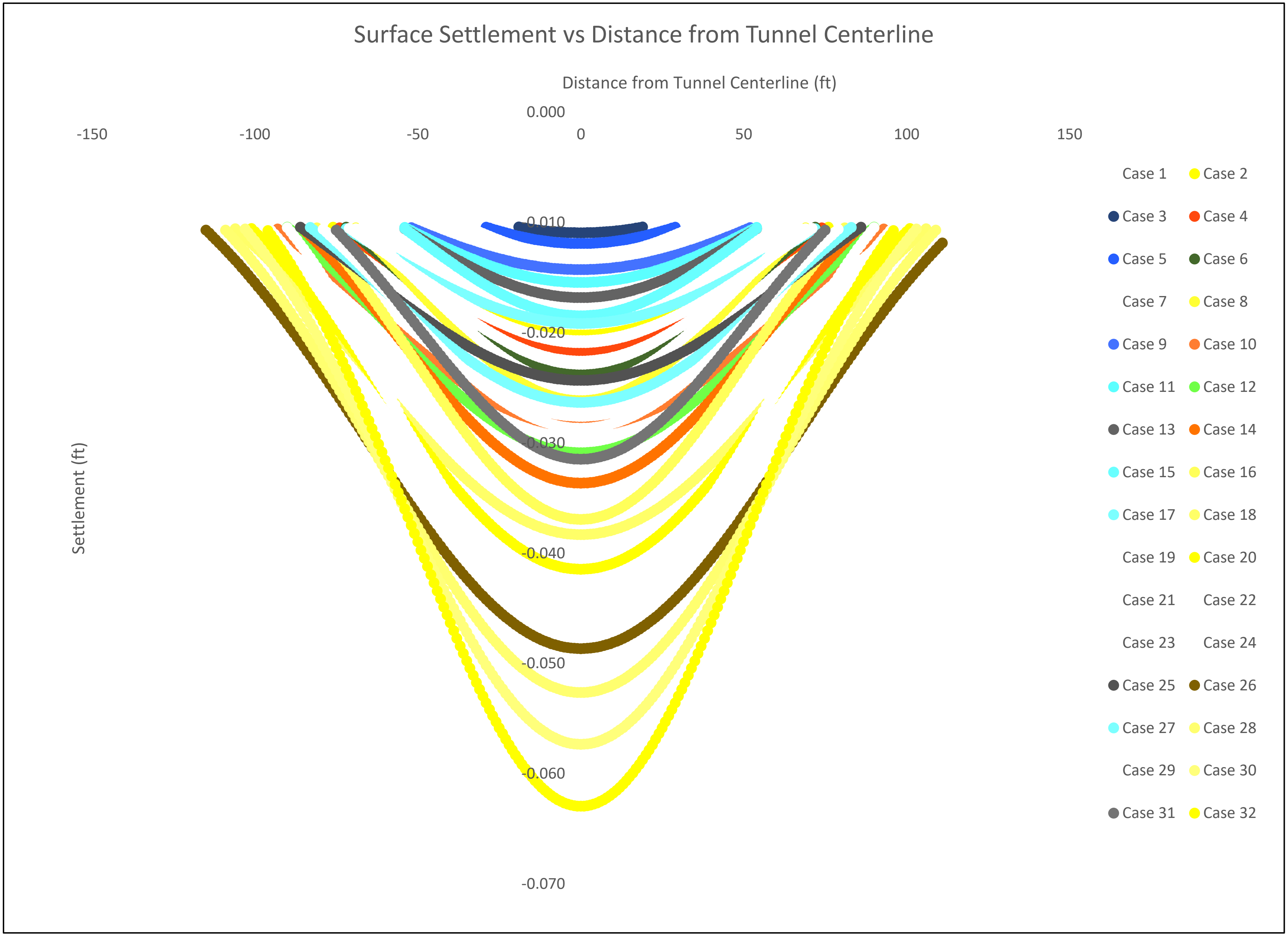
Input Parameter	Symbol	Value	Unit	Notes
Excavated Tunnel Radius	R_1	14.60	ft	26 ft inside diameter plus segments and excavation overcut
	R_2	17.35	ft	31 ft inside diameter plus segments and excavation overcut
	R_3	20.10	ft	36 ft inside diameter plus segments and excavation overcut
	R_4	22.65	ft	40 ft inside diameter plus segments and excavation overcut
Depth to Excavation Springline	Z_1	132.10	ft	Depth to springline on plan and profile
	Z_2	122.1	ft	Raise tunnel 10 feet
	Z_3	112.1	ft	Raise tunnel 20 feet
	Z_4	102.1	ft	Raise tunnel 30 feet
Trough Width Parameter	K	0.5	NA	Cohesive soil (O'Reilly and New, 1982) and cohesionless soil below groundwater table (Peck, 1969)
Ground Loss Percent	V_{L1}	0.25%	%	Assumed average value based on recent projects
	V_{L2}	0.50%	%	Assumed max value based on recent projects

By: _CPS______
Checked By: _SF_______

East Corridor Rail Road Crossing

Case	Parameter Combination				Maximum Settlement		Settlement Trough
	R (ft)	Z (ft)	K	V_L	ft	in	ft
1	14.6	132.1	0.5	0.25%	0.01	0.12	0.0
2	14.6	132.1	0.5	0.50%	0.02	0.24	152.2
3	14.6	122.1	0.5	0.25%	0.01	0.13	38.2
4	14.6	122.1	0.5	0.50%	0.02	0.26	148.8
5	14.6	112.1	0.5	0.25%	0.01	0.14	58.1
6	14.6	112.1	0.5	0.50%	0.02	0.29	144.2
7	14.6	102.1	0.5	0.25%	0.01	0.16	68.9
8	14.6	102.1	0.5	0.50%	0.03	0.31	138.6
9	17.35	132.1	0.5	0.25%	0.01	0.17	104.9
10	17.35	132.1	0.5	0.50%	0.03	0.34	187.6
11	17.35	122.1	0.5	0.25%	0.02	0.19	108.4
12	17.35	122.1	0.5	0.50%	0.03	0.37	180.1
13	17.35	112.1	0.5	0.25%	0.02	0.20	109.8
14	17.35	112.1	0.5	0.50%	0.03	0.40	171.7
15	17.35	102.1	0.5	0.25%	0.02	0.22	109.3
16	17.35	102.1	0.5	0.50%	0.04	0.44	162.5
17	20.1	132.1	0.5	0.25%	0.02	0.23	145.9
18	20.1	132.1	0.5	0.50%	0.04	0.46	213.2
19	20.1	122.1	0.5	0.25%	0.02	0.25	143.3
20	20.1	122.1	0.5	0.50%	0.04	0.50	203.0
21	20.1	112.1	0.5	0.25%	0.02	0.27	139.5
22	20.1	112.1	0.5	0.50%	0.05	0.54	192.0
23	20.1	102.1	0.5	0.25%	0.02	0.30	134.5
24	20.1	102.1	0.5	0.50%	0.05	0.60	180.4
25	22.65	132.1	0.5	0.25%	0.02	0.29	172.1
26	22.65	132.1	0.5	0.50%	0.05	0.58	232.0
27	22.65	122.1	0.5	0.25%	0.03	0.32	166.3
28	22.65	122.1	0.5	0.50%	0.05	0.63	219.8
29	22.65	112.1	0.5	0.25%	0.03	0.34	159.5
30	22.65	112.1	0.5	0.50%	0.06	0.69	207.1
31	22.65	102.1	0.5	0.25%	0.03	0.38	151.9
32	22.65	102.1	0.5	0.50%	0.06	0.76	193.7

By: CPS
Checked By: SF



By: CPS
Checked By: SF

Project Name: Delta Conveyance

Location: East corridor Highway 4 crossing

Approx Station: 2145+00

Purpose: To estimate the settlement caused by tunnel excavation

References:
Aoyagi, T. (1995) Representing Settlement for Soft Ground Tunneling
California Waterfix (2018) Conceptual Engineering Report Byron Tract Forebay Option
O'Reilly and New (1982) Settlements above tunnels in the United Kingdom - their magnitude and prediction
Peck, R.B. (1969) Deep Excavations and Tunneling in Soft Ground

Assumption(s):
Calculated settlement is from construction activities only
Ground conditions are similar to those in the Conceptual Engineering Report

Equations

Maximum Settlement $$S_{max} = \frac{\sqrt{2} \cdot V_s}{2 \cdot \sqrt{\pi} \cdot i}$$

Settlement Trough Inflection Distance $$i = K \cdot Z$$

Total Settlement Volume $$V_s = V_L \cdot \pi \cdot R^2$$

Settlement at Distance x from Tunnel Centerline $$S = S_{max} \cdot e^{\left(\frac{-x^2}{2 \cdot i^2}\right)}$$

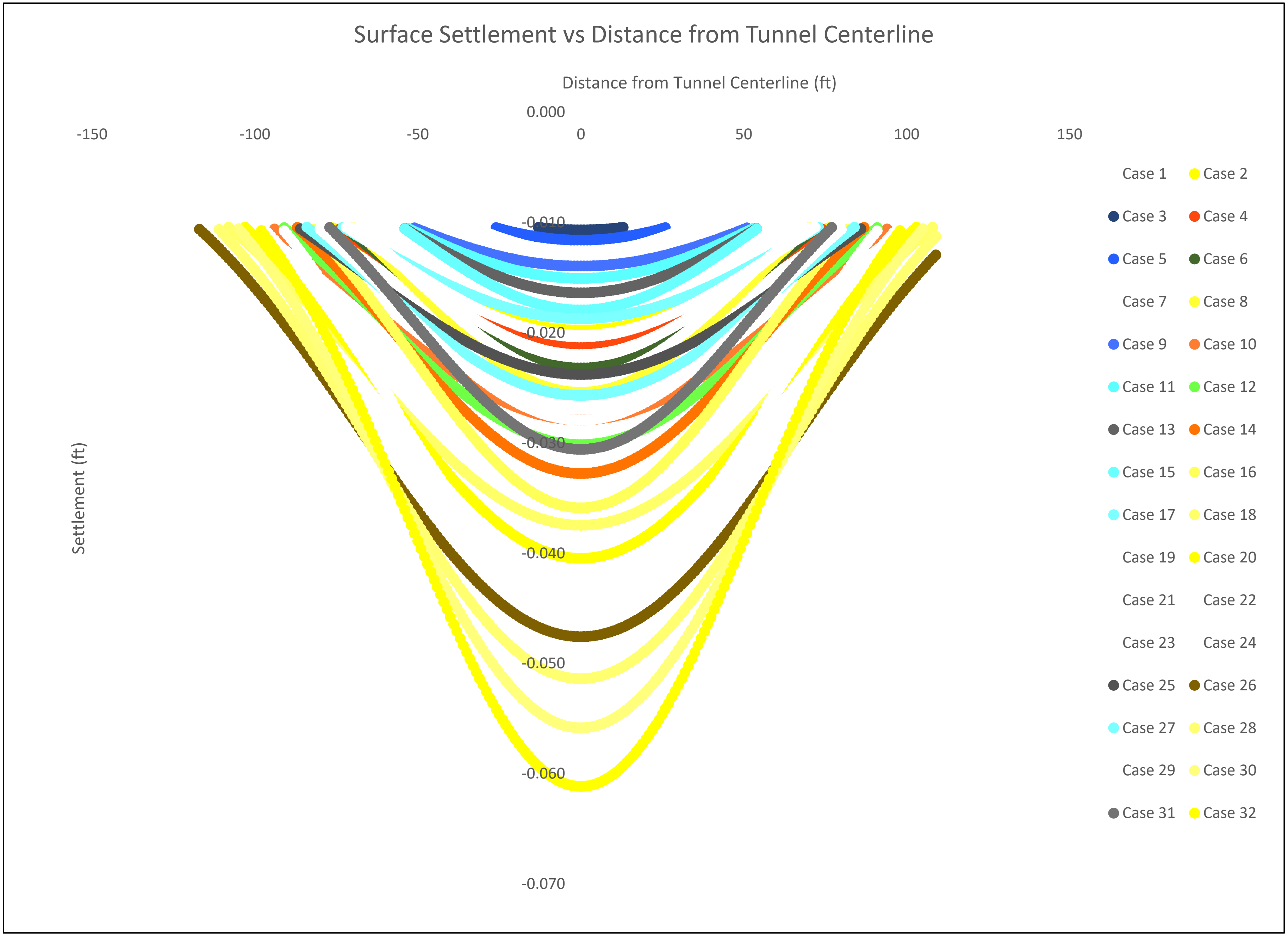
Input Parameter	Symbol	Value	Unit	Notes
Excavated Tunnel Radius	R_1	14.60	ft	26 ft inside diameter plus segments and excavation overcut
	R_2	17.35	ft	31 ft inside diameter plus segments and excavation overcut
	R_3	20.10	ft	36 ft inside diameter plus segments and excavation overcut
	R_4	22.65	ft	40 ft inside diameter plus segments and excavation overcut
Depth to Excavation Springline	Z_1	135.10	ft	Depth to springline on plan and profile
	Z_2	125.1	ft	Raise tunnel 10 feet
	Z_3	115.1	ft	Raise tunnel 20 feet
	Z_4	105.1	ft	Raise tunnel 30 feet
Trough Width Parameter	K	0.5	NA	Cohesive soil (O'Reilly and New, 1982) and cohesionless soil below groundwater table (Peck, 1969)
Ground Loss Percent	V_{L1}	0.25%	%	Assumed average value based on recent projects
	V_{L2}	0.50%	%	Assumed max value based on recent projects

By: _CPS_____
Checked By: _SF______

East Corridor Highway 4 Crossing

Case	Parameter Combination				Maximum Settlement		Settlement Trough
	R (ft)	Z (ft)	K	V_L	ft	in	ft
1	14.6	135.1	0.5	0.25%	0.01	0.12	0.0
2	14.6	135.1	0.5	0.50%	0.02	0.24	153.0
3	14.6	125.1	0.5	0.25%	0.01	0.13	27.8
4	14.6	125.1	0.5	0.50%	0.02	0.26	149.9
5	14.6	115.1	0.5	0.25%	0.01	0.14	53.5
6	14.6	115.1	0.5	0.50%	0.02	0.28	145.7
7	14.6	105.1	0.5	0.25%	0.01	0.15	66.3
8	14.6	105.1	0.5	0.50%	0.03	0.31	140.4
9	17.35	135.1	0.5	0.25%	0.01	0.17	103.4
10	17.35	135.1	0.5	0.50%	0.03	0.34	189.7
11	17.35	125.1	0.5	0.25%	0.02	0.18	107.6
12	17.35	125.1	0.5	0.50%	0.03	0.36	182.4
13	17.35	115.1	0.5	0.25%	0.02	0.20	109.6
14	17.35	115.1	0.5	0.50%	0.03	0.39	174.3
15	17.35	105.1	0.5	0.25%	0.02	0.22	109.6
16	17.35	105.1	0.5	0.50%	0.04	0.43	165.3
17	20.1	135.1	0.5	0.25%	0.02	0.22	146.4
18	20.1	135.1	0.5	0.50%	0.04	0.45	216.2
19	20.1	125.1	0.5	0.25%	0.02	0.24	144.2
20	20.1	125.1	0.5	0.50%	0.04	0.49	206.1
21	20.1	115.1	0.5	0.25%	0.02	0.26	140.7
22	20.1	115.1	0.5	0.50%	0.04	0.53	195.4
23	20.1	105.1	0.5	0.25%	0.02	0.29	136.1
24	20.1	105.1	0.5	0.50%	0.05	0.58	183.9
25	22.65	135.1	0.5	0.25%	0.02	0.29	173.7
26	22.65	135.1	0.5	0.50%	0.05	0.57	235.5
27	22.65	125.1	0.5	0.25%	0.03	0.31	168.1
28	22.65	125.1	0.5	0.50%	0.05	0.62	223.5
29	22.65	115.1	0.5	0.25%	0.03	0.34	161.7
30	22.65	115.1	0.5	0.50%	0.06	0.67	210.9
31	22.65	105.1	0.5	0.25%	0.03	0.37	154.3
32	22.65	105.1	0.5	0.50%	0.06	0.73	197.8

By: CPS
Checked By: SF



By: CPS
Checked By: SF

Project Name: Delta Conveyance

Location: East corridor Highway 12 crossing

Approx Station: 1170+00

Purpose: To estimate the settlement caused by tunnel excavation

References:
Aoyagi, T. (1995) Representing Settlement for Soft Ground Tunneling
California Waterfix (2018) Conceptual Engineering Report Byron Tract Forebay Option
O'Reilly and New (1982) Settlements above tunnels in the United Kingdom - their magnitude and prediction
Peck, R.B. (1969) Deep Excavations and Tunneling in Soft Ground

Assumption(s): Calculated settlement is from construction activities only
Ground conditions are similar to those in the Conceptual Engineering Report

Equations

Maximum Settlement

$$S_{max} = \frac{\sqrt{2} \cdot V_s}{2 \cdot \sqrt{\pi} \cdot i}$$

Settlement Trough Inflection Distance

$$i = K \cdot Z$$

Total Settlement Volume

$$V_s = V_L \cdot \pi \cdot R^2$$

Settlement at Distance x from Tunnel Centerline

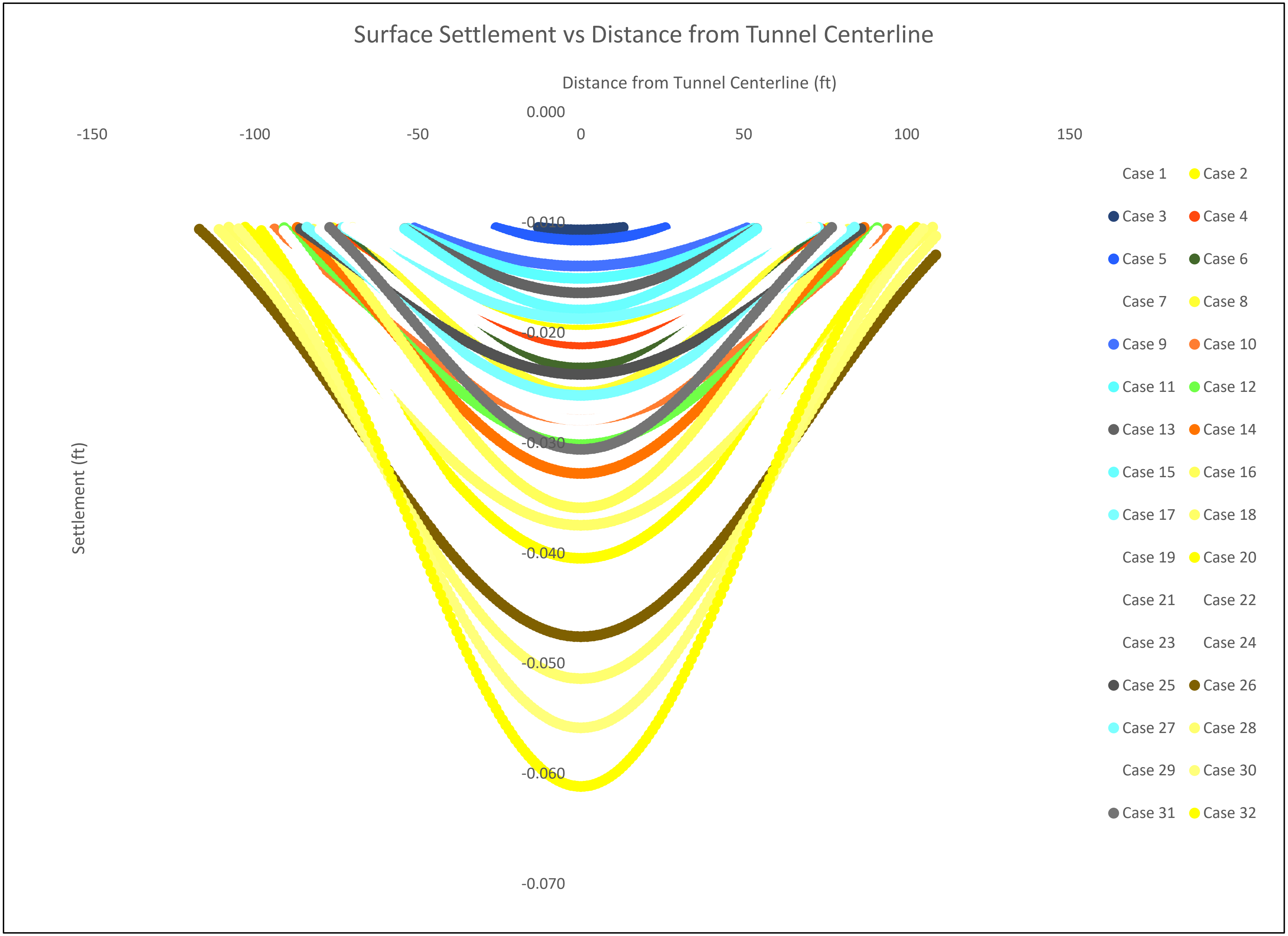
$$S = S_{max} \cdot e^{\left(\frac{-x^2}{2 \cdot i^2}\right)}$$

Input Parameter	Symbol	Value	Unit	Notes
Excavated Tunnel Radius	R_1	14.60	ft	26 ft inside diameter plus segments and excavation overcut
	R_2	17.35	ft	31 ft inside diameter plus segments and excavation overcut
	R_3	20.10	ft	36 ft inside diameter plus segments and excavation overcut
	R_4	22.65	ft	40 ft inside diameter plus segments and excavation overcut
Depth to Excavation Springline	Z_1	135.10	ft	Depth to springline on plan and profile
	Z_2	125.1	ft	Raise tunnel 10 feet
	Z_3	115.1	ft	Raise tunnel 20 feet
	Z_4	105.1	ft	Raise tunnel 30 feet
Trough Width Parameter	K	0.5	NA	Cohesive soil (O'Reilly and New, 1982) and cohesionless soil below groundwater table (Peck, 1969)
Ground Loss Percent	V_{L1}	0.25%	%	Assumed average value based on recent projects
	V_{L2}	0.50%	%	Assumed max value based on recent projects

0.03

Case	Parameter Combination				Maximum Settlement		Settlement Trough
	R (ft)	Z (ft)	K	V_L	ft	in	ft
1	14.6	135.1	0.5	0.25%	0.01	0.12	0.0
2	14.6	135.1	0.5	0.50%	0.02	0.24	153.0
3	14.6	125.1	0.5	0.25%	0.01	0.13	27.8
4	14.6	125.1	0.5	0.50%	0.02	0.26	149.9
5	14.6	115.1	0.5	0.25%	0.01	0.14	53.5
6	14.6	115.1	0.5	0.50%	0.02	0.28	145.7
7	14.6	105.1	0.5	0.25%	0.01	0.15	66.3
8	14.6	105.1	0.5	0.50%	0.03	0.31	140.4
9	17.35	135.1	0.5	0.25%	0.01	0.17	103.4
10	17.35	135.1	0.5	0.50%	0.03	0.34	189.7
11	17.35	125.1	0.5	0.25%	0.02	0.18	107.6
12	17.35	125.1	0.5	0.50%	0.03	0.36	182.4
13	17.35	115.1	0.5	0.25%	0.02	0.20	109.6
14	17.35	115.1	0.5	0.50%	0.03	0.39	174.3
15	17.35	105.1	0.5	0.25%	0.02	0.22	109.6
16	17.35	105.1	0.5	0.50%	0.04	0.43	165.3
17	20.1	135.1	0.5	0.25%	0.02	0.22	146.4
18	20.1	135.1	0.5	0.50%	0.04	0.45	216.2
19	20.1	125.1	0.5	0.25%	0.02	0.24	144.2
20	20.1	125.1	0.5	0.50%	0.04	0.49	206.1
21	20.1	115.1	0.5	0.25%	0.02	0.26	140.7
22	20.1	115.1	0.5	0.50%	0.04	0.53	195.4
23	20.1	105.1	0.5	0.25%	0.02	0.29	136.1
24	20.1	105.1	0.5	0.50%	0.05	0.58	183.9
25	22.65	135.1	0.5	0.25%	0.02	0.29	173.7
26	22.65	135.1	0.5	0.50%	0.05	0.57	235.5
27	22.65	125.1	0.5	0.25%	0.03	0.31	168.1
28	22.65	125.1	0.5	0.50%	0.05	0.62	223.5
29	22.65	115.1	0.5	0.25%	0.03	0.34	161.7
30	22.65	115.1	0.5	0.50%	0.06	0.67	210.9
31	22.65	105.1	0.5	0.25%	0.03	0.37	154.3
32	22.65	105.1	0.5	0.50%	0.06	0.73	197.8

By: CPS
Checked By: SF



By: CPS
Checked By: SF

Project Name: Delta Conveyance

Location: East corridor natural gas pipeline crossings

Approx Station: 1100+00

Purpose: To estimate the settlement caused by tunnel excavation

References:
Aoyagi, T. (1995) Representing Settlement for Soft Ground Tunneling
California Waterfix (2018) Conceptual Engineering Report Byron Tract Forebay Option
O'Reilly and New (1982) Settlements above tunnels in the United Kingdom - their magnitude and prediction
Peck, R.B. (1969) Deep Excavations and Tunneling in Soft Ground

Assumption(s):
Calculated settlement is from construction activities only
Ground conditions are similar to those in the Conceptual Engineering Report

Equations

Maximum Settlement $$S_{max} = \frac{\sqrt{2} \cdot V_s}{2 \cdot \sqrt{\pi} \cdot i}$$

Settlement Trough Inflection Distance $$i = K \cdot Z$$

Total Settlement Volume $$V_s = V_L \cdot \pi \cdot R^2$$

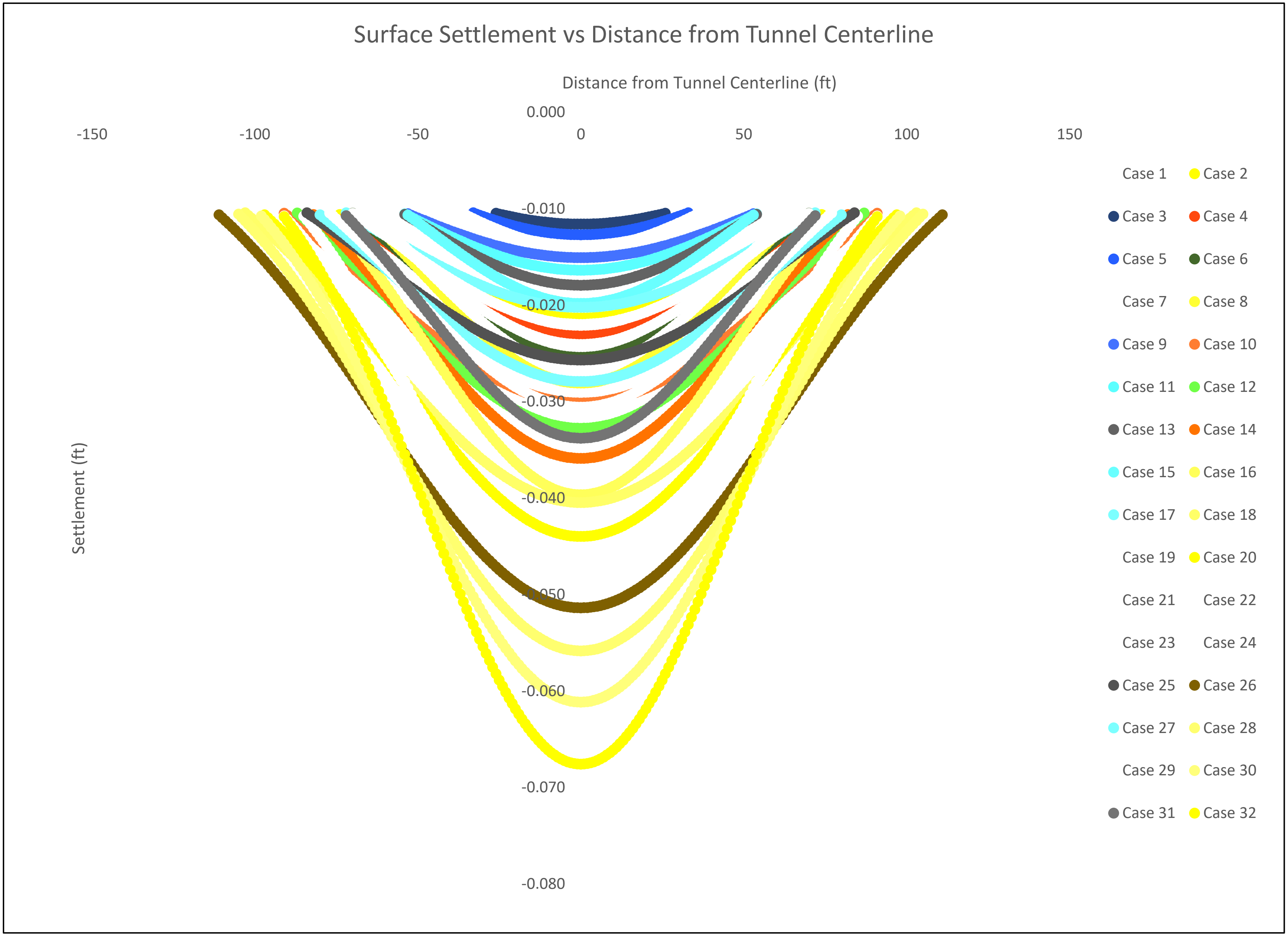
Settlement at Distance x from Tunnel Centerline $$S = S_{max} \cdot e^{\left(\frac{-x^2}{2 \cdot i^2}\right)}$$

Input Parameter	Symbol	Value	Unit	Notes
Excavated Tunnel Radius	R_1	14.60	ft	26 ft inside diameter plus segments and excavation overcut
	R_2	17.35	ft	31 ft inside diameter plus segments and excavation overcut
	R_3	20.10	ft	36 ft inside diameter plus segments and excavation overcut
	R_4	22.65	ft	40 ft inside diameter plus segments and excavation overcut
Depth to Excavation Springline	Z_1	125.10	ft	Depth to springline on plan and profile from 10 feet below GS
	Z_2	115.1	ft	Raise tunnel 10 feet
	Z_3	105.1	ft	Raise tunnel 20 feet
	Z_4	95.1	ft	Raise tunnel 30 feet
Trough Width Parameter	K	0.5	NA	Cohesive soil (O'Reilly and New, 1982) and cohesionless soil below groundwater table (Peck, 1969)
Ground Loss Percent	V_{L1}	0.25%	%	Assumed average value based on recent projects
	V_{L2}	0.50%	%	Assumed max value based on recent projects

East Corridor Natural Gas Pipeline Crossings

Case	Parameter Combination				Maximum Settlement		Settlement Trough
	R (ft)	Z (ft)	K	V_L	ft	in	ft
1	14.6	125.1	0.5	0.25%	0.01	0.13	27.8
2	14.6	125.1	0.5	0.50%	0.02	0.26	149.9
3	14.6	115.1	0.5	0.25%	0.01	0.14	53.5
4	14.6	115.1	0.5	0.50%	0.02	0.28	145.7
5	14.6	105.1	0.5	0.25%	0.01	0.15	66.3
6	14.6	105.1	0.5	0.50%	0.03	0.31	140.4
7	14.6	95.1	0.5	0.25%	0.01	0.17	73.5
8	14.6	95.1	0.5	0.50%	0.03	0.34	134.0
9	17.35	125.1	0.5	0.25%	0.02	0.18	107.6
10	17.35	125.1	0.5	0.50%	0.03	0.36	182.4
11	17.35	115.1	0.5	0.25%	0.02	0.20	109.6
12	17.35	115.1	0.5	0.50%	0.03	0.39	174.3
13	17.35	105.1	0.5	0.25%	0.02	0.22	109.6
14	17.35	105.1	0.5	0.50%	0.04	0.43	165.3
15	17.35	95.1	0.5	0.25%	0.02	0.24	107.9
16	17.35	95.1	0.5	0.50%	0.04	0.48	155.5
17	20.1	125.1	0.5	0.25%	0.02	0.24	144.2
18	20.1	125.1	0.5	0.50%	0.04	0.49	206.1
19	20.1	115.1	0.5	0.25%	0.02	0.26	140.7
20	20.1	115.1	0.5	0.50%	0.04	0.53	195.4
21	20.1	105.1	0.5	0.25%	0.02	0.29	136.1
22	20.1	105.1	0.5	0.50%	0.05	0.58	183.9
23	20.1	95.1	0.5	0.25%	0.03	0.32	130.3
24	20.1	95.1	0.5	0.50%	0.05	0.64	171.8
25	22.65	125.1	0.5	0.25%	0.03	0.31	168.1
26	22.65	125.1	0.5	0.50%	0.05	0.62	223.5
27	22.65	115.1	0.5	0.25%	0.03	0.34	161.7
28	22.65	115.1	0.5	0.50%	0.06	0.67	210.9
29	22.65	105.1	0.5	0.25%	0.03	0.37	154.3
30	22.65	105.1	0.5	0.50%	0.06	0.73	197.8
31	22.65	95.1	0.5	0.25%	0.03	0.41	145.9
32	22.65	95.1	0.5	0.50%	0.07	0.81	183.9

By: CPS
Checked By: SF



By: CPS
Checked By: SF

Project Name: Delta Conveyance

Location: East corridor overhead electrical transmission line crossing

Approx Station: 810+00

Purpose: To estimate the settlement caused by tunnel excavation

References:
Aoyagi, T. (1995) Representing Settlement for Soft Ground Tunneling
California Waterfix (2018) Conceptual Engineering Report Byron Tract Forebay Option
O'Reilly and New (1982) Settlements above tunnels in the United Kingdom - their magnitude and prediction
Peck, R.B. (1969) Deep Excavations and Tunneling in Soft Ground

Assumption(s):
Calculated settlement is from construction activities only
Ground conditions are similar to those in the Conceptual Engineering Report

Equations

Maximum Settlement $$S_{max} = \frac{\sqrt{2} \cdot V_s}{2 \cdot \sqrt{\pi} \cdot i}$$

Settlement Trough Inflection Distance $$i = K \cdot Z$$

Total Settlement Volume $$V_s = V_L \cdot \pi \cdot R^2$$

Settlement at Distance x from Tunnel Centerline $$S = S_{max} \cdot e^{\left(\frac{-x^2}{2 \cdot i^2}\right)}$$

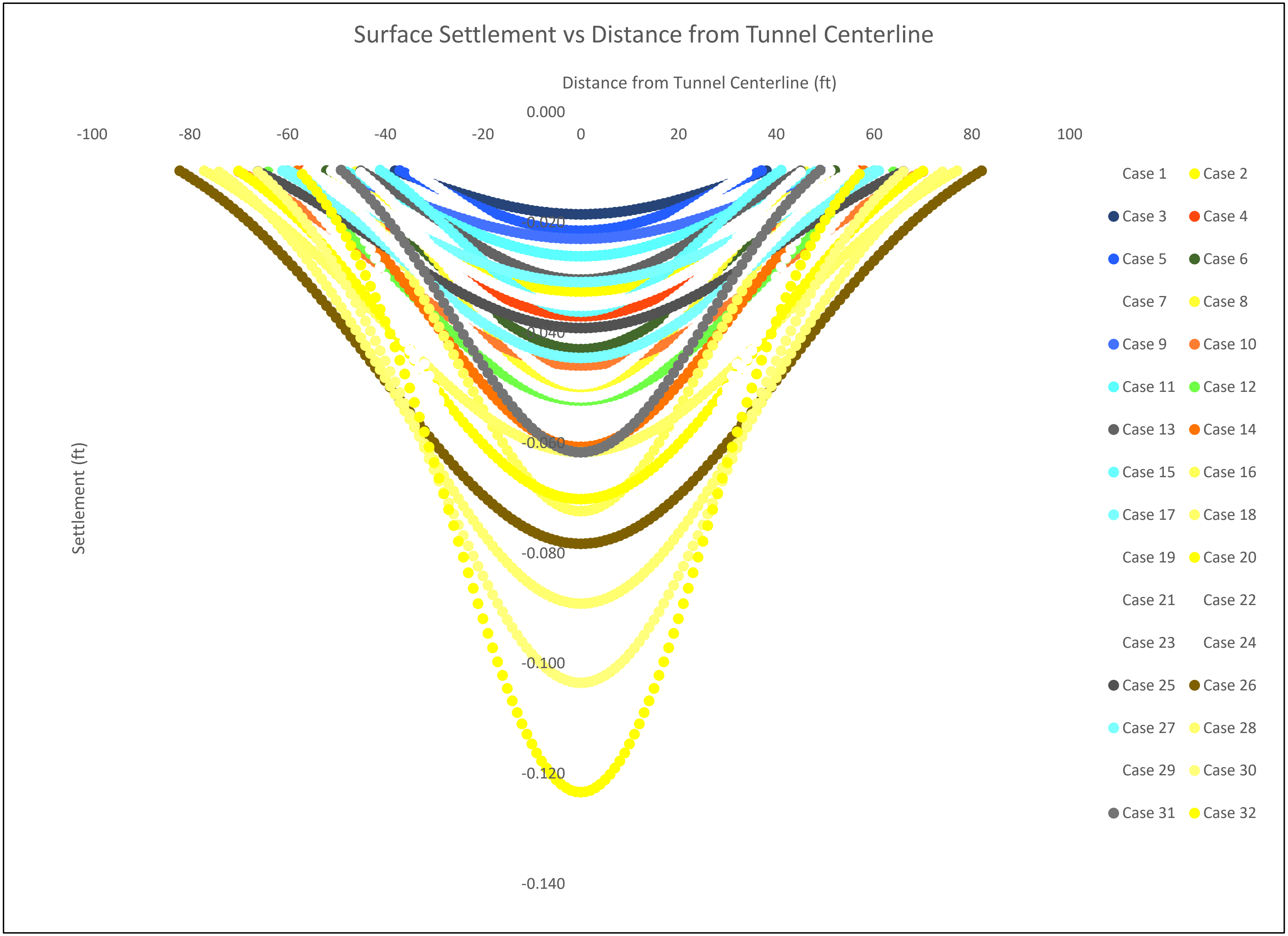
Input Parameter	Symbol	Value	Unit	Notes
Excavated Tunnel Radius	R_1	14.60	ft	26 ft inside diameter plus segments and excavation overcut
	R_2	17.35	ft	31 ft inside diameter plus segments and excavation overcut
	R_3	20.10	ft	36 ft inside diameter plus segments and excavation overcut
	R_4	22.65	ft	40 ft inside diameter plus segments and excavation overcut
Depth to Excavation Springline	Z_1	82.10	ft	Depth to springline on plan and profile from pile tip elev (EL -50)
	Z_2	72.1	ft	Raise tunnel 10 feet
	Z_3	62.1	ft	Raise tunnel 20 feet
	Z_4	52.1	ft	Raise tunnel 30 feet
Trough Width Parameter	K	0.5	NA	Cohesive soil (O'Reilly and New, 1982) and cohesionless soil below groundwater table (Peck, 1969)
Ground Loss Percent	V_{L1}	0.25%	%	Assumed average value based on recent projects
	V_{L2}	0.50%	%	Assumed max value based on recent projects

By: CPS
Checked By: SF

East Corridor Overhead Electrical Transmission Line Crossings

Case	Parameter Combination				Maximum Settlement		Settlement Trough
	R (ft)	Z (ft)	K	V_L	ft	in	ft
1	14.6	82.1	0.5	0.25%	0.02	0.20	77.5
2	14.6	82.1	0.5	0.50%	0.03	0.39	123.9
3	14.6	72.1	0.5	0.25%	0.02	0.22	77.4
4	14.6	72.1	0.5	0.50%	0.04	0.44	114.9
5	14.6	62.1	0.5	0.25%	0.02	0.26	74.8
6	14.6	62.1	0.5	0.50%	0.04	0.52	104.6
7	14.6	52.1	0.5	0.25%	0.03	0.31	69.9
8	14.6	52.1	0.5	0.50%	0.05	0.62	93.0
9	17.35	82.1	0.5	0.25%	0.02	0.28	103.3
10	17.35	82.1	0.5	0.50%	0.05	0.55	141.5
11	17.35	72.1	0.5	0.25%	0.03	0.31	97.9
12	17.35	72.1	0.5	0.50%	0.05	0.63	129.5
13	17.35	62.1	0.5	0.25%	0.03	0.36	90.9
14	17.35	62.1	0.5	0.50%	0.06	0.73	116.6
15	17.35	52.1	0.5	0.25%	0.04	0.43	82.2
16	17.35	52.1	0.5	0.50%	0.07	0.87	102.6
17	20.1	82.1	0.5	0.25%	0.03	0.37	121.0
18	20.1	82.1	0.5	0.50%	0.06	0.74	154.8
19	20.1	72.1	0.5	0.25%	0.04	0.42	112.4
20	20.1	72.1	0.5	0.50%	0.07	0.84	140.9
21	20.1	62.1	0.5	0.25%	0.04	0.49	102.6
22	20.1	62.1	0.5	0.50%	0.08	0.98	126.0
23	20.1	52.1	0.5	0.25%	0.05	0.58	91.4
24	20.1	52.1	0.5	0.50%	0.10	1.17	110.1
25	22.65	82.1	0.5	0.25%	0.04	0.47	133.6
26	22.65	82.1	0.5	0.50%	0.08	0.94	164.9
27	22.65	72.1	0.5	0.25%	0.04	0.54	123.0
28	22.65	72.1	0.5	0.50%	0.09	1.07	149.4
29	22.65	62.1	0.5	0.25%	0.05	0.62	111.2
30	22.65	62.1	0.5	0.50%	0.10	1.24	133.1
31	22.65	52.1	0.5	0.25%	0.06	0.74	98.3
32	22.65	52.1	0.5	0.50%	0.12	1.48	115.8

By: CPS
Checked By: SF



By: CPS
Checked By: SF

Project Name: Delta Conveyance

Location: East corridor shallowest tunnel cover

Approx Station: 930+00

Purpose: To estimate the settlement caused by tunnel excavation

References:
Aoyagi, T. (1995) Representing Settlement for Soft Ground Tunneling
California Waterfix (2018) Conceptual Engineering Report Byron Tract Forebay Option
O'Reilly and New (1982) Settlements above tunnels in the United Kingdom - their magnitude and prediction
Peck, R.B. (1969) Deep Excavations and Tunneling in Soft Ground

Assumption(s):
Calculated settlement is from construction activities only
Ground conditions are similar to those in the Conceptual Engineering Report

Equations

Maximum Settlement $$S_{max} = \frac{\sqrt{2} \cdot V_s}{2 \cdot \sqrt{\pi} \cdot i}$$

Settlement Trough Inflection Distance $$i = K \cdot Z$$

Total Settlement Volume $$V_s = V_L \cdot \pi \cdot R^2$$

Settlement at Distance x from Tunnel Centerline $$S = S_{max} \cdot e^{\left(\frac{-x^2}{2 \cdot i^2}\right)}$$

Input Parameter	Symbol	Value	Unit	Notes
Excavated Tunnel Radius	R_1	14.60	ft	26 ft inside diameter plus segments and excavation overcut
	R_2	17.35	ft	31 ft inside diameter plus segments and excavation overcut
	R_3	20.10	ft	36 ft inside diameter plus segments and excavation overcut
	R_4	22.65	ft	40 ft inside diameter plus segments and excavation overcut
Depth to Excavation Springline	Z_1	125.10	ft	Depth to springline on plan and profile
	Z_2	115.1	ft	Raise tunnel 10 feet
	Z_3	105.1	ft	Raise tunnel 20 feet
	Z_4	95.1	ft	Raise tunnel 30 feet
Trough Width Parameter	K	0.5	NA	Cohesive soil (O'Reilly and New, 1982) and cohesionless soil below groundwater table (Peck, 1969)
Ground Loss Percent	V_{L1}	0.25%	%	Assumed average value based on recent projects
	V_{L2}	0.50%	%	Assumed max value based on recent projects

By: CPS
Checked By: SF

East Corridor Shallowest Tunnel Crossing

Case	Parameter Combination				Maximum Settlement		Settlement Trough
	R (ft)	Z (ft)	K	V_L	ft	in	ft
1	14.6	125.1	0.5	0.25%	0.01	0.13	27.8
2	14.6	125.1	0.5	0.50%	0.02	0.26	149.9
3	14.6	115.1	0.5	0.25%	0.01	0.14	53.5
4	14.6	115.1	0.5	0.50%	0.02	0.28	145.7
5	14.6	105.1	0.5	0.25%	0.01	0.15	66.3
6	14.6	105.1	0.5	0.50%	0.03	0.31	140.4
7	14.6	95.1	0.5	0.25%	0.01	0.17	73.5
8	14.6	95.1	0.5	0.50%	0.03	0.34	134.0
9	17.35	125.1	0.5	0.25%	0.02	0.18	107.6
10	17.35	125.1	0.5	0.50%	0.03	0.36	182.4
11	17.35	115.1	0.5	0.25%	0.02	0.20	109.6
12	17.35	115.1	0.5	0.50%	0.03	0.39	174.3
13	17.35	105.1	0.5	0.25%	0.02	0.22	109.6
14	17.35	105.1	0.5	0.50%	0.04	0.43	165.3
15	17.35	95.1	0.5	0.25%	0.02	0.24	107.9
16	17.35	95.1	0.5	0.50%	0.04	0.48	155.5
17	20.1	125.1	0.5	0.25%	0.02	0.24	144.2
18	20.1	125.1	0.5	0.50%	0.04	0.49	206.1
19	20.1	115.1	0.5	0.25%	0.02	0.26	140.7
20	20.1	115.1	0.5	0.50%	0.04	0.53	195.4
21	20.1	105.1	0.5	0.25%	0.02	0.29	136.1
22	20.1	105.1	0.5	0.50%	0.05	0.58	183.9
23	20.1	95.1	0.5	0.25%	0.03	0.32	130.3
24	20.1	95.1	0.5	0.50%	0.05	0.64	171.8
25	22.65	125.1	0.5	0.25%	0.03	0.31	168.1
26	22.65	125.1	0.5	0.50%	0.05	0.62	223.5
27	22.65	115.1	0.5	0.25%	0.03	0.34	161.7
28	22.65	115.1	0.5	0.50%	0.06	0.67	210.9
29	22.65	105.1	0.5	0.25%	0.03	0.37	154.3
30	22.65	105.1	0.5	0.50%	0.06	0.73	197.8
31	22.65	95.1	0.5	0.25%	0.03	0.41	145.9
32	22.65	95.1	0.5	0.50%	0.07	0.81	183.9

By: CPS
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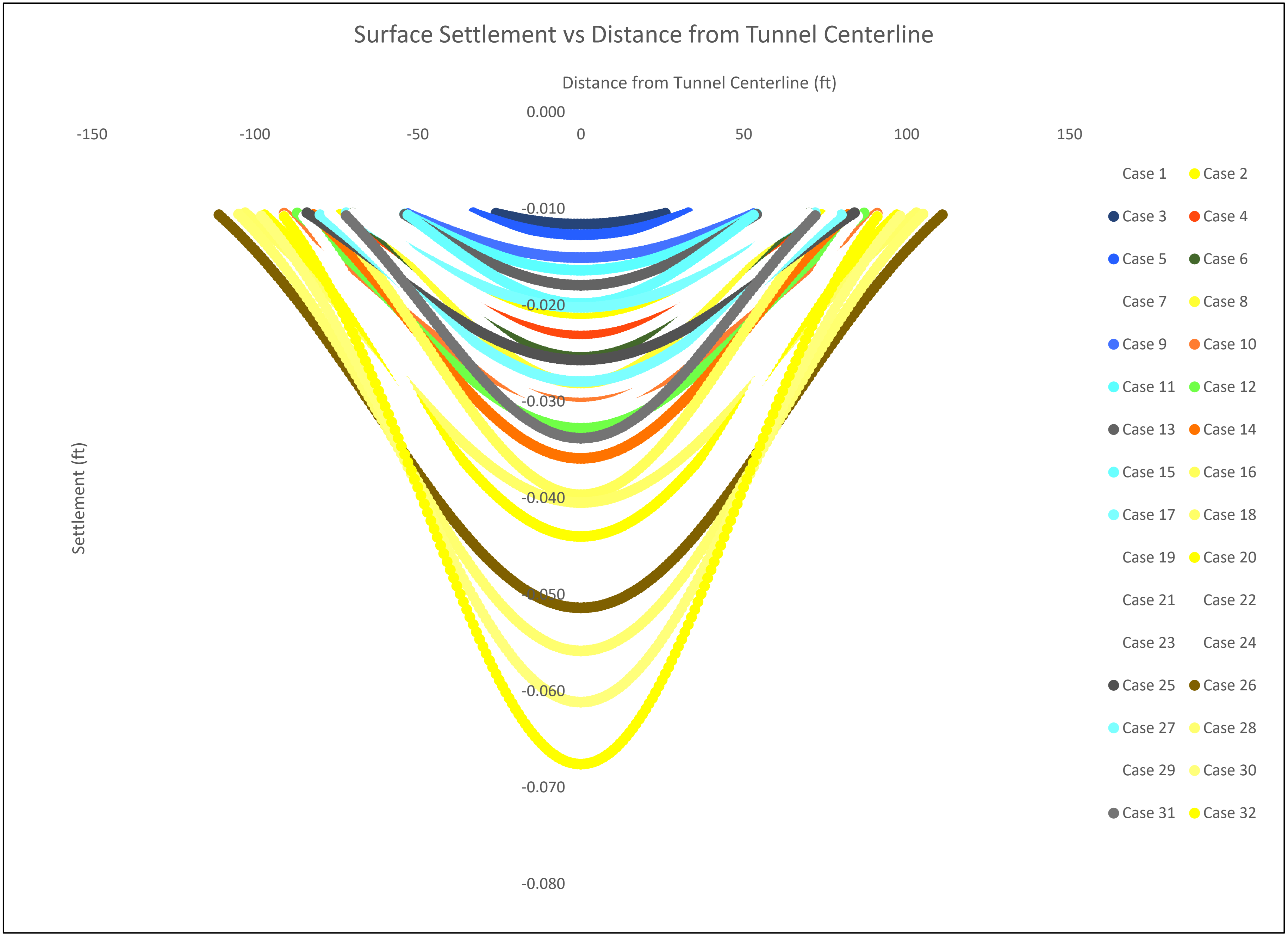


By: CPS
Checked By: SF

Project Name: Delta Conveyance

Location: East corridor deepest tunnel cover

Approx Station: 2280+00

Purpose: To estimate the settlement caused by tunnel excavation

References:
Aoyagi, T. (1995) Representing Settlement for Soft Ground Tunneling
California Waterfix (2018) Conceptual Engineering Report Byron Tract Forebay Option
O'Reilly and New (1982) Settlements above tunnels in the United Kingdom - their magnitude and prediction
Peck, R.B. (1969) Deep Excavations and Tunneling in Soft Ground

Assumption(s):
Calculated settlement is from construction activities only
Ground conditions are similar to those in the Conceptual Engineering Report

Equations

Maximum Settlement $$S_{max} = \frac{\sqrt{2} \cdot V_s}{2 \cdot \sqrt{\pi} \cdot i}$$

Settlement Trough Inflection Distance $$i = K \cdot Z$$

Total Settlement Volume $$V_s = V_L \cdot \pi \cdot R^2$$

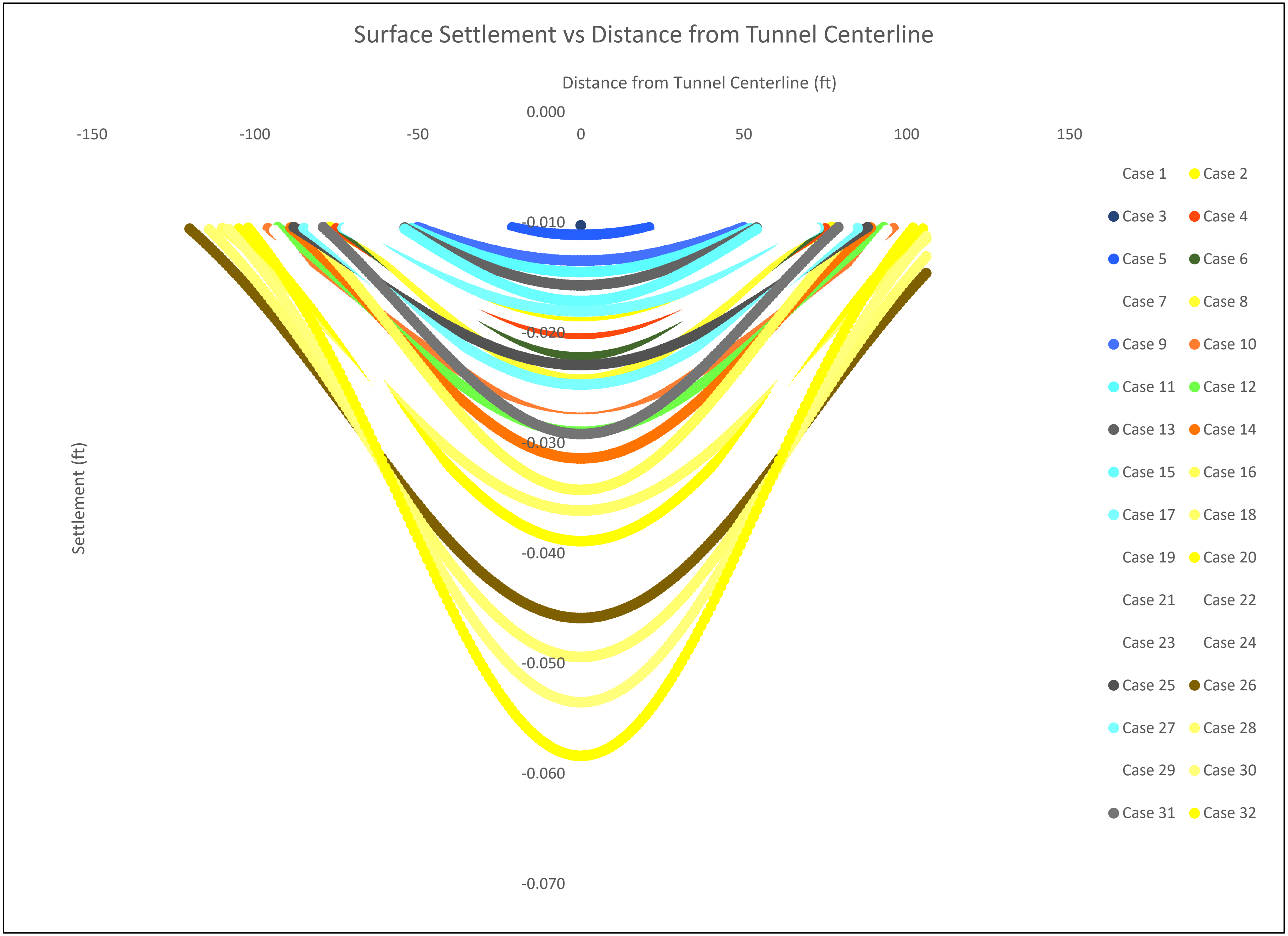
Settlement at Distance x from Tunnel Centerline $$S = S_{max} \cdot e^{\left(\frac{-x^2}{2 \cdot i^2}\right)}$$

Input Parameter	Symbol	Value	Unit	Notes
Excavated Tunnel Radius	R_1	14.60	ft	26 ft inside diameter plus segments and excavation overcut
	R_2	17.35	ft	31 ft inside diameter plus segments and excavation overcut
	R_3	20.10	ft	36 ft inside diameter plus segments and excavation overcut
	R_4	22.65	ft	40 ft inside diameter plus segments and excavation overcut
Depth to Excavation Springline	Z_1	140.10	ft	Depth to springline on plan and profile
	Z_2	130.1	ft	Raise tunnel 10 feet
	Z_3	120.1	ft	Raise tunnel 20 feet
	Z_4	110.1	ft	Raise tunnel 30 feet
Trough Width Parameter	K	0.5	NA	Cohesive soil (O'Reilly and New, 1982) and cohesionless soil below groundwater table (Peck, 1969)
Ground Loss Percent	V_{L1}	0.25%	%	Assumed average value based on recent projects
	V_{L2}	0.50%	%	Assumed max value based on recent projects

East Corridor Deepest Tunnel Cover Crossing

Case	Parameter Combination				Maximum Settlement		Settlement Trough
	R (ft)	Z (ft)	K	V_L	ft	in	ft
1	14.6	140.1	0.5	0.25%	0.01	0.11	0.0
2	14.6	140.1	0.5	0.50%	0.02	0.23	154.1
3	14.6	130.1	0.5	0.25%	0.01	0.12	0.0
4	14.6	130.1	0.5	0.50%	0.02	0.25	151.6
5	14.6	120.1	0.5	0.25%	0.01	0.13	43.5
6	14.6	120.1	0.5	0.50%	0.02	0.27	147.9
7	14.6	110.1	0.5	0.25%	0.01	0.15	60.8
8	14.6	110.1	0.5	0.50%	0.02	0.29	143.2
9	17.35	140.1	0.5	0.25%	0.01	0.16	100.4
10	17.35	140.1	0.5	0.50%	0.03	0.32	193.1
11	17.35	130.1	0.5	0.25%	0.01	0.17	105.8
12	17.35	130.1	0.5	0.50%	0.03	0.35	186.2
13	17.35	120.1	0.5	0.25%	0.02	0.19	108.8
14	17.35	120.1	0.5	0.50%	0.03	0.38	178.4
15	17.35	110.1	0.5	0.25%	0.02	0.21	109.8
16	17.35	110.1	0.5	0.50%	0.03	0.41	169.9
17	20.1	140.1	0.5	0.25%	0.02	0.22	147.1
18	20.1	140.1	0.5	0.50%	0.04	0.43	221.0
19	20.1	130.1	0.5	0.25%	0.02	0.23	145.5
20	20.1	130.1	0.5	0.50%	0.04	0.47	211.2
21	20.1	120.1	0.5	0.25%	0.02	0.25	142.6
22	20.1	120.1	0.5	0.50%	0.04	0.51	200.8
23	20.1	110.1	0.5	0.25%	0.02	0.28	138.6
24	20.1	110.1	0.5	0.50%	0.05	0.55	189.7
25	22.65	140.1	0.5	0.25%	0.02	0.28	176.1
26	22.65	140.1	0.5	0.50%	0.05	0.55	241.3
27	22.65	130.1	0.5	0.25%	0.02	0.30	171.0
28	22.65	130.1	0.5	0.50%	0.05	0.59	229.6
29	22.65	120.1	0.5	0.25%	0.03	0.32	165.0
30	22.65	120.1	0.5	0.50%	0.05	0.64	217.3
31	22.65	110.1	0.5	0.25%	0.03	0.35	158.1
32	22.65	110.1	0.5	0.50%	0.06	0.70	204.4

By: CPS
Checked By: SF



Purpose

To determine the trough width parameter for granular soils beneath the groundwater table

Reference

Peck, R.B. (1969). Deep Excavations and Tunnels in Soft Ground. Proceedings of the 7th International Conference on Soil Mechanics and Foundation Engineering.

Inputs

Approximate average tunnel depth at springline $z := 130\text{ft}$

Tunnel excavation radius for 36-foot ID tunnel $r := 19.915\text{ft}$

Ratio of tunnel depth over diameter $Ratio_z := \frac{z}{2 \cdot r} = 3.264$

Ratio of inflection point over radius (Fig 9) $Ratio_i := 3.25$

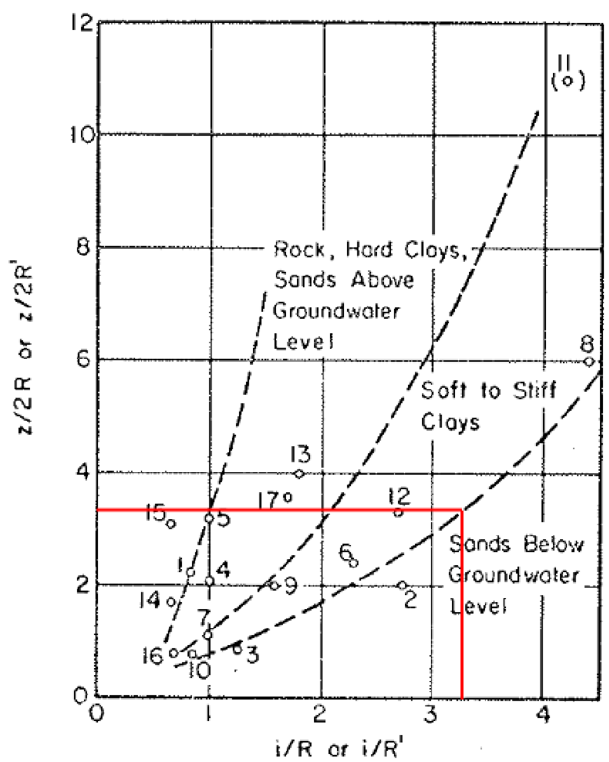


Fig. 9 Relation Between Width of Settlement Trough, as Represented by i/R, and Dimensionless Depth of Tunnel, z/2R, for Various Tunnels in Different Materials

Inflection point $i := Ratio_i \cdot r = 64.724 \cdot \text{ft}$

Settlement trough parameter $k := \frac{i}{z} = 0.498$