Structural Assessment and Project Scoping Report

City of Berkeley - Strawberry Creek Culvert

December 2023

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INTRODUCTION

Located within the City of Berkley (City), the existing Strawberry Creek Culvert transports stormwater beneath the City's infrastructure beginning near the UC Berkely Campus and releases into the San Francisco Bay. The culvert is comprised of three separate segments. Portions of these segments are located within the City's right-of-way while others are located within private property. We understand based on our discussions with the City, that the City is only responsible for those portions located within their right-of-way.

Figure 1 - Eastern Inlet to Culvert Section No. 1

Figure 2 - Eastern Inlet to Culvert Section No. 20

In 2022, following a partial collapse of the southern wall of the existing culvert which occurred below a private residence northwest of the intersection of Roosevelt Avenue and Allston Way, Voss Laboratories, Inc. (Voss) completed visual inspections, delamination surveys, and surface penetrating radar (SPR) scans in each of the various culvert sections. We understand that the partial collapse occurred primarily on private property and resulted in damage to an existing private garage at the ground surface. A portion of the impacted area from this partial collapse also extended into the City's right-of-way. The visual inspections consisted of locating cracks, areas of distressed concrete, and previously repaired areas. Areas of concrete delamination, or the separation of the outer surface layer of concrete from the reinforced section, were also delineated by sounding the various structural elements comprising the reinforced culvert sections. Lastly, SPR scans were completed to determine which segments of culvert consisted of reinforced concrete. It is our understanding that reinforcement size, condition, and layout was not determined. The Voss inspection reports, included in Appendix A, ultimately recommended that a more detailed structural assessment be completed particularly on the unreinforced segments of the culvert.

Figure 3 - Damage and Repairs made to partial collapse within Culvert Section No. 12 (ISI 2023)

Based upon information provided by the City, the City is only responsible for repairing the portions of the three separate continuous segments of culverts located within the City's right-of-way. The first and longest continuous segment of culvert begins at the inlet near the intersection of Oxford Street and Center Street and runs approximately 1 mile west along Allston Way to Sacramento Street. The second segment measures approximately 420 feet in length beginning just north of the intersection between Allston Way and Acton Street. The third and final segment of the culvert measures 790 feet in length beginning immediately south of the Berkeley Yoga Center along Bonar Street. Each of the three segments is comprised of multiple sections that differ in dimension, material, and condition. In total the three segments of culvert are comprised of twenty-four (24) different sections. A total of eighteen (18) of these segments are located within the City's right-of-way. The scope of the following assessment will be limited to only the portions of the 18 sections located within the City's right-of-way.

Figure 4 - Aerial map of the three culverts included within the assessment.

Following the investigations completed by Voss, the City hired Cornerstone Structural Engineering Group (Cornerstone), as a subconsultant to CSW|ST2, to perform a structural assessment of the existing Strawberry Creek Culvert sections that are located within the City's right-of-way. The structural assessment was completed for both the reinforced and unreinforced concrete sections. Based on information provided by CSW|ST2, a total of eighteen (18) different culvert sections are located within the City's right-of-way. As part of the structural assessment, CSW|ST2 also retained both Applied Materials Engineering (AME) and Inspection Services Inc. (ISI) to perform site investigation and materials testing.

FIELD OBSERVATION & TESTING PERFORMED

Prior to field observation and materials testing operation completed by AME and ISI, CSW|ST2 completed a layout survey of the existing culvert segments to assist in locating the various structural sections as well as to determine which portions of the culvert were located within the City's right-of-way.

The site investigation and materials testing operation completed by AME and ISI began on June 6th, 2023. The scope consisted of the following: concrete compressive strength testing utilizing concrete core samples taken from the culvert walls; petrographic analysis on concrete core samples taken from the culvert walls; determining bar reinforcing steel sizes and spacing in reinforced concrete sections; photo documentation of the bar reinforcing steel depicting its condition; thickness measurements of wall, roof, and invert slabs; depth to the top of the culvert; and photo and video documentation of each of the culvert sections located within the City's right-of-way. While Cornerstone was present for the first three days of the site investigation and materials testing operation, due to limited access as a result of not having appropriate personnel on site to safely access the confined space as well as equipment operation issues with the confined space tripod used to lower personnel into the various manhole locations, we were only able to observe a total of six (6) of the eighteen (18) culvert sections located within the City's right-of-way before expending our field data assessment budget. Cornerstone was able to observe Culvert Sections 1 through 4 as well as 20 and 21. At the time of our site visit, there was approximately 6 to 18 inches of water flowing in the culvert segments which made observing the invert slab and joint between the invert slab and the culvert walls very difficult. For the remaining twelve (12) culvert sections that we were not able to observe in person, Cornerstone resorted to relying on a combination of limited photo documentation collected in the field by AME and ISI as well as the photo documentation included in the previous Voss reports to assess the visible condition of the culvert walls, roof, and invert slabs. For the sections that Cornerstone was able to access, we confirmed the general condition of the culvert described in the Voss reports and intermittently sounded the concrete using a hammer to check for delamination. Cornerstone also recorded photographic documentation of various culvert deficiencies within these six (6) culverts sections.

Figure 5 - Access Manhole for Section No. 7.

Figure 6 - Coring Equipment in Culvert Section No. 1

FIELD OBSERVATION AND TESTING RESULTS

Following the field observations and concrete core sampling, the state of each culvert section was evaluated to determine their existing conditions. Documented during both Cornerstone's field visit to culvert sections 1 through 4, 20, and 21 as well as in the photo documentation captured by ISI, several deficiencies within the culvert concrete were noted. These deficiencies included longitudinal cracking along the crown of the arched culvert sections, transverse cracking within the culvert walls, scaling along the walls and invert slabs, and cracking/spalling of the existing concrete throughout the length of the culvert. Additionally, Cornerstone observed exposed reinforcement in the walls and invert slabs of several reinforced concrete sections. Lastly, Cornerstone observed several locations where the invert slab had failed resulting in scour holes ranging from 6 inches to 2 feet deep. A summary of the deficiencies found within each culvert section can be found in Table 1 shown below.

Figure 7 - Exposed Reinforcement in Section No. 8 Invert Slab (ISI 2023)

Existing Culvert Observed Deficiencies	
Culvert Section	Deficiencies Noted
Section No. 1	Moderate Invert Slab Scaling; Spalling/Cracking Around Pipe Penetrations; Minor Abrasion at Wall to Invert Joint; Exposed Wall Reinforcement
Section No. 2	Severe Scaling and Poor Consolidation in Culvert Walls; Longitudinal Cracking in the Crown; Moderate Abrasion at Wall to Invert Joint
Section No. 3	Severe Scaling and Poor Consolidation in Culvert Walls and at Wall to Invert Joint
Section No. 4	Minimal Scaling within Walls and Roof; Holes in Invert Slab up to 2ft Deep
Section No. 5	Light Abrasion and Scaling at Invert within the Water Flowline
Section No. 6	Surface Scaling and Poor Consolidation in Culvert Walls; Longitudinal Cracking in the Crown; Roof Spall Repaired using Timber Formwork
Section No. 7	Light Abrasion and Scaling at Invert within the Water Flowline
Section No. 8	Poor consolidation and Scaling in Culvert Walls; Severe Abrasion of the Invert Slab; Exposed Reinforcement in the Walls and Invert Slab
Section No. 9	Severe Surface Scaling and Poor Consolidation in Culvert Walls; Black Sludge Leaking Through Culvert Walls; 10ft Section of Invert Slab Eroded Away Leaving 2ft Scour Holes; Localized Underming of Culvert Wall
Section No. 10	Poor Consolidation and Scaling in Culvert Walls
Section No. 11	Out of the scope of this assessment since it is located outside of the City's right-of-way
Section No. 12	Scaling at Wall to Invert Joint; Poor Consolidation, Transverse Cracking, and Longitudinal Cracking in the Culvert Walls/Crown; Invert Slab Failure Causing Patial Wall Collapse
Section No. 13	Concrete Abrasion Along Invert Slab; Scaling in Culvert Walls
Section No. 14	Scaling and Poor Consolidation in Culvert Walls
Section No. 15	Out of the scope of this assessment since it is located outside of the City's right-of-way
Section No. 16	Out of the scope of this assessment since it is located outside of the City's right-of-way
Section No. 17	Light Abrasion and Scaling at Invert within the Water Flowline; Gaps Between Sections of Concrete Pipe
Section No. 18	Scaling Concentrated at Wall to Invert Joint; 3ft x 5ft Spall in Crown where the Crown is Bisected by a Sewer Pipe
Section No. 19	Severe Scaling in Invert Slab; 10in Deep 200ft Long Rutted Gap in Invert Slab; Transverse Cracking in Crown; Leaking Sludge; Significant Sediment Build Up at Culvert Exit
Section No. 20	Transverse Cracking in Crown and Walls; Water Seepage Through Cracking; Severe Scaling/Abrasion in Invert Slab; Spall in Crown Concrete due to Steel Pipe Intersecting Culvert Section
Section No. 21	Severe Scaling and Poor Consolidation Throughout Entire Section; Invert Slab Eroded and Washed Out in Several Locations

Table 1 - Existing Culvert Deficiencies Observed

After retrieving concrete core samples from each culvert section, ISI in combination with AME, performed concrete compressive strength tests on each sample to determine the representative strength of each culvert section. One concrete core was sampled from each culvert section that is located within the City's right-of-way. The results of the compressive strength testing completed ranged from a minimum of 1,740 psi in Section 6 up to 9,960 psi in Section 17.

In addition to the compressive strength testing, petrographic analysis was performed on the sampled concrete cores. The petrographic analysis evaluated the conditions of the aggregates, cement, and air void content. The full petrographic report produced by Atlas Technical Consultants can be found in Appendix D The analysis found that most of the concrete contained historic cement while Sections 4, 5, and 17 contained modern cement suggesting that the culvert sections were constructed during significantly different time periods. Additionally, the petrographic analysis found minor evidence of Alkali-Silica Reactivity (ASR) that was not significant enough to cause any significant reduction in strength or durability. Additionally, the petrographic report suggests that future ASR is unlikely to occur.

STRUCTURAL ASSESSMENT

After completion of field observation and materials testing, Cornerstone performed a structural assessment of each culvert section. Structural analysis was completed on each section using the existing geometry of the culvert openings provided by Voss as well as the section thicknesses and reinforcement layout provided by ISI. Each culvert was classified into three types: 1) Arch Culvert; 2) Box Culvert; and 3) Pipe Culvert. A summary of the culvert geometry can be found in Table 2 shown below.

Culvert Section	Existing Culvert Section Properties			
	Culvert Section Type	Culvert Opening Geometry	Available Existing Wall/Invert Data	Available Existing Reinforcement Data
Section No. 1	Box	5.5ft Tall x 7ft Wide	9" Walls; 18" Crown; Invert Unknown	Reinforced Data Unknown
Section No. 2	Arch	5.5ft Tall x 6ft Wide	20" Walls; 14" Crown; 18" Invert	Unreinforced
Section No. 3	Arch	6.5ft Tall x 8ft Wide	22" Walls; 22" Crown; 14" Invert	Unreinforced
Section No. 4	Arch	Unknown Height x 10ft Wide	10" Walls; 5" Crown; 10" Invert	8" Spacing Each Way Bar Sizes Unknown
Section No. 5	Pipe	7ft Diameter	9" Walls	7" Transversely 12" Longitudinally Bar Sizes Unknown
Section No. 6	Arch	7ft Tall x 6ft Wide	15" Walls; 5" Crown; 5" Invert	Unreinforced
Section No. 7	Pipe	6.5ft Diameter	6" Walls	30" Transversely 8" Longitudinally Bar Sizes Unknown
Section No. 8	Arch	5.5ft Tall x 6ft Wide	11" Walls; 9" Crown; 12" Invert	Reinforced Data Unknown
Section No. 9	Arch	7ft Tall x 8ft Wide	14" Walls; 11" Crown; 14" Invert	Unreinforced
Section No. 10	Arch	6.5ft Tall x 8ft Wide	15" Walls; 13" Crown; 13" Invert	Unreinforced
Section No. 11	Out of the scope of this assessment since it is located outside of the City's right-of-way			
Section No. 12	Arch	6.5ft Tall x 8ft Wide	13" Walls; 13" Crown; 14" Invert	Unreinforced
Section No. 13	Arch	6.5ft Tall x 8ft Wide	8" Walls; 12" Crown; 10" Invert	Unreinforced
Section No. 14	Arch	6.5ft Tall x 8ft Wide	24" Walls; 7" Crown; 12" Invert	Unreinforced
Section No. 15	Out of the scope of this assessment since it is located outside of the City's right-of-way			
Section No. 16	Out of the scope of this assessment since it is located outside of the City's right-of-way			
Section No. 17	Pipe	7.5ft Diameter	10" Walls	12" Transversely 24" Longitudinally Bar Sizes Unknown
Section No. 18	Arch	6ft Tall x 8ft Wide	17" Walls; 10" Crown; Invert Unknown	Unreinforced
Section No. 19	Arch	7ft Tall x 8ft Wide	15" Walls; 10" Crown; 5" Invert	Unreinforced
Section No. 20	Arch	6.5ft Tall x 8ft Wide	15" Walls; 10" Crown 5" Invert	Unreinforced
Section No. 21	Arch	6.5ft Tall x 8ft Wide	Unreinforced	Unreinforced

Table 2 - Existing Culvert Section Properties

Figure 8 - Section No. 1 Box Culvert Section

Figure 9 - Example Arch Culvert Section

Figure 10 - Example Pipe Culvert Section (ISI 2023)

Each culvert section was analyzed in accordance with current Caltrans design methodology for culverts using loading in accordance with the 8th edition of the AASHTO LRFD Bridge Design Specifications with California Amendments (AASHTO LRFD). The depth of each section below ground was estimated using survey elevations for the top of roadway and invert slab elevations provided by CSW|ST2. Standard culvert loading was determined for each culvert section, regardless of the classified type. Each culvert was analyzed for HL-93 live loading as described in the AASHTO LRFD which consists of a HS20 design truck and the design lane loading. Permit vehicle loading was not considered for the culvert analysis. Since a geotechnical investigation was not completed for the project, a maximum vertical earth pressure of 140pcf was assumed with a simultaneous maximum and minimum at rest earth pressure of 120pcf and 36pcf respectively in accordance with the standard Caltrans box culvert design parameters shown on Caltrans Standard Plan D82. An example of how the design pressures were computed and applied to each culvert section is shown below in Figure 11.

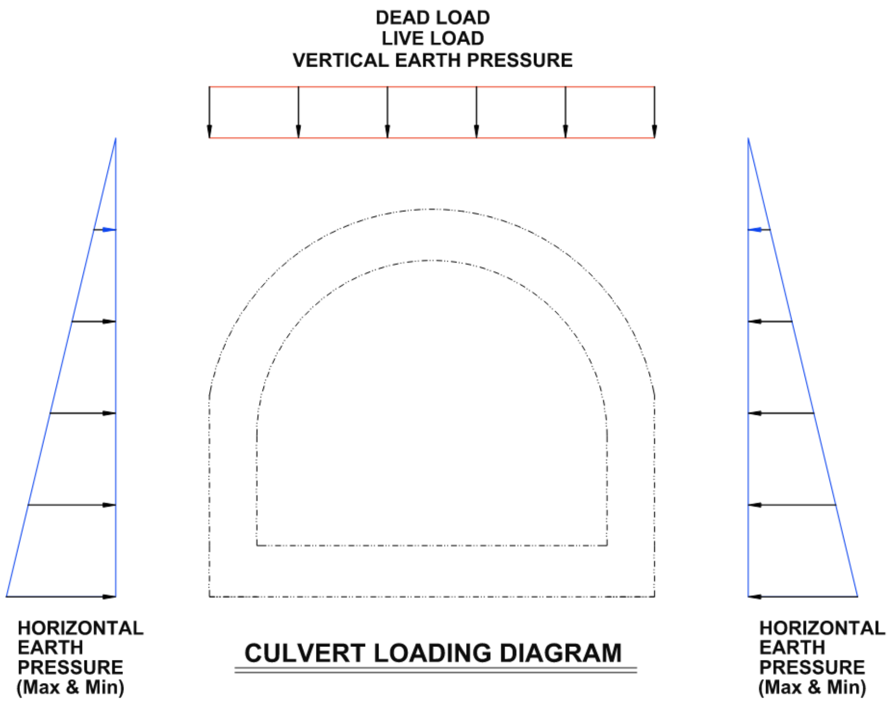

Figure 11 - Example Culvert Loading Diagram

It should be noted, the AASHTO Manual for Bridge Evaluation 3rd Edition (MBE), the current reference utilized by Caltrans and other state transportation agencies to establish inspection procedures and structural load rating evaluation practices for both bridges and buried culverts that meet the National Bridge Inspection Standards (NBIS), provides further commentary on the analysis methods used for buried structures. Section 6B.7 – Posting of Bridges in the MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

Arch Section Analysis

Sections 2 through4, 6, 8 through14, and 18 through21 consisted of arch culvert sections. Once the culvert loading was determined, a SAP2000 analysis model was created for each section modeling the existing wall and arch geometry of the section. The culvert walls were assumed to be pinned to the invert slab. Once the section was modeled, the pressure of each load was determined on a per lineal foot basis and applied in the SAP2000 analysis model. Load combinations were then applied in SAP2000 for both Service I and Strength I cases in accordance with AASHTO LRFD.

The arch portion of the culvert was assumed to be a compression only member while the culvert walls were assumed to take compression, shear, and flexure. The demand compression was investigated and determined to be negligible for the arch sections. Additionally, the shear demand and flexure demand in each wall was computed per the SAP2000 demand model.

The capacity of each member was then analyzed to determine if the existing structure had sufficient structural capacity to resist the demand loading, while neglecting the deficiencies found within each culvert section. Many of the arched culvert sections were determined to be unreinforced during field investigations. The proposed analysis was completed in accordance with the AASHTO LRFD and Caltrans design practices. However, neither the AASHTO LRFD nor Caltrans have design guidance for unreinforced concrete since unreinforced concrete would not be used in modern culvert design. The American Concrete Institute Building Code Requirements for Structural Concrete and Commentary (ACI 318) does have provisions for unreinforced concrete. Therefore, the capacity of each unreinforced concrete arch section was computed in accordance with the ACI 318. The capacity of each reinforced arch section was computed in accordance with the AASTHO LRFD.

Box Section Analysis

The existing box culvert section is found in Section 1 at the easternmost section of the culvert. The box culvert was analyzed similarly to the arch sections with the exception that the roof slab was analyzed to take both shear and moment in accordance with standard box culvert design. Since the section was reinforced, only the AASTHO LRFD design provisions were utilized to determine the shear and flexural capacities of the walls and roof slab. However, reinforcement data was not collected during the field investigation. Therefore, the capacity of the existing roof slab and existing walls cannot be determined at this time. Additional field investigation to determine the size and spacing of the existing reinforcement will be required to complete a structural analysis of the section.

Pipe Section Analysis

The existing pipe culvert sections were found in Sections 5, 7, and 17. Once the pressures above the pipes were determined, the structural demands on the sections were determined in accordance with the *Behavior and Design of Buried Concrete Pipes* (BDBCP) produced by the Nebraska Department of Transportation. The analysis document provides empirical coefficients to determine the shear, moment, and compression experienced by the section based upon the crown pressure, loading type, and installation type. Since the installation method of each culvert section is unknown, the method yielding the maximum structural demands in each pipe section was used conservatively.

The capacity of the pipe sections were analyzed in accordance with Chapter 5 of the AASHTO LRFD. The concrete pipe sections were analyzed for flexure, minimum reinforcement ratios, crack width control, shear, and radial tension. Each limit state was checked using the demands computed using the BDBCP to determine if the existing sections were adequate for the assumed loading.

ANALYSIS RESULTS

Section 1:

Culvert Section 1 consists of a reinforced concrete box culvert. However, neither the size nor the spacing of the existing bar reinforcing steel was provided by either ISI or AME. The section measures 7ft wide by 5.5ft tall and extends approximately 90ft into the eastern entrance of the culvert. During our field observations, the concrete appeared to be in good condition with moderate scaling on the invert slab, minor cracking in the culvert walls, spalls/cracking around pipe penetrations, and minor abrasion/erosion of the concrete near the joint between the top of the invert slab and the walls. Additionally, several exposed bars of reinforcement were found near the pipe openings that outlet stormwater runoff into the culvert. We did not note significant signs of structural distress during our time in this culvert section.

Figure 13 - Section No. 1 Typical Section

Figure 12 - Exposed Reinforcement and Spalling Concrete Around Pipe Inlet

As previously stated, reinforcement data for Culvert Section 1 was not collected during the field investigation and materials testing operation. Therefore, the capacity of the existing reinforced concrete roof slab and existing walls could not be determined. However, since we did not note any significant signs of structural distress, we do not feel that additional field investigation to determine the size and spacing of the existing bar reinforcing steel will be required to develop repair and rehabilitation recommendations for this section. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 2:

Culvert Section 2 consists of an unreinforced concrete arch culvert measuring 6ft wide by 5.5ft tall. During our field observations, the concrete appeared to be in fair condition. We noted the same areas of severe scaling and poor consolidation in the existing culvert walls first noted in Voss's report. Additionally, longitudinal cracking was observed along the crown throughout the arch section. Concrete abrasion was also noted in the walls in the vicinity of the joint with the invert slab.

Figure 14 – Section No. 2 Typical Section

Figure 16 - Longitudinal Cracking of Culvert Crown

Figure 15 – Scaling, Cracking, and Segregation of Culvert Wall

Our structural analysis determined the section to have sufficient shear and flexural capacity. The structural calculations for this section can be found in Appendix G.

While our structural analysis completed for this section resulted in the existing culvert elements having sufficient structural capacity, we believe the deterioration noted warrants repairs aimed at extending the service life of the culvert and preventing future failures. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 3:

Culvert Section 3 consists of an unreinforced concrete arch culvert measuring 8ft wide by 6.5ft tall. During our field observations, the concrete appeared to be in fair condition with some areas exhibiting severe scaling and poor consolidation within the lower portions of the existing culvert walls. Severe scaling and erosion were also noted within the wall near the joint with the invert slab. Both the severe scaling and poor consolidation were noted in the Voss reports.

Figure 17 - Section No. 3 Typical Section

Our structural analysis determined the section to have sufficient shear and flexural capacity. The structural calculations for this section can be found in Appendix G.

While our structural analysis completed for this section resulted in the existing culvert elements having sufficient structural capacity, we believe the deterioration noted warrants repairs aimed at extending the service life of the culvert. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 4:

Culvert Section 4 consists of a reinforced concrete arch culvert measuring 10ft wide with an estimated height of 5.5ft. The roof of this section is relatively flat in comparison to the rise of the walls, giving the culvert a wide but short cross section. The concrete within the roof and walls was in fair condition and appeared to have been repaired previously. Minimal scaling and sound concrete were found throughout the walls and roof. While the roof and the walls were found to be in good condition, the invert slab was observed to have been completely lost in some locations with water pooling as deep as 2ft in these areas. The extents of the invert slab failure could not be determined at the time of our site visit. Repair of the invert slab is critical to maintaining the structural integrity of the culvert section as will be discussed more in depth with respect to Culvert Section 12 where the undermining of the existing invert slab appears to have resulted in the failure of the adjacent culvert wall ultimately damaging private property at the surface.

Figure 18 - Section No. 4 Typical Section

ISI's field observation determined that the section was reinforced with rebar spaced at 8 inches both longitudinally and transversely. The size of the reinforcement was not determined during the field investigation. The reinforcement size was assumed to consist of No. 5 bars for the purpose of completing preliminary structural analysis. The structural analysis of the section determined the walls to have insufficient shear and flexural capacity. The structural calculations for this section can be found in Appendix G. However, while the structural analysis resulted in insufficient demand to capacity ratios, neither the walls nor the arched roof exhibited any significant signs of structural distress during our site visit. Since signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further bar reinforcing steel investigations at this time to determine the actual size of reinforcing steel present nor do we believe any further structural analysis is necessary.

While we did not note any significant signs of structural distress in the culvert section, we believe that structural repairs to the invert slab as well as a supplemental coating are necessary to maintain the structural integrity of culvert and extend the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 5:

Culvert Section 5 consists of a 7ft diameter reinforced concrete pipe section. While Cornerstone was not able to observe this section in the field, ISI determined bar reinforcing steel was present and spaced at 7 inches transversely and 12 inches longitudinally. Based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the concrete was noted to be in fair condition with light scaling and abrasion at the invert within the water flowline.

Figure 19 - Section No. 5 Typical Section (ISI 2023)

The structural analysis of the section determined the pipe to have sufficient shear and flexural capacity. The radial tension, crack width control, and minimum reinforcement for this section were also determined to be sufficient. The structural calculations for this section can be found in Appendix G.

While our structural analysis completed for this section resulted in the existing culvert elements having sufficient structural capacity, we believe the deterioration noted warrants repairs aimed at extending the service life of the culvert. Potential rehabilitation measures are shown schematically as described in the Rehabilitation Recommendations of the report.

Section 6:

Culvert Section 6 consists of an unreinforced concrete arch culvert measuring 6ft wide by 7ft tall. While Cornerstone was not able to observe this section in the field, based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the existing culvert concrete was noted as having surface scaling and poor consolidation in the walls. Voss also noted longitudinal cracking exceeding an 1/8" in width in the crown of the arch section. Additionally, a section of roof slab appeared to be repaired using wood formwork to seal the cracked crown concrete (see Figure 16).

Figure 21 – Section No. 6 Typical Section (ISI 2023)

Figure 20 – Culvert Roof Repair (ISI 2023)

The structural analysis of the section determined the walls to have insufficient shear and flexural capacity. The structural calculations for this section can be found in Appendix G. While the structural analysis resulted in insufficient demand to capacity ratios, neither the walls nor the arched roof exhibited any significant signs of distress. Since significant signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis at this time.

While we did not note any significant signs of structural distress in the culvert section, we believe that structural repairs to the cracked culvert crown as well as a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 7:

Culvert Section 7 consists of a 6.5ft diameter reinforced concrete pipe section. While Cornerstone was not able to observe this section in the field, ISI determined bar reinforcing steel was present and spaced at 30 inches transversely and 8 inches longitudinally. Based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the concrete was noted to be in fair condition with light scaling and abrasion at the invert within the water flowline.

Figure 22 - Section No. 7 Typical Section (ISI 2023)

The structural analysis of the section determined the walls to have sufficient shear and flexural capacity. The radial tension and crack width control for this section was determined to be sufficient, however the minimum reinforcement was insufficient. The structural calculations for this section can be found in Appendix G.

While our structural analysis completed for this section resulted in the existing culvert elements having sufficient structural capacity, we believe the deterioration noted warrants repairs aimed at extending the service life of the culvert. Potential rehabilitation measures are shown schematically as described in the Rehabilitation Recommendations of the report.

Section 8:

Culvert Section 8 consists of a reinforced concrete arch culvert measuring 6ft wide by 5.5ft tall. While Cornerstone was not able to observe this section in the field, based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the existing wall concrete exhibited poor consolidation with scaling. Severe abrasion of the invert slab was observed resulting in the invert slab reinforcement becoming exposed. Additionally, exposed reinforcement was noted within the walls of the arch section. The Voss report states that the section is unreinforced, but the ISI report observed exposed #5 reinforcement within the invert slab and the walls of the culvert. ISI determined the bar reinforcing steel was spaced at 8 inches on center in the invert slab, but did not provide spacing for the bar reinforcing steel in arch section of the culvert.

Figure 24 - Section No. 8 Typical Section (ISI 2023)

Figure 23 - Exposed Invert Slab Reinforcement (ISI 2023)

Due to the lack of information regarding the existing wall reinforcement, the structural analysis performed considered the section to be unreinforced. The structural analysis of the section determined the walls to have sufficient shear capacity, but insufficient flexural capacity. The structural calculations for this section can be found in Appendix G.

While our structural analysis completed for this section resulted in the existing culvert elements having insufficient structural capacity, neither the walls nor the arched roof exhibited any significant signs of structural distress. Since significant signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis or materials testing at this time. However, while we did not note any significant signs of structural distress in the culvert section, we believe that structural repairs to repair the heavily abraded sections of invert slab as well as a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 9:

Culvert Section 9 consists of an unreinforced concrete arch culvert measuring 8ft wide by 7ft tall. While Cornerstone was not able to observe this section in the field, based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the existing culvert concrete was noted as having severe surface scaling, poor consolidation in the existing wall concrete, and black sludge leaking into the culvert at the base of the walls over a 40ft long segment. Lastly, Voss noted there was a 10ft section of culvert where the floor slab was eroded away with 2ft deep scour holes which had undermined a localized portion of the adjacent culvert wall.

Figure 26 - Section No. 9 Typical Section (ISI 2023)

Figure 25 – Damaged Invert Slab (ISI 2023)

The structural analysis of the section determined the walls to have sufficient shear capacity, but insufficient flexural capacity. The structural calculations for this section can be found in Appendix G. While the structural analysis completed for this section resulted in the existing culvert elements having insufficient structural capacity, neither the walls nor the arched roof exhibited any significant signs of structural distress. Since significant signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis or materials testing at this time. However, while we did not note any significant signs of structural distress in the culvert section, we believe that structural repairs to repair the leaking areas at the base of the walls as well as the scoured sections of invert slab as well as a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 10:

Culvert Section 10 consists of an unreinforced concrete arch culvert measuring 8ft wide by 6.5ft tall. While Cornerstone was not able to observe this section in the field, based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the existing culvert concrete exhibited scaling and poor consolidation in the existing walls.

Figure 27 - Section No. 10 Typical Section (ISI 2023)

The structural analysis of the section determined the walls to have sufficient shear capacity, but insufficient flexural capacity. The structural calculations for this section can be found in Appendix G. While the structural analysis completed for this section resulted in the existing culvert elements having insufficient structural capacity, neither the walls nor the arched roof exhibited any significant signs of structural distress. Since significant signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis or materials testing at this time. However, while we did not note any significant signs of structural distress in the culvert section, we believe that structural repairs in the form of a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 12:

Culvert Section 12 consists of an unreinforced concrete arch culvert measuring 8ft wide by 6.5ft tall. While Cornerstone was not able to observe this section in the field, based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the existing culvert concrete exhibited scaling concentrated near the joint between the culvert walls and the invert slab. Further, poor consolidation, transverse cracking, and longitudinal cracking were also noted throughout the section. Failure of the invert slab was observed at several locations resulting in holes in the floor ranging from 6in to 2ft deep. The invert slab failures are believed to have resulted in the localized failure of the culvert wall as there was nothing to support the wall which remained subject to lateral earth pressures. Temporary repairs were made using timber and sandbags at the wall failure which resulted in damage to private property at the surface level.

Figure 29 - Section No. 12 Typical Section (ISI 2023)

Figure 28 - Damaged Culvert Wall and Temporary Repairs Made (ISI 2023)

The structural analysis of the section determined the walls to have sufficient shear capacity, but insufficient flexural capacity. The structural calculations for this section can be found in Appendix G. While the structural analysis completed for this section resulted in the existing culvert elements having insufficient structural capacity, neither the walls nor the arched roof exhibited any significant signs of structural distress outside of the areas where the invert slab had failed and was no longer present. Since significant signs of structural distress were not noted outside of these areas and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis or materials testing at this time. At this time, we believe that structural repairs consisting of reconstructing the failed areas of invert slab, concrete crack repairs, and the use of a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 13:

Culvert Section 13 consists of an unreinforced concrete arch culvert measuring 8ft wide by 6.5ft tall. While Cornerstone was not able to observe this section in the field, based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the existing culvert concrete appeared to be in fair condition with concrete abrasion noted along the invert slab and scaling in the walls. Voss noted that a repair overlay was previously performed and appeared to be well bonded.

Figure 30 - Section No. 13 Typical Section (ISI 2023)

The structural analysis of the section determined the walls to have sufficient shear capacity, but insufficient flexural capacity. The structural calculations for this section can be found in Appendix G. While the structural analysis completed for this section resulted in the existing culvert elements having insufficient structural capacity, neither the walls nor the arched roof exhibited any significant signs of structural distress. Since significant signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis or materials testing at this time. At this time, we believe that structural repairs consisting of a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 14:

Culvert Section 14 consists of an unreinforced concrete arch culvert measuring 8ft wide by 5ft tall. While Cornerstone was not able to observe this section in the field, based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the existing culvert concrete appeared to be in fair condition with scaling and poor concrete consolidation noted in the walls.

Figure 31 - Section No. 14 Typical Section (ISI 2023)

The structural analysis of the section determined the walls to have sufficient shear capacity, but insufficient flexural capacity. The structural calculations for this section can be found in Appendix G. While the structural analysis completed for this section resulted in the existing culvert elements having insufficient structural capacity, neither the walls nor the arched roof exhibited any significant signs of structural distress. Since significant signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis or materials testing at this time. At this time, we believe that structural repairs consisting of a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 17:

Culvert Section 17 consists of a 7.5ft diameter reinforced concrete pipe section. While Cornerstone was not able to observe this section in the field, ISI determined bar reinforcing steel was present and spaced at 12 inches transversely and 24 inches longitudinally. Based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the concrete was noted to be in fair condition with light scaling and abrasion at the invert within the water flowline. An elevation change of approximately 4ft was noted at the beginning of Section 17. Additionally, gaps between the segments of reinforced concrete pipe were observed throughout the section.

Figure 32 - Section No. 17 Typical Section (ISI 2023)

The structural analysis of the section determined the walls to have sufficient shear and flexural capacity under the anticipated culvert demands. The radial tension, crack width control, and minimum reinforcement for this section were also determined to be sufficient. The demand structural analysis for this section can be found in Appendix G.

While our structural analysis completed for this section resulted in the existing culvert elements having sufficient structural capacity, we believe the deterioration noted warrants repairs aimed at extending the service life of the culvert. Potential rehabilitation measures are shown schematically as described in the Rehabilitation Recommendations of the report.

Section 18:

Culvert Section 18 consists of an unreinforced concrete arch culvert measuring 8ft wide by 6ft tall. While Cornerstone was not able to observe this section in the field, based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the concrete exhibited scaling concentrated at the joint between the walls and invert slab. Additionally, a 3ft x 5ft concrete spall was noted in the roof of the arch section where the crown of the culvert is bisected by a sewer pipe.

Figure 34 – Spalled Concrete Around Intercepting Steel Pipe (ISI 2023)

Figure 33 – Section No. 18 Typical Section (ISI 2023)

The structural analysis of the section determined the walls to have sufficient shear capacity, but insufficient flexural capacity. The structural calculations for this section can be found in Appendix G. While the structural analysis completed for this section resulted in the existing culvert elements having insufficient structural capacity, neither the walls nor the arched roof exhibited any significant signs of structural distress. Since significant signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis or materials testing at this time. However, we believe that structural repairs consisting of a repairing the concrete spall in the vicinity of the bisecting sewer piper as well as a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 19:

Culvert Section 19 consists of an unreinforced concrete arch culvert measuring 8ft wide by 7ft tall. While Cornerstone was not able to observe this section in the field, based on the photos provided to Cornerstone by ISI as well as previous field observations made by Voss, the existing culvert concrete exhibited severe scaling concentrated on the invert slab. Additionally, the invert slab was rutted causing a 10in deep gap in the invert for approximately 200ft of culvert length. Transverse cracking was found within the crown of the culvert allowing sludge to leak into the culvert. Lastly, significant sediment build up was observed near the exit of the culvert.

Figure 36 – Black Sludge Leaking Through Culvert Wall (ISI 2023)

Figure 35 – Section No. 19 Typical Section (ISI 2023)

The structural analysis of the section determined the walls to have sufficient shear capacity, but insufficient flexural capacity. The structural calculations for this section can be found in Appendix G. While the structural analysis completed for this section resulted in the existing culvert elements having insufficient structural capacity, neither the walls nor the arched roof exhibited any significant signs of structural distress. Since significant signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis or materials testing at this time. However, we believe that structural repairs consisting of a repairing the concrete invert slab, repairing the existing transverse crack resulting in sludge leaking into the culvert section, as well as a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 20:

Culvert Section 20 consists of an unreinforced concrete arch culvert measuring 8ft wide by 6.5ft tall. During field observations, the wall concrete appeared to be in fair condition. However, transverse cracking was found within portions of the crown and walls, allowing water to seep into the culvert. The invert slab concrete exhibited sever scaling due to abrasion. Additionally, a large spall of concrete within the roof was observed due to a steel pipe that intersects the crown of the culvert.

Figure 37 - Section No. 20 Typical Section

Figure 38 - Spalled Concrete at Intercepting Steel Pipe

The structural analysis of the section determined the walls to have insufficient shear and flexural capacity. The structural calculations for this section can be found in Appendix G. While the structural analysis completed for this section resulted in the existing culvert elements having insufficient structural capacity, neither the walls nor the arched roof exhibited any significant signs of structural distress. Since significant signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis or materials testing at this time. However, we believe that structural repairs consisting of repairing the concrete invert slab, repairing the existing concrete spall in the vicinity of the intersecting steel pipe, as well as a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

Section 21:

Culvert Section 21 consists of an unreinforced concrete arch culvert measuring 8ft wide by 6.5ft tall. During field observations, the concrete was observed to have severe scaling and poor consolidation throughout the entire section. The invert slab was also observed to be eroded and washed out in several locations.

Figure 39 – Section No. 21 Typical Section

Figure 40 – Spalling and Scaling of Culvert Walls

The structural analysis of the section determined the walls to have insufficient shear and flexural capacity. The structural calculations for this section can be found in Appendix G. While the structural analysis completed for this section resulted in the existing culvert elements having insufficient structural capacity, neither the walls nor the arched roof exhibited any significant signs of structural distress. Since significant signs of structural distress were not noted and given that our assumed loading is conservative as it does not consider soil arching, we do not recommend any further structural analysis or materials testing at this time. However, we believe that structural repairs consisting of a repairing the concrete invert slab as well as a supplemental coating would be beneficial towards maintaining the structural integrity of culvert and extending the structure's remaining service life. Potential rehabilitation measures are shown schematically and described in the Rehabilitation Recommendations of the report.

REHABILITATION RECOMMENDATIONS

Following the analysis completed for each of the culvert sections, we are recommending repair and rehabilitation measures aimed at extending the service life of each culvert section included in the project's scope. These measures are intended to ensure the various sections are watertight and do not allow for undermining of existing invert slabs and surrounding soil backfill which we believe led to the failure of the culvert wall located in Section 12. The conceptual details for rehabilitating the various culvert sections are broken down into the three main section types: arch culvert, box culvert, and pipe culvert. The conceptual details for each of the main culvert section types are discussed below.

Arch Section Rehabilitation Recommendations:

As previously discussed, the various arch sections exhibited longitudinal and transverse cracking, concrete spalling, invert slab failures, undermining of backfill soils, and severe concrete scaling. To repair the arch culvert sections, two primary rehabilitation concepts were analyzed as discussed below. The concepts consist of a geopolymer lining as well as a shotcrete lining.

Geopolymer Solution

During our initial discussions with the City prior to beginning work on this structural assessment, the City requested that Cornerstone investigate the use of a geopolymer solution for portions of the culvert that require rehabilitation. Therefore, the first rehabilitation solution considered for the arch sections was the use of a geopolymer lining to coat the inside of the existing culvert section. The geopolymer lining consists of a high-performance fiber reinforced mortar that is sprayed similarly to shotcrete on the surface of the existing culvert. Layers of thin welded wire mesh reinforcement are provided as the geopolymer is placed. This geopolymer solution was utilized by various local agencies including the City of Orinda on their Group 1 Storm Drain Lining Project. One of the primary reasons for selecting the use of a geopolymer as the repair solution on Storm Drain Lining Project was how quickly after geopolymer placement water was allowed to flow within the culvert. In this case, water was allowed to flow through the culvert two hours following placement. For comparison, had shotcrete been utilized, the permitting agencies would have required the City of Orinda to wait 28 days before water would be allowed to flow over the newly lined culvert surfaces.

Cornerstone has coordinated with GeoTree Solutions (GeoTree), a company producing the proprietary GeoSpray Geopolymer mortar used on the City of Orinda Group 1 Storm Drain Lining Project, to determine an estimate of the required material thickness as well as the construction cost for the geopolymer solution in each culvert section. Their provided thickness estimates required to rehabilitate each of the various culvert sections as part of this project are included in Appendix H and vary between 1.5” and 2”. An example of the geopolymer solution is shown below in Figure 41. GeoTree Solutions GeoSpray Geopolymer has a 50-year design life. While our primary intent for utilizing the geopolymer as a supplemental coating Is to ensure the culvert sections are watertight and prevent future undermining of backfill soils, it should be noted that the high strength material will also have the added benefit of being designed by GeoTree to provide full structural support of the existing culvert.

Figure 41–- Example Geopolymer Application (GeoTree 2023)

During construction, the geopolymer will be designed and provided by the Contractor as a deferred submittal. Layout drawings and a performance specification will be provided by the Design Team as the construction documents. The Contractor's selected geopolymer provider will provide signed and stamped design documents and structural calculations for each geopolymer section in accordance with the specification requirements.

Prior to installation of the geopolymer, significant preparation work must be completed such that the geopolymer can be applied uniformly on the surface. The preparation work includes removing all soil and debris from the culvert, repairing significant cracks located at the crown and spring lines of the arch, and filling all concrete voids. One of the largest repairs that will need to be made prior to applying the geopolymer is repairing the invert slab failures. The large voids in the invert slabs will need to be filled with grout prior to application such that the costly geopolymer material is conserved. Additionally, any large cracks in the culvert will need to be repaired using injection grouting such that no voids are present above the geopolymer structure. Lastly, the eroded joint between the culvert walls and the invert slabs will need to be repaired such that a uniform surface is provided. This may be accomplished by dowelling reinforcement into the walls and invert slab and placing a small concrete pad such that the eroded joint is filled with sound concrete. Typical concrete repair details will be provided in the construction documents; however, it is anticipated that it will be the responsibility of the City's construction management personnel to determine where each of these repairs is required prior to applying the geopolymer coating.

Shotcrete Solution

While we also considered the use of a supplemental shotcrete lining, we ultimately did not recommend its use for the following reasons:

- A thicker overlay measuring 6" to 8" thick would be required
- The thicker section would reduce the hydraulic capacity of the culvert
- In addition to be requiring a thicker overlay, bar reinforcing steel would also need to be placed within the shotcrete section and drill and bonded dowels would also be required.
- Based on the information obtained regarding the regulatory permits on the City of Orinda Group 1 Stormdrain Lining Project, we would anticipate running into the same permitting issues of not being able to open the various culvert segments up to flow on the newly installed shotcrete surfaces for up to 28 days due to ecotoxicity concerns.
- Lastly, not being able to open the newly placed shotcrete surfaces to creek flows for up to 28 days was anticipated to increase the cost of construction as a temporary bypass would be required for up to four weeks in each section greatly complicating construction staging. Similar permit restrictions were required on the City of Orinda Group 1 Storm Drain Lining Project.

For the reasons listed above, we concur with the City's suggestion of using a sprayed geopolymer lining.

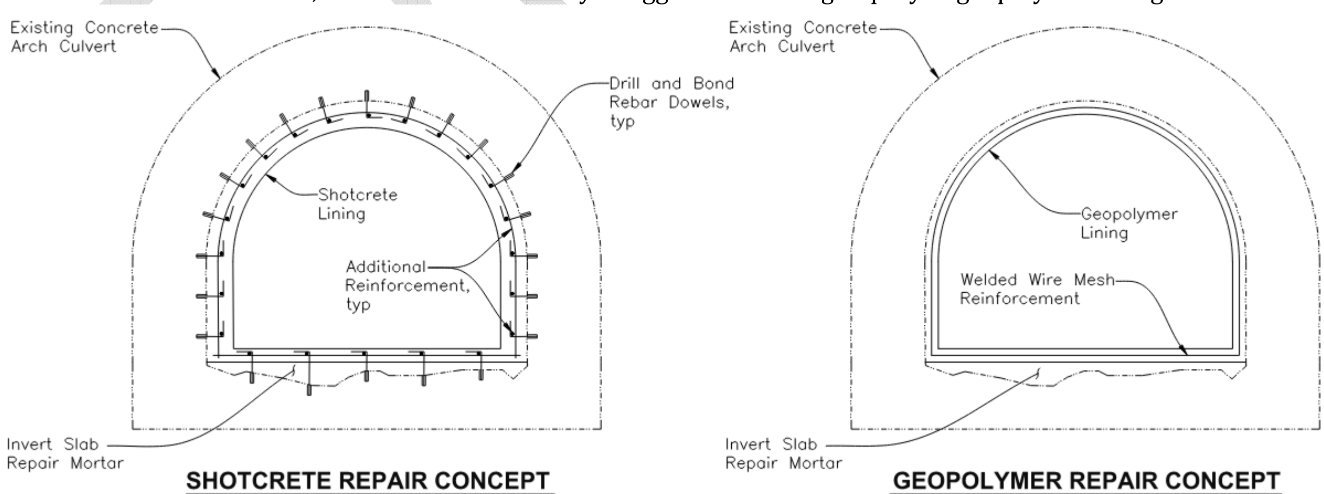

Figure 42 - Preliminary Repair Concepts for the Arched Culvert Sections

Pipe Section Rehabilitation Recommendations:

The structural analysis and evaluation of the pipe sections showed that the reinforced concrete pipes appear to meet current ASSHTO Standards for pipe culverts. However, scaling and spalling was observed in the inverts of the pipe sections. To repair the inverts within the pipe culvert sections, two rehabilitation concepts were analyzed as discussed below. The concepts consist of using the same geopolymer lining discussed for the arch culvert sections as well as a shotcrete invert repair.

Since the structural analysis resulted in the pipe culvert sections having sufficient capacity to resist the current AASHTO prescribed loading, the rehabilitation measures would be completed to extend the service life of the sections. Scaling and spalling of the invert portions of the pipes were observed during the field investigation. Therefore, Cornerstone recommends repairing the invert sections and protecting them from future erosion. This can be accomplished by applying a geopolymer lining throughout the pipe similar to the arch culvert sections. The other solution considered for protecting the existing inverts is to apply a 6" layer of shotcrete along the portion of the pipe culvert located below the ordinary highwater mark. The two rehabilitation concepts are shown in Figure 42 below.

For the same reasons as those given regarding the arch culvert sections, we again concur with the City's suggestion of using a sprayed geopolymer lining rather than the shotcrete solution.

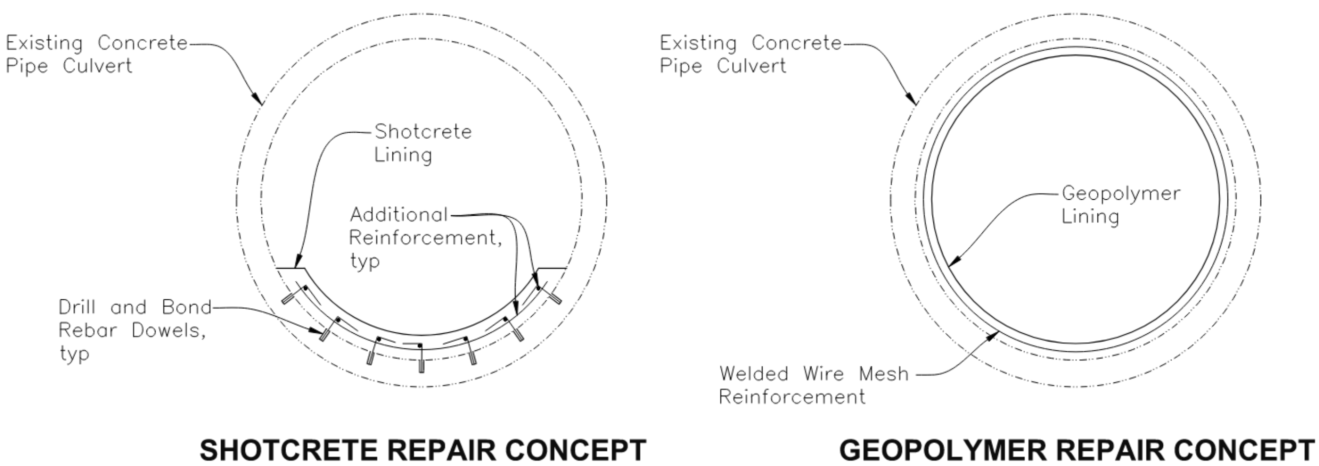

Figure 43 - Preliminary Repair Concepts for the Pipe Culvert Sections

Box Section Rehabilitation Recommendations:

The structural analysis completed for the box culvert section (Section 1) determined that the existing culvert walls and roof slab do not have sufficient shear or flexural capacity to meet the current AASHTO loading standards. The structural behavior of a box culvert acts much differently than the pipe/arch sections discussed previously since the members act as frame elements subject to shear and flexure rather than as compression elements. However, the two rehabilitation alternatives developed consisting of 1) shotcrete lining and 2) geopolymer lining are similar to the arch culvert sections. However, it is worth nothing that for the geopolymer repair alternative, carbon fiber wrap with also be required in addition to the geopolymer lining. GeoTree has successfully installed their proprietary RenewWrap CFRP Wrap on similar past projects.

For the same reasons as those given regarding the arch culvert and pipe culvert sections, we again concur with the City's suggestion of using a sprayed geopolymer lining rather than the shotcrete solution.

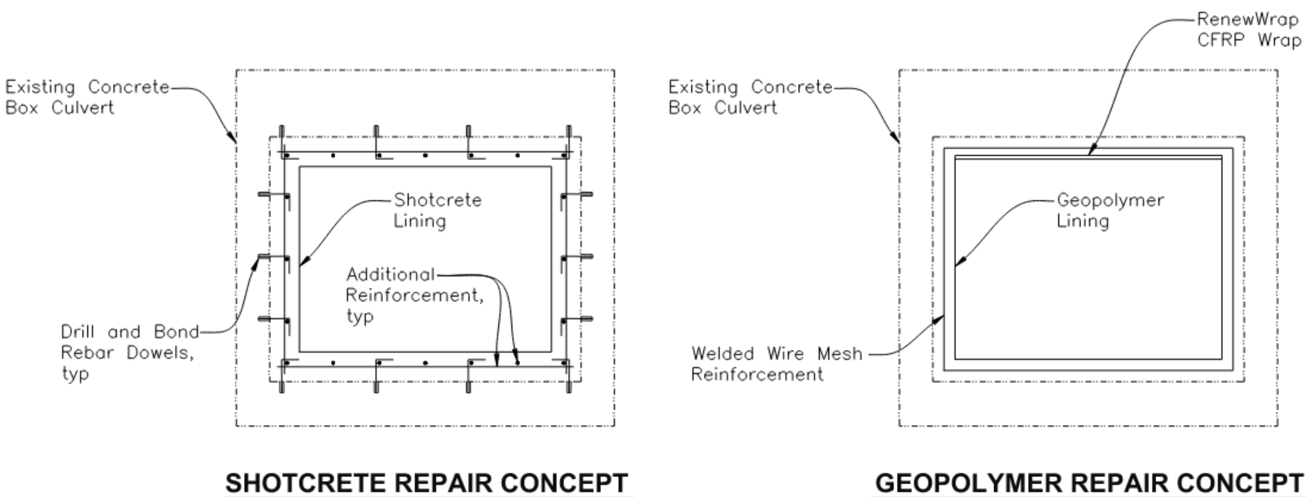

Figure 44 - Preliminary Repair Concepts for Box Culvert Section

CONSTRUCTABILITY

Due to the length and location of the existing culvert sections, constructability was one of the main factors considered when developing the various rehabilitation concepts. The existing culvert runs beneath the City's infrastructure including streets, sidewalks, buildings, residential homes, and parks. To minimize impacts to the public and overall construction cost, we only considered rehabilitation alternatives that could be implemented from within the culvert.

The largest of the existing culverts extends over 5,300 feet from beginning to end. Therefore, access to the inside of the culvert sections is limited to the open channel at the beginning/end of the culvert as well as the available intermediate manholes along the length of the structure. There are several manholes and drainage inlets that could theoretically be used for construction access. Unfortunately, based on our discussions with GeoTree, the smallest diameter manhole that can be utilized by potential contractors to accommodate personnel, equipment, and materials is 3ft. The existing culverts manholes are 2ft in diameter. Therefore, new larger diameter manholes and/or vault access openings will be required to be constructed as part of this project. The recommended geopolymer lining will be batched above grade and then pumped down into the culvert, reducing the amount of equipment required within the confined workspace. Typically, the staging area needed to accommodate raw materials, the geopolymer batching equipment, generators, confined space air blowers and ventilation equipment, and geopolymer pump measures 15ft wide by 60ft long. These staging areas will need to be set up at each access opening constructed and utilized by the contractor. Based upon conversations with GeoTree, geopolymer lining can be pumped up to a horizontal distance of 700ft. Therefore, the contractor will need multiple new culvert access openings to accommodate the various construction staging areas along the length of the structure longest continuous segment of culvert.

Construction of the proposed improvements will require dry working conditions. Based on our discussions with CSW|ST2, we understand that the culvert carries water year round. If water is present within the channel, a temporary bypass pipe will need to be used to allow water to flow through a pipe and extend beyond the portion of the culvert under construction and the coating and various other culvert repairs will need to be provided in stages.

Figure 45 - Example Temporary Water Bypass During Construction (GeoTree 2023)

Figure 46 – Example Construction Staging Area (GeoTree 2023)

PRELIMINARY STRUCTURAL CONSTRUCTION COST ESTIMATES

Our preliminary estimate of the structural construction cost is presented in the table below. The estimate for the geopolymer lining is conservatively taken from the high end of the preliminary estimate provided by GeoTree. While we don't have quantities for the various culvert repairs that we anticipate being required prior to constructing the geopolymer lining, the estimate presented is based on bid data from a similar culvert repair project completed in the City of Redwood City in 2016. Assuming a 5% construction cost escalation over each of the seven years since the reference project was bid and constructed, we roughly estimate the cost of the various repairs to be approximately $215 per lineal foot of culvert to receive geopolymer lining. Please note the cost of the various culvert repairs is a ballpark estimate for planning purposes only and the actual cost may vary significantly depending upon the condition of the culvert segments which could not be fully assessed based on the limited site photos provided to us and our limited field observations. The costs do not account for traffic handling, permitting, dewatering, new culvert access structures, utility coordination, etc.

GeoTree GeoSpray Geopolymer Lining	$3,500,000
Various Additional Culvert Repairs ($210 per Lineal Foot)	$750,000
Subtotal	$4,250,000
Contingency (25%)	$1,062,500
Preliminary Structural Construction Cost Estimate	**$5,312,500**

NEXT STEPS PRIOR TO FINAL DESIGN

Prior to beginning Final Design, the following services will be required:

- CSW|ST2 to verify the culvert's have sufficient hydraulic capacity to accommodate the proposed geopolymer overlay
- Geotechnical engineer to provide recommendations for subgrade preparation below segments of culvert requiring invert slab repair

Lastly and as previously mentioned, Cornerstone understands based on direction received from the City that we are only responsible for repairing culvert deficiencies that exist within the City's right-of-way. With that said, based on our observations of the field data collected by Voss, AME, and ISI as well as our own observations made during our limited time in the culvert, similar conditions found within the City's right-of-way also exist outside the City's right-of-way. Cornerstone recommends the City inform private property owners of the existence of the Strawberry Creek Culvert within their parcels as well as the conditions observed as part of all studies completed to date.

REFERENCES

American Association of State Highway and Transportation Officials, *AASHTO LRFD Bridge Design Specifications.* Eighth Edition. Washington, D.C. 2019.

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Appendices

Appendix A: Voss Labs Initial Investigation Reports

Appendix B: Applied Materials & Engineering Inc. Investigation Report

Appendix C: Inspection Services Inc. Investigation Report

Appendix D: ATLAS Petrographic Evaluation Report

Appendix E: 30% Level Schematic Drawings

Appendix F: 30% Level Schematic Cost Estimate

Appendix G: Structural Analysis of Existing Culvert Sections

Appendix H: Structural Analysis of Rehabilitated Culvert Sections

Appendix A
Voss Labs Initial Investigation Reports

October 14th, 2022 VL Project No. 22049

Mr. Robert Stevens
CSW/Stuber-Stroeh Engineering Group
45 Leveroni Ct.
Novato, CA 94949

RE: Berkeley Culvert
Concrete Investigation
Berkeley, California

Dear Mr. Stevens,

Voss Laboratories, Inc. (VL) has completed our visual inspection, testing, and evaluation of the above mentioned structure. The purpose of the evaluation was to develop an understanding of the condition of concrete throughout the culvert. This report includes a brief background, a description of field inspection, a sketch of findings, and a summary of results.

BACKGROUND

The culvert is located in Berkeley, California and travels roughly 1 mile from Oxford St. to Sacramento St. along Allston Way. It is comprised of multiple sections that differ in dimension, material, and condition. The culvert opens to Strawberry creek on both ends, one near the University of Berkeley and the other within private property near Sacramento St. A visual inspection was performed by VL engineers on September 13th and 14th of 2022.

FIELD TESTING PROCEDURES

Visual Inspection

The visual inspection consists of locating cracks, areas of distressed concrete and previously repaired areas. Inspectors are trained to recognize concrete conditions following the American Concrete Institute 201.1R, "Guide for Making a Condition Survey of Concrete in Service." Scaling of concrete surfaces is defined as the flaking or peeling away of the surface concrete. The disintegration of the paste component of concrete by acid attack results in scaling of the concrete surface. ACI breaks down the severity of scaling using the following terms:

1. *Light Scaling* – loss of surface mortar without exposure of coarse aggregate.
2. *Medium Scaling* – loss of surface mortar of 0.2 to 0.4 inches in depth and exposure of coarse aggregate.
3. *Severe Scaling* – loss of surface mortar of 0.2 to 0.4 inches in depth with some loss of mortar surrounding aggregate particles 0.4 to 0.8 inches in depth.
4. *Very Severe Scaling* – loss of coarse aggregate particles as well as surface mortar, generally to a depth greater than 0.8 inches.

Corrosion of reinforcing steel will ultimately generate the following defects:

1. Cracking – expansive corrosion products create internal tensile stresses that overcome the tensile strength of the concrete resulting in cracking along the corroded section of bar.
2. Delamination – a separation along a plane parallel to the surface. Corrosion will induce a failure plane roughly parallel to the surface along the corroded section of reinforcing steel.
3. Spalling – When a delaminated section becomes loose and ultimately falls or is removed by other means is called a spalled area. The reinforcing steel is usually exposed at this point.

Delamination Survey

Sounding accessible concrete for delaminations. A delamination survey is performed by striking a hammer on the surface of the concrete. A delaminated section of concrete caused by corrosion or other causes will have a different sound (or ring) than an intact section of concrete. The "drummy" sound of a delaminated section would be delineated, quantified, and marked up on drawings.

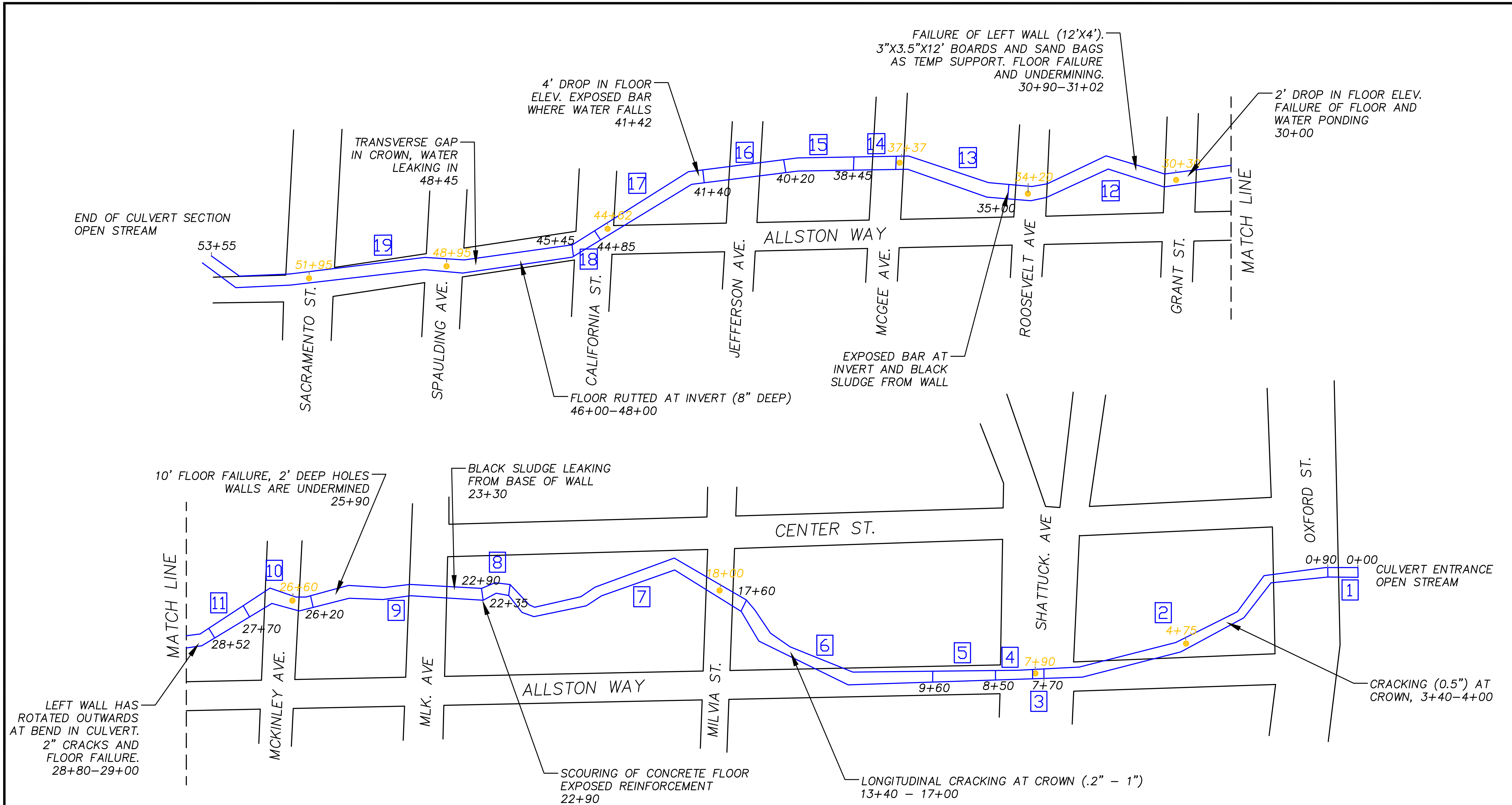
Surface Penetrating Radar (SPR)

SPR works by sending a tiny pulse of energy into the concrete element and recording the strength and the time required for the return of any reflected signal. A series of pulses over a single area make up what is called a scan. Reflections are produced whenever the energy pulse enters into a material with different electrical conduction properties (or dielectric permittivity) from the material it left. Metals (reinforcing steel) are considered to be a complete reflector and do not allow any amount of signal to pass through. The air gap of a void would act as a partial reflector which would only allow a partial signal to pass through to the backside of the wall section.

FIELD TESTING INSPECTION RESULTS

Visual Inspection

The focus of the visual inspection was to document the condition and quality of the culvert concrete. This typically involved noting the culvert dimensions, common observable defects or deteriorations, failures in the culvert structure, and transitions from one section of culvert to another. Stationing was established at the start of the culvert (0+00) near Oxford St. and continued through the culvert to the exit (53+55) near Sacramento St. Figures 1 and 2 on the following pages indicate section locations, lengths, and significant observations.



LEGEND

● MANHOLE OR DRAIN

[8] CULVERT SECTION ID.

REVISION 1	BERKELEY CULVERT CONCRETE INSPECTION	MICROFILM
DES :		BILL OF MATL
DRN : EMV		DWG LIST
CHKD: TAV		SUPSDS
SUPV:		SUPSD BY
APVD: TAV		SHEET 1 OF 1
APVD:	Voss Laboratories, Inc.	FIGURE 1 — REV. 0
DATE: 10/1/2022		

FIGURE 2 - CULVERT INSPECTION OBSERVATIONS

Section	Station	Section Construction	Observations
1	0+00 - 0+90	Rectangular, board formed, 5.5' H x 7' W, reinforced	Section is in good overall condition with light scaling of concrete surfaces.
2	0+90 - 7+70	Arch shape, board formed, 5.5' H x 6' W, unreinforced	Combination of severe scaling and poor consolidation. Longituindal cracking along crown of culvert observed from 3+40 - 4+00
3	7+70 - 7+90	Arch shaped, 6.5' H x 8'W, unreinforced	Severe scaling and poor consolidation
4	7+90 - 8+50	Arch section, plywood formed, sweeping ceiling, reinforced.	Section appears to have been repaired and in better conditon. Minimal scaling and sound conrete. Floor elevation drops at 8+00 and water collects in deep pool there.
5	8+50 - 9+60	Round 7' diameter reinforced pipe with 6' segment lengths	Concrete is in good condition with light scaling at the water flow line.
6	9+60 - 17+60	Arch section, 7' H 6' W, unreinforced	Scaling and poor consolidation. Longitudinal cracking (1/8" - 1" width) along the crown of the culvert from 13+40 - 17+00.
7	17+60 - 22+35	Round 6.5' diamter reinforced pipe	Concrete is in good condition with light scaling at the water flow line.
8	22+35 - 22+90	Arch section, 5.5' H x 6' W, unreinforced	Scaling and poor consolidation. Scouring of floor at 22+90
9	22+90 - 26+20	Arch, 7' H x 8' W, unreinforced	Severe scaling and poor consolidation throughout section. Black sludge leaking from base of wall at 23+30 - 23+70. 10' section of floor eroded with 2' deep holes at 25+90. Wall is undermined at this location.
10	26+20 - 27+70	Arch, 6.5' H x 8' W, unreinforced	Scaling and poor consolidation.
11	27+70 - 28+50	Arch, 6.5'H x 8'W, reinforced, transverse bar #6 bar at 9" centers	Section is in good overall condition with light scaling of concrete surfaces. Appears that the section may have been repaired. Exposed reinforcement at 28+50 due to shallow concrete cover.
12	28+50 - 35+00	Arch, 6.5' H x 8' W, unreinforced	Scaling concentrated at transition from floor to wall. Poor consolidation, cracking and floor failures. Deep holes in floor ranging from 6" - 2' deep. Undermining of walls. Wall failures or movement at 28+80 and 30+90.
13	35+00 - 37+37	Arch, 6.5' H x 8' W, unreinforced	Surfaces are in better condition, overlay repair was performed and is bonded well. Typical scaling of floor and walls observed.

Section	Station	Section Construction	Observations
14	37+37 - 38+45	Arch, 5' H x 8' W	Scaling and poor consolidation.
15	38+45 - 40+20	Arch, 6.5' H x 8' W, reinforced with 8" transverse spacing	Scaling and poor consolidation at wall/floor transition. Upper areas appear to be in good condition.
16	40+20 - 41+40	Arch, 6.5' H x 8' W, unreinforced	Scaling and poor consolidation.
17	41+40 - 44+85	7.5' diameter round section, reinforced	Concrete is in good condition, scaling and abrasion at invert where water flows. 4' elevation drop at 41+40. Occasional gaps between pipe sections
18	44+85 - 45+45	Arch section, 6' H x 8' W, unreinforced	Scaling and poor consolidation. 3' x 5' spall/void where sewer pipe bisects crown of culvert.
19	45+45 - 53+55	Arch section, 7' H x 8' W, unreinforced	Severe scaling and erosion of floor, walls are in better condition. Floor has rutted 10" deep gap from 46+00 - 48+00. Transverse gap or crack with water leaking through at the crown of the culvert at 48+45. Sediment builds up near exit of culvert.

Typical Section Types

The culvert was determined to have roughly 19 sections consisting of different dimensions and overall condition. Some sections were as short as 100 feet and others continued for several hundred feet. Details of each section are included in Figures 1 and 2. Some of the typical section types and their conditions are discussed below.

Un-reinforced Arch Section

Most of the culvert was constructed as an arch or horseshoe shape with no reinforcing steel in the section. Dimensions were typically between a height of 5-7 feet and a width of 6-8 feet. Poor consolidation of concrete was consistently observed between the stub walls and arch sections (Photo 1). Abrasion has resulted in severe scaling of the walls and floor in many areas (Photo 2). Significant longitudinal cracking, between 0.25 and 1 inch wide, was frequently observed along the crown of the culvert (Photos 3 and 4). These cracked sections and their locations are included in Figure 2. Pitting and failure of floor sections were frequent in unreinforced sections. These areas were often subject to deep holes and ponding of water (Photo 5). Walls were observed to be undermined in areas where the floor has eroded (Photo 6). All of the areas with significant distress within the culvert are located in unreinforced arch sections.

Reinforced Arch Section

Some of the concrete arch sections were scanned with surface penetrating radar and found to be reinforced. These sections have poor consolidation and scaling like the above mentioned sections but appear to be in better condition than unreinforced areas. Cracking, spalling and delamination were much less common when reinforced. Reinforced sections may have been repaired or replaced more recently than other areas in the culvert. Photo 7 depicts the typical condition of a reinforced arch section.

Reinforced Circular Pipe

There are 3 separate culvert sections consisting of reinforced circular concrete pipe. These sections are generally in good condition with scaling and abrasion along the invert where water flows (Photo 8). Gaps between segments of the pipe were observed in some areas.

Culvert Failures, Deteriorations, and Defects

Typical condition of the culvert has been discussed above but there are several areas that have experienced localized failures and/or significant defects. These areas are identified below and on Figures 1 and 2.

Longitudinal Cracking of Crown – STA 13+40 – 17+00

Longitudinal cracking was observed along the crown of an unreinforced arch section. The crack continued for approximately 360 feet and varied in width from 0.2" to 1". This type of cracking was common throughout much of the culvert.

Floor Failure and Undermining of Wall – STA 25+90

A 10 foot section of the floor was observed to have failed leaving 2 foot deep holes and a rutted surface. Water collected here and formed deep pools undermining the culvert wall on the left side.

Wall Rotation and Cracking – STA 28+80

The lower left wall has rotated 3 inches outwards at the bend in the culvert. This has resulted in a 2 inch crack in the crown, a large floor failure area, and a 2 inch wide opening/crack in the wall at 29+00. (Photos 9 and 10)

Failure of Left Wall and Floor – STA 30+90 – 31+03

A 12' x 4' section of the left wall was observed to have caved inwards leaving a large gap in the culvert. Three 3.5" x 12" x12' wooden boards and sandbags were in place as a form of temporary shoring. The floor has also eroded and has 2 foot deep holes in some areas. (Photos 11 and 12)

Surface Penetrating Radar Survey

Surface penetrating radar (SPR) was utilized to determine the concrete cover and reinforcement spacing throughout the culvert. A large percentage of the culvert sections were unreinforced.

Delamination Survey

Concrete surfaces were sounded throughout the culvert. Delaminations were found to exist mainly near already spalled areas. Delaminations due to corrosion of reinforcement were not common.

SUMMARY

The performance of the culvert was observed to be dependent upon the structural design of each section and the initial construction quality. Scaling and poor consolidation were located in both reinforced and non-reinforced sections, but significant cracking and failures were concentrated in areas without reinforcement.

Key observations and takeaways are listed below:

- The failure of the culvert at station 30+90, where the left wall has caved in and the floor has eroded, should be repaired to facilitate continued functionality of the culvert. This type of failure is evidence of the structural vulnerability of the unreinforced culvert sections.
- Despite areas of poor consolidation, voiding, penetrations, and widespread scaling the concrete is functioning as intended and is not suffering from specific material deterioration.
- Typical conditions of the unreinforced arch sections include:
  - Longitudinal cracking at the crown
  - Severe scaling
  - Poor consolidation from initial construction
  - Failures of floors with pitted holes and undermining of walls
  - Failure of walls, wall rotation and movement
- Reinforced arch sections and circular reinforced concrete sections were in better condition than the unreinforced areas. Scaling and exposed reinforcement were observed in some areas – typically from abrasion of water flows.

- Unreinforced concrete sections should be evaluated for structural and seismic stability by a licensed Structural Engineer. The intent of this report was to document found conditions and perform a general condition assessment of the concrete materials and not to comment on the structural capacity or lack thereof.

If you have any questions, please call.

Very truly yours,
VOSS LABORATORIES, INC.

Thomas A. Voss
Civil Engineer

Eric Voss
Engineer

Photo 1 – Poor Consolidation at the transition to arch

Photo 2: Scaling of Wall

Photo 3 – Cracking at crown of culvert

Photo 4 – Cracking at crown of culvert

Photo 5 – Floor failure and undermining

Photo 6 – Undermining of wall

Photo 7 – Reinforced arch section

Photo 8 – Reinforced circular pipe section

Photo 9 – Wall rotation and cracking at STA 28+80

Photo 10 – Gap in culvert wall at STA 29+00

Photo 11 – Wall failure at STA 30+90

Photo 12 – Wall Failure at STA 30+90

December 7th, 2022 VL Project No. 22049

Mr. Robert Stevens
CSW/Stuber-Stroeh Engineering Group
45 Leveroni Ct.
Novato, CA 94949

RE: Berkeley Culvert – Acton Street to Browning Street
Concrete Investigation
Berkeley, California

Dear Mr. Stevens,

Voss Laboratories, Inc. (VL) has completed our visual inspection, testing, and evaluation of the above mentioned structure. The purpose of the evaluation was to develop an understanding of the condition of concrete throughout the culvert. This report includes a brief background, a description of field inspection, a sketch of findings, and a summary of results.

BACKGROUND

Voss Laboratories completed the inspection of the two culvert sections located between Acton Street and Browning Street on November 17th, 2022. Previous inspections of the upstream culvert were performed in prior months.

FIELD TESTING PROCEDURES

Visual Inspection

The visual inspection consists of locating cracks, areas of distressed concrete and previously repaired areas. Inspectors are trained to recognize concrete conditions following the American Concrete Institute 201.1R, "Guide for Making a Condition Survey of Concrete in Service." Scaling of concrete surfaces is defined as the flaking or peeling away of the surface concrete. The disintegration of the paste component of concrete by acid attack results in scaling of the concrete surface. ACI breaks down the severity of scaling using the following terms:

1. *Light Scaling* – loss of surface mortar without exposure of coarse aggregate.
2. *Medium Scaling* – loss of surface mortar of 0.2 to 0.4 inches in depth and exposure of coarse aggregate.
3. *Severe Scaling* – loss of surface mortar of 0.2 to 0.4 inches in depth with some loss of mortar surrounding aggregate particles 0.4 to 0.8 inches in depth.
4. *Very Severe Scaling* – loss of coarse aggregate particles as well as surface mortar, generally to a depth greater than 0.8 inches.

Corrosion of reinforcing steel will ultimately generate the following defects:

1. Cracking – expansive corrosion products create internal tensile stresses that overcome the tensile strength of the concrete resulting in cracking along the corroded section of bar.

2. Delamination – a separation along a plane parallel to the surface. Corrosion will induce a failure plane roughly parallel to the surface along the corroded section of reinforcing steel.
3. Spalling – When a delaminated section becomes loose and ultimately falls or is removed by other means is called a spalled area. The reinforcing steel is usually exposed at this point.

Delamination Survey

Sounding accessible concrete for delaminations. A delamination survey is performed by striking a hammer on the surface of the concrete. A delaminated section of concrete caused by corrosion or other causes will have a different sound (or ring) than an intact section of concrete. The “drummy” sound of a delaminated section would be delineated, quantified, and marked up on drawings.

Surface Penetrating Radar (SPR)

SPR works by sending a tiny pulse of energy into the concrete element and recording the strength and the time required for the return of any reflected signal. A series of pulses over a single area make up what is called a scan. Reflections are produced whenever the energy pulse enters into a material with different electrical conduction properties (or dielectric permittivity) from the material it left. Metals (reinforcing steel) are considered to be a complete reflector and do not allow any amount of signal to pass through. The air gap of a void would act as a partial reflector which would only allow a partial signal to pass through to the backside of the wall section.

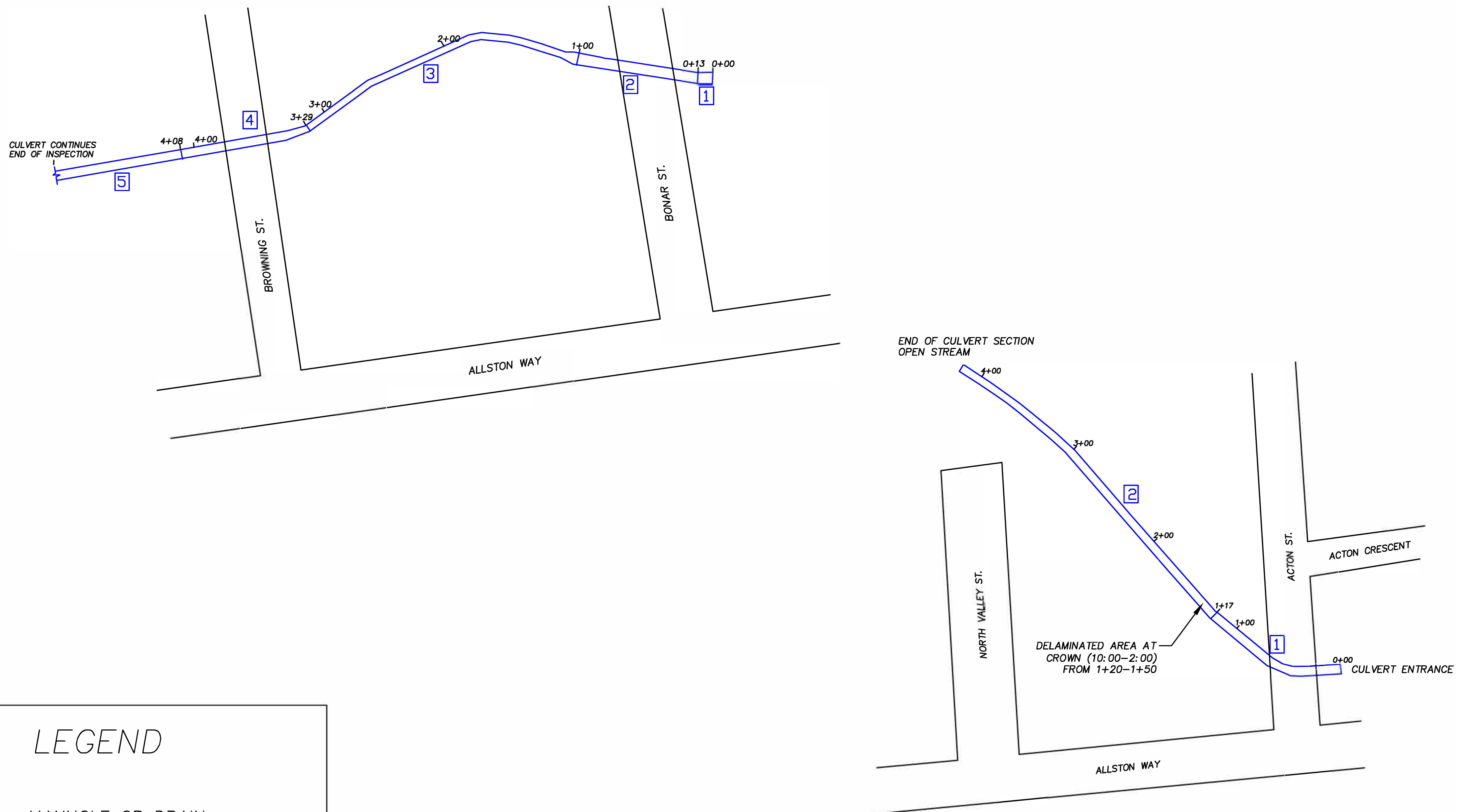
FIELD TESTING INSPECTION RESULTS

Visual Inspection

The focus of the visual inspection was to document the condition and quality of the culvert concrete. This typically involved noting the culvert dimensions, common observable defects or deteriorations, failures in the culvert structure, and transitions from one section of culvert to another.

The first culvert begins at Oxford Street where it continues for a mile before daylighting into an open stream near Sacramento Street. This stream continues until the second culvert begins, near Acton Street. This culvert is approximately 430 feet long and daylights near North Valley Street. The stream continues through Strawberry Creek Park and then enters the third culvert near Bonar Street. The inspection continued for roughly 800 feet until a steep narrow section prevented further progress. This report details the findings from the second and third culvert section.

The two culverts were observed to be in similar condition to the previously inspected culvert. Each culvert has multiple sections with different dimensions, concrete condition, and observations. Figures 1 and 2 on the following pages indicate culvert locations, lengths and significant observations.



LEGEND

● MANHOLE OR DRAIN

8 CULVERT SECTION ID.

REVISION 1	
DES :	
DRN : EMV	
CHKD: TAV	
SUPV:	
APVD: TAV	
APVD:	
DATE: 12/2/2022	

BERKELEY CULVERT
CONCRETE INSPECTION

Voss Laboratories, Inc.

MICROFILM	
BILL OF MATL	
DWG LIST	
SUPSDS	
SUPSD BY	
SHEET 1 OF 1	
FIGURE 1	REV. 0

FIGURE 2 - CULVERT INSPECTION RESULTS

CULVERT 2 - ACTON ST. TO NORTH VALLEY ST.			
Section	**Station**	**Section Construction**	**Observations**
1	0+00 - 1+17	Arch shape, board formed, 6.5' H x 8' W, unreinforced	Arch walls are in fair condition. Typical severe scaling of culvert floor due to abrasion. Initial construction appeared to have been performed well. Section shown in Photo 1.
2	1+17 - 4+20	Arch shape, Shotcrete/Hand Finished, 5.5' H x 6.5' W, reinforced	It appears the section has been repaired with a layer of reinforced shotcrete. The material was poorly finished but appears to be performing thus far. Section shown in Photo 2.

CULVERT 3 - BONAR ST. TO BROWNING ST.			
Section	**Station**	**Section Construction**	**Observations**
1	0+00 - 0+13	Arch shape, board formed, 6.5' H x 8' W, unreinforced	Arch walls are in fair condition with light scaling. Typical severe scaling of culvert floor due to abrasion. Section shown in Photo 3.
2	0+13 - 1+00	Arch shape, board formed 6.5' H x 8' W, unreinforced	Poor consolidation and scaling observed throughout the entire section. Floor is largely eroded and washed out. Significant cracking not observed. Section shown in Photo 4.
3	1+00 - 3+29	Arch shape, board formed, 6.0 H x 5' W, reinforced	Arch walls appear to be in fair condition. Medium scaling is concentrated near flow levels, around 2 feet from the floor. Typical abrasion and scaling of floor. Section may have been repaired as the cross section is reduced relative to the previous and following sections. Section shown in Photo 5.
4	3+29 - 4+08	Arch shape, board formed, 6.5' H x 8' W, unreinforced	Severe scaling of arch walls, worsening near the floor. Poor consolidation throughout the section. Floor consists of mortared stone that is eroded in some areas. Significant cracking not observed. Section shown in Photo 6.
5	4+08 - 7+90	Arch shape, board formed, 6' H x 5' W, reinforced	Arch walls are in fair condition with light scaling. Typical scaling associated with abrasion from flows on floor. Section shown in Photo 7.

SUMMARY

The two culverts were observed to be in similar condition to previously inspected culverts. Some lengths of the culvert were in good condition while others have deteriorated over time. Severe failures such as wall rotation, caving in, wide cracks, and undermining **were not** observed in culverts 2 and 3.

Key observations and takeaways are listed below:

- Each culvert is comprised of sections that have been repaired and areas that were left as constructed.
- The repairs vary in approach but are generally functioning as intended
- Section 2 in culvert 2 was repaired with a fiber reinforced shotcrete. A delaminated area (30 feet in length) at the crown of the culvert was identified, this was most likely an area where the repair material was not adequately bonded to the substrate concrete.
- The original, un-repaired culvert areas are unreinforced with significant scaling, poor consolidation, and abrasion of concrete surfaces. Yet, significant cracking, spalling and delaminations were not observed in any of these areas.
- Unreinforced concrete sections should be evaluated for structural and seismic stability by a licensed Structural Engineer. The intent of this report was to document found conditions and perform a general condition assessment of the concrete materials and not to comment on the structural capacity or lack thereof.

If you have any questions, please call.

Very truly yours,
VOSS LABORATORIES, INC.

Thomas A. Voss   Eric Voss

Thomas A. Voss
Civil Engineer

Eric Voss
Engineer

Photo 1: Culvert 2, Section 1

Photo 2: Culvert 2, Section 2

Photo 3: Entrance to Culvert 3, showing section 1

Photo 4: Culvert 3, section 2

Photo 5: Culvert 3, Section 3

Photo 6: Culvert 4, Section 4

Photo 7: Culvert 3, End of Section 5

Appendix B
Applied Materials & Engineering Inc. Investigation Report

APPLIED MATERIALS & ENGINEERING, INC.
980 41st Street
Oakland, CA 94608
Tel: (510) 420-8190
FAX: (510) 420-8186
e-mail: info@appmateng.com

July 17, 2023

Project Number: 1230306C

Mr. Robert Stevens, PE
CSW ST 2
45 Leveroni Ct
Novato, CA 94949

Email: Rstevens@cswst2.com

Subject: Strawberry Creek Culvert with Side Streets - Concrete Core Testing
Berkeley, CA

Dear Mr. Stevens:

As requested, Applied Materials & Engineering, Inc. (AME) has examined three (3) concrete core samples, removed by us from the above-captioned project. The objectives of the examination were to determine the physical and mineralogical properties of the concrete, and the concrete compressive strength.

SAMPLE IDENTIFICATION

Three (3) concrete cores were samples brought to our laboratory in June 2023. The samples were 2.8" in diameter and approximately 6" in length. The top surface of two core samples was flat and the top surface of one core was rough. The sample description is given in Table I and shown, as received, in Photo 1.

The samples were removed from the following plan locations as provided by you: C1 from #1, C2 from #18 and C3 from #19.

TEST METHODS

1) ASTM C856, "*Standard Practice for Petrographic Examination of Hardened Concrete*",

2) ASTM C42, "*Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*".

The following information was obtained:

1. Petrographic Examination

- Sample C1 was composed of portland cement and normal weight siliceous aggregate with the maximum size of 3/4". No fly ash or other admixtures were detected.

- The coarse aggregate consisted mostly of angular to subangular graywacke rocks with a small amount of quartzite. Sandstone, chert, and volcanic rocks were in a trace amount. Flat and elongated particles were in the amount of 3% (approximately).

- The fine aggregate was composed of particles common to the coarse aggregate with a small amount of schist, quartz and feldspars minerals. Opal and serpentine rock particles were in a trace amount.

- The carbonation of the cement paste was total to a depth of approximately 0.3" measured from the top surface.

- The hydration of the paste was relatively good with the amount of unhydrated portland cement (UPC) particles of approximately 3%.

- Microcracks in the cement paste were extremely rare.

- Entrapped air voids occasionally appeared at the contact between the coarse aggregate and the paste.

- The bulk cement paste was medium gray and moderately hard, with a Mohs Hardness of 6.

- The water absorption was 1.5% and apparent porosity was 3.6%. Water absorption and apparent porosity for all three examined samples are shown in Table II.

- The concrete was well mixed and consolidated. The aggregate-to-paste bond was good with no deleterious reaction observed.

- <u>Sample C2</u> was composed of portland cement and normal weight siliceous aggregate with the maximum size of 3/4". No fly ash or other admixtures were detected.

- The coarse aggregate consisted of subangular to subrounded graywacke and quartzite rocks with a small amount of chert. Sandstone and volcanic rocks were in a small amount. Flat and elongated particles were in the amount of 2% (approximately).

- The fine aggregate was composed of particles common to the coarse aggregate with a small amount of quartz and feldspars minerals. Gneiss, granitic and schist rock particles were in a trace amount.

- The carbonation of the cement paste was variable and extended to a depth of approximately 0.8" measured from the top surface.

- The hydration of the paste was relatively good with the amount of unhydrated portland cement (UPC) particles of approximately 5%.

- Microcracks were rare and usually appeared in the transition zone at the contact of the aggregate and concrete paste, as shown in Photo 2.

- The bulk cement paste was medium gray and moderately hard, with a Mohs Hardness of 5.

-
- The water absorption was 1.6% and apparent porosity was 3.7% (Table II).
- The concrete was well mixed and consolidated. The aggregate-to-paste bond was good with no deleterious reaction observed.
- Sample C3 was composed of portland cement and normal weight siliceous aggregate with the maximum size of 1-3/4". No fly ash or other admixtures were detected.
- The coarse aggregate consisted mostly of angular to subangular graywacke with a smaller amount of quartzite sandstone and volcanic (dacite) rock types. Basalt, metabazalt and chert were in a small amount. Flat and elongated particles were in the amount of 1% (approximately).
- The fine aggregate was composed of particles common to the coarse aggregate with a small amount of quartz, feldspars, and zeolite minerals. Gabbroic and schist rock particles were in a trace amount.
- Carbonation of the cement paste varied, often total, throughout the bulk of concrete due to the high volume of air voids.
- The hydration of the paste was relatively good with the amount of unhydrated portland cement (UPC) particles of approximately 5% - 7%.
- A high volume of the air cavities was detected through the entire concrete sample with the appearance of some microcracks.
- The bulk cement paste was medium gray and moderately hard, with a Mohs Hardness of 3.5.
- The water absorption was 4.9% and apparent porosity was 11.6% (Table II).
- The concrete was well mixed without unusual accumulation of aggregates but was poorly consolidated with a high volume of air voids. The contact between the aggregate and the paste often covered a small area of the aggregate grain and no deleterious reaction was observed between them.

2. Compressive Strength

- The compressive strength for Sample C1 was 6200 psi, for Sample C2 was 4230 psi, and for Sample C3 was1950 psi.
- The compressive strength test results are given in Table III.

SUMMARY OF FINDINGS

1) The concrete in all three examined samples was composed of portland cement and normal weight siliceous aggregate. The aggregate maximum size in Samples C1 and C2 was 3/4" and in Sample C3 was 1-3/4".

2) Samples C1 and C2 were well mixed and well consolidated but Sample C3 was poorly consolidated.

3) The water absorption was 1.5% and 1.6% for Samples C1 and C2, respectively. For sample C3, the water absorption was 4.9%.

4) The compressive strength was 6200 psi and 4230 psi for Samples C1 and C2 respectively. For Sample C3, the compressive strength was 1950 psi.

Please call if any questions arise.

Sincerely,

APPLIED MATERIALS & ENGINEERING, INC.

Miroslav Puric

Miroslav Puric, B.S.
Materials Scientist/Petrographer

Reviewed by:

Armen Tajirian, Ph.D., P.E.
Principal

TABLE I

SAMPLE IDENTIFICATIONS

Strawberry Creek Culvert, Berkeley CA

AME Project No. 1230306C

AME Sample ID	Client Sample ID	Diameter (in.)	Maximum Length (in.)	Description
C1	#1	2.75	6.01	Flat top surface. Bulk of the concrete in good condition. No rebar.
C2	#18	2.75	6.52	Flat top surface. Bulk of the concrete in good condition. No rebar
C3	#19	2.75	6.09	Rough top surface. Significant amount of air voids. No rebar.

TABLE II

WATER ABSORPTION AND APPARENT POROSITY

Strawberry Creek Culvert, Berkeley CA

AME Project No. 1230306C

Sample ID	Water Absorption (%)	Apparent Porosity (%)
C1	1.5	3.6
C2	1.6	3.7
C3	4.9	11.6

TABLE III

CONCRETE CORE COMPRESSIVE STRENGTH

Strawberry Creek Culvert, Berkeley CA

AME Project No. 1230306C

Sample ID	Length (in.)	Diameter (in.)	Area (in.^{2})	L/D Ratio	Correction Factor	Load (lbs)	Compressive Strength (psi)
C1	4.61	2.74	5.89	1.68	0.974	37,490	6200
C2	4.60	2.74	5.89	1.68	0.974	25,610	4230
C3	4.00	2.74	5.89	1.46	0.955	12,050	1950

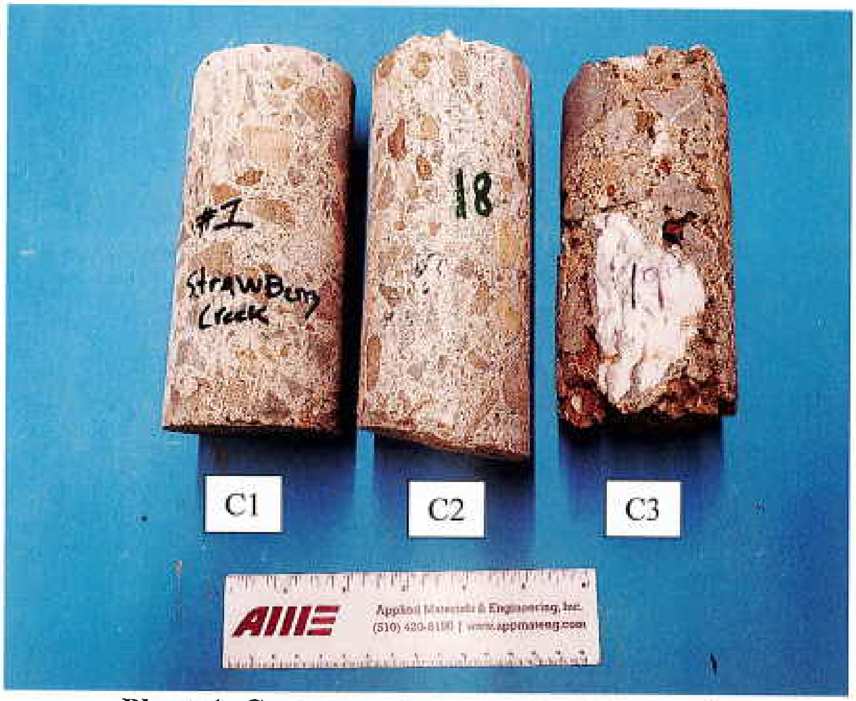


Photo 1. Concrete core samples, as received.

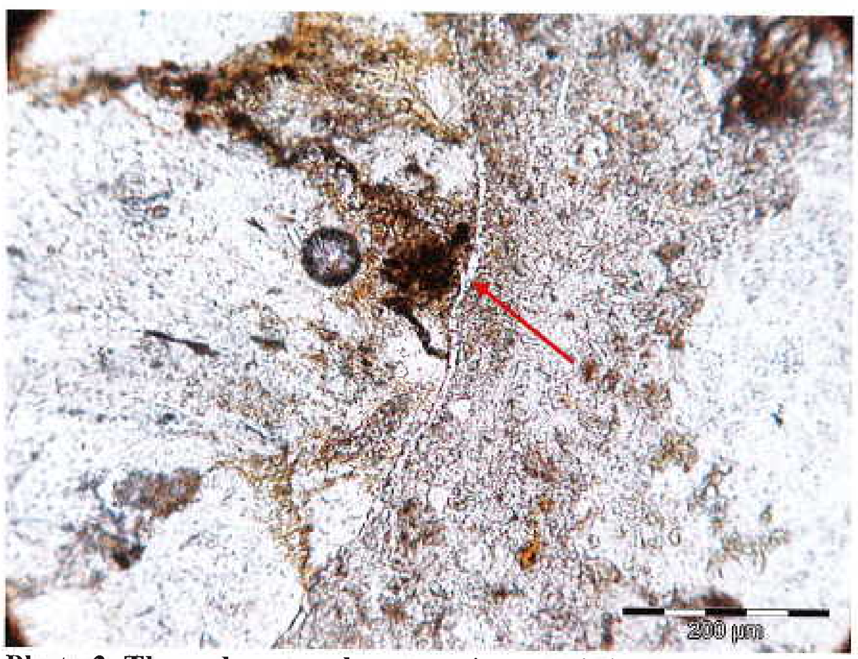


Photo 2. The red arrow shows a microcrack in the transition zone between the aggregate (left) and the paste (right) in Sample C2. Microscope, plane polarized light illumination, 200x magnification.

Appendix C
Inspection Services Inc. Investigation Report

August 3, 2023
ISI Project #: 3084-001.0
ISI Laboratory #: L-67710

Attn.: Mr. Srinivas Muktevi, P.E. & Mr. Ricardo Salcedo, P.E.
City of Berkeley – Public Works
2180 Milvia St.
Berkeley, CA 94704

Re: Strawberry Creek Culvert Investigation

Dear Mr. Muktevi & Mr. Salcedo:

As requested by CSW/ST2, Inspection Services, Inc. (ISI) personnel performed a photographic and material sampling investigation of the Strawberry Creek Culvert on June 20 through June 28 with laboratory testing conducted through July 31, 2023. The specific scope and locations of sampling were identified in the "Revised Strawberry Creek Culvert Materials Testing and Repair Documents", dated March 23, 2023 ("Test Program"), superseded in part by the "Coring Map", sent by CSW/ST2 to ISI via email on June 9, 2023. All locations sampled by ISI were in the City of Berkeley's Right of Way, between the culvert openings at Oxford and Sacramento Streets.

ISI was informed by the City of Berkeley that the station markings (STA) on the Coring Map were not accurate, and were superseded by the Strawberry Creek Culvert Survey map, dated 10/1/2022 ("Survey Map"). Hence, efforts were made by ISI to transpose pertinent culvert section locations from the Coring Map into station values as noted on the Survey Map for the purpose of this report.

The Strawberry Creek culvert is a confined space, as defined by Occupational Safety and Health Administration (OSHA). The work performed by ISI was coordinated with the City of Berkeley to ensure appropriate staff training, safe access, rescue protocols, and street-level traffic control. ISI technicians entered the culvert by way of five different manholes or stormwater grates. ISI was given permission to move coring/scanning locations noted on the Coring Map to alternate locations closer to culvert entry points, so long as said cores were extracted from the same culvert sections originally prescribed on the Coring Map.

ISI was instructed to photograph the cross-sectional geometry of each culvert section, each structural deficiency noted on the Coring Map, as well as any other encountered deficiencies. Since work was concentrated within a few hundred feet of each entry point, ISI technicians did not travel along the entirety of the culvert, and our reporting is not intended to be an extensive account of all deficiencies present in the culvert.

Final sampling locations may be found in Table 1 below, with accompanying photographs appended to this report.

Table 1. Summary of Sampling Locations	
Location Description (new section start in blue)	Approximate Station
Section 1 Start	0+00
Section 2 Start	0+70
Large Wall Cavity	1+50
Transverse Cracking	1+90
Transverse Cracking (multiple locations)	2+40 to 3+40
Horizontal & Transverse Crack	3+50
Longitudinal Crown Crack	4+10 to 4+40
Core 2	8+10
Section 3 Start	8+30
Core 3	8+38
Section 4 Start	8+60
Core 4 and Rebar Mapping	9+20
Section 5 Start	9+50
Core 5 and Rebar Mapping	9+50
Section 6 Start	11+00
Wood Crown Repair	12+50
Longitudinal cracking at crown (0.2"-1")1/2" Invert Overlay	12+40 to 15+50
Transverse Wall Cracking	14+50
Core 6	15+50
Section 7 Start	15+80
Core 7 and Rebar Mapping	18+60
Section 8 Start	22+35
Core 8	22+70
Scouring of Concrete Floor, Exposed Wall and Invert Reinforcement (#5 round bars)	22+90
Section 9 Start	22+90
Black Sludge Leaking from Base of Wall	23+30
Core 9	25+50
10' Floor Failure, 2' Deep Holes, Walls are Undermined	26+10
Section 10 Start	26+20
Core 10	26+62
Section 11 Start	27+70
Section 12 Start	28+50
Left wall has Rotated Outwards at Bend in Culvert, 2" Cracks and Floor Failure	28+80 to 29+00
Core 11	28+80
Concrete Honeycombing and Exposed Vertical Reinforcement (#7 round bars)	28+50
Failure of Floor and Water Ponding	30+00
Failure of Left Wall (12'x4') Temporary Wood Board Support, Floor Failure and Undermining	30+90 to 31+00
Core 12	34+50
Exposed Bar at Invert and Black Sludge from Wall	35+20
Section 13 Start	35+20
Core 13	37+00
Section 14 Start	37+30
Core 14	37+70
Section 15 Start	38+70
Section 16 Start	40+50
Section 17 Start	41+40
4' Drop in Floor Elevation, Exposed Bar Where Water Falls	41+42
Core 15 and Rebar Mapping	44+00
Section 18 Start	45+00
Large Crown Cracks and Exposed Steel Pipe	45+00
Core 16	45+25
Section 19 Start	45+40
Core 17	46+00
Transverse Wall and Crown Crack	48+00
Section 19 End	53+60

1. **Culvert Geometry, Structural Deficiencies, and Rebar Mapping**

ISI technicians recorded and photographed the cross-sectional shape of nineteen interior culvert sections, photographed structural deficiencies and performed Ground Penetrating Radar (GPR) scanning of four specified wall locations to identify the spacing of reinforcing steel. In those locations, scanning areas spanned areas of at least 5 feet by 5 feet.

GPR was also used to measure the concrete wall, crown, and invert thicknesses at each of the nineteen culvert sections Due to certain invert conditions and high-water areas, four invert thicknesses could not be confirmed by our team.

The areas that were scanned with GPR only reveal the reinforcement spacing. This technology does not provide bar diameters. To obtain size measurements, the rebar would need to be exposed by chipping and measured. In various locations noted in Table 2 below, exposed rebar was observed, ranging from #5 to #7 round bars (no grade markings were found).

Table 2. Culvert Geometry

Culvert Section	Wall Depth (in.)	Crown Depth (in.)	Invert Depth (in.)	Culvert Shape	Reinforcement
S1	9	18	Not confirmed	Square Box	
S2	20	14	18	Round Top, Flat Bottom	
S3	22	22	14	Round Top, Flat Bottom	
S4	10	5	10	Wide Round Top, Flat Bottom	Wall Rebar Spacing: 8 inches on center each way
S5	9	9	Not confirmed	Tubular, Flat Bottom	Wall Rebar Spacing: 6-7 inches verticals on center; 12 inches horizontals on center
S6	15	5	5	Round Top, V-channel Bottom	
S7	6	6	6.5	Tubular	Wall Rebar Spacing: 30 inches verticals on center; 8 inches horizontals on center
S8	11	9	12	Round Top, Flat Bottom	Exposed Wall Rebar: round #5; Exposed Invert Rebar: round #5, 8 inches on center each way
S9	14	11	14	Round Top, Flat Bottom	
S10	15	13	13	Round Top; Flat Bottom	

S11	12	6.5	Not confirmed	Round Top; Flat Bottom	Exposed Wall Rebar: round #7 verticals
S12	13	13	14	Round Top; Flat Bottom	
S13	8	12	10	Round Top, V-channel Bottom	
S14	24	7	12	Round Top, V-channel Bottom	
S15	12	8	14	Round Top, V-channel Bottom	
S16	17	8	8	Round Top, V-channel Bottom	
S17	10	10	10	Tubular	Wall Rebar Spacing: 12 inch verticals on center; 24 inch horizontals on center
S18	17	10	Not confirmed	Round Top, V-channel Bottom	
S19	15	10	5	Round Top, V-channel Bottom	

2. **Compressive Strength of Concrete Cores**

ISI sampled a total of sixteen 4-inch nominal concrete cores in sections depicted on the Coring Map. All coring locations were first scanned with GPR to avoid cutting through any reinforcing steel. Each of the sixteen cores were transported to ISI's testing laboratory and tested for compressive strength. These tests were performed in accordance with the latest edition of ASTM C42 (Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete) and ASTM C39 (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens).

As directed, all concrete locations were patched by ISI using high strength non-shrink grout. The replacement of waterproofing (if any) and/or surface finishes such as paints or other coatings were excluded from our scope.

TABLE 3. Core Compressive Strength									
Culvert Section	**Core ID**	**Approximate Station**	**Diameter (in.)**	**Length (in.)**	**Ult. Load (lbs)**	**Comp. Strength (psi)**	**Corr. Factor**	**Corr. Comp. Strength (psi)**	**Fracture Pattern per ASTM C39**
S2	C2	8+10	3.71	6.71	46100	4260	0.98	4170	III
S3	C3	8+38	3.7	6.889	32350	3010	0.99	2980	III
S4	C4	9+20	3.72	6.78	68600	6310	0.99	6250	III
S5	C5	9+50	3.71	5.98	32200	2980	0.97	2890	II
S6	C6	15+50	3.72	7.119	19150	1760	0.99	1740	II
S7	C7	18+60	3.715	6.74	44260	4080	0.98	4000	II
S8	C8	22+70	3.714	7.184	34840	3220	0.99	3190	III
S9	C9	25+50	3.71	7.214	32550	3010	1.00	3010	II
S10	C10	26+62	3.704	7.171	34770	3230	1.00	3230	III
S12	C11	28+80	3.715	6.718	28530	2630	0.98	2580	II
S12	C12	34+50	3.701	6.119	39280	3650	0.97	3540	IV
S13	C13	37+00	3.703	6.125	58360	5420	0.97	5260	II
S14	C14	37+70	3.713	3.96	61700	5700	0.89	5070	II
S17	C15	44+00	3.713	3.744	124000	11450	0.87	9960	V
S18	C16	45+25	3.692	7.633	23380	2180	1.00	2180	I
S19	C17	46+00	3.711	7.168	31660	2930	0.99	2900	I

3. **Petrographic Evaluation of Concrete Cores**

A 2 inch to 6 inch section from the inside face (“exposed core surface”) of each of the sixteen extracted concrete cores were sent to Atlas Technical Consultants for petrographic evaluation in accordance with ASTM C856/C856M (Standard Practice for Petrographic Examination of Hardened Concrete). This analysis evaluation includes an analysis of physical and mineralogical properties observed in aggregates, cement, air voids, cementitious paste, and secondary deposits.

The Atlas petrography report has been attached in full.

4. **Results and Conclusions:**

The concrete cores sampled from the culvert show an ultimate corrected compressive strength ranging from 1,740 to 9,960 psi (average of 3,930 psi). The coefficient of variations was 49.1%. There appear to be several outliers in the lower strength range (cores 6 and 16, at 1,740psi and 2,180psi respectively) as well as in the higher range (cores 4 and 15, at 6,250psi and 9,960psi respectively). If those four samples are removed, the coefficient of variations reduces to 23.5% and the average to 3,570 psi.

It is apparent, both visually and in our test data that the nineteen culvert sections were constructed/reconstructed in different eras and using different design and construction techniques over the years. For the most part, ISI technicians were able to use the culvert geometry and appearance as evidence of section boundaries. Atlas's petrographical analysis of the cores shows a range of aggregates, color, air contents from one section to another, from which we can draw consistent comparisons to the compressive strength data. The Atlas report notes that most of the tunnel was constructed using "historical Portland cement based on the grain size and mineralogy of the cement." However, sections 4, 5, and 10 contained a modern cement showing a significant span of time between their construction and the rest of the culvert. It is possible that sections 8 and 9 may have been constructed around the same time. This petrography report makes note of similar hardness, color and paste hardness between these cores, while we also observing similar tunnel geometry, similar member thicknesses and concrete compressive strengths within 180 psi of one another.

The majority of observed structural deficiencies were concentrated in culvert sections 2, 6, 9, 12, 18. Incidentally, cores from sections 6, 12, and 18 were amongst the lowest in compressive strength. We would assume that the majority of repair design considerations will be focused on these areas.

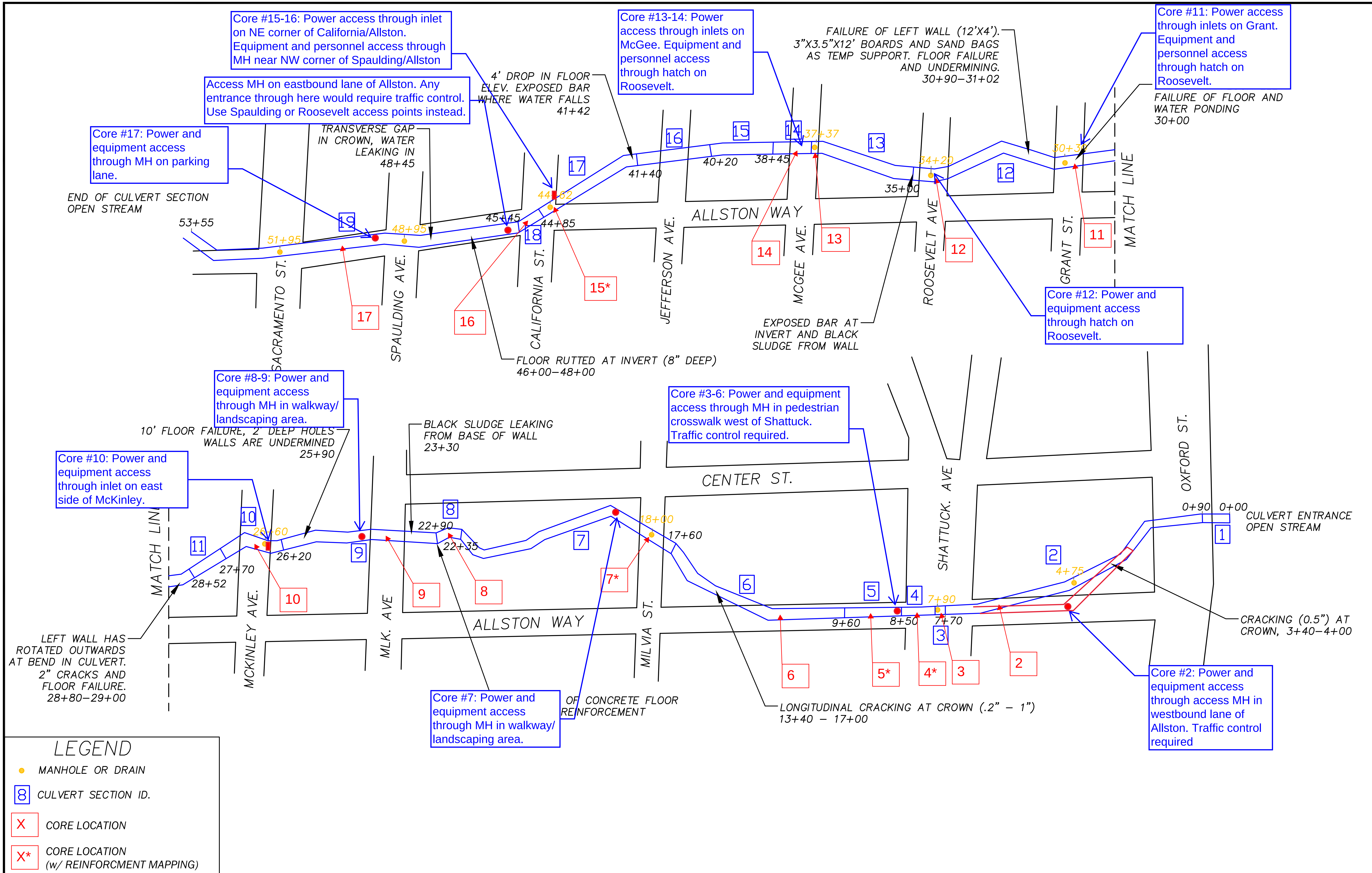
Respectfully Submitted,
INSPECTION SERVICES, INC.

Prepared By: William Fong
Laboratory Engineer

Reviewed By: Antoine Megevand, P.E.
Project Manager

Attachments: "Coring Map (RS notes)" (1 page), "Strawberry Creek Culvert Survey Map" (6 pages), ISI Culvert Photos (23 pages), Atlas Technical Consultants' Petrography Report (41 pages),

cc: Robert Stevens, Jed Diaz, Denise Hartman (CSW/ST2), Bobby Zermeno (CSEG)



Core #15-16: Power access through inlet on NE corner of California/Allston. Equipment and personnel access through MH near NW corner of Spaulding/Allston
Core #13-14: Power access through inlets on McGee. Equipment and personnel access through hatch on Roosevelt.
Core #11: Power access through inlets on Grant. Equipment and personnel access through hatch on Roosevelt.
FAILURE OF LEFT WALL (12'X4'). 3"X3.5"X12' BOARDS AND SAND BAGS AS TEMP SUPPORT. FLOOR FAILURE AND UNDERMINING. 30+90–31+02
FAILURE OF FLOOR AND WATER PONDING 30+00
Access MH on eastbound lane of Allston. Any entrance through here would require traffic control. Use Spaulding or Roosevelt access points instead.
4' DROP IN FLOOR ELEV. EXPOSED BAR WHERE WATER FALLS 41+42
Core #17: Power and equipment access through MH on parking lane.
TRANSVERSE GAP IN CROWN, WATER LEAKING IN 48+45
END OF CULVERT SECTION OPEN STREAM
53+55
51+95
48+95
45+45
44+62
44+85
41+40
40+20
38+45
37+37
35+00
34+20
30+37
19
18
17
16
15
14
13
12
11
ALLSTON WAY
SACRAMENTO ST.
SPAULDING AVE.
CALIFORNIA ST.
JEFFERSON AVE.
MCGEE AVE.
ROOSEVELT AVE
GRANT ST.
MATCH LINE
17
16
15*
14
13
12
11
EXPOSED BAR AT INVERT AND BLACK SLUDGE FROM WALL
Core #12: Power and equipment access through hatch on Roosevelt.
FLOOR RUTTED AT INVERT (8" DEEP) 46+00–48+00
Core #8-9: Power and equipment access through MH in walkway/ landscaping area.
10' FLOOR FAILURE, 2' DEEP HOLES WALLS ARE UNDERMINED 25+90
BLACK SLUDGE LEAKING FROM BASE OF WALL 23+30
Core #3-6: Power and equipment access through MH in pedestrian crosswalk west of Shattuck. Traffic control required.
CENTER ST.
OXFORD ST.
SHATTUCK. AVE
0+90
0+00
CULVERT ENTRANCE OPEN STREAM
Core #10: Power and equipment access through inlet on east side of McKinley.
MATCH LINE
11
10
9
8
7
6
5
4
3
2
1
26+60
26+20
27+70
28+52
22+90
22+35
18+00
17+60
9+60
8+50
7+90
7+70
4+75
10
9
8
7*
6
5*
4*
3
2
MCKINLEY AVE.
MLK. AVE
ALLSTON WAY
MILVIA ST.
LEFT WALL HAS ROTATED OUTWARDS AT BEND IN CULVERT. 2" CRACKS AND FLOOR FAILURE. 28+80–29+00
Core #7: Power and equipment access through MH in walkway/ landscaping area.
OF CONCRETE FLOOR REINFORCEMENT
LONGITUDINAL CRACKING AT CROWN (.2" – 1") 13+40 – 17+00
CRACKING (0.5") AT CROWN, 3+40–4+00
Core #2: Power and equipment access through access MH in westbound lane of Allston. Traffic control required
LEGEND
MANHOLE OR DRAIN
8 CULVERT SECTION ID.
X CORE LOCATION
X* CORE LOCATION (w/ REINFORCMENT MAPPING)

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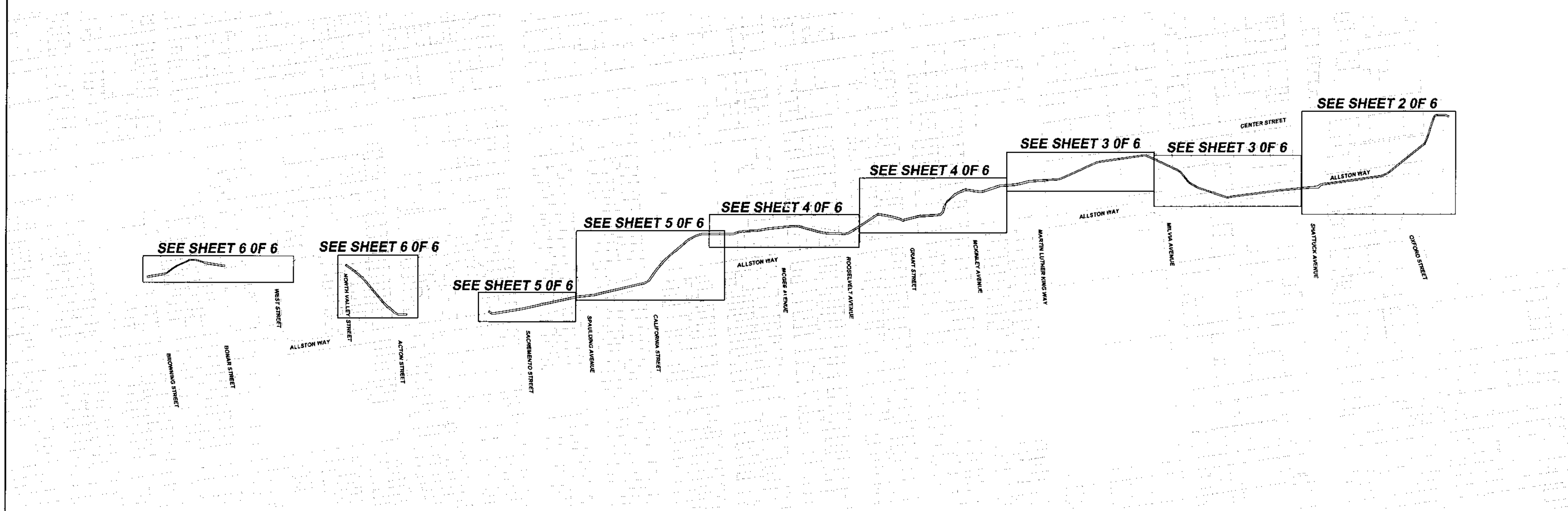
STRAWBERRY CREEK CULVERT

EXISTING CONDITIONS MAPPING



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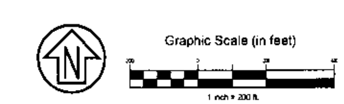
SHEET 1 INDEX AND COVER SHEET
SHEET 2 TOPOGRAPHIC MAPPING
SHEET 3 TOPOGRAPHIC MAPPING
SHEET 4 TOPOGRAPHIC MAPPING
SHEET 5 TOPOGRAPHIC MAPPING
SHEET 6 TOPOGRAPHIC MAPPING
SHEET 7 VOSS LABORATORIES CONCRETE INSPECTION ASSESSMENT



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INDEX AND COVER SHEET

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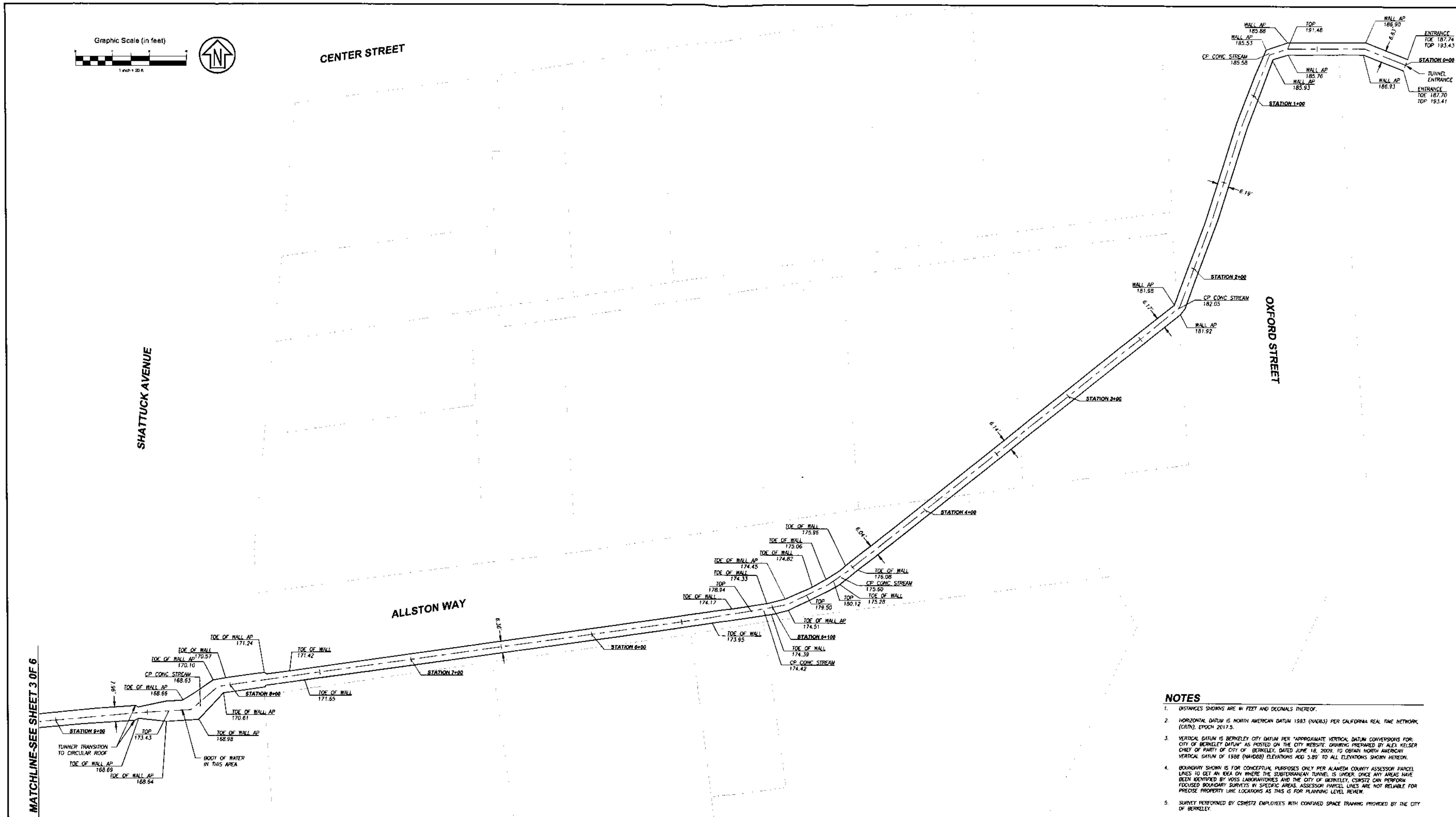

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LEGEND

....	ADJOINERS PROPERTY LINES
———	WALL OF TUNNEL
— — —	CENTERLINE OF TUNNEL

ABBREVIATIONS

AP	ANGLE POINT
CONC	CONCRETE
CP	CONTROL POINT/MAG NAIL
FL	FLOWLINE
TOP	TOP/CEILING OF TUNNEL

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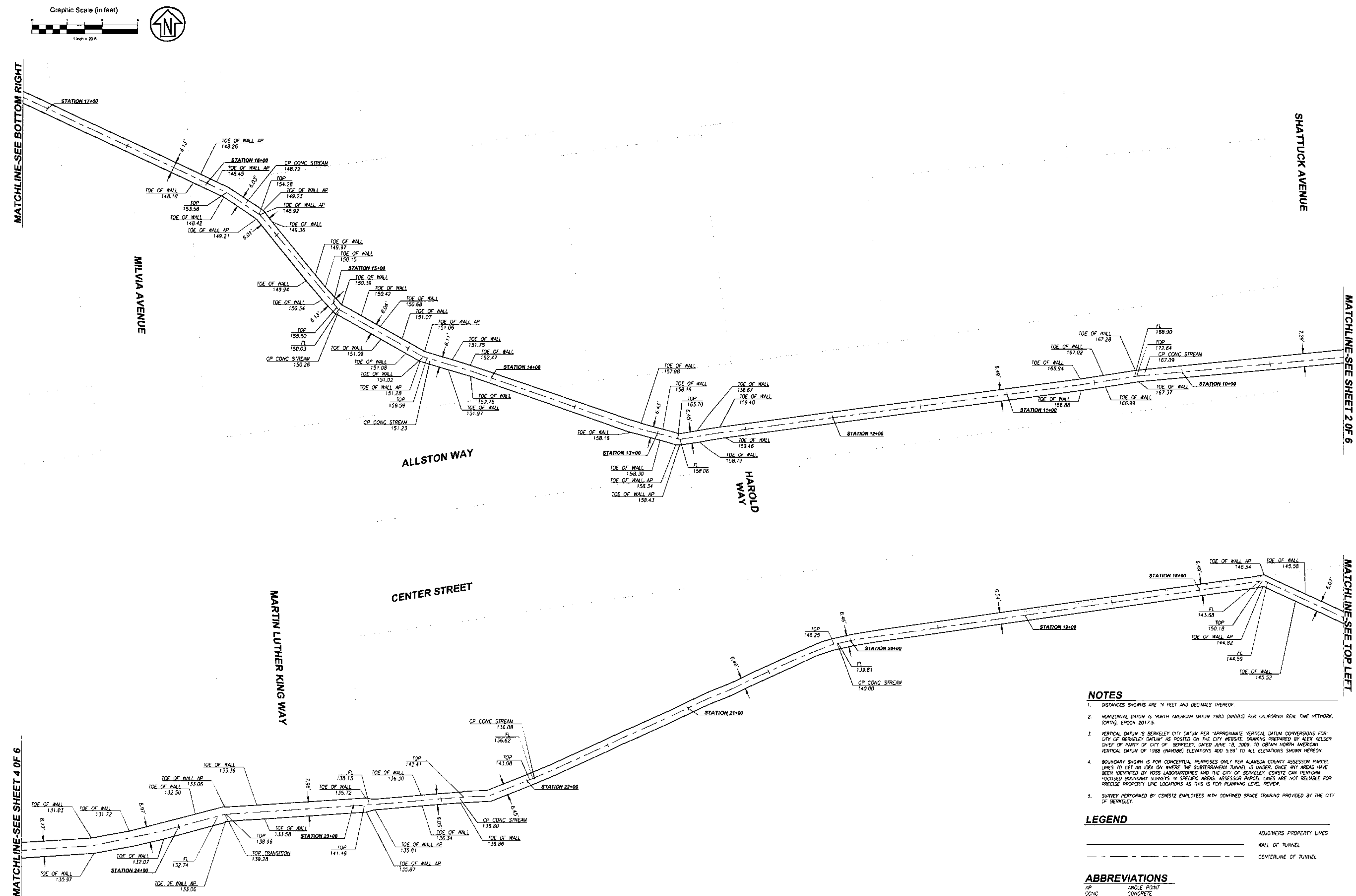

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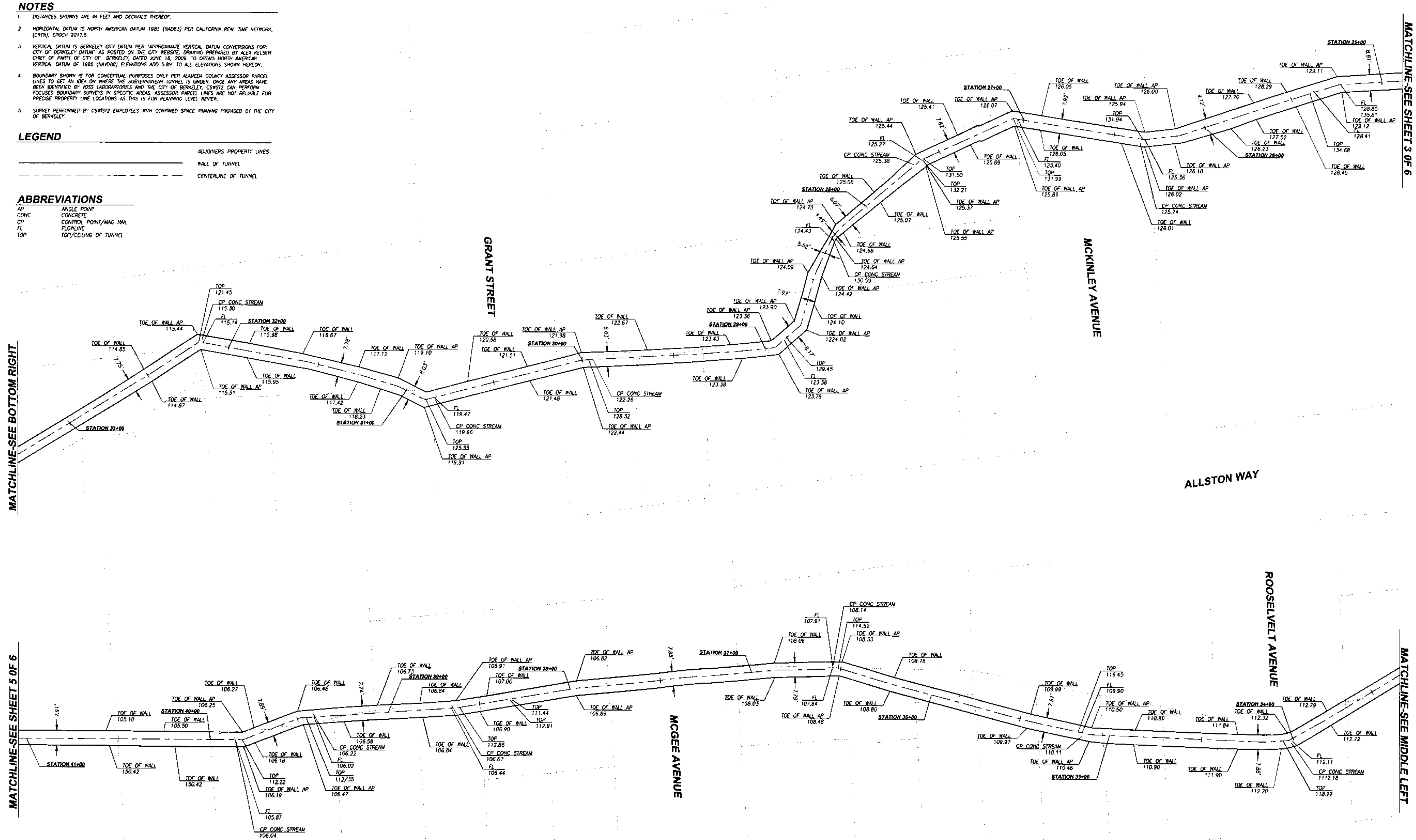

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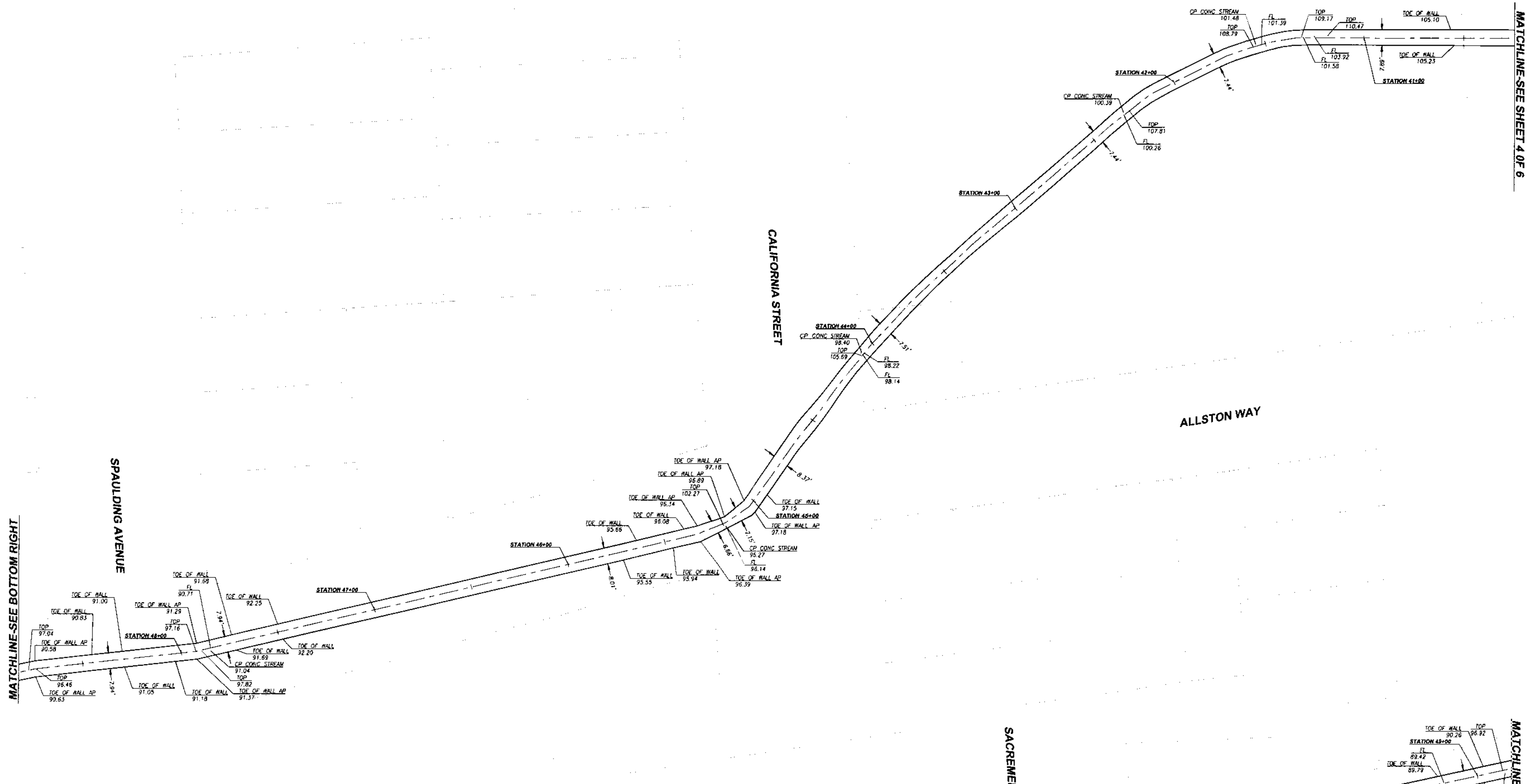

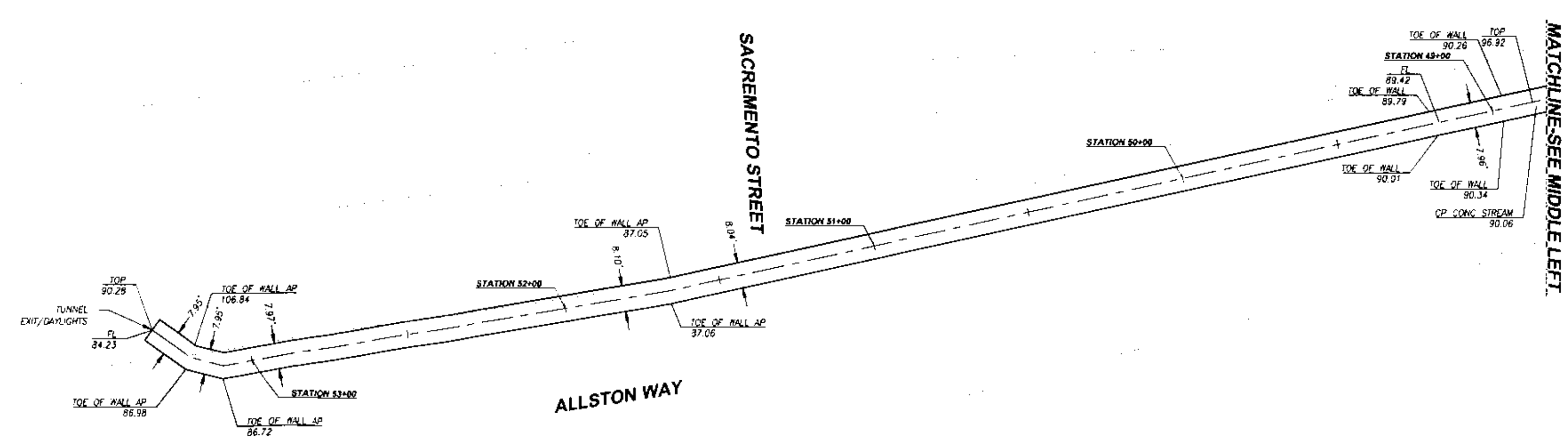

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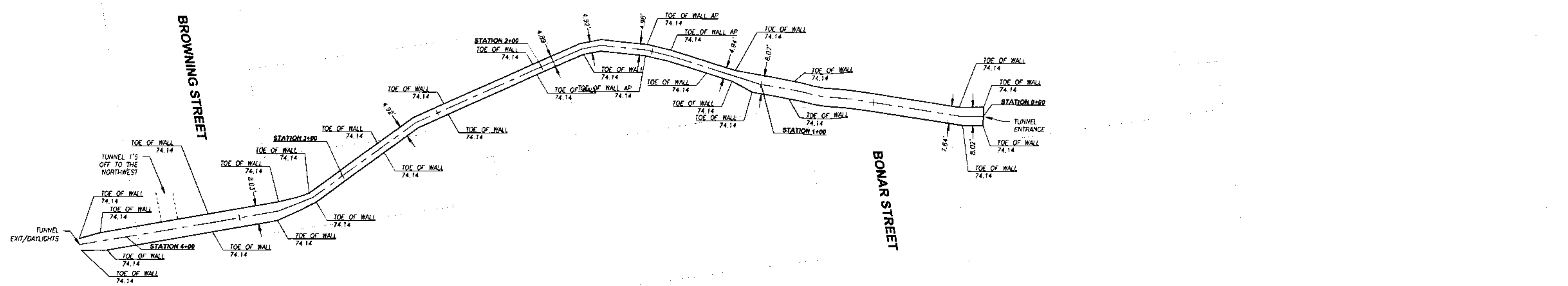

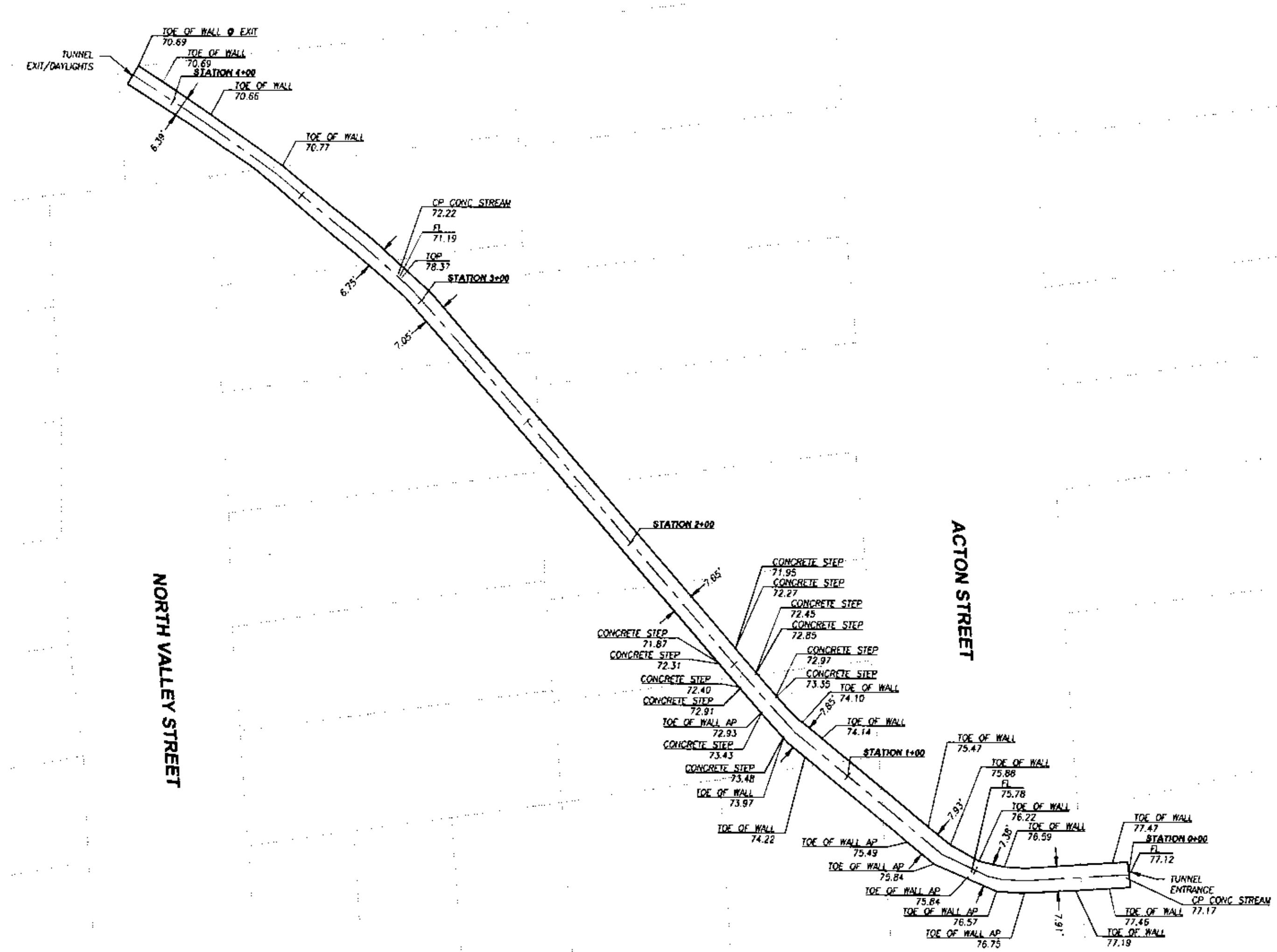

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LEGEND

ADJOINERS PROPERTY LINES

WALL OF TUNNEL

CENTERLINE OF TUNNEL

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Strawberry Creek Culvert Investigation
Attachment 3: ISI Culvert Photo Report

Photo 1: Section 1 Geometry - Box Shaped (STA 0+00)

Photo 2: Section 2 Geometry - Round Top, Flat Bottom (STA 1+00)

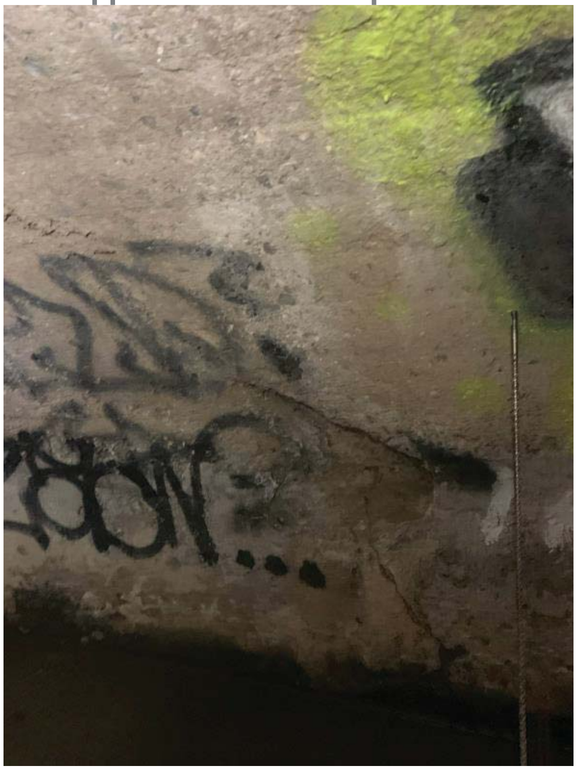


Photo 3: Section 2 – Large Wall Cavity (STA 1+50)

Photo 4: Section 2 – Transverse Wall Cracking (STA 1+90)

Photo 5: Section 2 – Transverse Wall Cracking (STA 2+50)

Photo 6: Section 2 – Transverse Crown Cracking (STA 3+00)

Photo 7: Section 2 Transverse and Longitudinal Cracking (STA 3+50)

Photo 8: Section 2 – Longitudinal Crown Cracking (STA 4+10)

Photo 9: Section 3 Geometry – Round Top, Flat Bottom (STA 8+30)

Photo 10: Section 4 – Wide Round Top, Flat Bottom (STA 8+60)

Note: Crown Cracking

Photo 11: Section 4 – GPR Scanning of Wall Reinforcement (STA 9+20)

Photo 12: Section 5 Geometry – Tubular, Flat Bottom (STA 9+50)

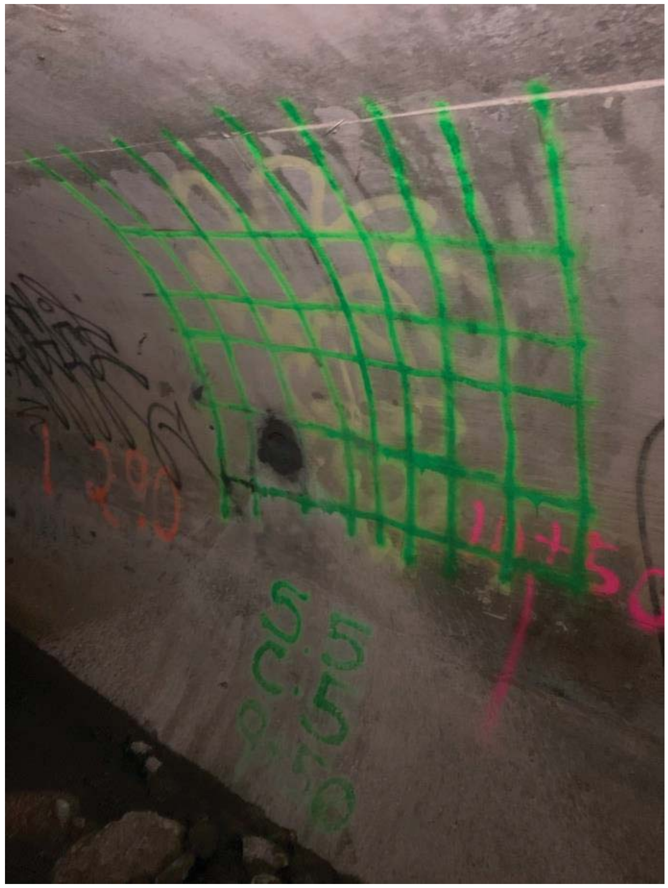


Photo 13: Section 5 – GPR Scanning of Wall Reinforcement (STA 9+50)

Photo 14: Section 6 Geometry – Round Top, V-Shaped Bottom (STA 11+00)

Photo 15: Section 6 – Wood Crown Repair (STA 12+50)

Photo 16: Section 6 Longitudinal Crown Cracking (STA 12+60)

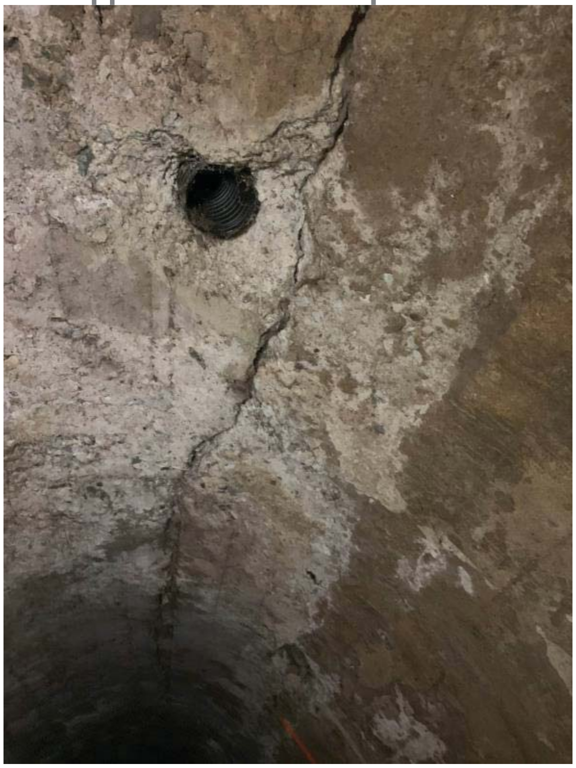


Photo 17: Section 6 – Longitudinal Crown Cracking (STA 14+00)

Photo 18: Section 6 – Transverse Wall Cracking (STA 14+50)

Photo 19: Section 7 Geometry – Tubular (STA 16+00)

Photo 20: Section 7 – GPR Scanning of Wall Reinforcement (STA 18+60)

Photo 21: Section 8 Geometry – Round Top, Flat Bottom

Photo 22: Section 8 – Exposed Wall Rebar (STA 22+88)

Photo 23: Section 8 – Invert Scouring and Exposed Reinforcement (STA 22+90)

Photo 24: Section 9 Geometry – Round Top, Flat Bottom (STA 22+90)

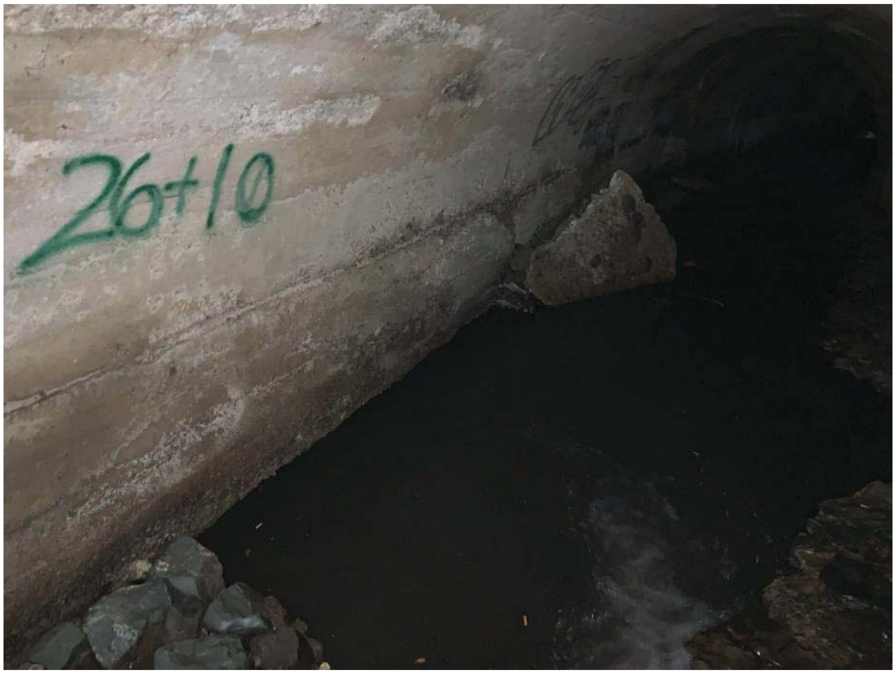


Photo 25: Section 9 – Floor Failure (STA26+10)

Photo 26: Section 9 – Floor Failure and Undermined Walls (STA 26+10)

Strawberry Creek Culvert Investigation
Appendix 1: Photo Report

Photo 27: Section 9 – Floor Failure Continued (STA 26+10)

Photo 28: Section 10 Geometry – Round Top, Flat Bottom (STA 26+20)

Photo 29: Section 11 Geometry – Round Top, Flat Bottom (STA 27+70)

Photo 30: Section 12 Geometry – Round Top, Flat Bottom (STA 28+80)

Note: Left Wall Rotation

Photo 31: Section 12 – Floor Failure (STA 28+80)

Photo 32: Section 12 – Honeycombing and Exposed Wall Reinforcement (STA 28+50)

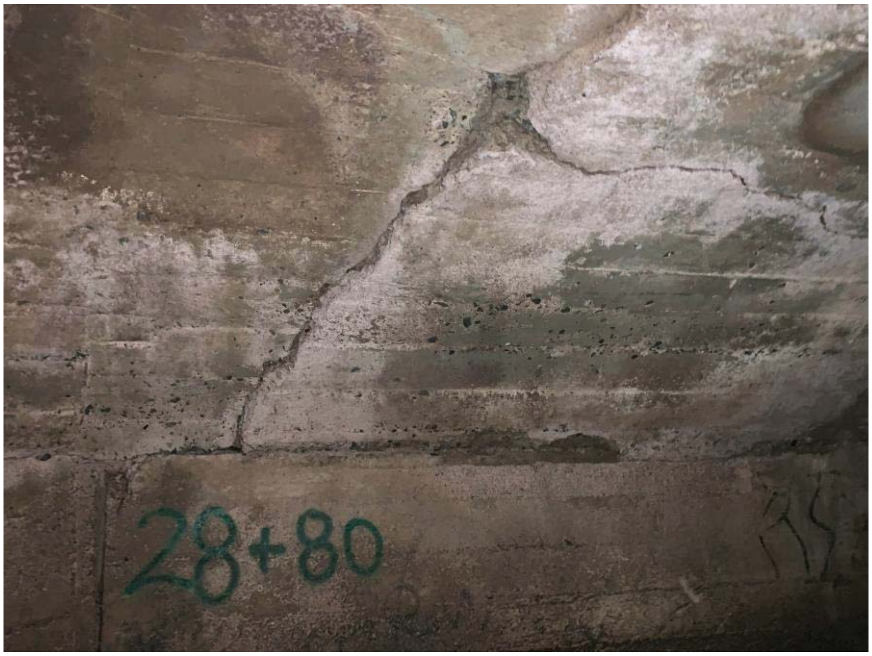


Photo 33: Section 12 – Transverse Wall Cracking (STA 28+80)

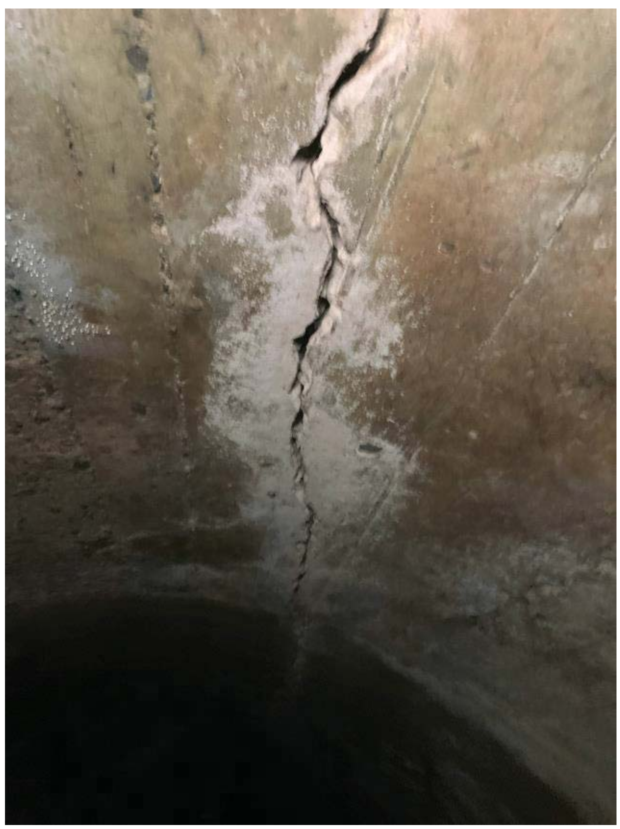


Photo 34: Section 12 – Longitudinal Crown Cracking (STA 30+00)

Photo 35: Section 12 – Floor Failure and Ponding (STA 30+00)

Photo 36: Section 12 – Wall Failure and Temporary Repair (STA 30+90)

Photo 37: Section 13 Geometry – Round Top, Wide V-Channel Bottom (STA 35+30)

Photo 38: Section 14 Geometry – Round Top, V-Channel Bottom (STA 37+30)

Photo 39: Section 15 Geometry – Round Top, V-Channel Bottom (STA 38+70)

Photo 40: Section 16 Geometry – Round Top, V-Channel Bottom (STA 40+50)

Photo 41: Section 17 Geometry – Tubular (STA 41+40)

Photo 42: Section 17 – GPR Scanning of Wall Reinforcement (STA 44+00)

Photo 43: Section 18 Geometry – Round Top, V-Channel Bottom (STA 45+00)

Photo 44: Section 18 – Crown Failure and Exposed Steel Pipe (STA 45+00)

Photo 45: Section 19 Geometry – Round Top, V-Channel Bottom (STA 46+00)

Photo 46: Section 19 – Transverse Wall and Crown Crack (STA 48+00)

Appendix D
ATLAS Petrographic Evaluation Report

July 31,2023

Project Number: 50-66312-P

Mr. Antoine Megevand
ISI INSPECTION SERVICES, INC.
1798 University Avenue
Berkeley, CA 94703-1514

Email: amegevand@inspectionservices.net

Subject: Petrographic Evaluation of Concrete Cores
ISI Project No. 3084-001.0
ISI Lab No. L-67624

Dear Mr. Antoine Megevand:

As requested, Atlas Technical Consultants has received and evaluated 16 concrete cores for petrographic evaluation. The objectives of the evaluation were to assess the condition of the material as represented by the submitted core portions, including both the physical and mineralogical properties present, and to evaluate any distress or deleterious secondary chemical reactions.

Core Identification and Background Information

Twelve concrete cores were received on 6/27/23 and an addition 4 cores were received on 6/28/23 all the cores were delivered by Salvador Ramirez-Rosales. The description of the as received the cores is presented in Table I and the as-received photographs are presented in Appendix 1. In addition to the cores, photographs of core Nos. 4, 5, and 15 were supplied via email.

TABLE I. Core Descriptions

Core No.	Approximate dimensions (Diameter X Length)	Date Received	Description	Reinforcing Steel
2	3.7” X 3.4”	6/28/2023	Concrete core marked 2	None
3	3.7” X 3.6”	6/28/2023	Concrete core marked 3	None
4	3.7” X 8.6”	6/28/2023	Concrete core marked 4	No. 4 rebar 5.9” from Exposed surface
5	3.7” X 2.5”	6/28/2023	Concrete core marked 5	None
6	3.7” X 4.0”	6/27/2023	Concrete core marked 6	None
7	3.7” X 5.2”	6/27/2023	Concrete core marked 7	None

TABLE 1. Core Descriptions Continued				
Core No.	Approximate dimensions (Diameter X Length)	Date Received	Description	Reinforcing Steel
8	3.7" X 3.8"	6/27/2023	Concrete core marked 8	None
9	3.7" X 4.3"	6/27/2023	Concrete core marked 9	None
10	3.7" X 2.4"	6/27/2023	Concrete core marked 10	None
11	3.7" X 2.5"	6/27/2023	Concrete core marked 11	None
12	3.7" X 2.5"	6/27/2023	Concrete core marked 12	None
13	3.7" X 2.4"	6/27/2023	Concrete core marked 13	None
14	3.7" X 1.9"	6/27/2023	Concrete core marked 14	None
15	3.7" X 1.9"	6/27/2023	Concrete core marked 15	None
16	3.7" X 3.1"	6/27/2023	Concrete core marked 16	None
17	3.7" X 3.1"	6/27/2023	Concrete core marked 17	None

Procedure

The petrographic examination was conducted in accordance with ASTM C856/C856M, "Standard Practice for Petrographic Examination of Hardened Concrete,". The cores were measured with calipers and photographed in their as-received condition. An initial examination was conducted using a stereo zoom microscope. The cores were saw cut longitudinally. A section was lapped. Thin sections were prepared from selected areas along the exposed and interiors of the cores. The remaining concrete pieces were broken to examine the interior properties of the concrete. The lapped sections were photographed and examined with a stereo zoom microscope to evaluate the physical properties of the concrete. The thin sections were examined with a petrographic microscope to study the mineralogical properties.

FINDINGS & DISCUSSION

The results of the physical and mineralogical properties of the concrete are presented in Tables II to V. The photographs of the as-received cores are presented in Appendix 1 and the photographs of the lapped sections are presented in Appendix 2.

Aggregates:
The coarse and fine aggregates in all the cores were consistent with material from the Franciscan Formation. The differences in the relative amount of each type of rock in the cores are consistent with the range of rock and minerals within the formation. The aggregates were generally sub angular to sub-rounded, well to fairly well graded, and fairly hard to hard. No segregation of the coarse aggregate was detected except in Core No.15 which was severely segregated based on the supplied sample and photographs. The cause of the segregation in Core No. 15 could not be determined based on the supplied sample, but it was not caused by an excessively high water to cement ratio based on

the amount of unhydrated portland cement and excellent strength properties. The aggregate materials are composed primarily of: graywacke, metagraywacke, chert, radiolarian chert, weathered basalt, metabasalt, sandy argillite, serpentinite, schist, quartz, feldspars limestone, felsite, opaline shale, chalcedonic chert, gabbro, volcanic glass, and chalcedony. The maximum nominal size of the coarse aggregate particles was 1.5” in Core Nos. 6, 7, 8, and 10, 1.0” in Core Nos. 2, 3, 9, and 12, 0.75” in Core Nos. 13, 14, 16, and 17, Size No. 4 in Core Nos. 4 and 11, Size No. 8 in Core No. 5. Core No. 15 contained fine sand that graded to a 0.5” particle on the interior surface.

Cement:
Most of the concrete contained historical portland cement based on the grain size and mineralogy of the cement. Core Nos. 4, 5, and 15 contained a modern cement. No fly ash particles or other pozzolanic materials were detected in any of the concrete specimens.

Air Contents:
The concretes all contained entrapped air voids (irregular voids >1 mm diameter). Core Nos. 2, 3, 6, 7, 9, 10, 11, 14, 16, and 17 contained significant amounts of small (<1mm diameter) spherical air voids. By definition these are entrained air voids. The air-entrainment was likely caused by historical grinding aids used in the production of the portland cement as opposed to purposefully added air entrainment. There is no benefit for air entrained concrete in this type of structure. The gaps adjacent to the coarse aggregate particles in core Nos. 2, 3, 6, 7, 8, 9, and 11 are consistent with air voids that coalesce on the bottom side of coarse aggregate particles during consolidation of the concrete. The range of total air contents observed among the supplied concrete is usually associated with inconsistent placement/consolidation of the concrete. The gaps are also present in Core No. 8 but did not contain enough small voids to be considered air entrained.

Carbonation and Calcium Hydroxide:
The depth of carbonation of the cementitious paste varied from negligible to very deep, however the carbonation did not extend the full length in any of the supplied core specimens based on the thin section analysis. The cores that contained historical cement did have low amounts of carbonated hydrated lime, which was most likely from unburned or relic calcium oxide (CaO) in the historic cement that was not intentionally added to the concrete.

Secondary Reactions:
The ettringite ($3CaO \cdot Al_2O \cdot 3CaSO_4 \cdot 32H_2O$) and secondary calcium carbonate ($CaCO_3$) are a product of a reorganization of the cement paste as a result of cyclic wetting and drying of the concrete. The very low amounts of thermonatrite ($Na_2CO_3 \cdot H_2O$) and monosulfate ($3CaO \cdot Al_2O \cdot CaSO_4 \cdot 18H_2O$) are in very low amounts and are consistent with reorganization of the cement paste as opposed to chemical attack or Alkali-Silica Reactivity (ASR). No extraneous excessive amounts of sulfate compounds were detected in any of the concretes. Areas of ASR gel and reacted particles were detected in Core Nos. 2, 5, 7, 10, 11, and 14. The amount of gel and localized microcracking were not significant enough to cause any significant reduction in the strength properties or durability of the concrete based on the supplied samples at the time of this investigation. Future ASR is highly unlikely.

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMENS
ASTM C856-20

Table II Physical Descriptions of Concretes				
Core No.	Exposed Surface	Interior/Non-Exposed Surface	Surface Deposits/Coatings	Cracks/Gaps
2	Light brown, fairly hard with few fairly soft areas, formed surface to very light to lightly scaled.	Light brown-gray, hard to fairly hard, saw cut surface.	Small patches of dark brown debris on exposed surface.	No large cracks, very few to few small random cracks throughout lap section. Few gaps on one side of coarse aggregate particles.
3	Light brown, fairly hard with few fairly soft areas, lightly scaled to formed surface.	Light brown-gray, fairly hard to hard, saw cut surface.	Patches of dark brown debris on exposed surface.	No large cracks, very few very small random cracks throughout lap section. Few gaps on one side of coarse aggregate particles.
4	Hard to very hard, intact, with a rough finish.	Fairly hard, intact.	Exposed surface coated in yellow paint, interior surface covered in sand.	No large cracks, some honeycomb (fair to poor consolidation) adjacent to rebar and random area, few to some very small random cracks throughout lap section.
5	Light brown-gray, fairly soft, very lightly scaled formed surface.	Light brown-gray, fairly hard, saw cut surface.	None	No large cracks, few very small random throughout lap section.
6	Fairly hard to fairly soft, light to moderately scaled.	Medium brown-gray, fairly hard to fairly soft, saw cut surface.	Exposed surface covered in dark brown debris.	No large cracks, very few very small random cracks throughout lap section. Very few gaps on one side of coarse aggregate particles.
7	Medium brown to dark brown, hard, very light to lightly scaled formed surface.	Medium brown-gray, fairly hard with few fairly soft areas, saw cut surface.	Exposed surface contained yellow and black paint, secondary $CaCO_3$, and coring mud. The interior surface had a few voids lined with secondary $CaCO_3$ and ettringite.	No large cracks, few small traverse cracks exposed surface to 2-3 mm. Few gaps on one side of coarse aggregate particles.

Table II Physical Descriptions of Concretes Continued				
Core No.	Exposed Surface	Interior/Non-Exposed Surface	Surface Deposits/Coatings	Cracks/Gaps
8	Mottled light brown medium brown-gray and dark brown, fairly soft to fairly hard, light to very lightly scaled formed surface.	Light brown-gray, fairly hard, saw cut surface.	Exposed surface had patches of dark brown debris.	No large cracks, few small random cracks throughout lap section. Few gaps on one side of coarse aggregate particles.
9	Medium brown to light brown, fairly hard with fairly soft areas, very lightly scaled to formed surface.	Medium brown-gray, fairly hard, saw cut surface.	Exposed surface covered in medium brown debris.	No large cracks, few very small random cracks throughout lap section. Few gaps on one side of coarse aggregate particles.
10	Dark gray to dark brown, soft to fairly soft, light to moderately scaled surface.	Medium brown-gray, fairly soft with fairly hard areas, saw cut surface.	Exposed surface covered in dark gray debris. Interior surface contained a 4-10 mm patch of corrosion products, and few voids lined with secondary $CaCO_3$.	No large cracks, few small random cracks throughout lap section.
11	Light brown-gray, fairly soft, intact formed surface.	Light brown-gray to medium brown-gray, fairly soft to fairly hard, saw cut surface.	None	No large cracks, very few very small random cracks throughout lap section. Few to some gaps on one side of coarse aggregate particles.
12	Medium brown to light brown, fairly soft to soft, light to moderately scaled surface.	Medium brown-gray, fairly hard to fairly soft, saw cut surface.	None	No large cracks, very few very small random cracks throughout lap section.
13	Medium brown, fairly hard to hard, very light to lightly scaled formed surface.	Light brown-gray, hard to fairly hard saw cut surface.	None	No large cracks, very few very small random cracks throughout lap section. Few transverse cracks 2 mm from exposed surface.
14	Dark gray to dark brown-gray, hard to fairly hard, intact, formed surface.	Medium brown-gray, hard, saw cut surface.	Dark gray to dark brown coating.	No large cracks, very few very small random cracks throughout lap section.

Table II Physical Descriptions of Concretes Continued				
Core No.	Exposed Surface	Interior/Non-Exposed Surface	Surface Deposits/Coatings	Cracks/Gaps
15	Light brown-gray to medium-gray, hard to very hard, intact to spalled on edge, fairly smooth finish.	Dark brown gray, hard to very hard, saw cut surface.	None	No large cracks, few small shrinkage cracks from exposed surface to 10-15 mm. Few small transverse cracks in exterior 5mm.
16	Medium brown to light brown, hard to fairly hard with few fairly soft areas, very light to moderately scaled, formed surface.	Medium brown-gray, fairly soft, saw cut surface.	None	No large or small cracks detected.
17	Light brown to medium brown, soft to fairly soft, formed surface.	Medium brown-gray, fairly hard to fairly soft, saw cut surface.	Exposed surface covered in yellow and blue paint.	No large or small cracks detected.

Table III Physical Properties of Concrete						
Core No.	Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content %	Consolidation
2	Hard with few fairly hard and fairly soft areas.	Medium brown exposed surface to 5-7 mm, medium gray to medium brown-gray below.	Moderately low	Moderate to moderately weak	4-6	Good with few gaps of coalesced air voids on one side of coarse aggregate particles.
3	Fairly hard to hard with fairly soft areas.	Medium brown exposed surface to 10-17 mm, buff 10-30 mm, medium gray to light brown-gray below.	Moderately low	Moderate to moderately strong 10-30 mm from exposed surface, moderately weak below.	5-7	Good with few gaps of coalesced air voids on one side of coarse aggregate particles.
4	Hard to very hard, with fairly soft and fairly hard areas.	Medium brown-gray exposed surface to 3 mm, buff 4-10 mm, light brown-gray below.	Moderate	Moderately Strong	2-3	Good with bands of fair and poor consolidation.
5	Fairly hard exposed surface to 4 mm, hard below.	Medium brown-gray exposed surface to 3-5 mm, buff below to 18-30 mm, light gray to medium gray below buff area.	Moderate	Moderately weak	0.5-1	Good
6	Fairly soft to soft	Medium brown exposed surface to 2-5 mm, medium brown-gray below.	Moderately low	Moderate	3-4	Good with very few gaps of coalesced air voids on one side of coarse aggregate particles.

Table III Physical Properties of Concrete (Continued)						
Core No.	Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content %	Consolidation
7	Fairly soft exposed surface to 15-20 mm, fairly hard to hard below.	Medium brown exposed surface to 3-8 mm, medium brown gray below.	Moderately low	Moderately week. Moderate interior 60 mm.	2-3	Good with few gaps of coalesced air voids on one side of coarse aggregate particles.
8	Fairly soft to soft with fairly hard areas.	Medium brown to medium brown-gray.	Moderate to moderately low.	Moderate to moderately weak.	2-3	Good with few gaps of coalesced air voids on one side of coarse aggregate particles.
9	Fairly hard with fairly soft area.	Light brown-gray exposed surface to 2-20 mm, medium gray to medium brown-gray below.	Moderate	Moderate to moderately weak	2-3	Good with few gaps of coalesced air voids on one side of coarse aggregate particles.
10	Fairly soft with few fairly hard areas.	Dark brown exposed surface to 1 mm, medium brown-gray below.	Moderately low	Moderately weak	4-6	Good
11	Fairly soft with few fairly hard areas.	Light buff exposed surface to 30-40 mm, light brown-gray below.	Moderate	Moderately weak	1-3	Good with few to some gaps of coalesced air voids on one side of coarse aggregate particles.
12	Fairly soft with soft and fairly hard areas.	Buff exposed surface to 3-6 mm, medium brown-gray below.	Moderate	Moderately weak	0.5-1	Good
13	Fairly hard to hard	Buff exposed surface to 20-30 mm, light gray to light brown-gray below.	Moderate	Moderate	0.5-1	Good

Table III Physical Properties of Concrete (Continued)						
Core No.	Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content %	Consolidation
14	Hard to fairly hard with few fairly soft areas.	Dark gray exposed surface to 1-5 mm medium brown to medium brown gray below.	Moderately low	Moderately weak	4-5	Good
15	Very hard	Medium gray to dark gray exposed surface to 6-10 mm with a dark brown patch, dark brown-gray below.	Moderate to moderately high	Very strong	<0.5	Good but segregated. Sand gets coarser the farther from the exposed surface.
16	Fairly soft with fairly hard areas exposed surface to 6-10 mm, soft to fairly soft below.	Medium brown-gray to dark brown-gray exposed surface to 8-12mm, medium brown gray below.	Moderately low	Moderately weak	4-5	Good
17	Fairly soft to fairly hard with soft areas.	Light brown-gray to medium brown-gray.	Moderately low	Exposed surface to 40 mm moderately weak, strong below.	3-4	Good

Table IV Mineralogical Properties of Cementitious Paste					
Core No.	Location	Unhydrated Cement, %	Calcium Hydroxide, %	Microcracks	Depth of carbonation
2	Exposed surface to 20 mm	1-3	<5	Few random	2-8 mm from exposed surface
	Interior surface to 35 mm	3-7	<5	Very few very small random	Trace to 2 mm
3	Exposed surface to 20 mm	1-7	<5	Few longitudinal from exposed surface to 5 mm.	18 mm to through section
	Interior surface to 35 mm	3-7	<5	Few random throughout section.	None
4	Exposed surface to 35 mm	3-5 from exposed surface to 1 mm,1-5 below.	0-5	Very few very small random throughout section.	3-6 mm
	Interior surface to 35 mm	5-7	3-10	None	<1-1 mm
5	Exposed surface to 20 mm	10-15	0-12	Few longitudinal from exposed surface to 2 mm.	4-10 mm
	Interior surface to 35 mm	15-20	0-10	Tracy random throughout section.	None
6	Exposed surface to 35 mm	3-5	0	1 longitudinal from exposed surface to 12 mm, trace random throughout section.	Through section
	Interior surface to 35 mm	<1-5	0	Few random throughout section.	Carbonation goes through the core to 30 mm from interior surface
7	Exposed surface to 35 mm	5-15 from exposed surface to 10 mm,3-7 below.	<5	Few transverse from exposed surface to 1mm, few random below.	10-30 mm from exposed surface
	Middle 65-85 mm from exposed surface	3-7	<5	Few to some adjacent to reacted particle.	None

Table IV Mineralogical Properties of Cementitious Paste (Continued)					
Core No.	Location	Unhydrated Cement, %	Calcium Hydroxide, %	Microcracks	Depth of carbonation
8	Exposed surface to 35 mm	1-5	0	Few random throughout section.	Through section
	Interior surface to 35 mm	1-5	<5	Trace random throughout section.	Patchy throughout section.
9	Exposed surface to 35 mm	1-5	0-5	Few random throughout section.	15 mm to through section.
	Interior surface to 35 mm	1-5	<5	Few to some random throughout section.	None
10	Exposed surface to 20 mm	1-5	<5	Few adjacent to chert particle.	9-17 mm from exposed surface.
	Interior surface to 35 mm	1-3	<5	Very few random	5-10 mm from interior surface.
11	Exposed surface to 20 mm	1-3	0	Trace random	Through section
	Interior surface to 35 mm	<1-2	<5	Very few random	Carbonation goes through the core to 15-25 mm from interior surface.
12	Exposed surface to 20 mm	1-5	0	Very few random	Through section
	Interior surface to 35 mm	1-3	0	Few adjacent to coarse aggregate particle.	Carbonation goes through the core to >35-31 mm from interior surface.
13	Exposed surface to 20 mm	<1-3	0	Few transverse exposed surface to 1 mm.	19 mm to through section.
	Interior surface to 35 mm	<1-2	0-5	Trace random	<1 mm

Table IV Mineralogical Properties of Cementitious Paste (Continued)					
Core No.	Location	Unhydrated Cement, %	Calcium Hydroxide, %	Microcracks	Depth of carbonation
14	Exposed surface to 20 mm	2-5	0-5	Few random throughout section.	<1-5 mm from exposed surface.
	Interior surface to 20 mm	3-7	<5	Very few random throughout section.	None
15	Exposed surface to 20 mm	12-17	15-20	None	0-<1mm from exposed surface. 20 mm along small shrinkage cracks.
	Interior surface to 20 mm	12-17	15-20	None	None
16	Exposed surface to 20 mm	1-5 with areas of 5-10	0	Few transverse exterior 1 mm.	Through section
	Interior surface to 35 mm	1-3	0-5	None	Through core to 7 mm from interior surface.
17	Exposed surface to 20 mm	1-5	0	None	Through section
	Interior surface to 35 mm	1-3	<5	Very few random	Through core to 10-15 mm from interior surface.

Table V Secondary Deposits			
Core No.	Concrete section	Exposed Thin Section	Interior/Middle Thin Section
2	Few voids lined with secondary calcium carbonate ($CaCO_3$) and a trace amount of thermonatrite ($Na_2CO_3 \cdot H_2O$).	Low amount of ettringite ($3CaO \cdot Al_2O \cdot 3CaSO_4 \cdot 32H_2O$) in very few small voids.	Low amount of alkali-silica gel ($NaO \cdot K_2O \cdot CaO \cdot SiO_2$) in microcracks.
3	Few voids lined with secondary calcium carbonate.	Few voids lied with low amount of ettringite below carbonation layer.	None
4	Many voids lined/filled with ettringite in interior 15-25 mm. No corrosion of the reinforcing steel.	None	Many voids lined/filled with ettringite throughout section.
5	None	None	Alkali-silica gel soaked paste adjacent to chert and argillite particles.
6	Many voids lined with secondary calcium carbonate throughout core.	None	Some voids lined with low amount of secondary calcium carbonate throughout section.
7	Some to many voids lined/filled with ettringite and secondary calcium carbonate below 50-65 mm.	Some voids lined/filled with secondary calcium carbonate below 15 mm.	Some areas of alkali silica gel soaked paste, few voids lined/filled with ettringite.
8	None	Few voids lined/filled with secondary calcium carbonate.	Many voids lined with secondary calcium carbonate; few voids lined/filled with ettringite above carbonation layer.
9	None	None	None
10	Few to some voids lined/filled with ettringite and secondary calcium carbonate.	Alkali-silica gel adjacent to chalcedony particle.	Few voids lined/filled with ettringite and secondary calcium carbonite.
11	Very few voids lined with secondary calcium carbonite.	Trace voids lined with secondary calcium carbonite.	Trace voids lined with secondary calcium carbonite, areas of gel soaked paste.
12	Very few voids lined with secondary calcium carbonite.	None	None

Table V Secondary Deposits (Continued)			
Core No.	Concrete section	Exposed Thin Section	Interior/Middle Thin Section
13	Very few voids lined with very low amount of ettringite.	None	None
14	Many voids lined/filled with ettringite and secondary calcium carbonate through core, more concentrated along exposed surface.	Ettringite in voids, many voids lined/filled with secondary calcium carbonate in carbonated area.	Many voids lined/filled with ettringite, very few areas of alkali-silica gel. very low amount of monosulfate ($3CaO \cdot Al_2O \cdot CaSO_4 \cdot 18H_2O$) in voids that contained ettringite.
15	None	None	None
16	Many voids lined/filled with secondary calcium carbonate interior 35 mm.	None	Few voids lined with ettringite below carbonation layer.
17	None	None	None

Findings

Findings of this study are based solely on the examination of the provided cores and may not necessarily represent the materials and condition of materials elsewhere in the same project location. In performing its services, Atlas Technical Consultants used that degree of care and skill ordinarily exercised under similar circumstances by reputable members of its profession currently practicing in the same locality. No warranty, express or implied, is made.

The cores will be retained for at least 30 days from the date of this report. Unless we are instructed otherwise, the cores may be discarded. Storage of held cores will be billed monthly. There is a $100 per month storage fee beyond 30 days. Return shipment charges are the responsibility of the client.

If you have any questions or concerns, please do not hesitate to contact Bill Nickison at 510.846.4593.

Sincerely,

Atlas Technical Consultants

Bill Nickison
Senior Petrographer

Attachments:

- *Appendix 1 As-Received Photographs*
- *Appendix 2 Photographs of Lapped Sections*

Appendix 1
As-Received Photographs

Photo 1. Exposed surface of core 2.

Photo 2. Side of core 2 exposed surface at left of photo.

Core 3. Exposed surface of core 3.

Core 4. Side of core 3 exposed surface at left of photo.

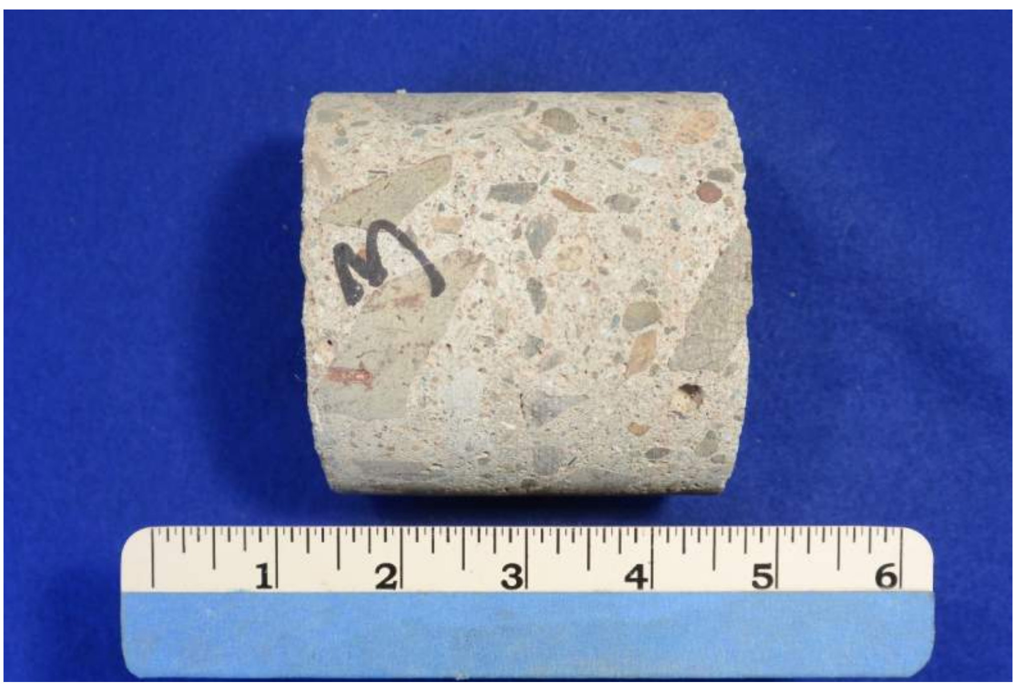


Photo 5. Exposed surface of core 4.

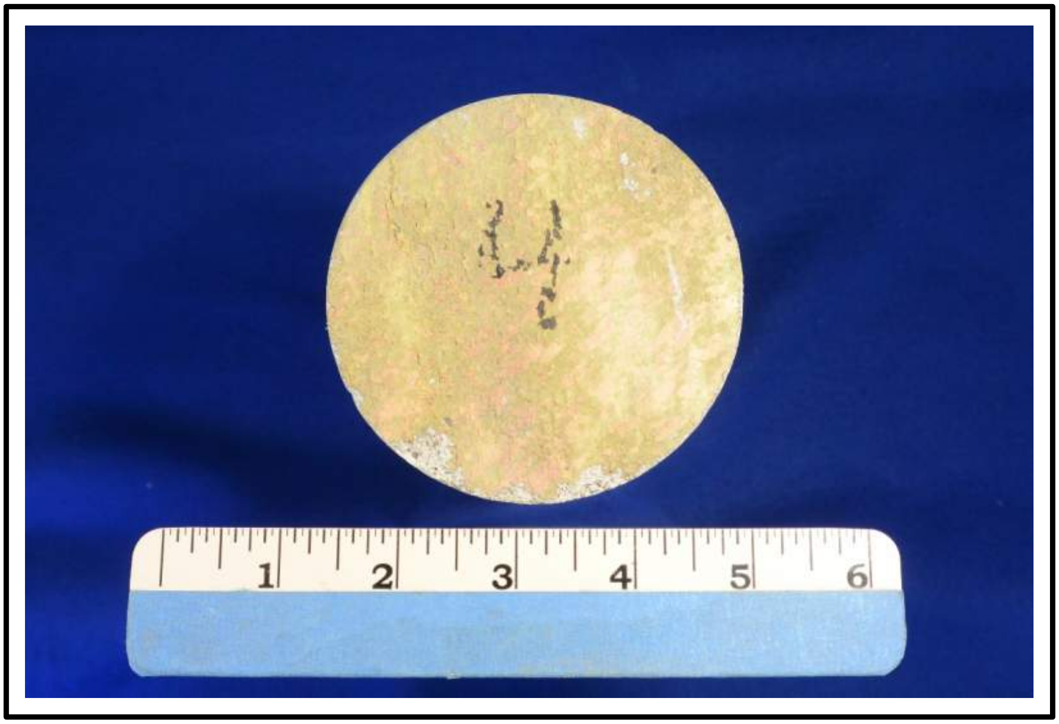


Photo 6. Side of core 4 exposed surface at left of photo.

Photo 7. Exposed surface of core 5.

Photo 8. Side of core 5 exposed surface at left of photo.

Photo 9. Exposed surface of core 6.

Photo 10. Side of core 6 exposed surface at left of photo.

Photo 11. Exposed surface of core 7.

Photo 12. Side of core 7 exposed surface at left of photo.

Photo 13. Exposed surface of core 8.

Photo 14. Side of core 8 exposed surface at left of photo.

Photo 15. Exposed surface of core 9.

Photo 16. Side of core 2 exposed surface at left of photo.

Photo 17. Exposed surface of core 10.

Photo 18. Side of core 10 exposed surface at left of photo.

Photo 19. Exposed surface of core 11.

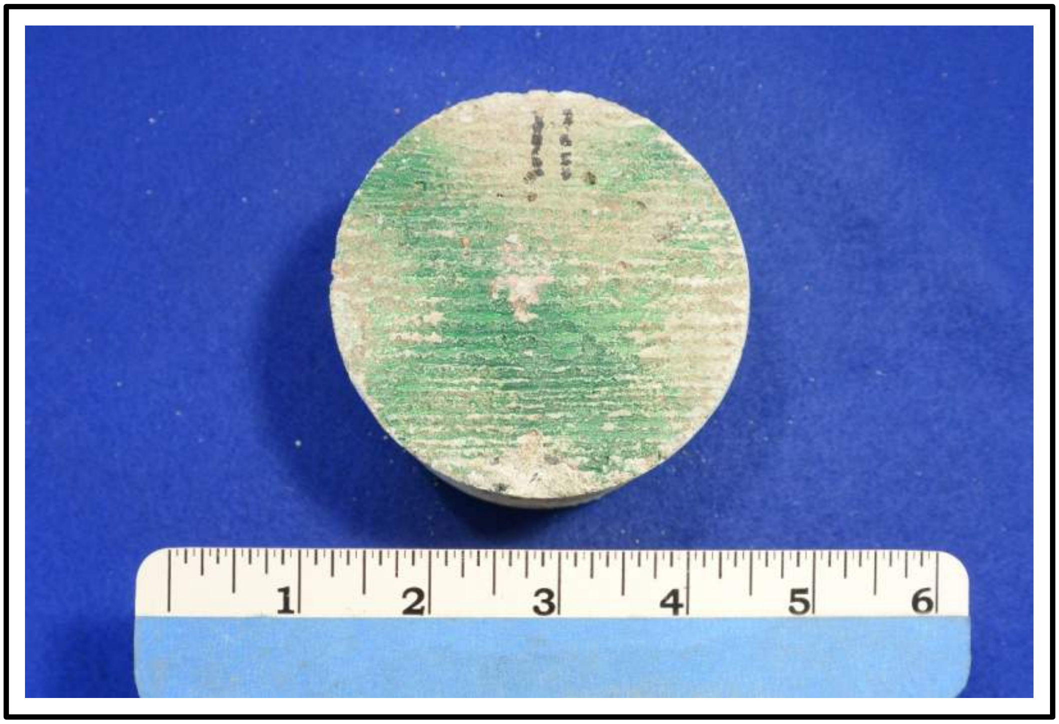


Photo 20. Side of core 11 exposed surface at left of photo.

Photo 21. Exposed surface of core 12

Photo 22. Side of core 12 exposed surface at left of photo.

Photo 23. Exposed surface of core 13

Photo 24. Side of core 13 exposed surface at left of photo.

Photo 25. Exposed surface of core 14.

Photo 26. Side of core 14 exposed surface at left of photo.

Photo 27. Exposed surface of core 15.

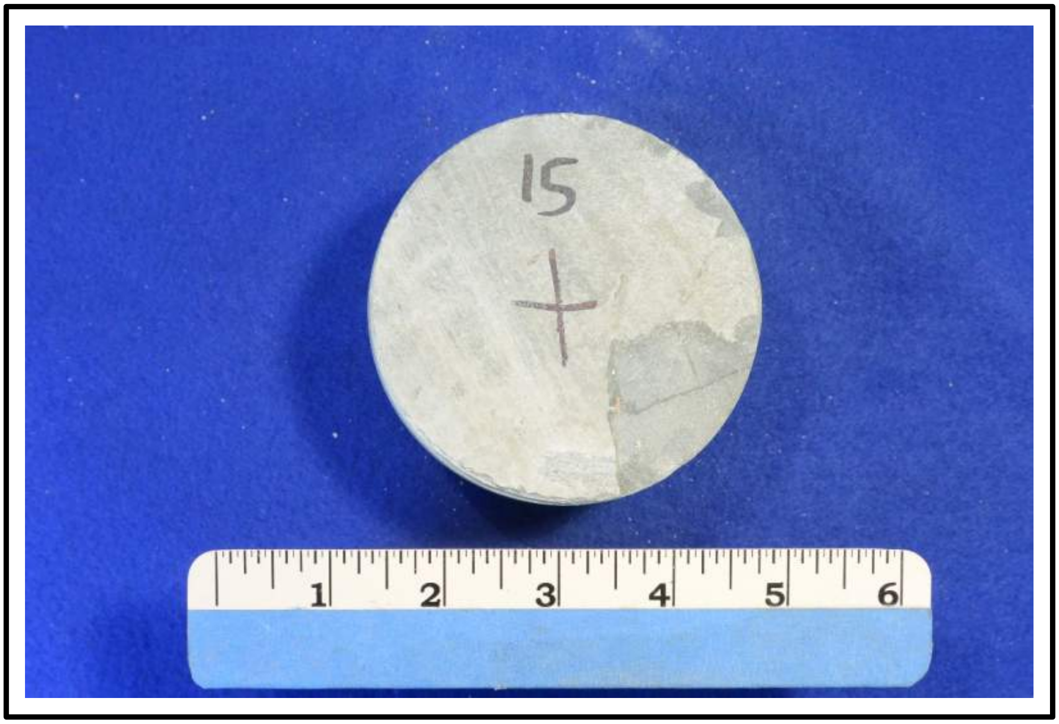


Photo 28. Side of core 15 exposed surface at left of photo.

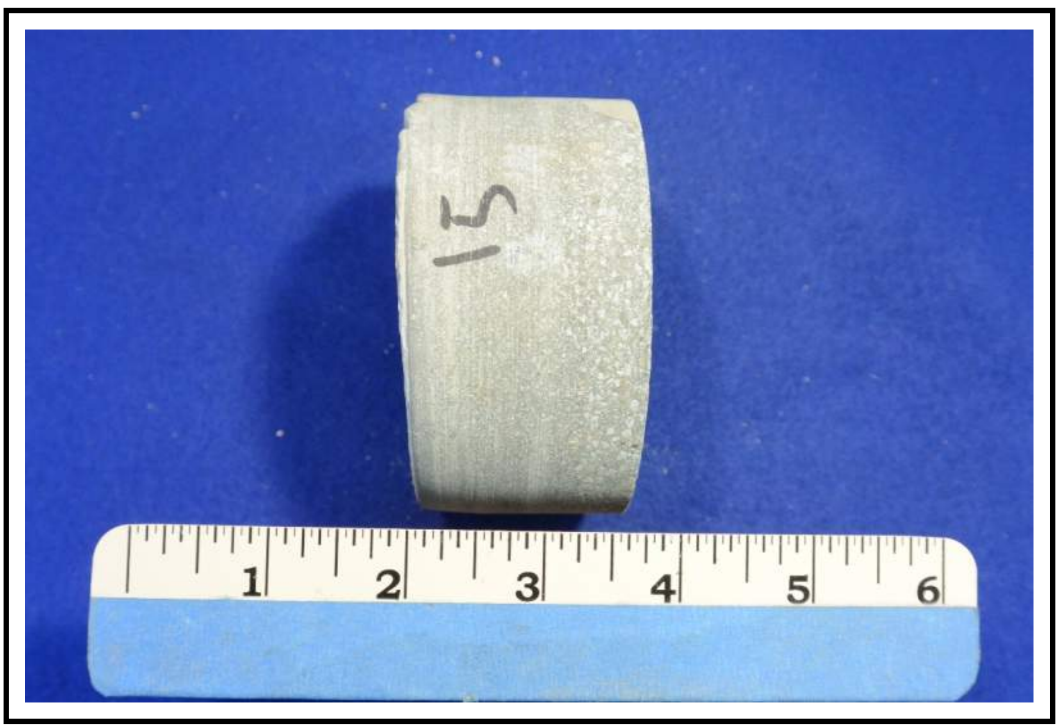


Photo 29. Exposed surface of core 16.

Photo 30. Side of core 16 exposed surface at left of photo.

Photo 31. Exposed surface of core 17.

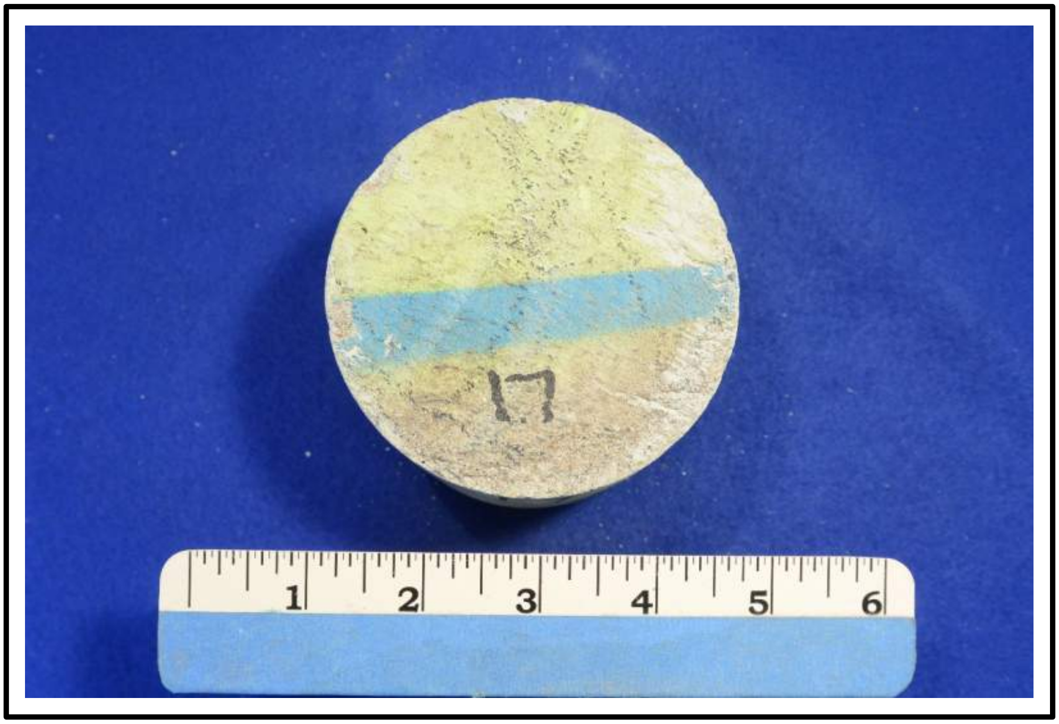


Photo 32. Side of core 17 exposed surface at left of photo.

Appendix 2
Photographs of Lapped Sections

Photo 33. Lapped surface of core No. 2. Exposed surface at top of photo.

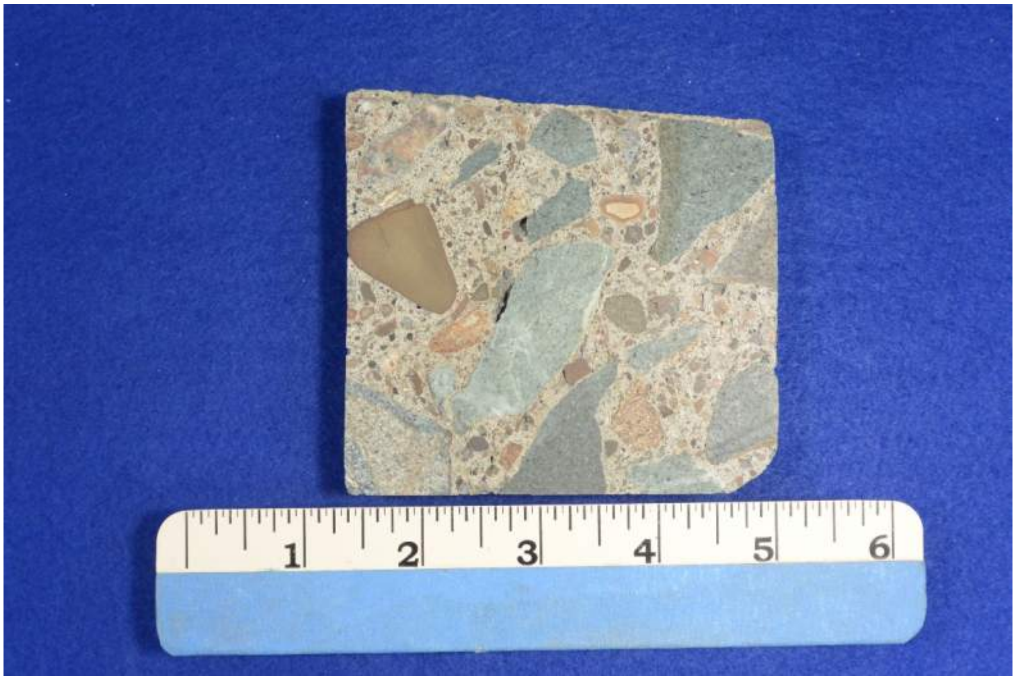


Photo 34. Lapped surface of core No. 3. Exposed surface at top of photo.

Photo 35. Lapped surface of core No. 4. Exposed surface at left of photo.

Photo 36. Lapped surface of core No. 5. Exposed surface at top of photo.

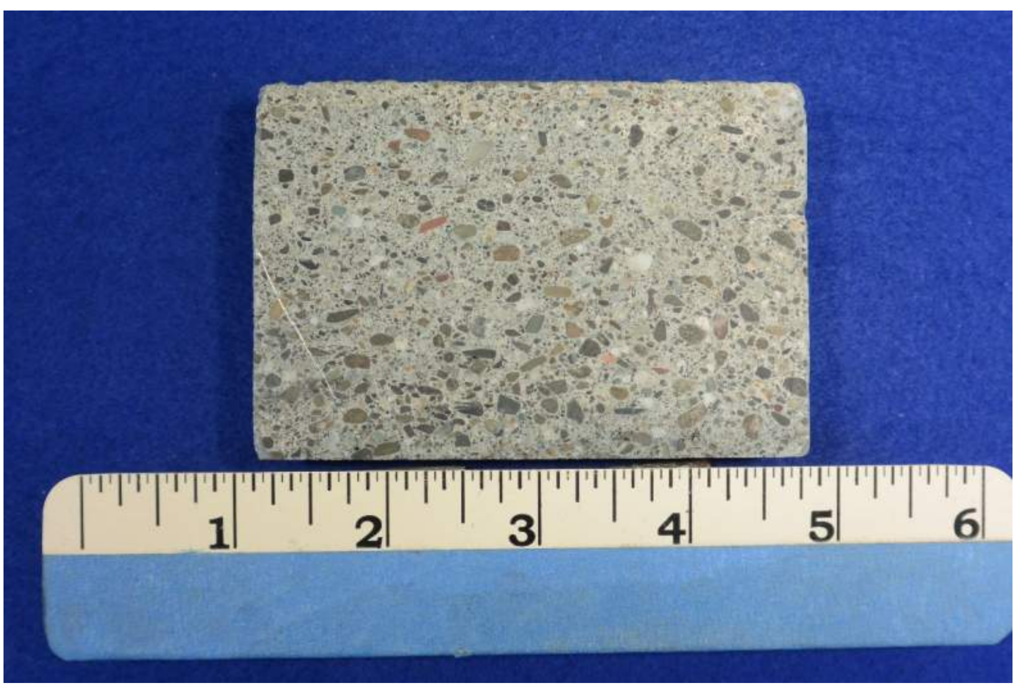


Photo 37. Lapped surface of core No. 6. Exposed surface at top of photo.

Photo 38. Lapped surface of core No. 7. Exposed surface at top of photo.

Photo 39. Lapped surface of core No. 8. Exposed surface at top of photo.

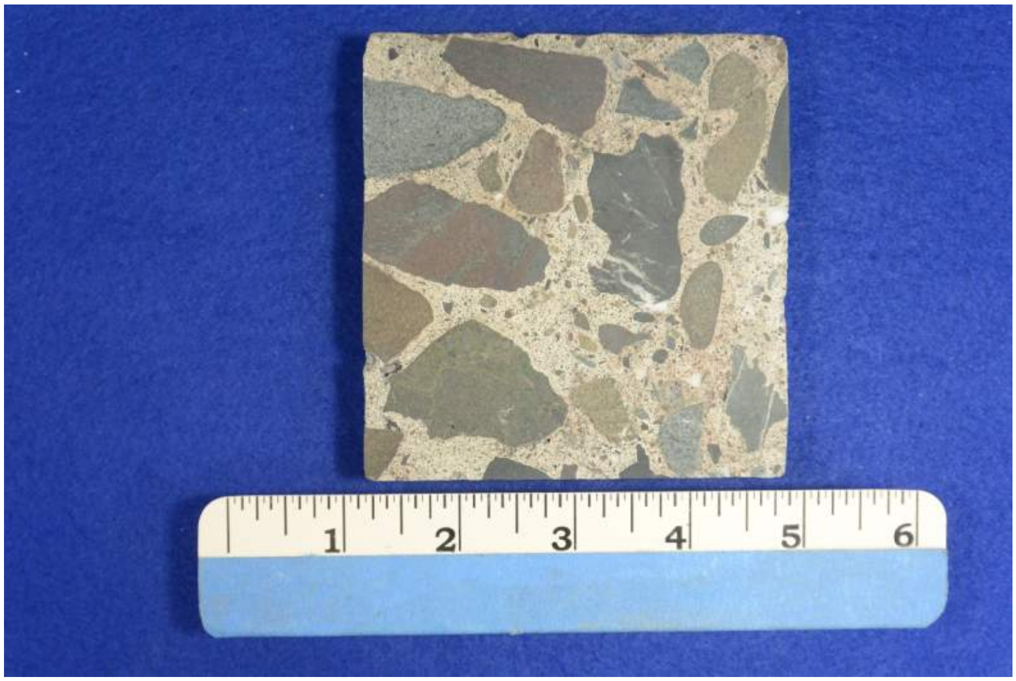


Photo 40. Lapped surface of core No. 9. Exposed surface at top of photo.

Photo 41. Lapped surface of core No. 10. Exposed surface at top of photo.

Photo 42. Lapped surface of core No. 11. Exposed surface at top of photo.

Photo 43. Lapped surface of core No. 12. Exposed surface at top of photo.

Photo 44. Lapped surface of core No. 13. Exposed surface at top of photo.

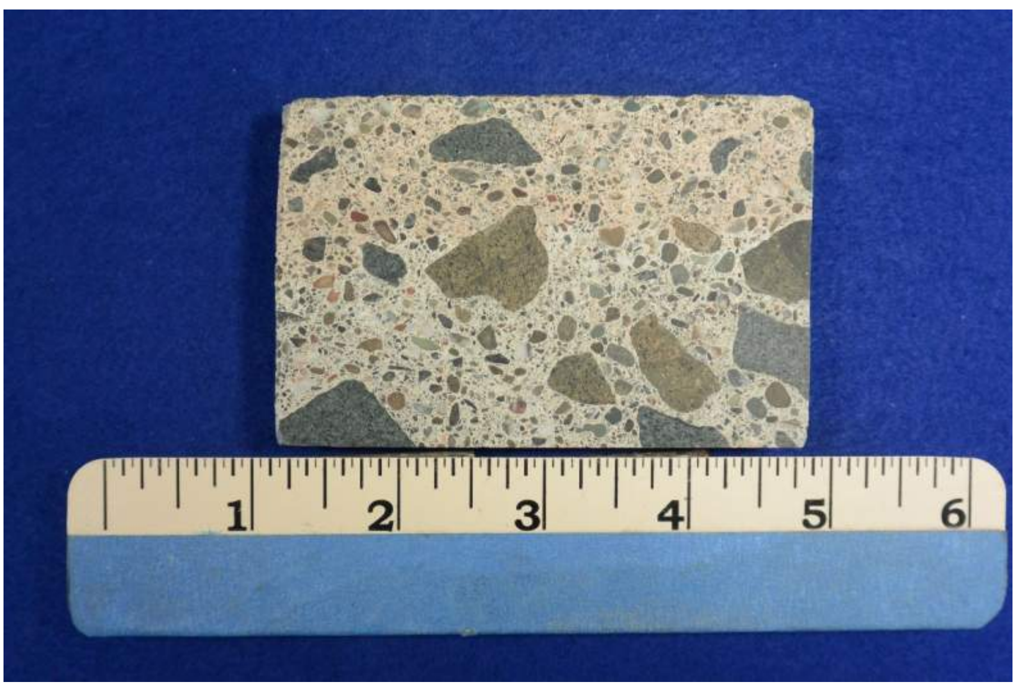


Photo 45. Lapped surface of core No. 14. Exposed surface at top of photo.

Photo 46. Lapped surface of core No. 15. Exposed surface at top of photo.

Photo 47. Lapped surface of core No. 16. Exposed surface at top of photo.

Photo 48. Lapped surface of core No. 17. Exposed surface at top of photo.

Appendix E
30% Level Schematic Drawings

STRAWBERRY CREEK CULVERT
STRUCTURAL ASSESSMENT
BERKELEY, CA

LAYOUT

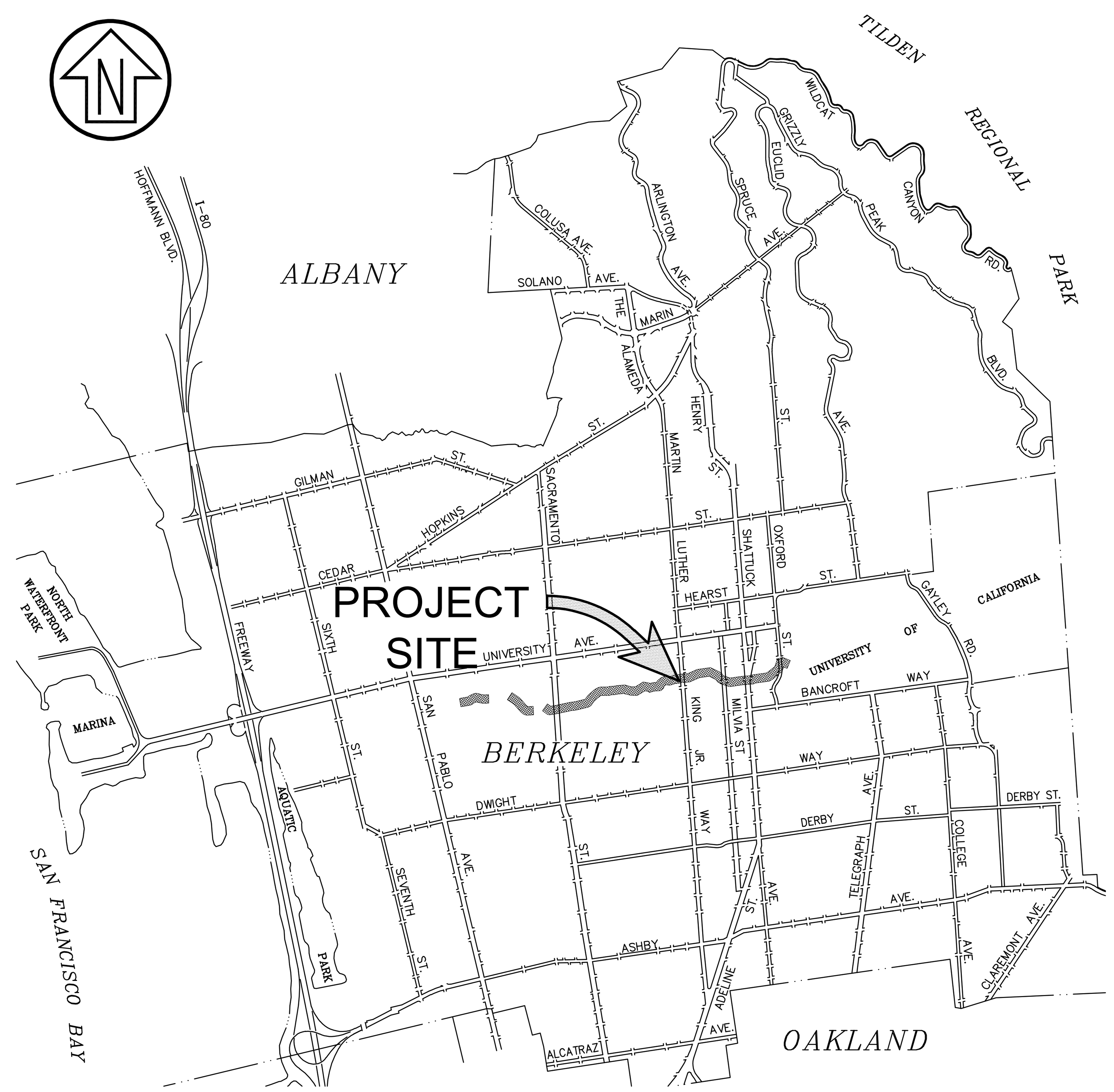
CSEG

CITY OF BERKELEY

ALAMEDA COUNTY, CALIFORNIA

STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT

SPECIFICATION NO. 24-XXXXXX



LOCATION MAP

SCALE: N.T.S.

KEY MAP

SCALE: N.T.S.

SHEET INDEX

CONTACT INFORMATION

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CITY OF BERKELEY:	RICARDO SALCEDO 510-981-6407 RSalcedo@berkeleyca.gov

Know what's **below.** **Call** before you dig.

REVISION	MARK	DATE	DESCRIPTION	APPROVAL

CSW/Stuber-Stroeh Engineering Group, Inc.
121 Park Place
Richmond, CA 94801
tel: 415.883.9850
fax: 415.883.9835
http://www.cswst2.com
© 2023

PROJECT MANAGER: ______ DATE ______

0 1 2 3
FOR REDUCED PLANS – ORIGINAL SCALE IS IN INCHES

DEPICTION OF MONUMENTS: DATE ______
SURVEY CHIEF OF PARTY
WATERSHED REVIEW: DATE ______

SUBMITTED: ______ DATE ______ REGISTR. ______ EXP. ______
SUPERVISING ENGINEER
APPROVED: ______ DATE ______ R.C.E. ______ EXP. ______
CITY ENGINEER

DESIGN JD
DRAWN JD
CHECK RS
AS BUILT ______

HORIZ. ______
VERT. ______
BOOK ______
DATE 11/03/23

CITY OF BERKELEY
DEPARTMENT OF PUBLIC WORKS

STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
COVER SHEET

PLAN –
FILE –
T1
SHEET 1 OF 14

CONSTRUCTION NOTES:

1. PROTECT AND PRESERVE ALL SURVEY MONUMENTS. SEE MONUMENT PRESERVATION NOTE.
2. PROTECT ALL DRAINAGE AND SEWAGE STRUCTURES (INCLUDING PIPES) FROM INFILTRATION OF ALL CONSTRUCTION DEBRIS FOR THE DURATION OF THE WORK.

GENERAL NOTES:

1. ALL DRAWINGS AND SPECIFICATIONS ARE CONSIDERED PART OF THE CONTRACT DOCUMENTS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR REVIEW AND COORDINATION OF ALL DRAWINGS AND SPECIFICATIONS PRIOR TO START OF CONSTRUCTION. ANY DISCREPANCIES THAT OCCUR SHALL BE BROUGHT TO THE ATTENTION OF THE ENGINEER PRIOR TO THE START OF CONSTRUCTION SO THAT A CLARIFICATION MAY BE ISSUED. WORK NOT CONFORMING TO THE CONTRACT DOCUMENTS SHALL BE CORRECTED BY THE CONTRACTOR AT NO EXPENSE TO THE CITY.
2. CONSTRUCTION SHALL BE LIMITED BETWEEN THE HOURS OF 7:30 AM AND 5:00 PM, MONDAY THROUGH FRIDAY AND INSPECTION REQUESTS SHALL BE LIMITED TO NORMAL BUSINESS HOURS: 8:00 AM TO 5:00 PM, MONDAY THROUGH FRIDAY. ARRANGEMENTS FOR ANY OVERTIME INSPECTION SERVICES AND PAYMENTS OF FEES FOR SAME SHOULD BE MADE 48 HOURS IN ADVANCE AND ARE SUBJECT TO AVAILABILITY AND APPROVAL BY THE ENGINEER.
3. UTILITIES AS SHOWN CONFORM TO AVAILABLE RECORD DATA. THE EXISTENCE, LOCATION AND CHARACTERISTICS OF UNDERGROUND UTILITY INFORMATION SHOWN ON THESE PLANS HAVE BEEN OBTAINED FROM A REVIEW OF AVAILABLE RECORD DATA. NO REPRESENTATION IS MADE AS TO THE ACCURACY OR COMPLETENESS OF SAID UTILITY INFORMATION. IT IS THE CONTRACTOR'S RESPONSIBILITY REFEERENCE ALL SURFACE UTILITIES PRIOR TO COMMENCING WORK AND TO VERIFY LOCATION AND DEPTHS BY POTHOLING OF ALL UTILITIES WITH APPROPRIATE AGENCIES, AND TO TAKE PRECAUTIONARY MEASURES TO PROTECT THE UTILITY LINES SHOWN AND ANY OTHER LINES NOT OF RECORD OR NOT SHOWN ON THESE PLANS. ANY CONFLICTS SHALL BE REPORTED IMMEDIATELY TO THE ENGINEER.
4. THE CONTRACTOR IS RESPONSIBLE FOR MAINTAINING ADEQUATE DRAINAGE OF THE SITE, DURING INTERIM CONDITIONS OF CONSTRUCTION.
5. CONTRACTOR SHALL PROVIDE ALL MATERIAL, LABOR, EQUIPMENT, FOR INSTALLATION, IMPLEMENTATION, AND MAINTENANCE OF ALL SURFACE WATER POLLUTION PREVENTION MEASURES THROUGHOUT THE FULL EXTENT OF THE PROJECT. SURFACE WATER IS CLASSIFIED AS ANY BODY OF WATER ABOVE GROUND.
6. OVERHEAD UTILITY SERVICE DROPS ARE NOT SHOWN ON THE PLANS. THE CONTRACTOR SHALL INVESTIGATE THE SITE AND BE AWARE OF LIMITED OVERHEAD CLEARANCES.
7. PAVEMENT MARKINGS DISTURBED, DAMAGED IN ANY FORM, OR TO ANY DEGREE WHILE THE CONTRACTOR HAS CUSTODY OF THE SITE SHALL BE REPLACED IN THEIR ENTIRETY AT CONTRACTOR'S EXPENSE.
8. CONTRACTOR SHALL CONTACT CITY ARBORIST AT LEAST 48 HOURS IN ADVANCE OF PERFORMING WORK UNDER THE DRIP LINE OF EXISTING TREES. THE CITY ARBORIST WILL REVIEW EACH LOCATION ON A CASE-BY-CASE BASIS TO CONFIRM THE ALLOWABLE EXTENT OF ROOT AND BRANCH PRUNING REQUIRED. CONTRACTOR SHALL ADHERE TO CITY SPECIFICATIONS AND RECOMMENDATIONS FOR TREE PRESERVATION.
9. TREE PROTECTION - PROVIDE FOR WRAPPING TREES, KEEPING EXPOSED ROOTS MOIST, AND USE OF AIR TOOLS FOR EXCAVATING. MEET WITH CITY ARBORIST BEFORE ANY WORK IS DONE.

PRESERVATION OF SURVEY MONUMENTS

ALL CITY OF BERKELEY MONUMENTS LOCATED WITHIN THE PROJECT AREA MUST BE REFERENCED, PRIOR TO WORK COMMENCING, BY A LICENSED LAND SURVEYOR AS REQUIRED BY SECTION 8771 OF THE BUSINESS AND PROFESSIONS CODE. CORNER RECORDS OF THIS WORK MUST BE SUBMITTED FOR FILING TO BOTH THE COUNTY SURVEYOR OF ALAMEDA COUNTY, AND THE CITY OF BERKELEY PUBLIC WORKS DEPARTMENT, ENGINEERING DIVISION, SURVEY SECTION.

THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE PRESERVATION OF EXISTING SURVEY MONUMENTS, BENCHMARKS, REFERENCE MARKS AND STAKES. SHOULD ANY SURVEY MONUMENTS, BENCHMARKS, REFERENCE POINTS, OR STAKES BE DAMAGED OR DESTROYED DURING THE PERFORMANCE OF THIS WORK, THE CONTRACTOR SHALL REPLACE SAID ITEMS PER CITY STANDARDS IN ACCORDANCE WITH THE SPECIAL PROVISIONS AND CONTACT A CITY OF BERKELEY, SURVEY SECTION, CHIEF OF PARTY FOR FINAL INSPECTION AND ACCEPTANCE OF THE WORK.

POLLUTION CONTROL NOTES:

1. IF SIGNIFICANT SEDIMENT OR OTHER VISUAL SYMPTOMS OF IMPURITIES ARE NOTICED IN THE STORM WATER, CONTACT THE CITY ENGINEER IMMEDIATELY.
2. CONTRACTOR IS RESPONSIBLE FOR INSPECTION AND RESTORATION OF ALL ASPECTS OF THIS PLAN. SEDIMENT ON SIDEWALKS AND GUTTERS SHALL BE REMOVED BY SHOVEL AND/OR BROOM AND PLACED IN STOCKPILES.
3. ALL DUMPSTERS OR OTHER TRASH STORAGE ENCLOSURES SHALL BE UTILIZED SOLELY FOR NON-HAZARDOUS MATERIALS.
4. ALL EMPLOYEES, CONTRACTORS, AND SUBCONTRACTORS ARE RESPONSIBLE FOR CONFORMING TO THE ELEMENTS SHOWN ON THIS PLAN OR RELATED DOCUMENTS.
5. THE CONTRACTOR IS RESPONSIBLE FOR OBTAINING ALL PERMITS AND FILING ALL PLANS WITH RELATED AGENCIES ASSOCIATED WITH THEIR WORK. THIS SHALL INCLUDE, BUT NOT BE LIMITED TO, PERMITS FOR STORAGE OF HAZARDOUS MATERIALS, BUSINESS PLANS, PERMITS FOR STORAGE OF FLAMMABLE LIQUIDS, GRADING PERMITS, OR OTHER PLANS OR PERMITS REQUIRED BY ALAMEDA COUNTY, THE CITY OF BERKELEY, OR OTHER AGENCIES. ALL CONTRACTORS, OR SUBCONTRACTORS WORKING ON-SITE ARE INDIVIDUALLY RESPONSIBLE FOR OBTAINING AND SUBMITTING ANY BUSINESS PLANS OR PERMITS REQUIRED BY CITY, STATE OR LOCAL AGENCIES.
6. CONTRACTOR SHALL LOCATE STORAGE, DELIVERY, OR WASH-OUT AREAS, TO SUIT THEIR OPERATIONS. CONTRACTOR TO MAINTAIN SECONDARY CONTAINMENT AS NECESSARY TO PROHIBIT POLLUTION AND TOXIC MATERIALS FROM ENTERING STORM DRAIN.
7. CONTRACTOR SHALL UTILIZE SILT FILTERS DURING CONCRETE CONSTRUCTION NEAR EXISTING STORM DRAINAGE SYSTEM. AFTER COMPLETION OF THE SIDEWALK, DRIVEWAYS, CURB, GUTTER, AND PAVING, THE SILT FILTERS SHALL BE MODIFIED TO BURLAP SACKS FILLED WITH 3/4" DRAIN ROCK OR OTHER ACCEPTED BMP POSITIONED SURROUNDING EACH CATCH BASIN.

EROSION CONTROL NOTES:

1. NO VEHICLES SHALL BE ALLOWED TO TRACK OR SPREAD SOIL FROM THE CONSTRUCTION AREAS ONTO EXISTING PAVED PUBLIC STREETS.
2. THE EROSION AND SEDIMENT CONTROL MEASURES WILL BE OPERABLE DURING THE RAINY SEASON, OCTOBER 1ST TO APRIL 15TH. NO GRADING WILL OCCUR BETWEEN OCTOBER 1ST AND APRIL 15TH, UNLESS AUTHORIZED BY THE CITY ENGINEER.
3. DURING THE RAINY SEASON, ALL PAVED AREAS WILL BE KEPT CLEAR OF EARTH MATERIAL AND DEBRIS. THE SITE WILL BE MAINTAINED SO THAT A MINIMUM OF SEDIMENT-LADEN RUNOFF ENTERS THE STORM DRAIN SYSTEM. THESE PLANS SHALL REMAIN IN EFFECT UNTIL THE TRACT IMPROVEMENTS ARE ACCEPTED BY THE CITY, AND ALL SLOPES ARE STABILIZED FROM EROSION.

URBAN RUNOFF POLLUTION NOTES:

1. STABILIZE ALL DENUDED AREAS AND MAINTAIN EROSION CONTROL MEASURES CONTINUOUSLY FOR THE DURATION OF THE PROJECT.
2. REMOVE SPOILS PROMPTLY AND AVOID STOCKPILING OF FILL MATERIALS WHEN RAIN IS FORECAST. IF RAIN THREATENS, STOCK- PILED SOILS AND OTHER MATERIALS SHALL BE TARPED, AT THE REQUEST OF THE CITY ENGINEER.
3. STORE, HANDLE AND DISPOSE OF CONSTRUCTION MATERIALS AND WASTES SO AS TO PREVENT THEIR ENTRY TO THE STORM DRAIN SYSTEM. CONTRACTOR MUST NOT ALLOW CONCRETE, WASHWATERS, SLURRIES, PAINT OR OTHER MATERIALS TO ENTER CATCH BASINS OR TO ENTER SITE RUNOFF.
4. USE FILTRATION OR OTHER MEASURES TO REMOVE SEDIMENT FROM DEWATERING EFFLUENT.
5. NO CLEANING, FUELING OR MAINTAINING VEHICLES ON SITE SHALL BE PERMITTED IN ANY MANNER THAT ALLOWS DELETERIOUS MATERIALS TO ENTER CATCH BASINS OR TO ENTER SITE RUNOFF.
6. CONTRACTOR TO RELOCATE CONCRETE WASHDOWN, VEHICLE STORAGE DELIVERY, AND NON HAZARDOUS WASTE AREAS AS NECESSARY TO FACILITATE THEIR OPERATION AND PROMOTE POLLUTION CONTROL.

BMP IMPLEMENTATION SCHEDULE:

1. BMP'S APPROPRIATE FOR THE WORK BEING DONE SHALL BE IN PLACE AT ALL TIMES.
2. PERIMETER CONTROL, EXISTING INLET PROTECTION, AND CONSTRUCTION ENTRANCE SHALL BE INSTALLED PRIOR TO ANY DEMOLITION.
3. ALL OTHER BMP'S SHALL BE INSTALLED AT COMPLETION OF CONSTRUCTION OF EACH INLET.

LINETYPES LEGEND

EXISTING		PROPOSED
30	CONTOUR - MAJOR	30
	CONTOUR - MINOR	
x x x x x	FENCE	x x x x x
G	GAS LINE	N/A
E	ELECTRICAL LINE(S)	N/A
TS	TRAFFIC SIGNAL LINE(S)	N/A
W	WATER LINE	N/A
TV	CABLE/TELEVISION LINE	N/A
N/A	LIMITS OF CONSTRUCTION	
	PROPERTY / LOT LINE	N/A
SS	SANITARY SEWER	N/A
	STORM DRAIN CULVERT	N/A
SD	STORM DRAIN	
	TIES	
	TREE DRIPLINE	N/A

MATERIAL LEGEND

INSTALL GEOPOLYMER LINING (APPROXIMATE LIMITS SHOWN, TO BE VERIFIED IN FIELD WITH ENGINEER)

SYMBOLS LEGEND

EXISTING

- WM GM – Ex. Water/Gas Meter
- WV GV – Ex. Water/Gas Valve
- – Ex. Fire Hydrant
- JP – Ex. Utility Pole
- JP – Ex. Utility Pole w/Light
- – Ex. Wheel Chair Ramp
- – Ex. Tree
- Bxxxx – Ex. Miscellaneous Survey Monument
- Bxxxx – Ex. Survey Well Monument
- – Ex. Benchmark
- CPxxxx – Ex. Control Point
- – Ex. Misc. Survey Point
- CPxxxx – Control Point Set
- MH – Ex. Maintenance hole
- JB – Ex. Junction Box
- – Ex. Catch Basin
- – Ex. Curb Inlet
- – Ex. Culvert Inlet/Outlet
- – Ex. Culvert Inlet/Outlet
- – Ex. Culvert Inlet/Outlet
- – Ex. Light–Post Mounted
- PP – Ex. Power Pole with Guy
- SSCO – Ex. Sanitary Sewer Clean Out
- SS – Ex. Sanitary Sewer Maintenance hole
- – Storm Drainage Area Drain
- SDCO – Storm Drainage Clean Out
- SD – Ex. Storm Drain
- EM EM – Ex. Electric Meter
- PB – Ex. Pullbox
- – Ex. BOLLARD
- – Ex. SIGN
- TS – Ex. Traffic Signal

PROPOSED

- – BOLLARD
- – SIGN
- – TREE / TREE TO BE REMOVED
- – LIGHT – POST MOUNTED
- – STREETLIGHT
- – TRAFFIC LIGHT
- PP – POWER POLE (WITH GUY)
- SSCO – SANITARY SEWER – CLEANOUT
- SS – SANITARY SEWER – MAINTENANCE HOLE
- – STORM DRAINAGE – AREA DRAIN
- SDCO – STORM DRAINAGE – CLEANOUT
- – STORM DRAINAGE – CATCH BASIN
- – STORM DRAINAGE – CURB INLET
- – STORM DRAINAGE – DROP INLET
- SD – STORM DRAINAGE – MAINTENANCE HOLE
- GM GM – GAS/ELECTRIC METER
- GV – GAS VALVE
- PB – PULLBOX
- HYD – FIRE HYDRANT
- WM – WATER METER
- WV – WATER VALVE
- TS – TRAFFIC SIGNAL & TRAFFIC BOX
- – ELECTRIC CABINET
- 1 / X – DETAIL NO. / SHEET NO.

ABBREVIATIONS

AB	- AGGREGATE BASE
AC	- ASPHALT CONCRETE
AD	- AREA DRAIN
AP	- ANGLE POINT
BC	- BEGINNING OF CURVE
B/L	- BASE LINE
BSW	- BACK OF SIDEWALK
CAMUTCD	- CALIFORNIA MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES
CB	- CATCH BASIN
CDFW	- CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE
C&G	- CURB AND GUTTER
CI	- CAST IRON
℄	- CENTERLINE
CONC	- CONCRETE
CP	- CONTROL POINT
DI	- DROP INLET
DEP	- DEPRESSED
DESC	- DESCRIPTION
DWY	- DRIVEWAY
EC	- END OF CURVE
EG	- EXISTING GRADE
EP	- EDGE OF PAVEMENT
EL	- ELEVATION
EX	- EXISTING
FG	- FINISH GRADE
FL	- FLOWLINE
FS	- FINISH SURFACE
FSP	- FLATTENED STEEL PIPE
GB	- GRADE BREAK
GS	- GROUND SURFACE
HC	- HANDICAP
HDPE	- HIGH DENSITY POLYETHYLENE PIPE
HP	- HIGH POINT
HSS	- HOLLOW STRUCTURAL SECTION
INV	- INVERT
JB	- JUNCTION BOX
JP	- JOINT POLE
LC	- LEVELING COURSE
LF	- LINEAR FEET
LP	- LOW POINT
LOW	- LIMIT OF WORK
MH	- MAINTENANCE HOLE
MON	- SURVEY MONUMENT
NG	- NATURAL GROUND
NTS	- NOT TO SCALE
PB	- PULL BOX
PCC	- PORTLAND CEMENT CONCRETE
PC	- POINT OF COMPOUND CURVE
POC	- POINT ON CURVE
PVC	- POLYVINYL CHLORIDE PIPE
PRC	- POINT OF REVERSE CURVE
PVC	- POLY VINYL CHLORIDE PIPE
R&R	- REMOVE AND REPLACE
RCP	- REINFORCED CONCRETE PIPE
RW	- RIGHT OF WAY
SS	- SANITARY SEWER
SSMH	- SANITARY SEWER MAINTENANCE HOLE
SD	- STORM DRAIN
SDCO.	- STORM DRAIN CLEAN OUT
SDMH	- STORM DRAIN MAINTENANCE HOLE
SQ	- SQUARE FEET
SWRCB	- STATE WATER REGIONAL CONTROL BOARD
SSMH	- STANITARY SEWER MAINTENANCE HOLE
SW	- SIDEWALK
TC	- TOP OF CURB
TOP	- TOP/CEILING OF CULVERT
TS	- TURNING STRUCTURE
UNO	- UNLESS NOTED OTHERWISE
VIF	- VERIFY IN FIELD

REVISION	MARK	DATE	DESCRIPTION	APPROVAL

SURVEY CONTROL POINTS

CONTROL SET

CP#	NORTHING	EASTING	ELEVATION	DESCRIPTION
1	2144168.9087	6052096.8136	189.840	CP MN CNC STREAM
2	2144188.7004	6052046.5439	186.999	CP MN CNC STREAM
3	2144124.6248	6052124.7522	201.369	CP MN AC PATH
4	2144184.4032	6051996.2683	185.582	CP MN CNC STREAM
6	2144044.8898	6051946.8067	182.047	CP MN CNC STREAM
7	2144180.0210	6051998.3664	187.753	CP MNW WALL
8	2143897.6338	6051763.6488	175.596	CP MN CNC STREAM
9	2144046.2754	6051943.9923	183.742	CP MNW WALL
11	2143901.5929	6051762.9899	177.376	CP MNW WALL
12	2143841.6380	6051432.1625	171.070	CP MN CNC STREAM
15	2143835.3252	6051430.8786	172.742	CP MNW WALL
16	2143810.4033	6051212.9466	167.090	CP MN CNC STREAM
18	2143771.9199	6050951.8105	158.321	CP MN CNC STREAM
21	2143776.2054	6050948.8411	160.232	CP MNW WALL
23	2143821.9421	6050805.8396	153.590	CP MNW WALL
24	2143905.8213	6050702.4094	148.720	CP MN CNC STREAM
26	2143985.6304	6050534.4123	144.791	CP MN CNC STREAM
27	2143900.2460	6050703.5936	150.967	CP MNW WALL
28	2143950.9444	6050290.0150	140.000	CP MN CNC STREAM
29	2143981.0984	6050534.5865	147.062	CP MNW WALL
32	2143863.3060	6050076.4369	136.799	CP MN CNC STREAM

CONTROL SET

CP#	NORTHING	EASTING	ELEVATION	DESCRIPTION
35	2143866.5924	6050072.2882	139.278	CP MNW WALL
36	2143826.6918	6049781.5003	128.554	CP MN CNC STREAM
38	2143799.6129	6049687.1334	125.741	CP MN CNC STREAM
39	2143832.4852	6049780.8153	131.053	CP MNW WALL
40	2143813.4570	6049619.8697	125.692	CP MN CNC STREAM
43	2143807.9373	6049620.9112	128.391	CP MNW WALL
44	2143747.1405	6049518.4840	124.507	CP MN CNC STREAM
46	2143690.3676	6049495.8282	123.554	CP MN CNC STREAM
47	2143679.5484	6049389.3152	122.262	CP MN CNC STREAM
48	2143657.8535	6049303.3180	119.664	CP MN CNC STREAM
49	2143690.1004	6049175.9134	115.303	CP MN CNC STREAM
50	2143590.3134	6049017.1654	112.181	CP MN CNC STREAM
51	2143593.6055	6048903.5730	110.113	CP MN CNC STREAM
52	2143630.8431	6048767.6622	108.138	CP MN CNC STREAM
53	2143608.6336	6048558.4836	106.674	CP MN CNC STREAM
55	2143590.4565	6048439.9422	106.040	CP MN CNC STREAM
56	2143586.4719	6048271.8225	101.483	CP MN CNC STREAM
57	2143552.2271	6048205.3466	100.390	CP MN CNC STREAM
58	2143432.3656	6048072.9791	98.401	CP MN CNC STREAM
59	2143344.7508	6048005.3800	96.269	CP MN CNC STREAM
60	2143283.0764	6047745.4507	91.038	CP MN CNC STREAM

CONTROL SET

CP#	NORTHING	EASTING	ELEVATION	DESCRIPTION
61	2143269.9414	6047645.7341	90.059	CP MN CNC STREAM
65	2143186.2256	6047237.2167	86.801	CP STK TACK TEMP
69	2143222.1918	6047200.1129	96.618	CP MN CNC WL
70	2143163.2780	6047288.7240	97.442	CP MNW
72	2143082.5560	6046778.9580	88.747	CP MNW CURB
73	2143059.8821	6046622.2404	86.218	CP MN CURB
74	2143187.0292	6046814.7967	85.663	CP SPK
75	2143183.1485	6046793.1036	77.168	CP MN CNC STREAM
77	2143227.7705	6046689.8110	74.040	CP MN CNC STREAM
78	2143370.5410	6046564.3101	72.220	CP MN CNC STREAM
82	2143454.1764	6046004.0902	69.880	CP MN
83	2143427.3691	6045878.4851	58.662	CP MN CNC BLK
84	2143255.6794	6046136.8913	77.389	CP MN CULDESAC
86	2143459.1165	6045702.2721	56.673	CP MN CNC STREAM
89	2143364.6127	6045427.4596	53.300	CP MN CNC STREAM
90	2143757.4440	6045915.8240	75.331	CP MN SW
91	2143168.2303	6047410.6868	100.339	CP MN CURB

SURVEY NOTES

1. DISTANCES SHOWNS ARE IN FEET AND DECIMALS THEREOF.
2. HORIZONTAL DATUM IS NORTH AMERICAN DATUM 1983 (NAD83) PER CALIFORNIA REAL TIME NETWORK, (CRTN), EPOCH 2017.5.
3. VERTICAL DATUM IS BERKELEY CITY DATUM PER "APPROXIMATE VERTICAL DATUM CONVERSIONS FOR: CITY OF BERKELEY DATUM" AS POSTED ON THE CITY WEBSITE. DRAWING PREPARED BY ALEX KELSER CHIEF OF PARTY OF CITY OF BERKELEY, DATED JUNE 18, 2009. TO OBTAIN NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88) ELEVATIONS ADD 5.89' TO ALL ELEVATIONS SHOWN HEREON.
4. BOUNDARY SHOWN IS FOR CONCEPTUAL PURPOSES ONLY PER ALAMEDA COUNTY ASSESSOR PARCEL LINES. ASSESSOR PARCEL LINES ARE NOT RELIABLE FOR PRECISE PROPERTY LINE LOCATIONS.
5. CONTRACTOR SHALL PROTECT IN PLACE ALL CITY MONUMENTS, UNLESS NOTED OTHERWISE. SEE MONUMENT PRESERVATION NOTES ON SHEET T2.

REVISION | MARK | DATE | DESCRIPTION | APPROVAL

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CSW/Stuber-Stroeh Engineering Group, Inc.
121 Park Place Richmond, CA 94801
tel: 415.883.9850 fax: 415.883.9835
http://www.cswst2.com

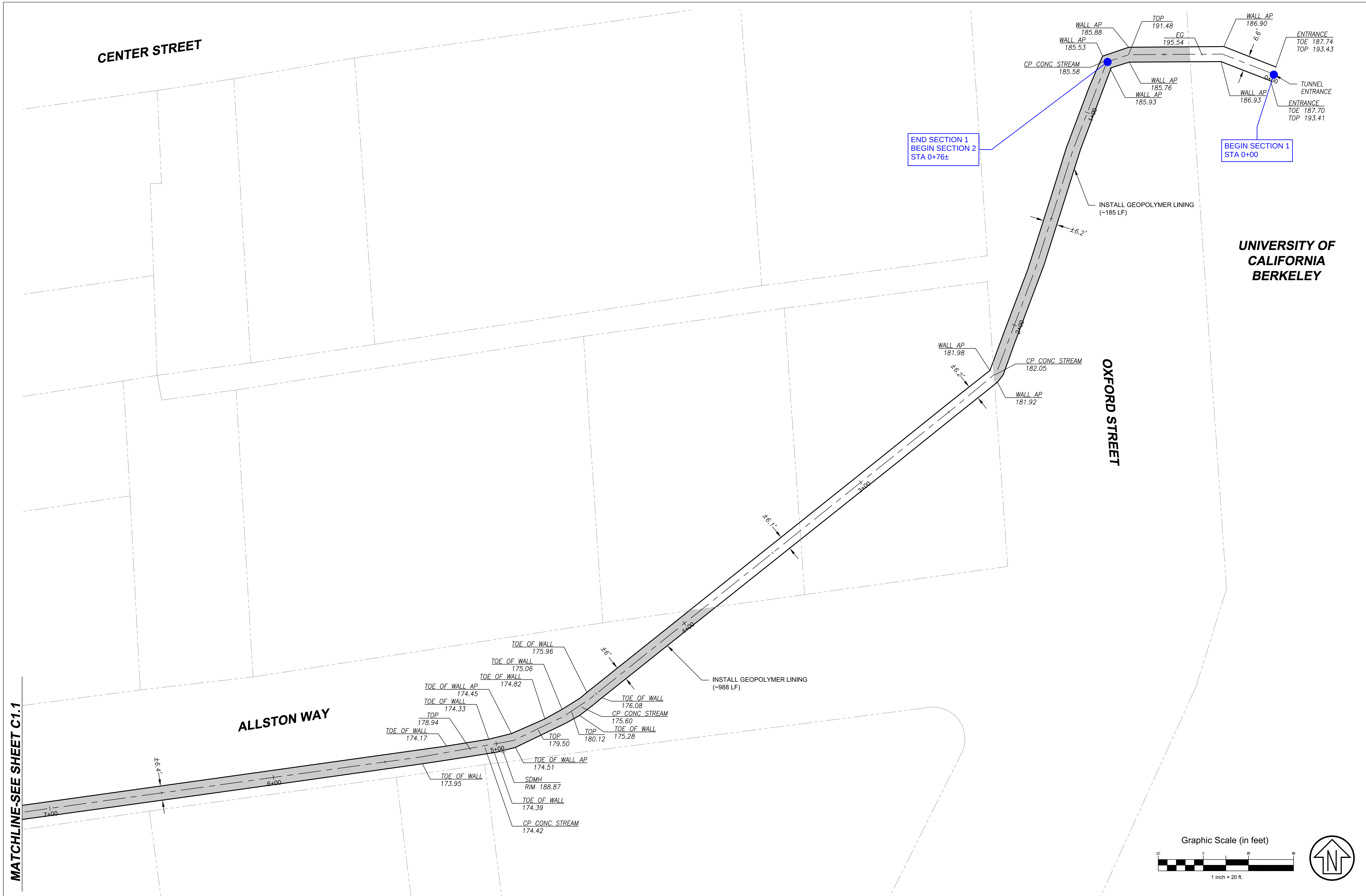
PROJECT MANAGER: DATE
DEPICTION OF MONUMENTS: DATE
SURVEY CHIEF OF PARTY
WATERSHED REVIEW: DATE
SUBMITTED: SUPERVISING ENGINEER
APPROVED: CITY ENGINEER
DATE REGISTR. EXP. DATE R.C.E. EXP.
0 1 2 3
FOR REDUCED PLANS – ORIGINAL SCALE IS IN INCHES

DESIGN JD
DRAWN JD
CHECK RS
AS BUILT
HORIZ.
VERT.
BOOK
DATE 11/03/23

CITY OF BERKELEY
DEPARTMENT OF PUBLIC WORKS

STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
INDEX & SURVEY CONTROL PLAN

PLAN –
FILE –
T3
SHEET 3 OF 14



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STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
LAYOUT PLAN – OXFORD STREET
(STA: 0+00 TO STA: 7+00)

PLAN –
FILE –
C1.0
SHEET 4 OF 14

REVISION	MARK	DATE	DESCRIPTION	APPROVAL

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STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT

LAYOUT PLAN – SHATTUCK AVENUE (STA: 7+00 TO STA: 13+00)

PLAN –
FILE –
C1.1
SHEET 5 OF 14

CSW ST2 CSW/Stuber-Stroeh Engineering Group, Inc. 121 Park Place Richmond, CA 94801 tel: 415.883.9850 fax: 415.883.9835 http://www.cswst2.com ©2023	PROJECT MANAGER: DATE; 0 1 2 3 FOR REDUCED PLANS – ORIGINAL SCALE IS IN INCHES	DEPICTION OF MONUMENTS: DATE; SURVEY CHIEF OF PARTY; WATERSHED REVIEW: DATE	SUBMITTED: DATE REGISTR. EXP.; SUPERVISING ENGINEER; APPROVED: DATE R.C.E. EXP.; CITY ENGINEER	DESIGN JD; DRAWN JD; CHECK RS; AS BUILT	HORIZ.; VERT.; BOOK; DATE 11/03/23

CITY OF BERKELEY
DEPARTMENT OF PUBLIC WORKS

STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
LAYOUT PLAN – MILVIA STREET
(STA: 13+00 TO STA: 19+00)

PLAN –
FILE –
C1.2
SHEET 6 OF 14

REVISION	MARK	DATE	DESCRIPTION	APPROVAL

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DEPICTION OF MONUMENTS: DATE
SURVEY CHIEF OF PARTY
WATERSHED REVIEW: DATE

SUBMITTED: DATE REGISTR. EXP.
SUPERVISING ENGINEER
APPROVED: DATE R.C.E. EXP.
CITY ENGINEER

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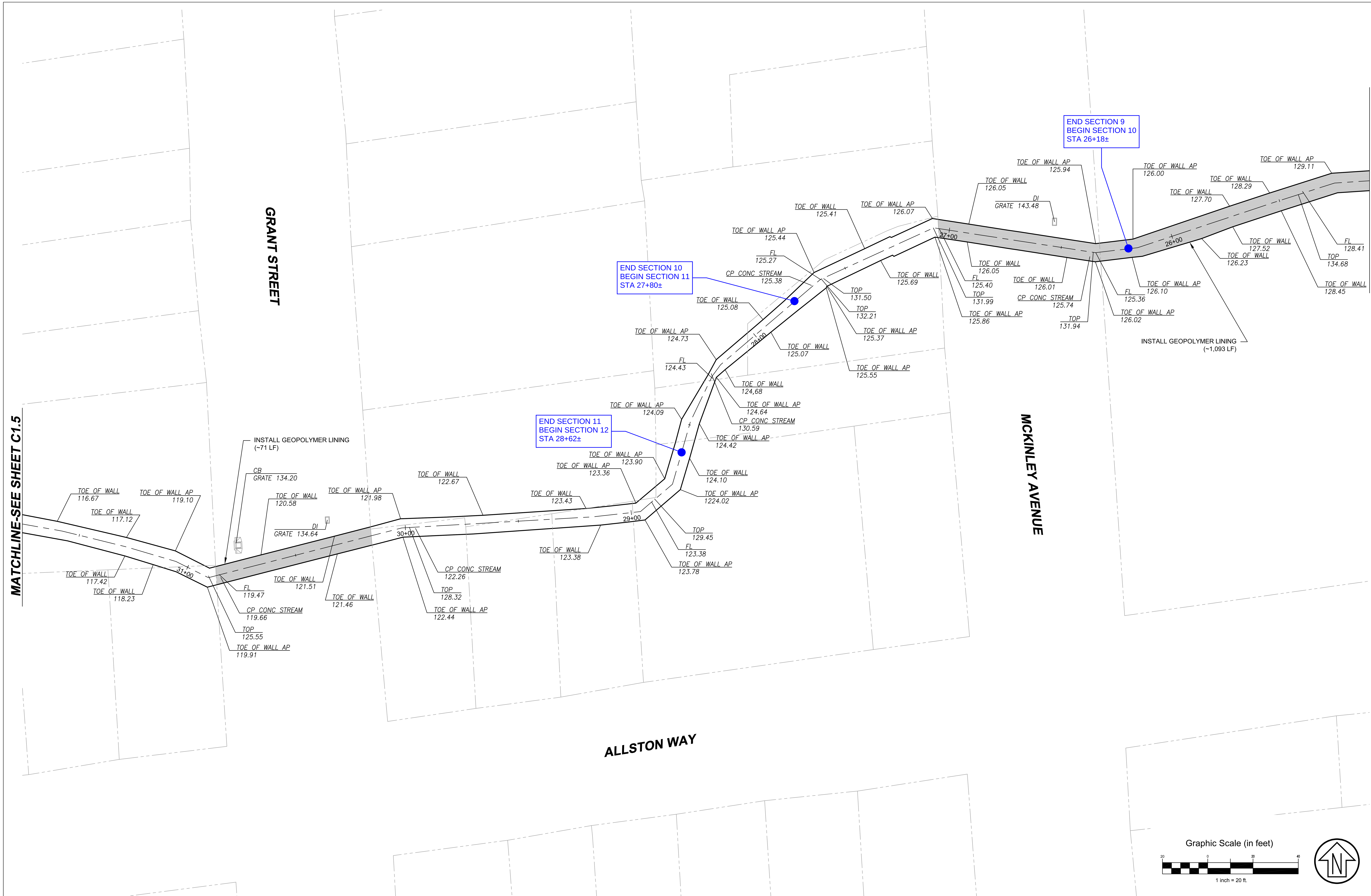
VERT.
BOOK
DATE 11/03/23

CITY OF BERKELEY
DEPARTMENT OF PUBLIC WORKS

STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
LAYOUT PLAN – MLK JR WAY
(STA: 19+00 TO STA: 25+00)

PLAN –
FILE –
C1.3
SHEET 7 OF 14



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DEPICTION OF MONUMENTS: DATE
SURVEY CHIEF OF PARTY
WATERSHED REVIEW: DATE

SUBMITTED: DATE
SUPERVISING ENGINEER REGISTR. EXP.
APPROVED: DATE
CITY ENGINEER R.C.E. EXP.

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VERT.
BOOK
DATE 11/03/23

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DEPARTMENT OF PUBLIC WORKS

STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
LAYOUT PLAN – MCKINLEY AVENUE, GRANT STREET
(STA: 25+00 TO STA: 31+50)

PLAN –
FILE –
C1.4
SHEET 8 OF 14

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CITY OF BERKELEY
DEPARTMENT OF PUBLIC WORKS

STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
LAYOUT PLAN – ROOSEVELT AVENUE, MCGEE AVENUE
(STA: 31+50 TO STA: 37+50)

PLAN –
FILE –
C1.5
SHEET 9 OF 14

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DEPICTION OF MONUMENTS: DATE
SURVEY CHIEF OF PARTY
WATERSHED REVIEW: DATE

SUBMITTED: DATE REGISTR. EXP.
SUPERVISING ENGINEER
APPROVED: DATE R.C.E. EXP.
CITY ENGINEER

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VERT.
BOOK
DATE 11/03/23

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STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
LAYOUT PLAN – JEFFERSON AVENUE
(STA: 37+50 TO STA: 44+00)

PLAN –
FILE –
C1.6
SHEET 10 OF 14

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	WATERSHED REVIEW: DATE	APPROVED: DATE R.C.E. EXP.	CHECK RS
		CITY ENGINEER	AS BUILT

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VERT.
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DATE 11/03/23

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STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
LAYOUT PLAN – CALIFORNIA STREET, SPAULDING AVENUE
(STA: 44+00 TO STA: 50+50)

PLAN –
FILE –
C1.7
SHEET 11 OF 14

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	0 1 2 3 FOR REDUCED PLANS – ORIGINAL SCALE IS IN INCHES	WATERSHED REVIEW: ______ DATE ______	APPROVED: ______ CITY ENGINEER, DATE ______ R.C.E. ______ EXP. ______		

CITY OF BERKELEY
DEPARTMENT OF PUBLIC WORKS

STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
LAYOUT PLAN – SACRAMENTO STREET
(STA: 50+50 TO STA: 53+50)

PLAN –
FILE –
C1.8
SHEET 12 OF 14

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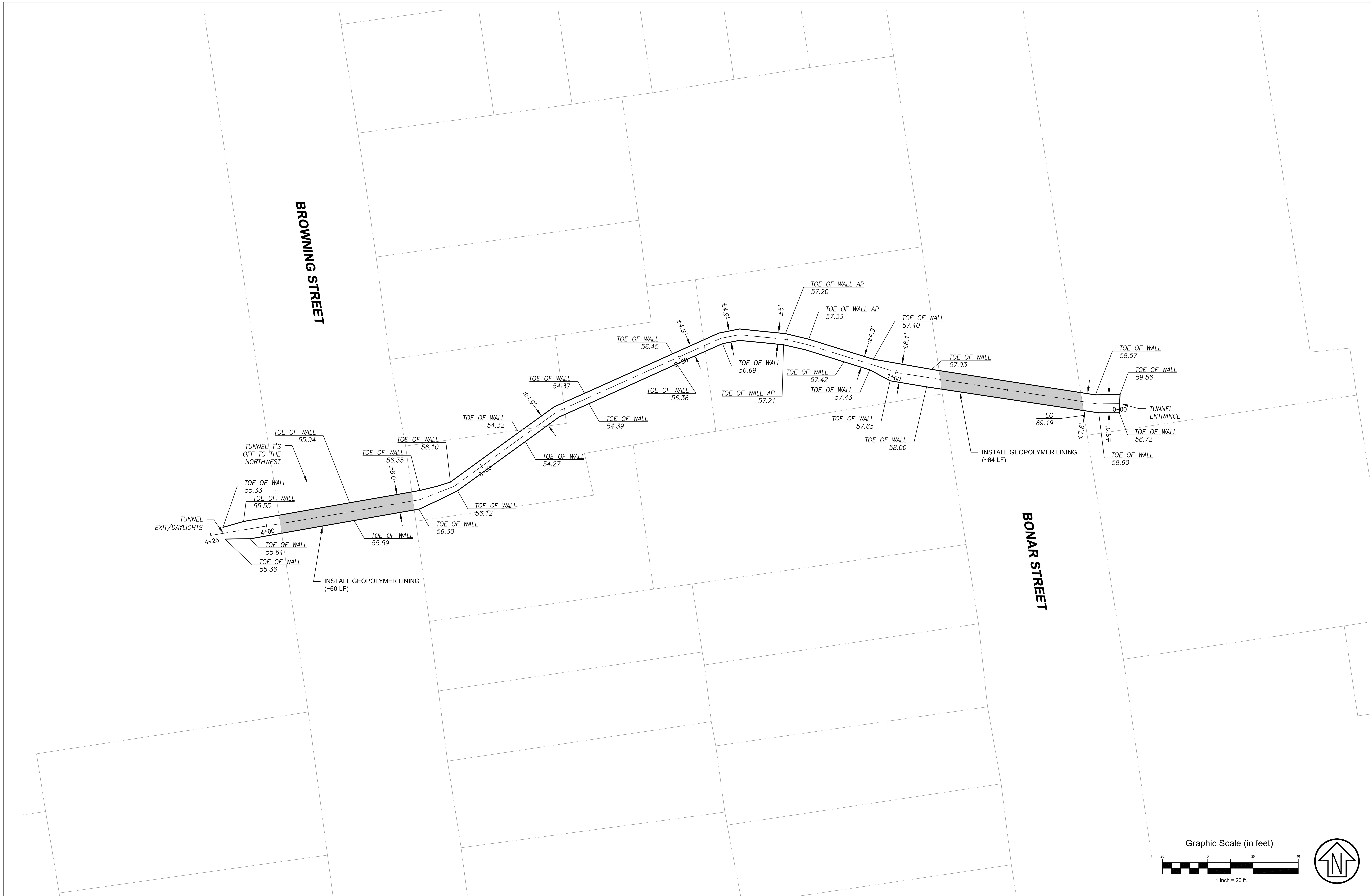

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WATERSHED REVIEW: DATE

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EXP.
SUPERVISING ENGINEER
APPROVED: DATE
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EXP.
CITY ENGINEER

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HORIZ.
VERT.
BOOK
DATE 11/03/23

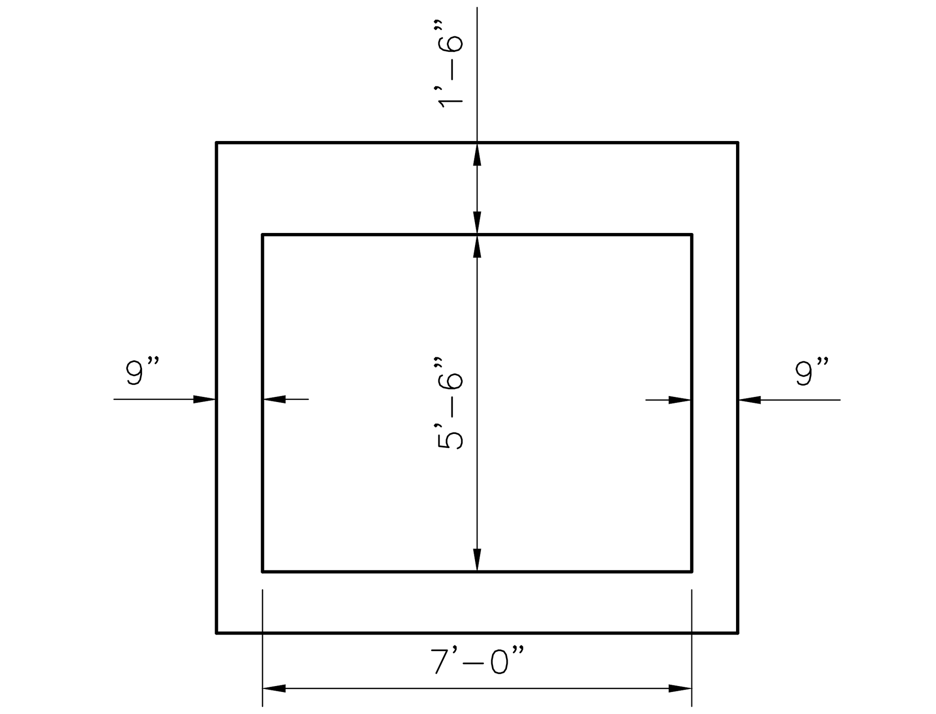
CITY OF BERKELEY
DEPARTMENT OF PUBLIC WORKS

STRAWBERRY CREEK CULVERT MAINTENANCE PROJECT
LAYOUT PLAN – BONAR STREET, BROWNING STREET
(STA: 0+00 TO STA: 4+25)

PLAN –
FILE –
C1.10
SHEET 14 OF 14

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT
BERKELEY, CA

TYPICAL SECTIONS



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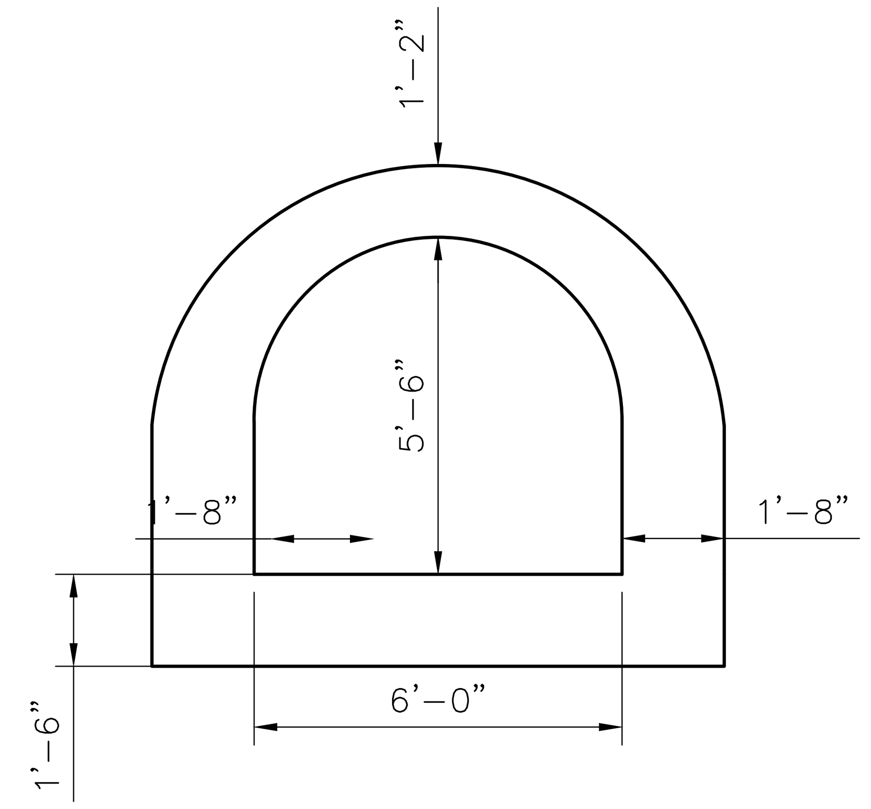

SECTION 2 - (STA 0+70)
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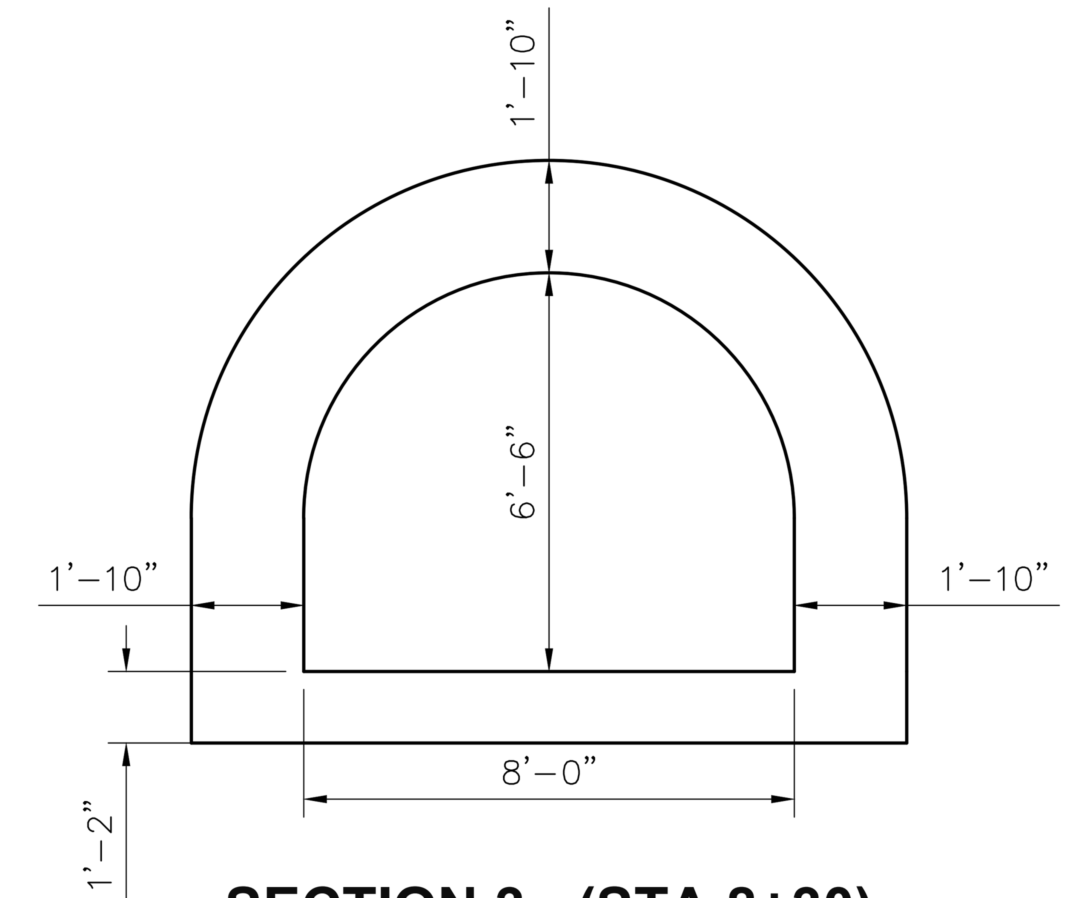

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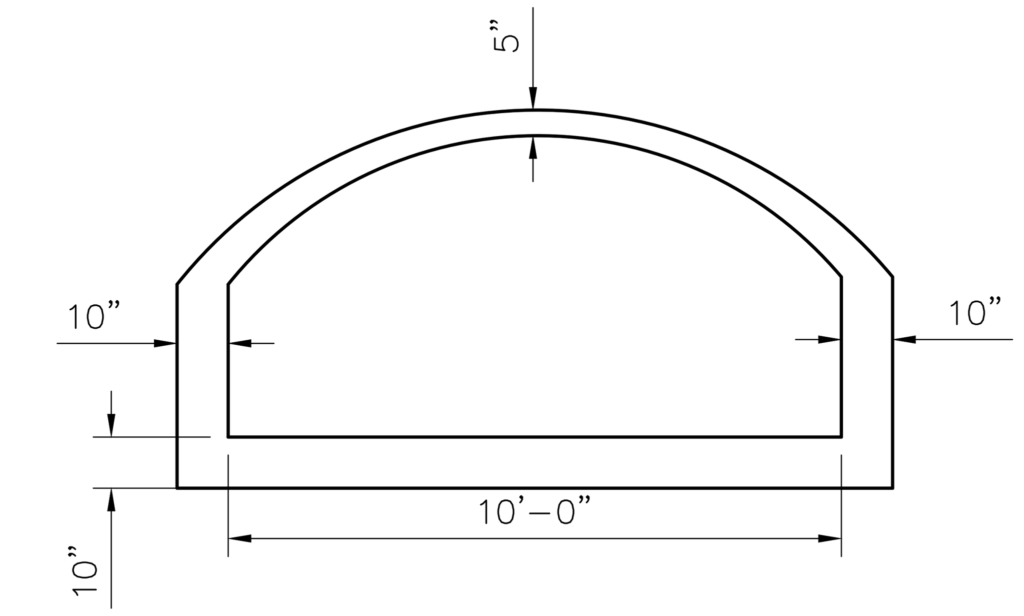

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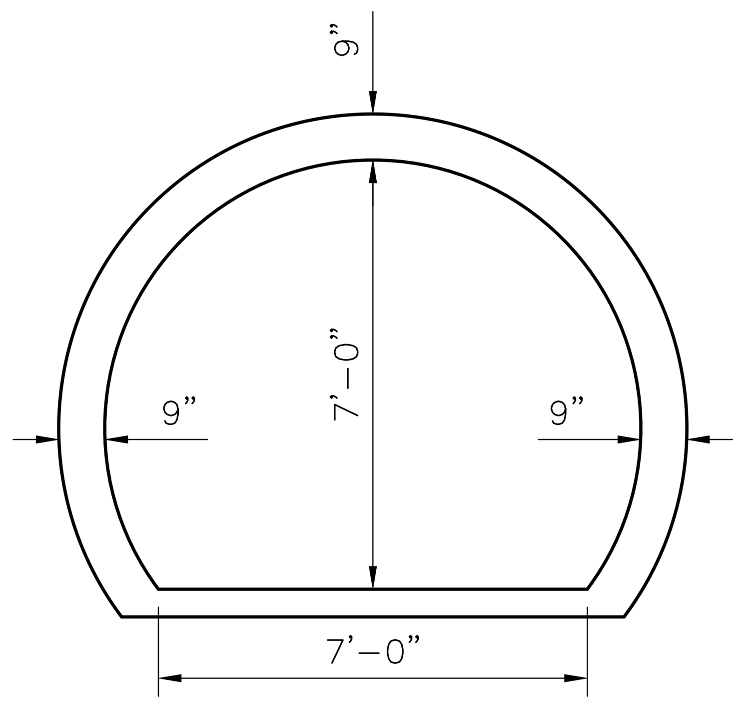

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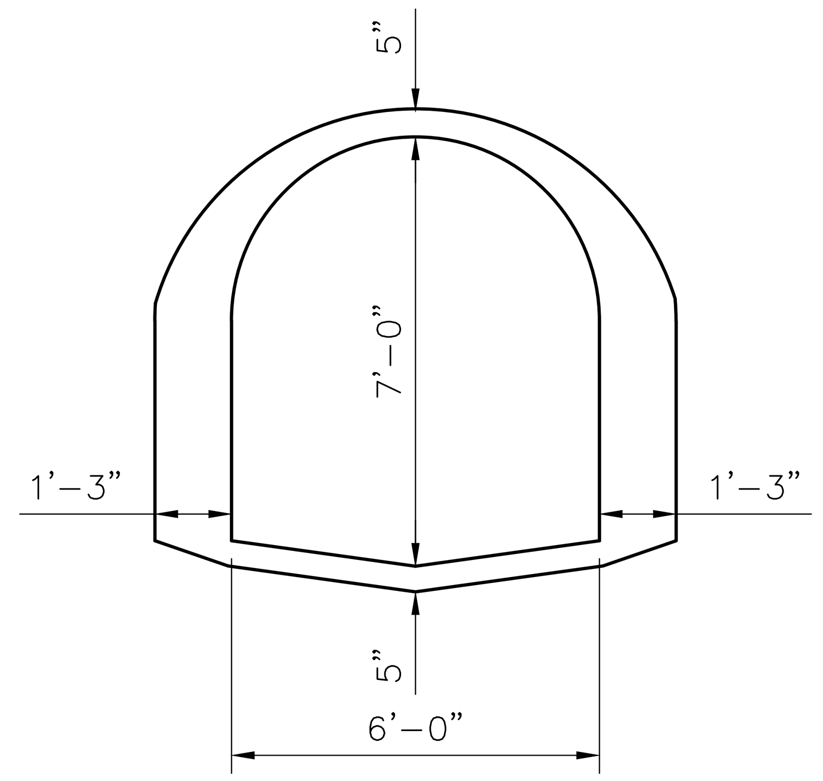

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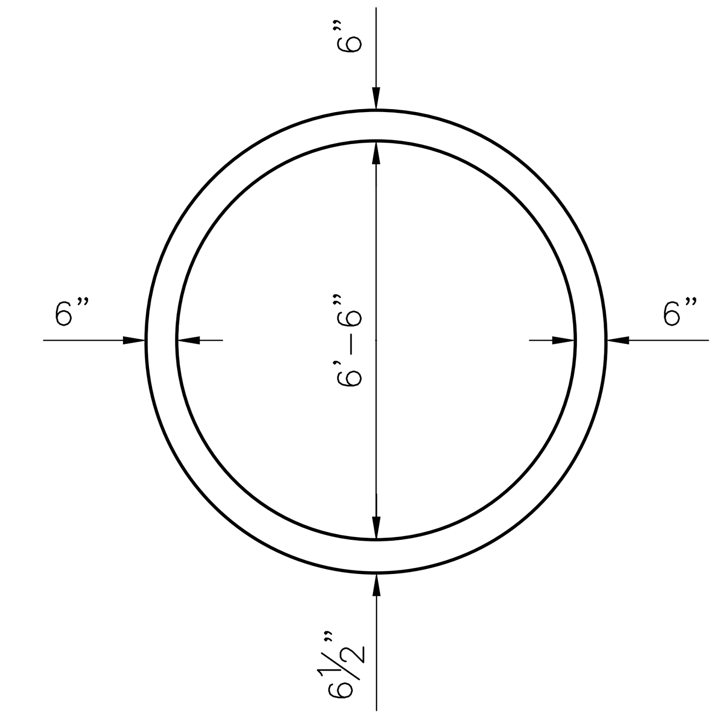

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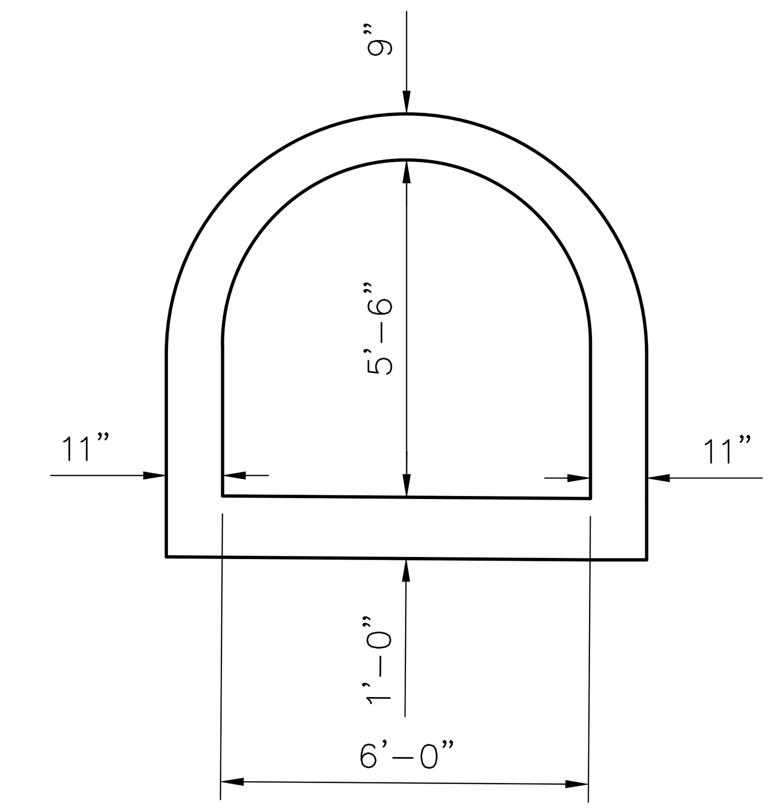

SECTION 8 - (STA 0+70)
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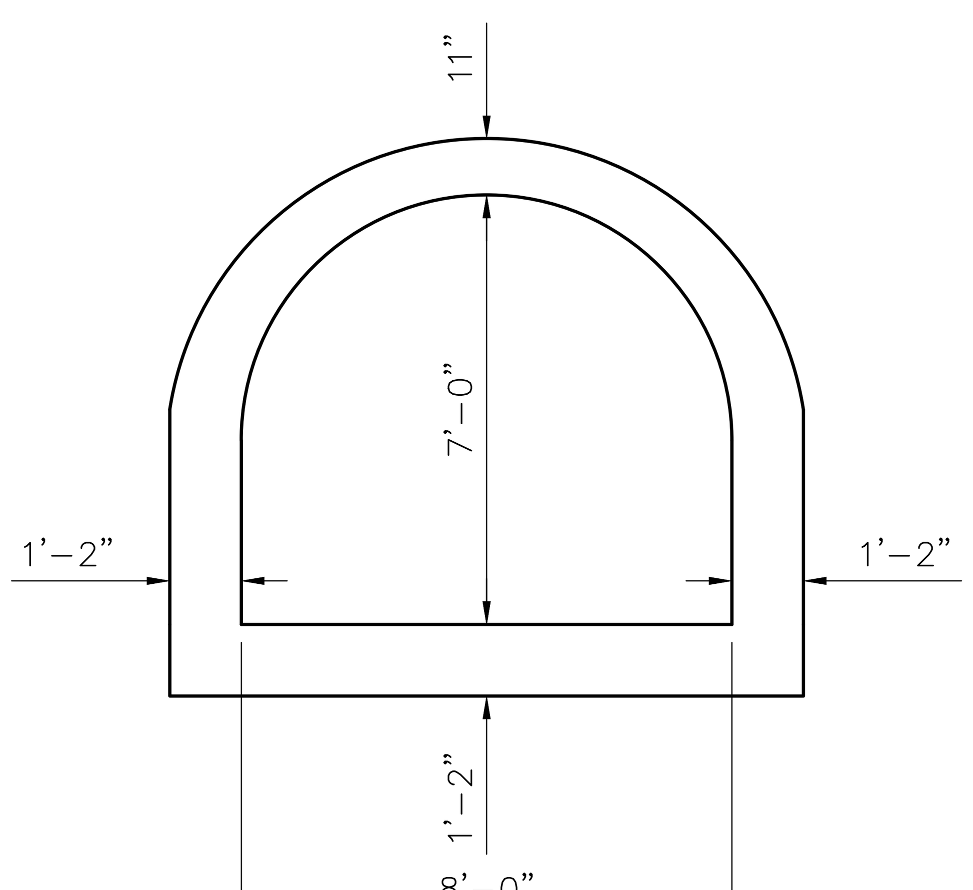

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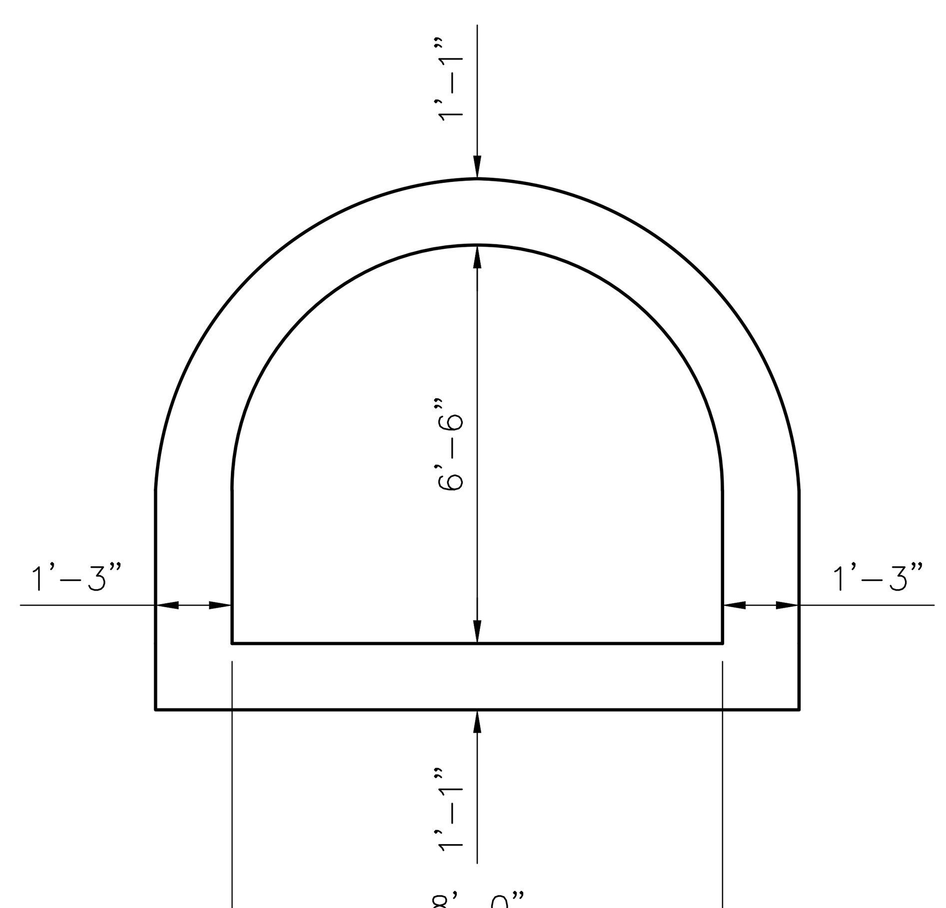

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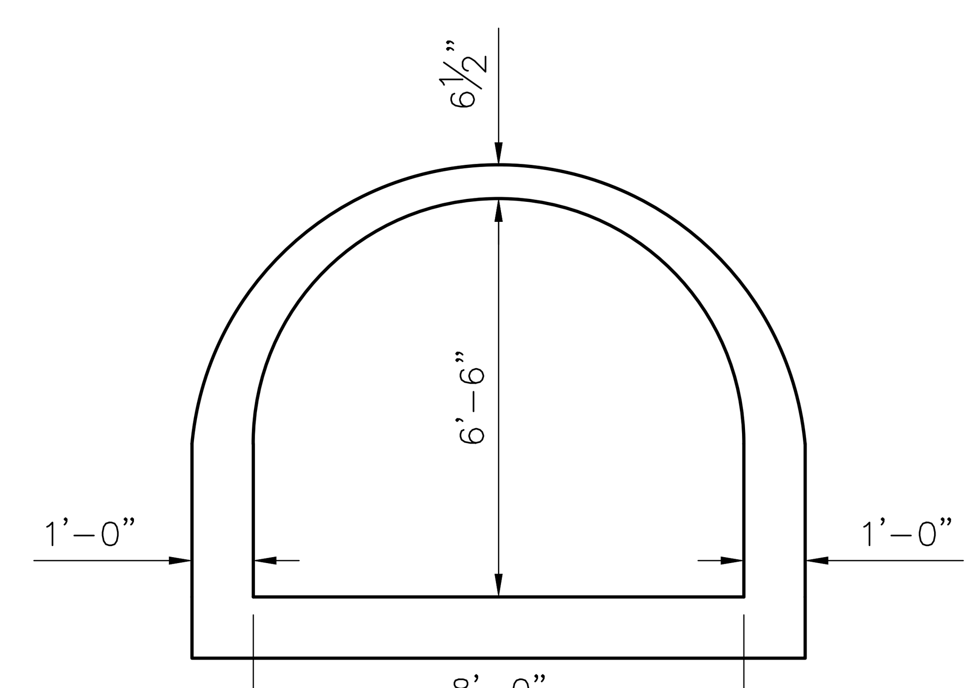

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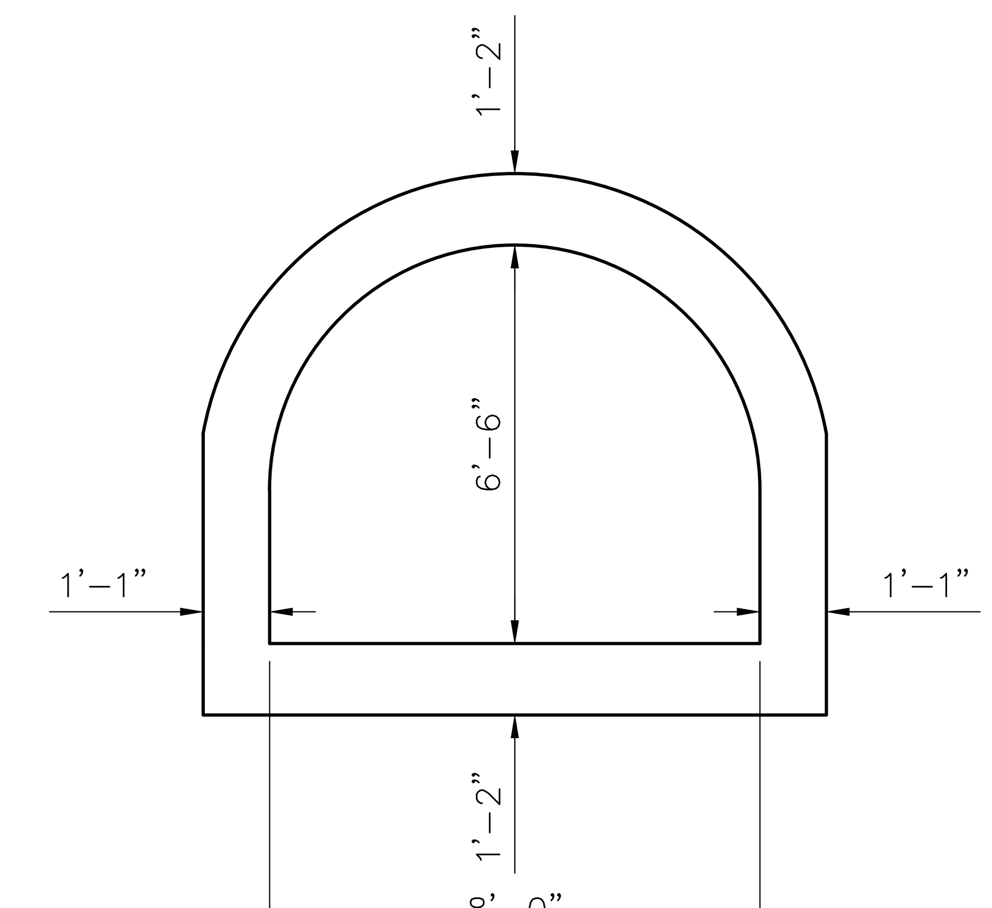

SECTION 12 - (STA 28+50)
NOT TO SCALE

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DRAWN BY: HAK
CHECKED BY:
DATE: 9/6/23

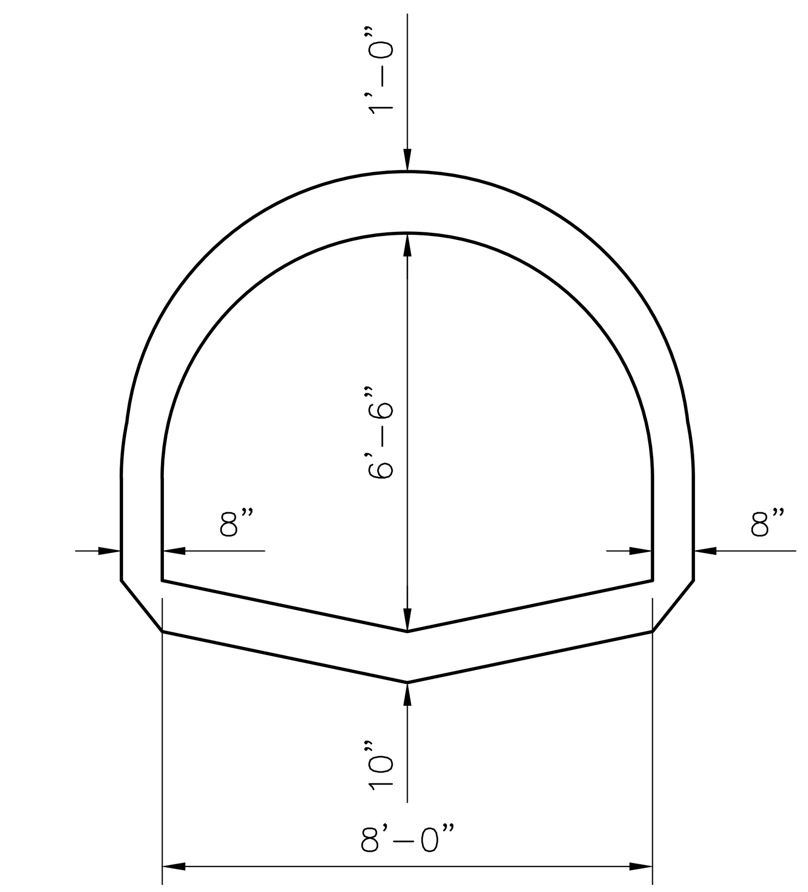
REV.	DATE	DESCRIPTION	BY
-	-		-

CORNERSTONE
structural engineering group
986 W. Alluvial Ave – Suite 201
Fresno, California 93711
559.320.3200
fax 559.320.3201

STRAWBERRY CREEK CULVERT ASSESSMENT
ALAMEDA CALIFORNIA

SHEET NUMBER
OF # SHEETS
DRAWING NO.

W:\2023\2023025 Strawberry Creek Culvert Assessment\2023025–Typical Sections.dwg – 9/13/2023 1:14 PM



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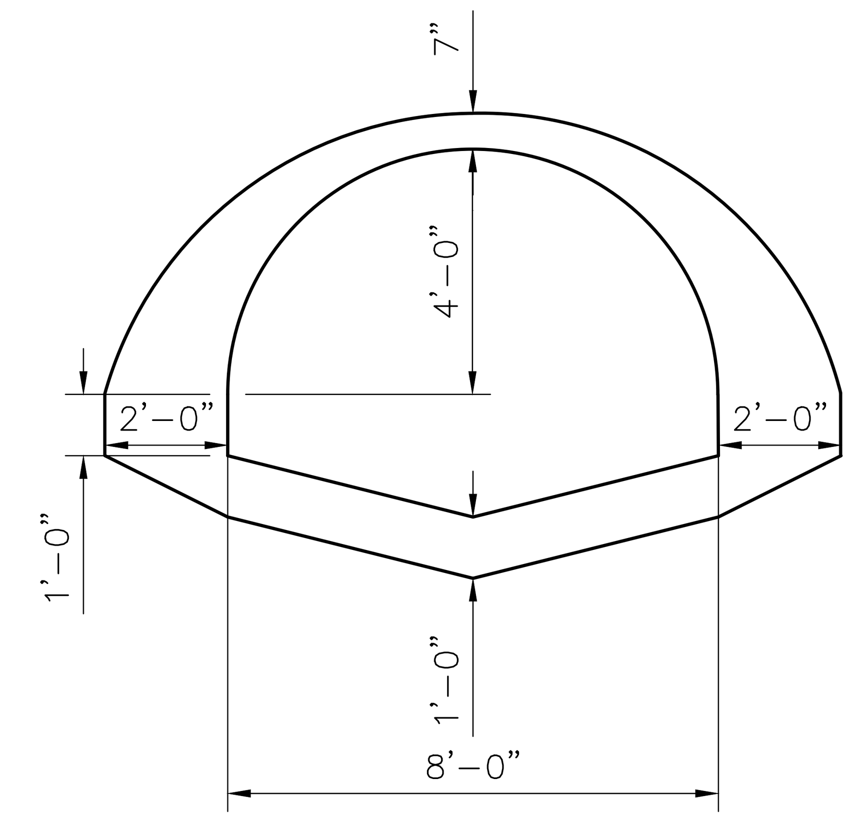

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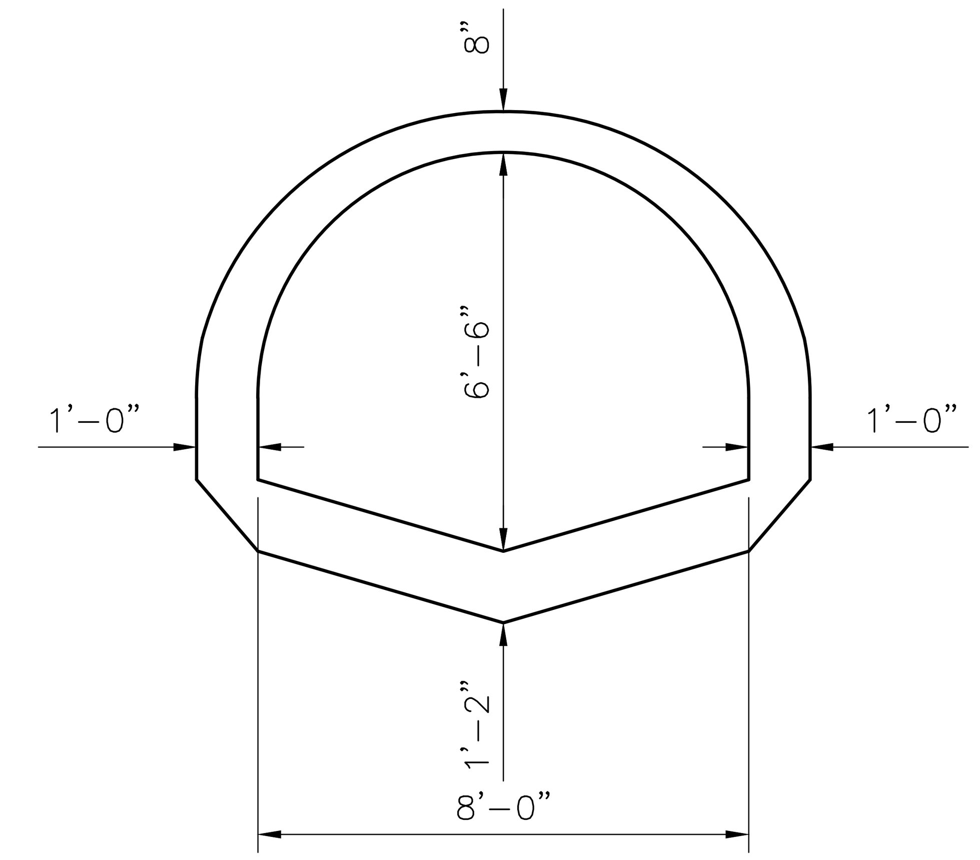

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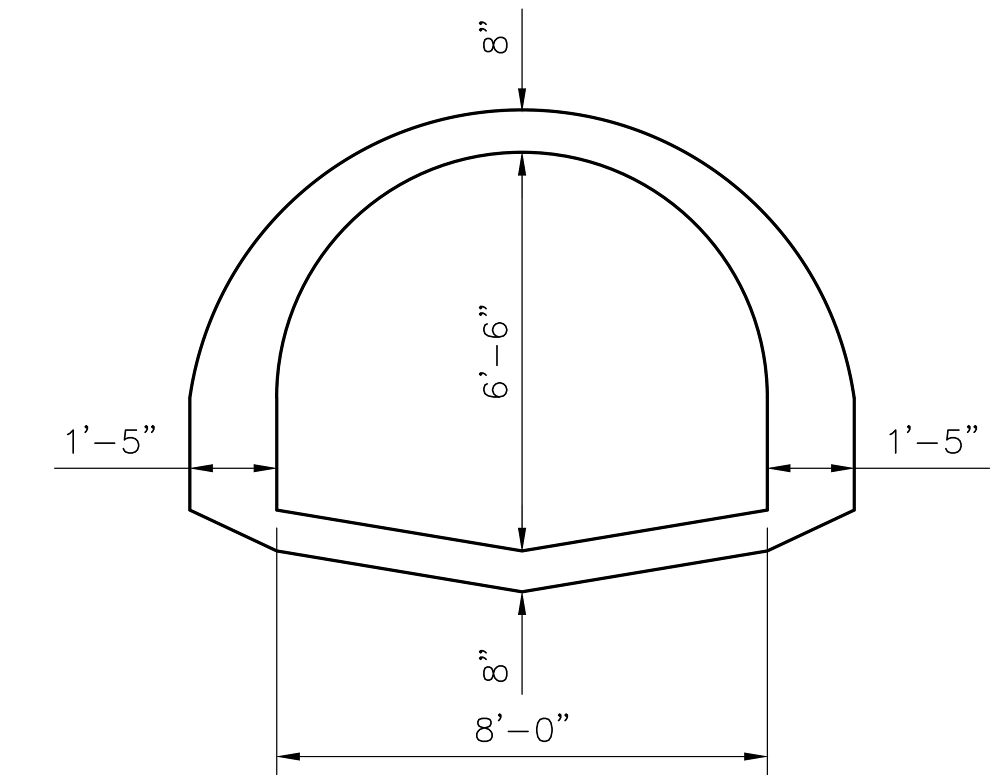

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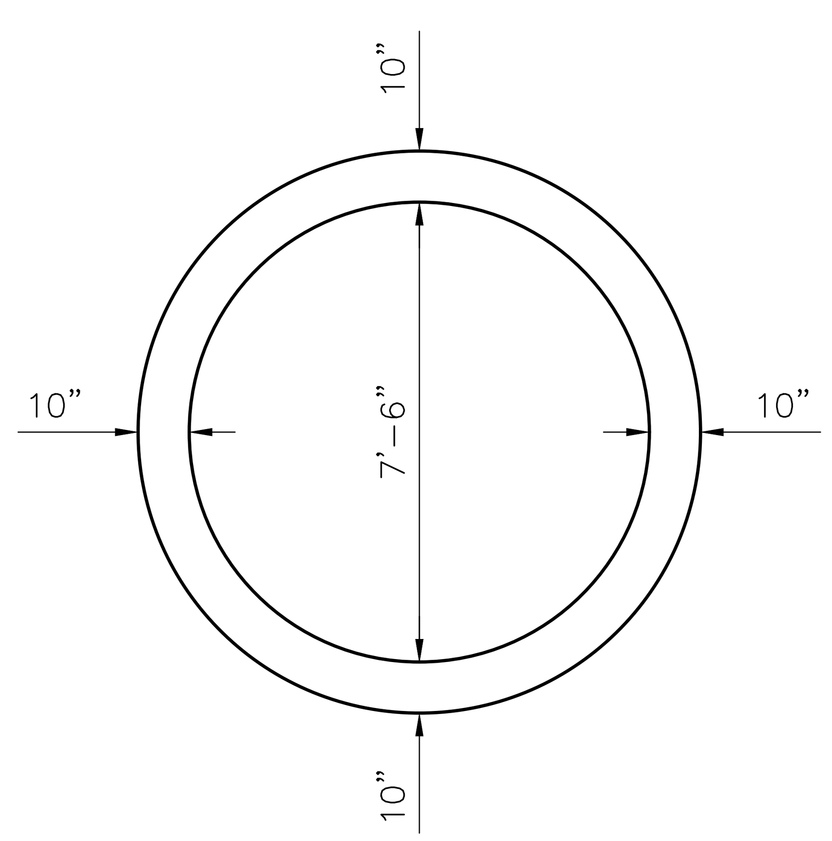

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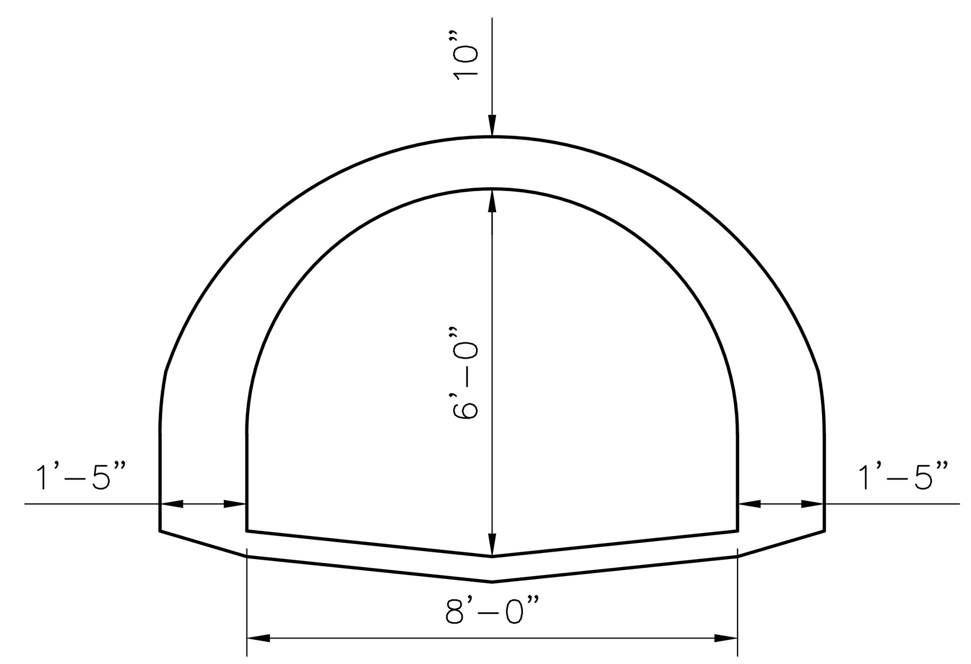

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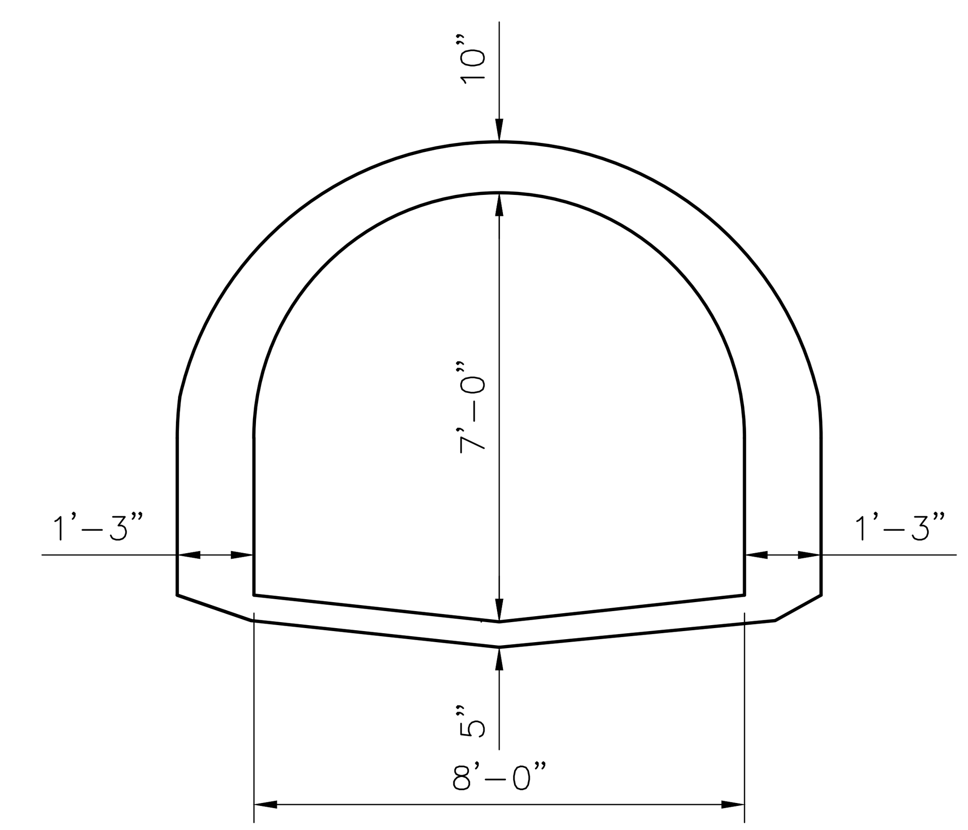

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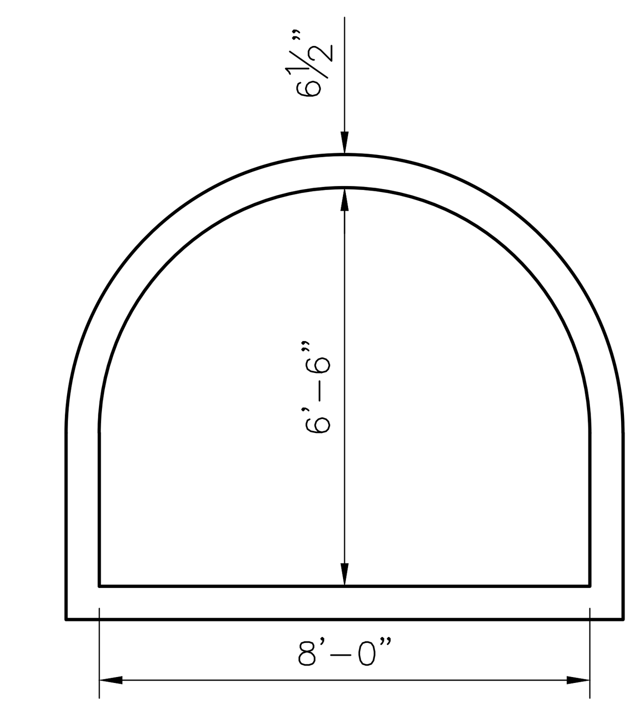

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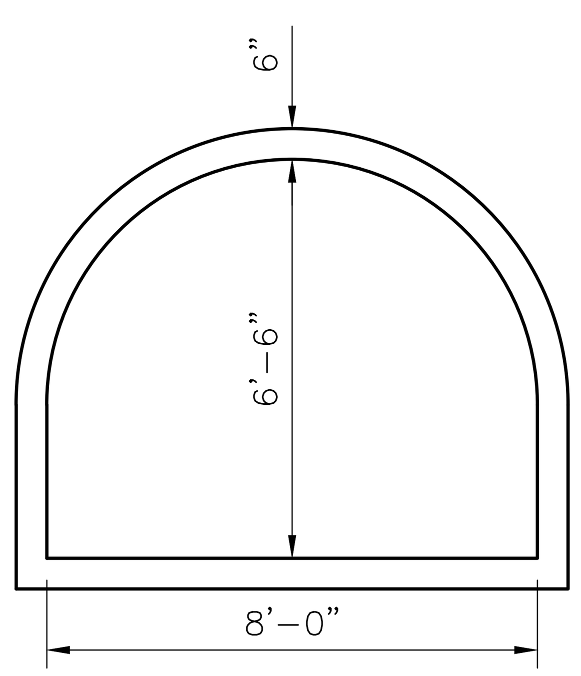
NOT TO SCALE



SECTION 21 - (Culvert 3)
NOT TO SCALE

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DRAWN BY: HAK
CHECKED BY:
DATE: 9/6/23

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-	-	-	-

CORNERSTONE structural engineering group
986 W. Alluvial Ave – Suite 201
Fresno, California 93711
559.320.3200
fax 559.320.3201

STRAWBERRY CREEK CULVERT ASSESSMENT
ALAMEDA CALIFORNIA

SHEET NUMBER
OF # SHEETS
DRAWING NO.

Appendix F
30% Level Schematic Cost Estimate

GEOTREE

Todays Date							
Project Name							
GeoTree Project Number							
Project Asset Owner							
Contact phone and email of person providing initial design assumptions pulled from draft or final plans and Specs							
Installation Contractor -Contact responsible for confirming design input geometry assumptions							
Initial Draft Design Done by							
Design Pipe Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Structure Location (ie MH 1 to MH 4)	**00+00 to 00+76±**	**00+76± to 07+80±**	**07+80± to 08+07±**	**08+07± to 08+55±**	**08+55± to 10+26±**	**10+26± to 15+92±**	**15+92± + 22+39±**
Description	**7' Wide by 5.5' Tall Reinforced Concrete Box Shaped**	**6' Wide by 5.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	**8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	**10' Wide Reinforced Concrete Wide Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	**7' Wide by 7' Tall Reinforced Concrete Tubular, Flat Bottom**	**6' Wide by 7' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 4.0 ft tall)**	**6.5' Diameter Reinforced Concrete Tubular**
Pipe Shape: Round, Egg / Oval, Horseshoe, Arch, Box, Other	Box	Arch or Horseshoe	Arch or Horseshoe	Arch or Horseshoe	Round	Arch or horseshoe	Round
Average Daily Dry Weather Flow (MGD)	NA	NA	NA	NA	NA	NA	NA
Length (ft.)	40	550	30	50	170	360	630
Largest Horizontal Dimension -X Axis (used in liner design) (in)	84	72	96	120	84	72	78
Typical Height Dimension - Y Axis (in)	66	66	78	60	84	84	78
Estimated Original Pipe size or theoretical avgerage ID or box side dimension (in)							78
Design Evaluation - External Soil Water & Live Load	Y	Y	Y	Y	Y	Y	Y
Ovality % (Mean ID -Min ID)/ Mean ID per ASTM F1216	0	0	0	0	0	0	0
Min. Cover Depth above crown; Not Applicable (NA) if over 8' (ft)							
Max Cover Depth above crown (ft)	1.60	7.90	2.50	1.90	3.90	3.40	7.60
Does Min or Max cover depth govern design	MAX	max	max	max	max	max	max
Water Table depth measured down from the surface (ft)	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Material Type ie Brick, RCP, Stone, CMP, PCCP, Steel Other	RC	URC	URC	RC	RC	URC	RC
Pipe Function: ie Storm (ST), Sanitary Sewer (SS), Combined Sewer (CS), Potable (P)	ST	ST	ST	ST	ST	ST	ST
Live Load: ie None, HS20, HS25, HL93, E80 Railroad, Airport, Building, Other, Unknown	HS25	HS25	HS25	HS25	HS25	HS25	HS25
What is above the pipe? Ie Road pavement, woods, building	Road	Road	Road	Road	Road	Road	Road
Level of deterioration- partially or fully	Fully	Fully	Fully	Fully	Fully	Fully	Fully
Safety Factor	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Direction of pipe with respect to traffic, ie perpendicular or parallel	Perp	Perp	Perp	Perp	Perp	Perp	Perp
Assume Soil Arching: No or Yes (If "Yes" Height of Soil used to calculate soil load on pipe will be capped at 3X the pipe diameter)	No	No	No	No	No	No	No
Soil Density (pcf)	140	140	140	140	140	140	140
Soil Type	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any
Compressive Strength -28 Day ASTM C39 (not used in design) (psi)	8000	8000	8000	8000	8000	8000	8000
Tensile Strength -28 Day ASTM C496 (used in pressure design)(psi)	800	800	800	800	800	800	800
Flex Strength (FS) -28 Day ASTM C78 (used in gravity design) (psi)	1500	1500	1500	1500	1500	1500	1500
Tmin as required by project specifications if any	NA	NA	NA	NA	NA	NA	NA
Global Suggested Tmin using distibuted beam model per flex listed above (in)	2.00	1.15	0.80	0.82	0.90	0.70	1.10
Global Tmin propose for construction to nearest .05" (in)	**2.00**	**1.50**	**1.50**	**1.50**	**1.50**	**1.50**	**1.50**
Global Tmin propose for construction to nearest .05" * Note: per the Distributed Beam Design Method, Thickness Minimum (Tmin) (for pipe not MH) is correlated to the ASTM C78 - 28 day Flexural Strength (FS) in psi for the specific Geopolymer strength used. (in)	**2.00"** x $(1500/FS)^{0.5}$	**1.50"** x $(1500/FS)^{0.5}$	**1.5"** x $(1500/FS)^{0.5}$	**1.50"** x $(1500/FS)^{0.5}$	**1.5"** x $(1500/FS)^{0.5}$	**1.5"** x $(1500/FS)^{0.5}$	**1.5"** x $(1500/FS)^{0.5}$
Design Notes: * Distributed beam model is not applicable for pressure pipes, box sewer & MH. For a structural enhancement, use the project specified thickness, or if none is given, consider 1/2" min for potable water, 1 to 2" for box pipe & 1" for MH							

Strawberry Creek Culvert Rehabilitation

10/9/2023
Strawberry Creek Culvert Rehabilitation

City of Berkeley

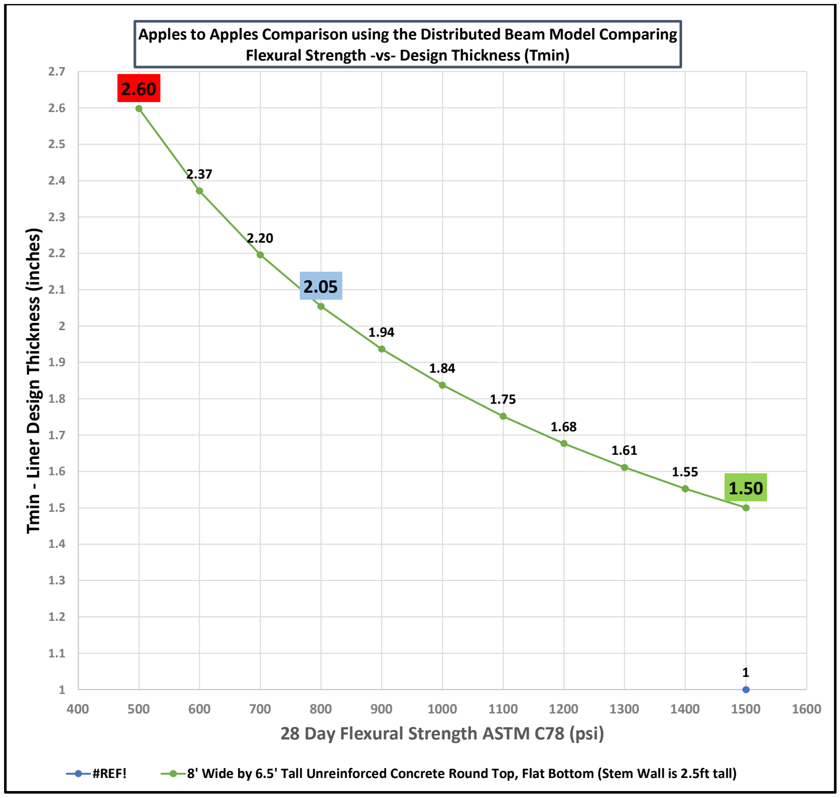
Darren Fagundes, PE, Cornerstone Structural Engineering Group

Kurt Chirbas, PE; Western Region Manager, GeoTree Solutions
C: 916-215-3163 E: kchirbas@CS-NRI.com
Jon Babson, Inside Sales Engineer, GeoTree Solutions
C: 518-225-1840 E: jbabson@CS-NRI.com

8	9	10	12	14	17	18	19	20	21	TOTALS
22+39± to 22+92±	22+92± to 26+18±	26+18± to 27+80±	28+62± to 34+88±	36+89± to 38+25±	41+32± to 44+52±	44+52± to 45+19±	45+19± to 53+37±	00+00 to 01+22±	00+00 to 01+12±	
6' Wide by 5.5' Tall Reinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	**8' Wide by 7' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 3.0 ft tall)**	**8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	**8' Wide by 6.5' Tall Reinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	**8' Wide by 5' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 1.0ft tall)**	**7.5' Diameter Reinforced Concrete Tubular**	**8' Wide by 6' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 2.0 ft tall)**	**8' Wide by 7' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 3.0 ft tall)**	**8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	**8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	
Arch or Horseshoe	Arch or Horseshoe	Arch or Horseshoe	Arch or Horseshoe	Arch or Horseshoe	Round	Arch or Horseshoe	Arch or horseshoe	Arch or Horshoe	Arch or Horseshoe	
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
55	330	90	145	70	40	70	810	70	65	**3575**
72	96	96	96	96	90	96	96	96	96	
66	84	78	78	60	90	72	84	78	78	
				78						
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
0	0	0	0	0	0	0	0	0	0	
10.10	11.00	9.90	6.70	8.20	4.50	6.00	5.70	8.60	10.70	
max	max	max	max	max	max	max	max	max	max	
6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	
RC	URC	URC	RC	URC	RCP	URC	URC	URC	URC	
ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	
HS25	HS25	HS25	HS25	HS25	HS25	HS25	HS25	HS25	HS25	
Road	Road	Road	Road	Road	Road	Road	Road	Road	Road	
Fully	Fully	Fully	Fully	Fully	Fully	Fully	Fully	Fully	Fully	
2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
Perp	Perp	Perp	Perp	Perp	Perp	Perp	Perp	Perp	Perp	
No	No	No	No	No	No	No	No	No	No	
140	140	140	140	140	140	140	140	140	140	
LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	
8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	
800	800	800	800	800	800	800	800	800	800	
1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1.20	1.60	1.60	1.30	1.40	1.00	1.20	1.20	1.40	1.60	
1.50	**1.60**	**1.60**	**1.50**	**1.50**	**1.50**	**1.50**	**1.50**	**1.50**	**1.60**	
1.5" x (1500/FS)$^{0.5}$	**1.6" x (1500/FS)$^{0.5}$**	**1.6" x (1500/FS)$^{0.5}$**	**1.5" x (1500/FS)$^{0.5}$**	**1.50" x (1500/FS)$^{0.5}$**	**1.50" x (1500/FS)$^{0.5}$**	**1.5" x (1500/FS)$^{0.5}$**	**1.5" x (1500/FS)$^{0.5}$**	**1.5" x (1500/FS)$^{0.5}$**	**1.6" x (1500/FS)$^{0.5}$**	

TABLE 1	10/9/2023	
Apples to Apples Comparison of GeoSpray Geopolymer and Ordinary Portland Cement (OPC) Minimum Liner Design Thickness (Tmin) Examples		
Material	*28 day Flexural Strength (FS) per ASTM C78 (psi)	8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall) $T\,min = 1.50'' x \sqrt{\frac{1500}{Fs}}$ OR $T\,min = 2.60'' x \sqrt{\frac{500}{Fs}}$ (in.)
GeoTree's GeoSpray Geopolymer	1500	1.50
	1400	1.55
	1300	1.61
	1200	1.68
	1100	1.75
	1000	1.84
	900	1.94
Lower End Alternative Spray on Material	800	2.05
	700	2.20
	600	2.37
Ordinary Portland Cement (OPC)	500	2.60
% (OPC-GeoSpray)	-67%	73%

When all dead load geometry and live load values are held constant, the distributed beam model can be simplified per the formula above. This shows how the 28 day Flexural Strength (FS) per ASTM C78 has a direct correlation to liner thickness that is almost linear. OPC has 67% less flexural strength, however an equal load bearing capacity design would require 73% more thickness. In addition, typically wire mesh would be added to the OPC because the flexural strength is so low. For questions



	COST ESTIMATE:	Strawberry Creek Culvert Rehabilitation					
Structure Location (ie MH 1 to MH 4)	Description	Design Thickness at (Specific flex) (in.)	LF	$/ LF Range		Total Cost Range	
00+00 to 00+76±	7' Wide by 5.5' Tall Reinforced Concrete Box Shaped	2.00	40	$ 1,025	$ 1,275	$ 41,000	$ 51,000
00+76± to 07+80±	6' Wide by 5.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	1.50	550	$ 625	$ 800	$ 343,750	$ 440,000
07+80± to 08+07±	8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	1.50	30	$ 775	$ 975	$ 23,250	$ 29,250
08+07± to 08+55±	10' Wide Reinforced Concrete Wide Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	1.50	50	$ 950	$ 1,175	$ 47,500	$ 58,750
08+55± to 10+26±	7' Wide by 7' Tall Reinforced Concrete Tubular, Flat Bottom	1.50	170	$ 1,050	$ 1,300	$ 178,500	$ 221,000
10+26± to 15+92±	6' Wide by 7' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 4.0 ft tall)	1.50	360	$ 725	$ 900	$ 261,000	$ 324,000
15+92± + 22+39±	6.5' Diameter Reinforced Concrete Tubular	1.50	630	$ 625	$ 775	$ 393,750	$ 488,250
22+39± to 22+92±	6' Wide by 5.5' Tall Reinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	1.50	55	$ 625	$ 775	$ 34,375	$ 42,625
22+92± to 26+18±	8' Wide by 7' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 3.0 ft tall)	1.60	330	$ 875	$ 1,100	$ 288,750	$ 363,000
26+18± to 27+80±	8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	1.60	90	$ 825	$ 1,050	$ 74,250	$ 94,500
28+62± to 34+88±	8' Wide by 6.5' Tall Reinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	1.50	145	$ 775	$ 975	$ 112,375	$ 141,375
36+89± to 38+25±	8' Wide by 5' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 1.0ft tall)	1.50	70	$ 700	$ 875	$ 49,000	$ 61,250
41+32± to 44+52±	7.5' Diameter Reinforced Concrete Tubular	1.50	40	$ 725	$ 900	$ 29,000	$ 36,000
44+52± to 45+19±	8' Wide by 6' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 2.0 ft tall)	1.50	70	$ 1,150	$ 1,425	$ 80,500	$ 99,750
45+19± to 53+37±	8' Wide by 7' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 3.0 ft tall)	1.50	810	$ 825	$ 1,025	$ 668,250	$ 830,250
00+00 to 01+22±	8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	1.50	70	$ 775	$ 975	$ 54,250	$ 68,250
00+00 to 01+12±	8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	1.60	65	$ 825	$ 1,050	$ 53,625	$ 68,250
						$ 2,733,125	$ 3,417,500

1. GeoSpray Geopolymer installation is for the above thickness required by the flexural strength stated in the desing summary. If a material with a weaker or stronger flexural strength is used, this will directly impact the thickness, hydraulic capacity and construction unit costs
2. Unit price assumes unrestricted access via open culvert end or unobstructed
3. If the lining contractor is not the prime on the project, unit price does not include a GC mark up for a trenchless contractor sub

EXCLUSIONS:

1. Access Roads
2. Bypass Pumping or Cofferdams
3. Clearing
4. Permits
5. Water
6. Traffic Control
7. Restoration
8. Dump Fees and transportation of debris from the cleaning operation
9. Patching of major defects of the pipe or sealing of joints due to heavy infiltration for "weepers or gushers" as defined by NASSCO
10. E&S Controls
11. Material Sampling and Testing
12. Heavy Cleaning of Pipe
13. Pipe Fusing
14. Mobilization and Demob
15. MH Installation
16. Tax

Appendix G
Structural Analysis of Existing Culvert Sections

CORNERSTONE
structural
engineering
group

www.cseg.com

Strawberry Creek Culvert Structural Assessment

Job No. 2023025

REGISTERED PROFESSIONAL ENGINEER
NARCISO R. ZERMENO
No. S6783
STRUCTURAL
STATE OF CALIFORNIA

PRELIMINARY STRUCTURAL CALCULATIONS

November 29, 2023

986 W. Alluvial, Ste. 201
Fresno, CA 93711

tel. (415)369-9100
fax. (415) 369-9101

STRAWBERRY CREEK CULVERT ASSESSMENT

TABLE OF CONTENTS

CSEG

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT
BERKELEY, CA

ELEVATION DETERMINATION

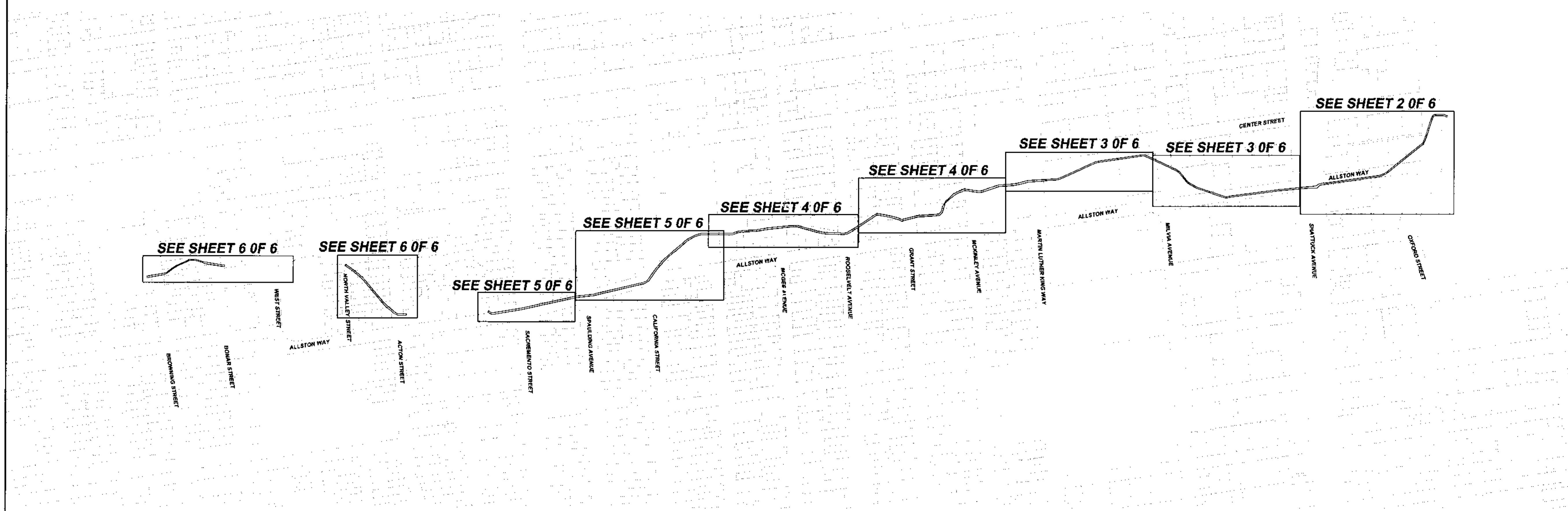
CSW took survey shots of the invert slabs and the top of roadway elevations. The difference between the two were used to approximate the depth of each culvert section.

CITY OF BERKELEY

STRAWBERRY CREEK CULVERT

EXISTING CONDITIONS MAPPING

Coring locations are from ISI Inspection Services's Attachment 1 - SCC Coring Map.
Culvert elevations are from ISI Inspection Services's Attachment 2 - SCC Survey Map.
Roadway elevations are from Top of Roadway Survey from CSW.



INDEX SHEET

Graphic Scale (in feet)

1 inch = 200 ft.

Rev	Date	Description	Designed	Drawn	Checked
-	10/11/22	SUBMITTED TO CLIENT	-	BJH	JLW

CSW ST2
CSW/Stuber-Stroeh Engineering Group, Inc.

City	Berkeley
County	Alameda
State	California

STRAWBERRY CREEK CULVERT SURVEY

INDEX AND COVER SHEET

CITY OF BERKELEY

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Date:	10/11/22
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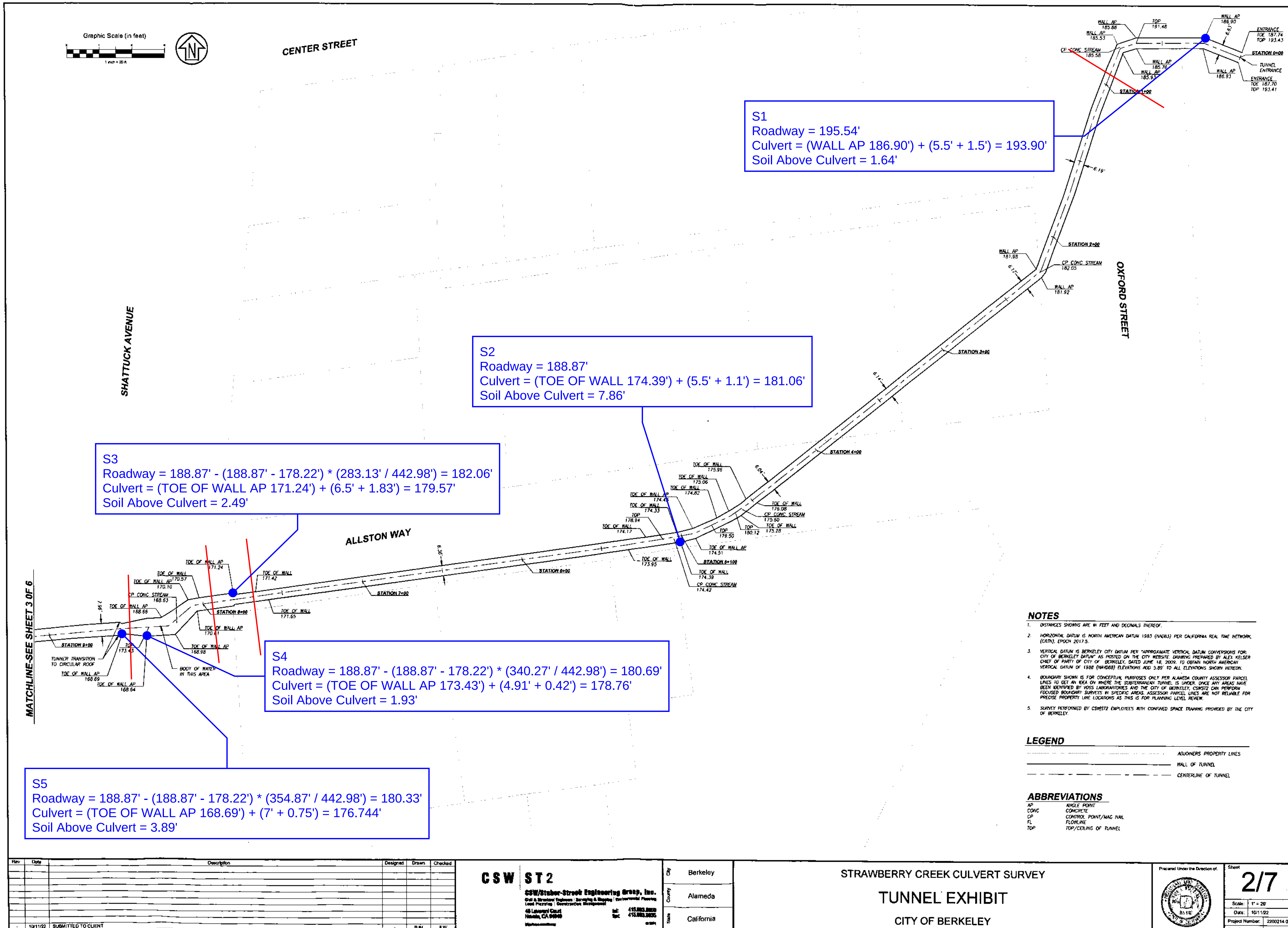
Plan File:	-


Graphic Scale (in feet)
CENTER STREET
SHATTUCK AVENUE
OXFORD STREET
ALLSTON WAY
MATCHLINE-SEE SHEET 3 OF 6
S1
Roadway = 195.54'
Culvert = (WALL AP 186.90') + (5.5' + 1.5') = 193.90'
Soil Above Culvert = 1.64'
S2
Roadway = 188.87'
Culvert = (TOE OF WALL 174.39') + (5.5' + 1.1') = 181.06'
Soil Above Culvert = 7.86'
S3
Roadway = 188.87' - (188.87' - 178.22') * (283.13' / 442.98') = 182.06'
Culvert = (TOE OF WALL AP 171.24') + (6.5' + 1.83') = 179.57'
Soil Above Culvert = 2.49'
S4
Roadway = 188.87' - (188.87' - 178.22') * (340.27' / 442.98') = 180.69'
Culvert = (TOE OF WALL AP 173.43') + (4.91' + 0.42') = 178.76'
Soil Above Culvert = 1.93'
S5
Roadway = 188.87' - (188.87' - 178.22') * (354.87' / 442.98') = 180.33'
Culvert = (TOE OF WALL AP 168.69') + (7' + 0.75') = 176.744'
Soil Above Culvert = 3.89'
NOTES
LEGEND
ABBREVIATIONS
10/11/22 SUBMITTED TO CLIENT
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California
STRAWBERRY CREEK CULVERT SURVEY
TUNNEL EXHIBIT
CITY OF BERKELEY
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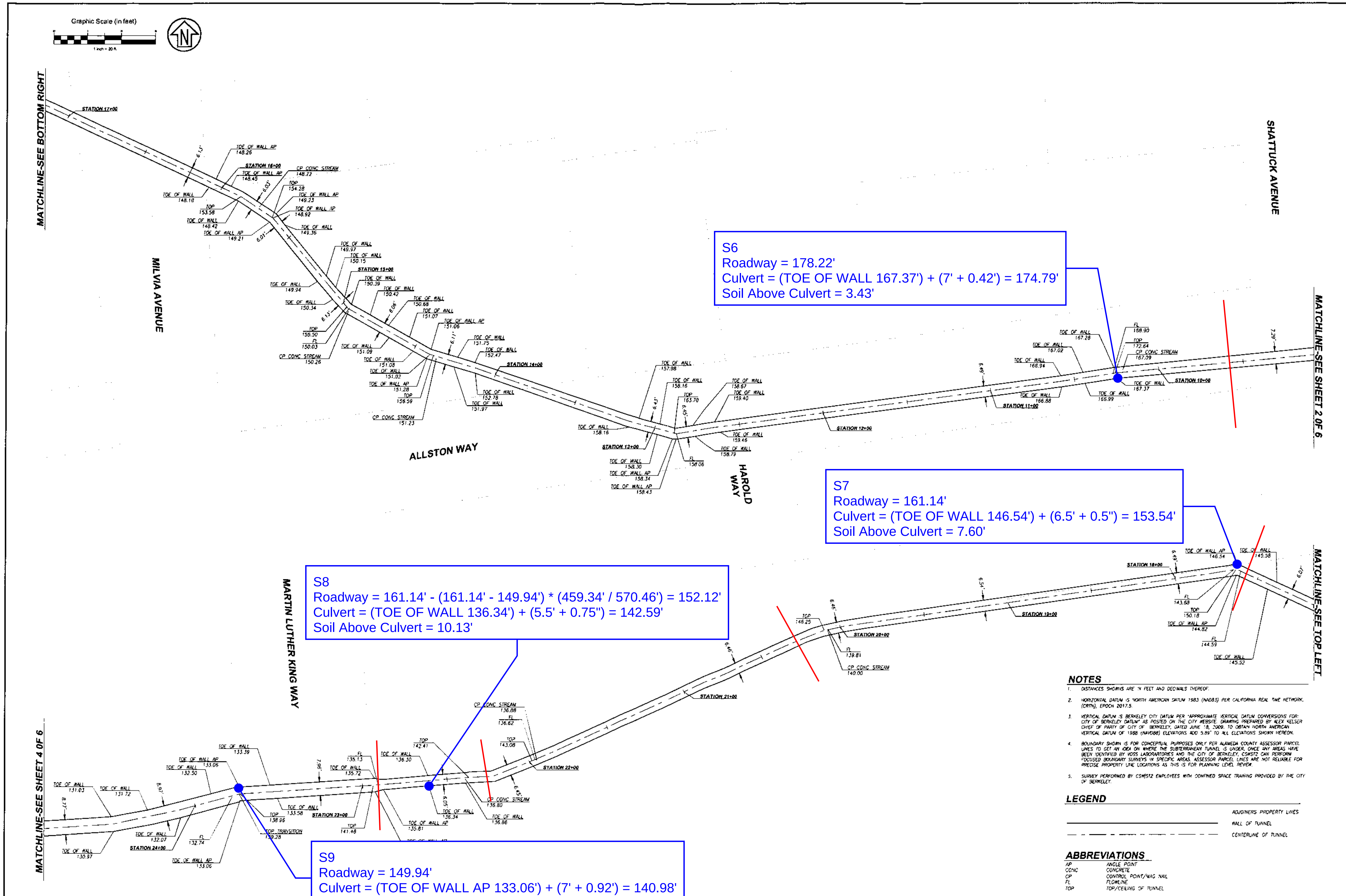

NOTES

1. DISTANCES SHOWN ARE IN FEET AND DECIMALS THEREOF.
2. HORIZONTAL DATUM IS NORTH AMERICAN DATUM 1983 (NAD83) PER CALIFORNIA REAL TIME NETWORK, (CRTN), EPOCH 2017.5.
3. VERTICAL DATUM IS BERKELEY CITY DATUM PER "APPROXIMATE VERTICAL DATUM CONVERSIONS FOR: CITY OF BERKELEY DATUM" AS POSTED ON THE CITY WEBSITE. DRAWING PREPARED BY ALEX KELSER CHIEF OF PARTY OF CITY OF BERKELEY, DATED JUNE 18, 2009. TO OBTAIN NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88) ELEVATIONS ADD 5.89' TO ALL ELEVATIONS SHOWN HEREON.
4. BOUNDARY SHOWN IS FOR CONCEPTUAL PURPOSES ONLY PER ALAMEDA COUNTY ASSESSOR PARCEL LINES TO GET AN IDEA ON WHERE THE SUBTERRANEAN TUNNEL IS UNDER. ONCE ANY AREAS HAVE BEEN IDENTIFIED BY VOSS LABORARTORIES AND THE CITY OF BERKELEY, CSWST2 CAN PERFORM FOCUSED BOUNDARY SURVEYS IN SPECIFIC AREAS. ASSESSOR PARCEL LINES ARE NOT RELIABLE FOR PRECISE PROPERTY LINE LOCATIONS AS THIS IS FOR PLANNING LEVEL REVIEW.
5. SURVEY PERFORMED BY CSW|ST2 EMPLOYEES WITH CONFINED SPACE TRAINING PROVIDED BY THE CITY OF BERKELEY.

LEGEND

- ADJOINERS PROPERTY LINES
- WALL OF TUNNEL
- CENTERLINE OF TUNNEL

ABBREVIATIONS

AP	ANGLE POINT
CONC	CONCRETE
CP	CONTROL POINT/MAG NAIL
FL	FLOWLINE
TOP	TOP/CEILING OF TUNNEL

Rev	Date	Description		
-	10/11/22	SUBMITTED TO CLIENT	BJH	JLW

CSW ST2
CSW/Stuber-Stroeh Engineering Group, Inc.
45 Leveroni Court, Novato, CA 94949

City	Berkeley
County	Alameda
State	California

STRAWBERRY CREEK CULVERT SURVEY

TUNNEL EXHIBIT

CITY OF BERKELEY

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Sheet	3/7
Scale:	1" = 20'
Date:	10/11/22
Project Number:	2200214.01
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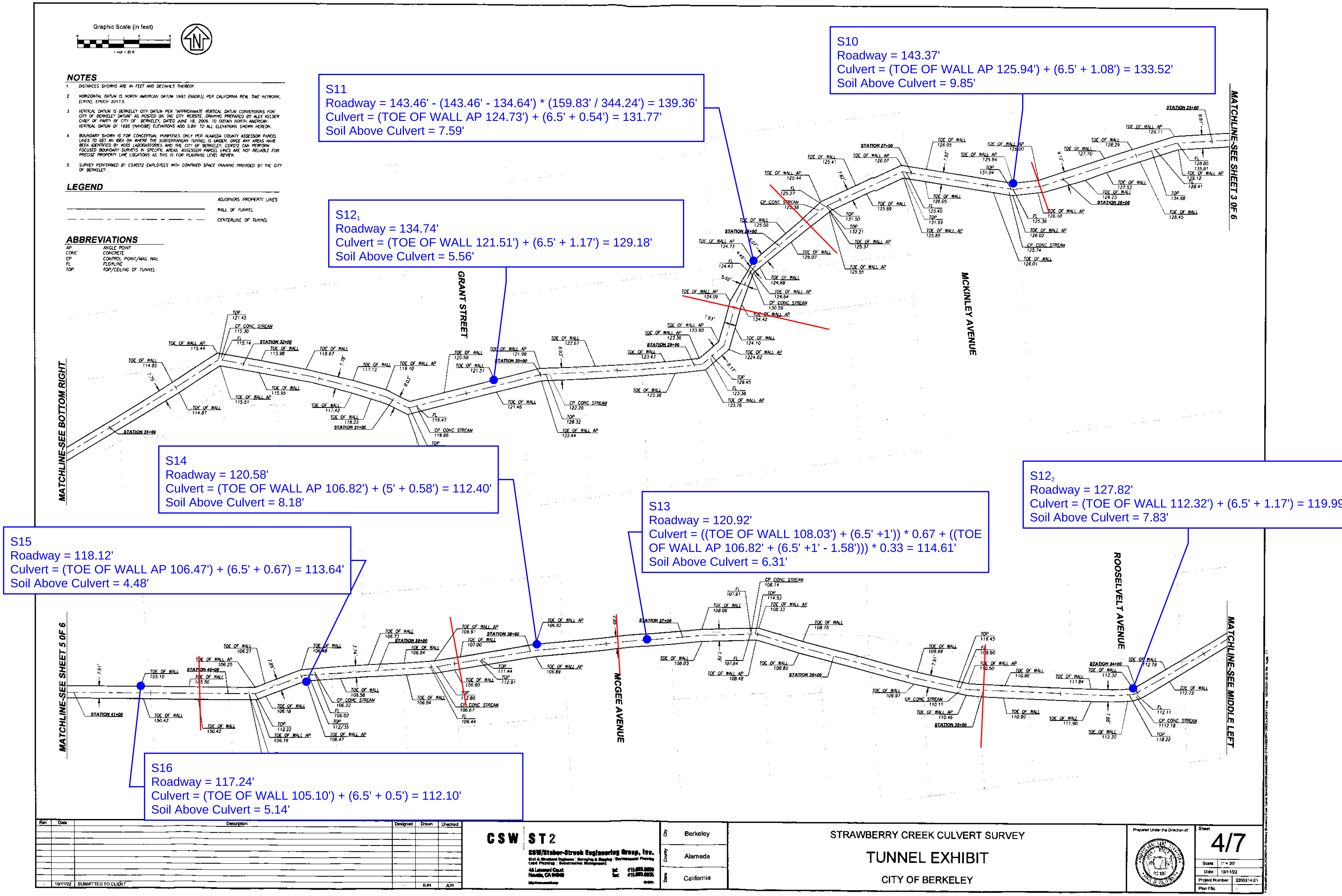
Graphic Scale (in feet)
NOTES
LEGEND
ABBREVIATIONS
S11
Roadway = 143.46' - (143.46' - 134.64') * (159.83' / 344.24') = 139.36'
Culvert = (TOE OF WALL AP 124.73') + (6.5' + 0.54') = 131.77'
Soil Above Culvert = 7.59'
S10
Roadway = 143.37'
Culvert = (TOE OF WALL AP 125.94') + (6.5' + 1.08') = 133.52'
Soil Above Culvert = 9.85'
S12₁
Roadway = 134.74'
Culvert = (TOE OF WALL AP 121.51') + (6.5' + 1.17') = 129.18'
Soil Above Culvert = 5.56'
GRANT STREET
MCKINLEY AVENUE
MATCHLINE-SEE SHEET 3 OF 6
MATCHLINE-SEE BOTTOM RIGHT
S14
Roadway = 120.58'
Culvert = (TOE OF WALL AP 106.82') + (5' + 0.58') = 112.40'
Soil Above Culvert = 8.18'
S12₂
Roadway = 127.82'
Culvert = (TOE OF WALL 112.32') + (6.5' + 1.17') = 119.99'
Soil Above Culvert = 7.83'
S13
Roadway = 120.92'
Culvert = ((TOE OF WALL 108.03') + (6.5' +1')) * 0.67 + ((TOE OF WALL AP 106.82' + (6.5' +1' - 1.58'))) * 0.33 = 114.61'
Soil Above Culvert = 6.31'
S15
Roadway = 118.12'
Culvert = (TOE OF WALL AP 106.47') + (6.5' + 0.67) = 113.64'
Soil Above Culvert = 4.48'
ROOSEVELT AVENUE
MCGEE AVENUE
MATCHLINE-SEE SHEET 5 OF 6
MATCHLINE-SEE MIDDLE LEFT
S16
Roadway = 117.24'
Culvert = (TOE OF WALL 105.10') + (6.5' + 0.5') = 112.10'
Soil Above Culvert = 5.14'
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STRAWBERRY CREEK CULVERT SURVEY
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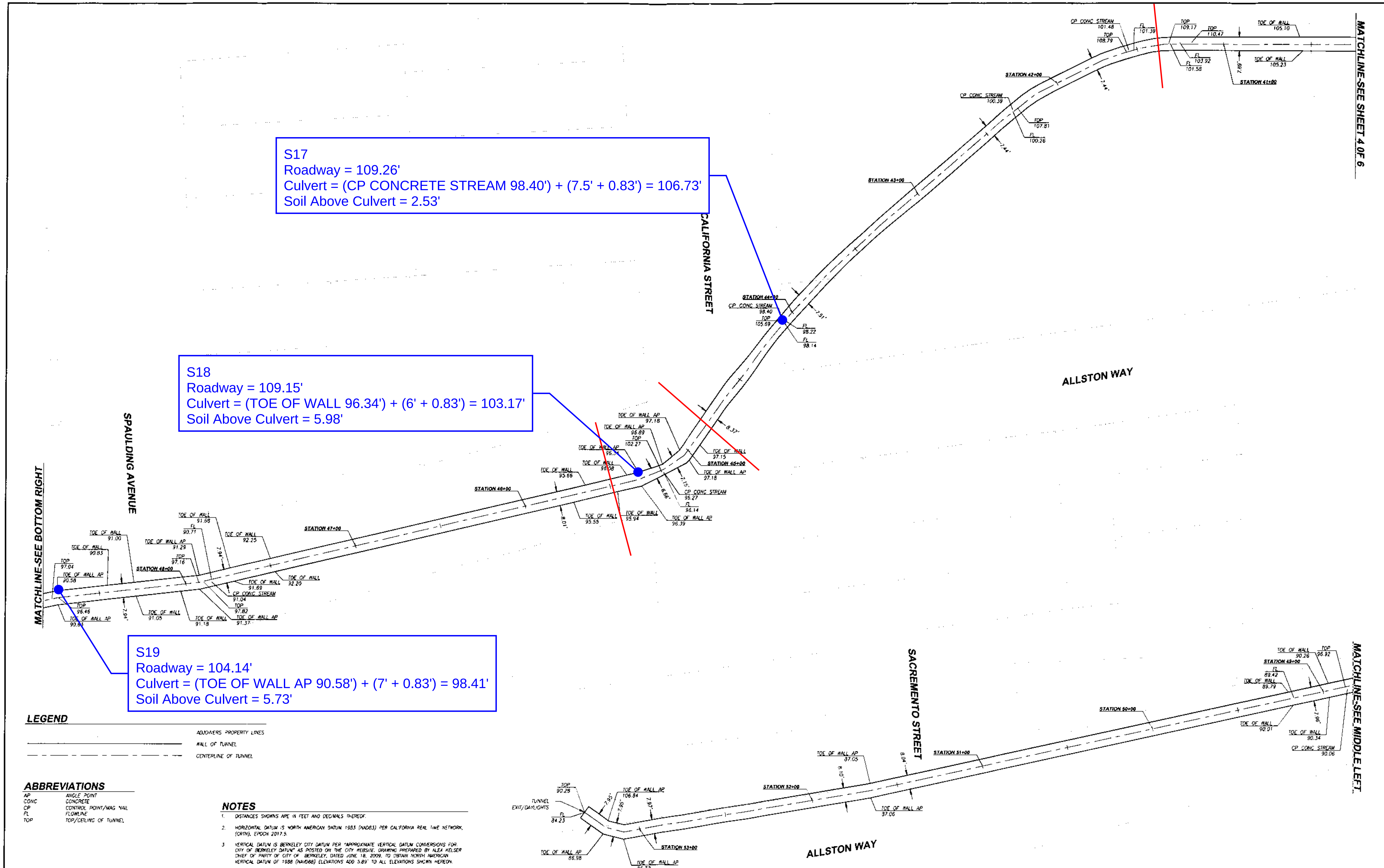

LEGEND

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CENTERLINE OF TUNNEL

ABBREVIATIONS

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CSW ST2
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45 Leveroni Court
Novato, CA 94949

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STRAWBERRY CREEK CULVERT SURVEY
TUNNEL EXHIBIT
CITY OF BERKELEY

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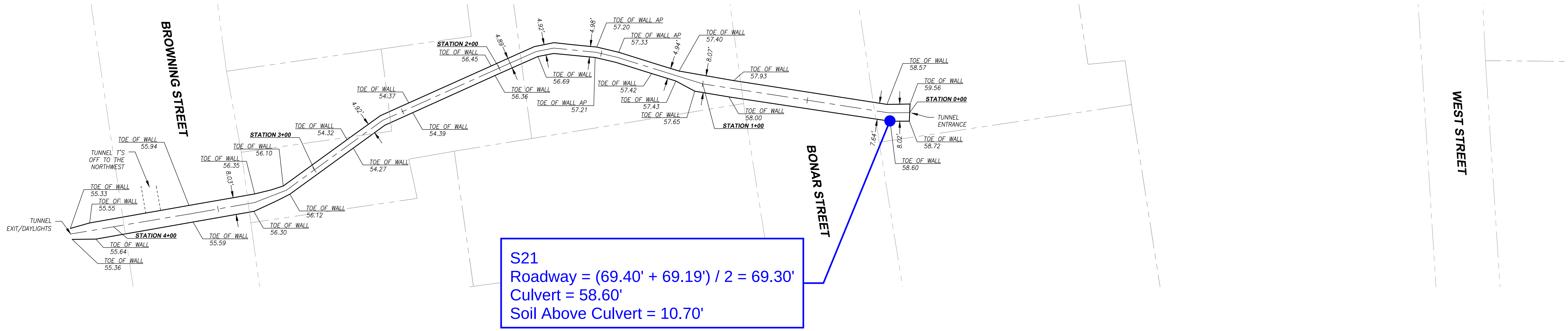
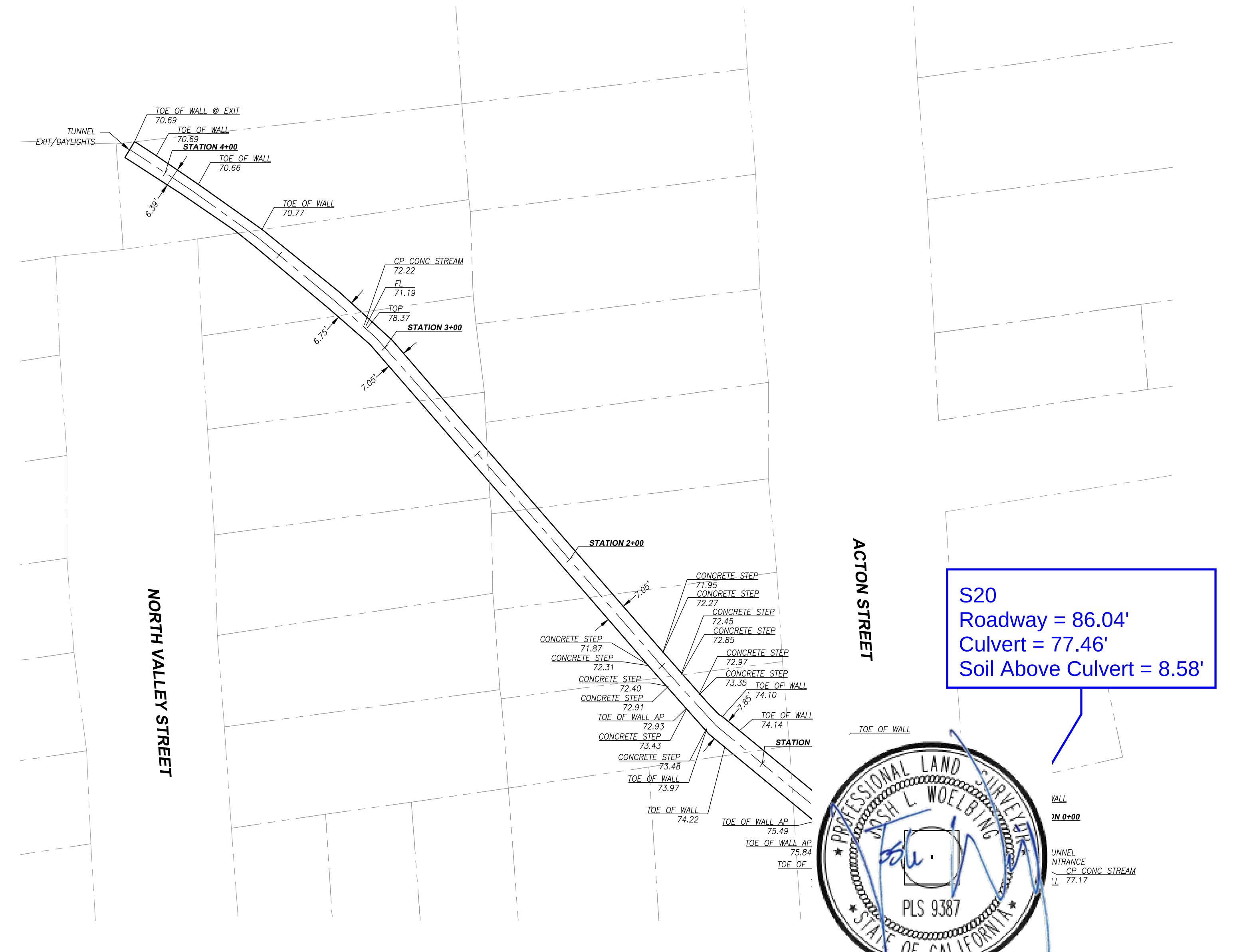
Plan File:	-





ABBREVIATIONS

AP	ANGLE POINT
CONC	CONCRETE
CP	CONTROL POINT/MAG NAIL
FL	FLOWLINE
TOP	TOP/CEILING OF TUNNEL

NOTES

1. DISTANCES SHOWNS ARE IN FEET AND DECIMALS THEREOF.
2. HORIZONTAL DATUM IS NORTH AMERICAN DATUM 1983 (NAD83) PER CALIFORNIA REAL TIME NETWORK, (CRTN), EPOCH 2017.5.
3. VERTICAL DATUM IS BERKELEY CITY DATUM PER "APPROXIMATE VERTICAL DATUM CONVERSIONS FOR: CITY OF BERKELEY DATUM" AS POSTED ON THE CITY WEBSITE. DRAWING PREPARED BY ALEX KELSER CHIEF OF PARTY OF CITY OF BERKELEY, DATED JUNE 18, 2009. TO OBTAIN NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88) ELEVATIONS ADD 5.89' TO ALL ELEVATIONS SHOWN HEREON.
4. BOUNDARY SHOWN IS FOR CONCEPTUAL PURPOSES ONLY PER ALAMEDA COUNTY ASSESSOR PARCEL LINES TO GET AN IDEA ON WHERE THE SUBTERRANEAN TUNNEL IS UNDER. ONCE ANY AREAS HAVE BEEN IDENTIFIED BY VOSS LABORARTORIES AND THE CITY OF BERKELEY, CSWST2 CAN PERFORM FOCUSED BOUNDARY SURVEYS IN SPECIFIC AREAS. ASSESSOR PARCEL LINES ARE NOT RELIABLE FOR PRECISE PROPERTY LINE LOCATIONS AS THIS IS FOR PLANNING LEVEL REVIEW.
5. SURVEY PERFORMED BY CSW|ST2 EMPLOYEES WITH CONFINED SPACE TRAINING PROVIDED BY THE CITY OF BERKELEY.

Graphic Scale (in feet)

20 0 20 40

1 inch = 20 ft.

N

LEGEND

— — —	ADJOINERS PROPERTY LINES
———	WALL OF TUNNEL
— - —	CENTERLINE OF TUNNEL

Rev	Date	Description	Designed	Drawn	Checked
-	10/11/22	SUBMITTED TO CLIENT	-	BJH	JLW

CSW | ST2

CSW/Stuber-Stroeh Engineering Group, Inc.

Civil & Structural Engineers | Surveying & Mapping | Environmental Planning | Land Planning | Construction Management

45 Leveroni Court, Novato, CA 94949 — tel: 415.883.9850 fax: 415.883.9835

City	Berkeley
County	Alameda
State	California

STRAWBERRY CREEK CULVERT SURVEY

TUNNEL EXHIBIT

CITY OF BERKELEY

Sheet 6/7

Scale:	1" = 20'
Date:	10/11/22
Project Number:	2200214.01
Plan File:	-

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 2

CSEG

Crown Pressure
Strawberry Creek Culvert Section 2

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	7.193333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 1.007067 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 7.9 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.55 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 8.49 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	72	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 2

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 13.02 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 27.02 ft
Per AASHTO 3.6.1.2.6b-6

lw = 13.02 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 14.21 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 20.21 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 20.21 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 2 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - P_L

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 7.9 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.01 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	13.02	20.21	32	0.211
2	1	13.02	30.21	64	0.228
3	0.85	13.02	40.21	96	0.221
4	0.65	13.02	50.21	128	0.192

Crown Pressure
Strawberry Creek Culvert Section 2

Tire Distribution - Tandem
Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft   Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 2.04 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 72 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 13.02 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 17.02 ft
Per AASHTO 3.6.1.2.6b-6

lw = 17.02 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 14.21 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 20.21 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 20.21 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 2

Determine the Crown Pressure - P_L

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 7.9 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.01 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

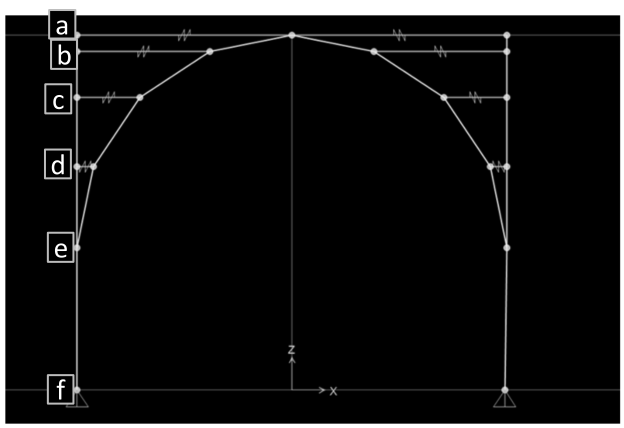
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	17.02	20.21	50	0.239
2	1	17.02	30.21	100	0.260
3	0.85	17.02	40.21	150	0.251
4	0.65	17.02	50.21	200	0.217

Max pressure is from tandem truck = 0.260 ksf

Crown Pressure
Strawberry Creek Culvert Section 2

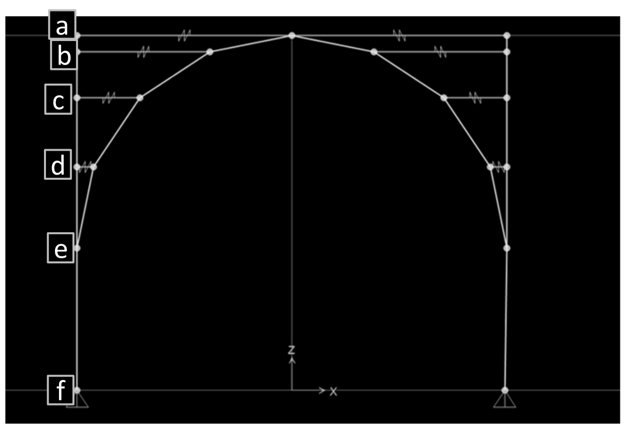
5.) Horizontal Earth Pressure - EH Minimum

Depth =	7.193333	ft	(Soil Above a)
a =	6.083	ft	(Top of Culvert Arch Height, Height at a)
b =	5.811	ft	(Height at b)
c =	5.034	ft	(Height at c)
d =	3.871	ft	(Height at d)
e =	2.500	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	259.0	plf	(Trap. EH Value at a)
EH_b =	268.8	plf	(Trap. EH Value at b)
EH_c =	296.7	plf	(Trap. EH Value at c)
EH_d =	338.6	plf	(Trap. EH Value at d)
EH_e =	387.9	plf	(Trap. EH Value at e)
EH_f =	477.9	plf	(Trap. EH Value at f)



6.) Horizontal Earth Pressure - EH Maximum

Depth =	7.193333	ft	(Soil Above a)
a =	6.083	ft	(Top of Culvert Arch Height, Height at a)
b =	5.811	ft	(Height at b)
c =	5.034	ft	(Height at c)
d =	3.871	ft	(Height at d)
e =	2.5	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	863.2	plf	(Trap. EH Value at a)
EH_b =	895.8	plf	(Trap. EH Value at b)
EH_c =	989.1	plf	(Trap. EH Value at c)
EH_d =	1128.6	plf	(Trap. EH Value at d)
EH_e =	1293.2	plf	(Trap. EH Value at e)
EH_f =	1593.2	plf	(Trap. EH Value at f)



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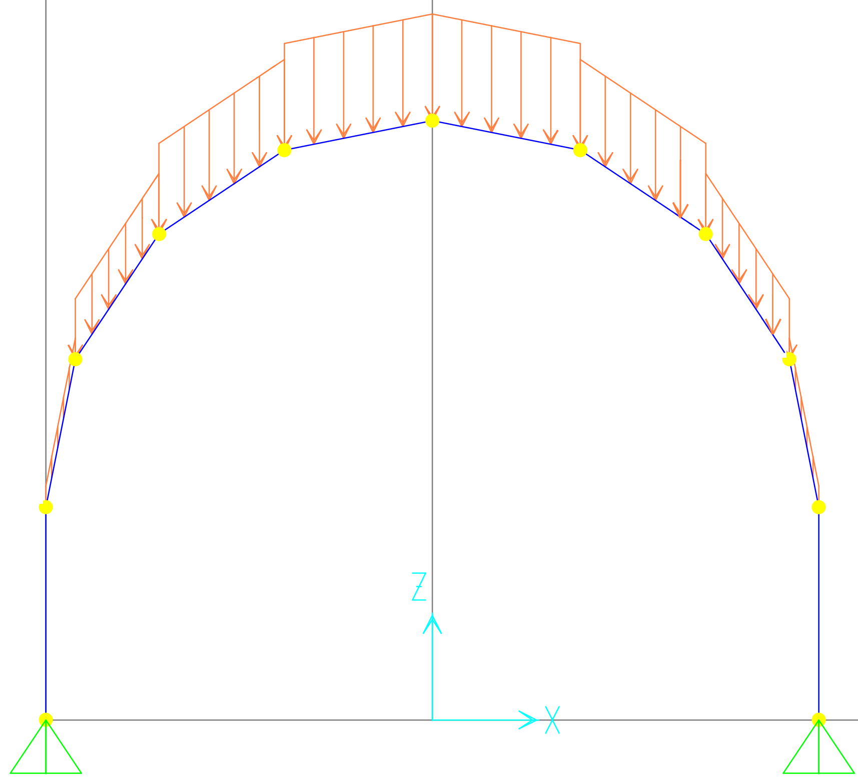

Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.

Section 2 - Frame Span Loads (EV) - Kip, ft, F Units

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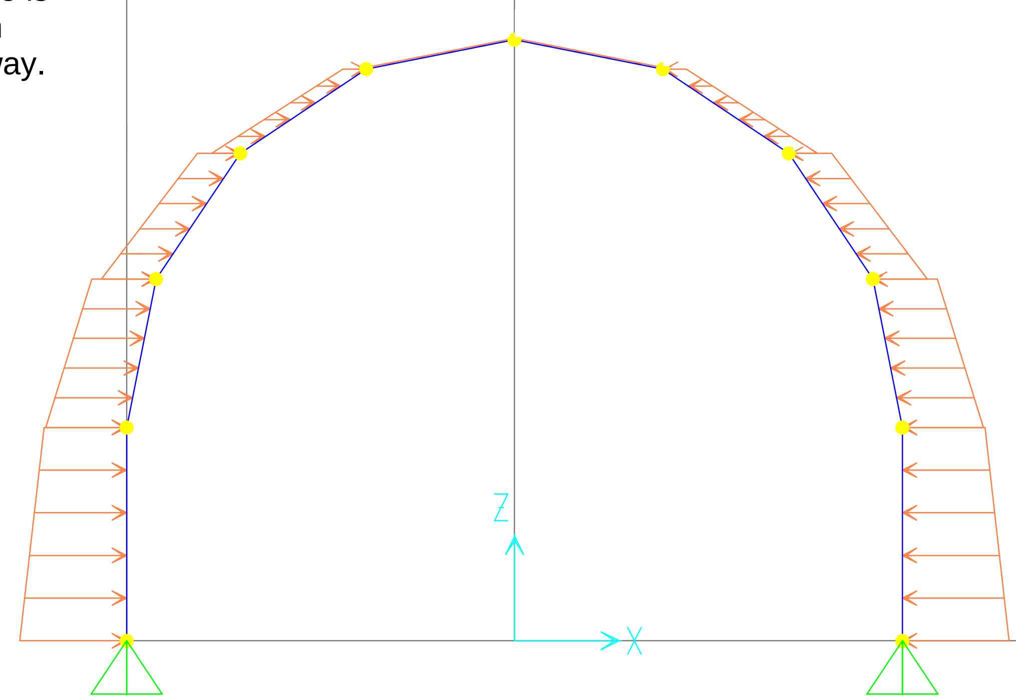
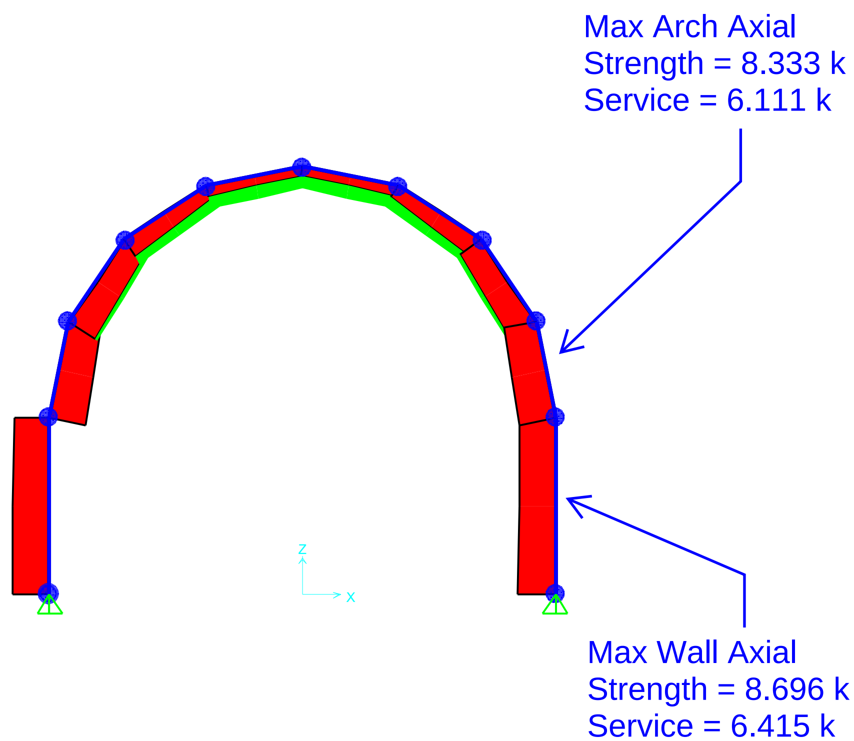


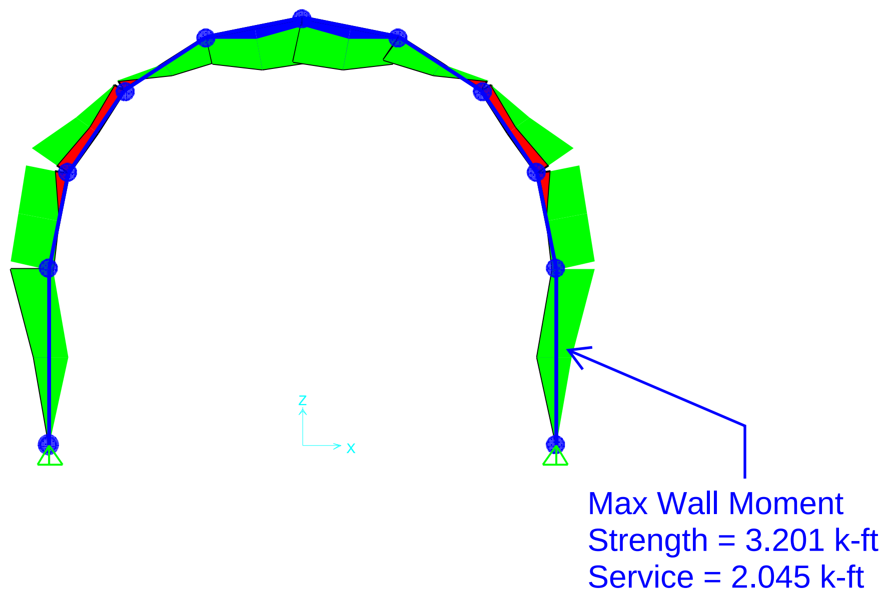
Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.

Section 2 - Frame Span Loads (EHMin) - Kip, ft, F Units



Max Arch Axial
Strength = 8.333 k
Service = 6.111 k
Z
X
Max Wall Axial
Strength = 8.696 k
Service = 6.415 k


Z
X
Max Wall Moment
Strength = 3.201 k-ft
Service = 2.045 k-ft

SECTION 2 ARCH CULVERT FLEXURE CHECK

Geometry

h =	14.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	7.00	in	(Distance from extreme comp. fiber to center)
I_y =	2744	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	4.000	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.48	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

M_n = $Min[\,5 * \lambda * \sqrt{f'c} * S_m;\;\; 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

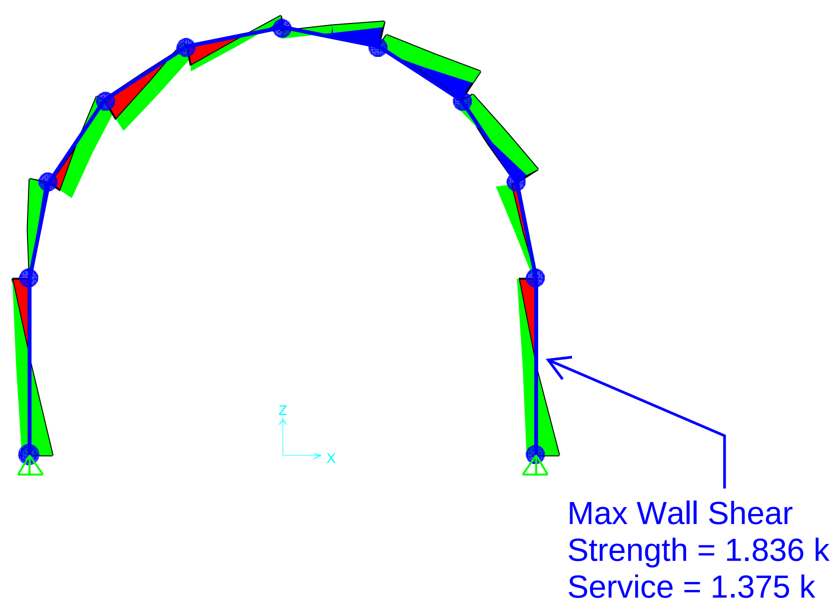
M_n = 10.33 k-ft

Φ = 0.6 (ACI 21.2.1)

ΦM_n = 6.20 k-ft > 3.20 k-ft = Critical Moment from SAP Model **OK**

D/C = 0.52

Flexural capacity is sufficient.


Z
X
Max Wall Shear
Strength = 1.836 k
Service = 1.375 k

SECTION 2 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h =	14.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	168.00	in^2	(Area of concrete section)

Materials

f'_c =	4.000	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	3640	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.48	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 1.84 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)

Concrete Shear Capacity

$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$ 14.17 k (ACI 14.5.5.1)

$\phi V_n = V_c > V_U$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 8.50 k > $V_u = V_{crit}$ = 1.84 k **OK** D/C = 0.22

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 3

Crown Pressure
Strawberry Creek Culvert Section 3

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	1.823333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 0.255267 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 2.5 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.75 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{S_a - \frac{l_t}{12}}{LLDF}$ = 7.52 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	96	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{S_W - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 3

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 5.19 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 19.19 ft
Per AASHTO 3.6.1.2.6b-6

lw = 5.19 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 6.50 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 12.5 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 12.50 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 2 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - P_L

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 2.5 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.23 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$ (AASHTO 3.6.1.2.6b−7) $A_{LL} = L_w * W_w$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	5.19	12.50	32	0.790
2	1	5.19	22.50	64	0.736
3	0.85	5.19	32.50	96	0.658
4	0.65	5.19	42.50	128	0.527

Crown Pressure
Strawberry Creek Culvert Section 3

Tire Distribution - Tandem
Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft   Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 1.81 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 5.19 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 9.19 ft
Per AASHTO 3.6.1.2.6b-6

lw = 9.19 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 6.50 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 12.5 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 12.50 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 3

Determine the Crown Pressure - P_L

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 2.5 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.23 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

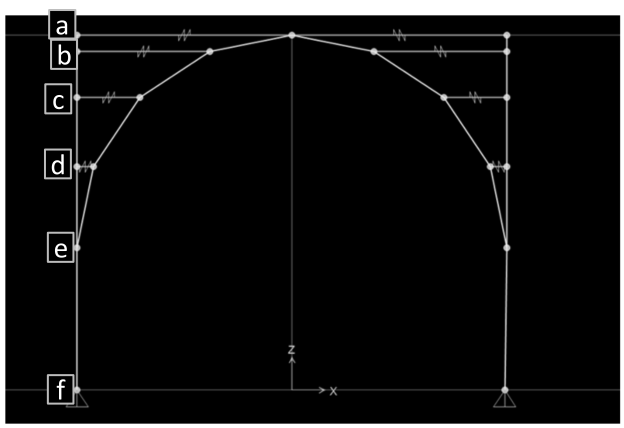
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	9.19	12.50	50	0.705
2	1	9.19	22.50	100	0.657
3	0.85	9.19	32.50	150	0.588
4	0.65	9.19	42.50	200	0.472

Max pressure is from HL-93 truck = 0.790 ksf

Crown Pressure
Strawberry Creek Culvert Section 3

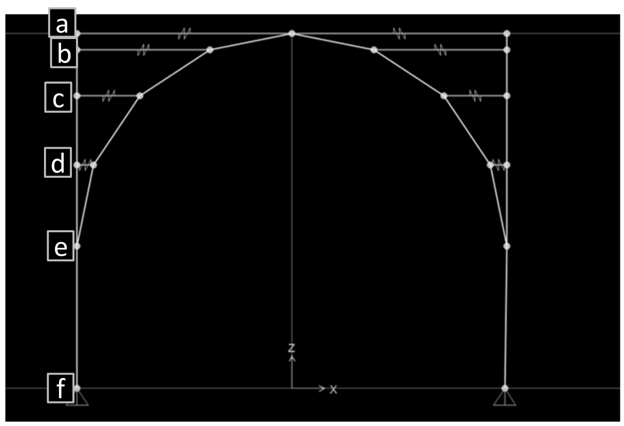
5.) Horizontal Earth Pressure - EH Minimum

Depth =	1.823333	ft	(Soil Above a)
a =	7.417	ft	(Top of Culvert Arch Height, Height at a)
b =	7.042	ft	(Height at b)
c =	5.977	ft	(Height at c)
d =	4.382	ft	(Height at d)
e =	2.500	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	65.6	plf	(Trap. EH Value at a)
EH_b =	79.1	plf	(Trap. EH Value at b)
EH_c =	117.5	plf	(Trap. EH Value at c)
EH_d =	174.9	plf	(Trap. EH Value at d)
EH_e =	242.7	plf	(Trap. EH Value at e)
EH_f =	332.7	plf	(Trap. EH Value at f)



6.) Horizontal Earth Pressure - EH Maximum

Depth =	1.823333	ft	(Soil Above a)
a =	7.417	ft	(Top of Culvert Arch Height, Height at a)
b =	7.042	ft	(Height at b)
c =	5.977	ft	(Height at c)
d =	4.382	ft	(Height at d)
e =	2.5	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	218.8	plf	(Trap. EH Value at a)
EH_b =	263.8	plf	(Trap. EH Value at b)
EH_c =	391.6	plf	(Trap. EH Value at c)
EH_d =	583.0	plf	(Trap. EH Value at d)
EH_e =	808.8	plf	(Trap. EH Value at e)
EH_f =	1108.8	plf	(Trap. EH Value at f)



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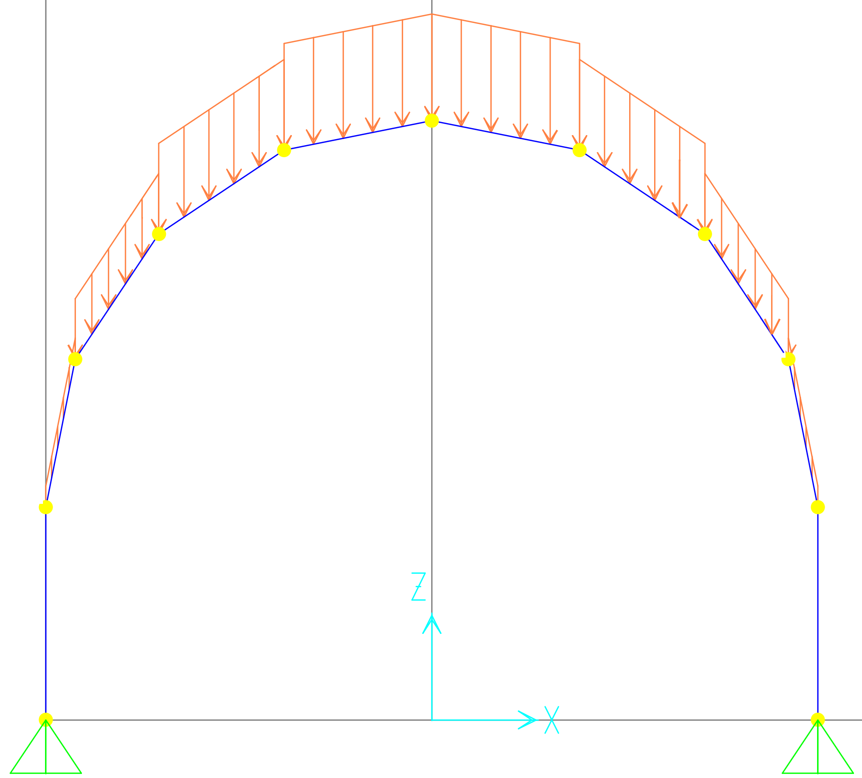
Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.



Section 3 - Frame Span Loads (EV) - Kip, ft, F Units

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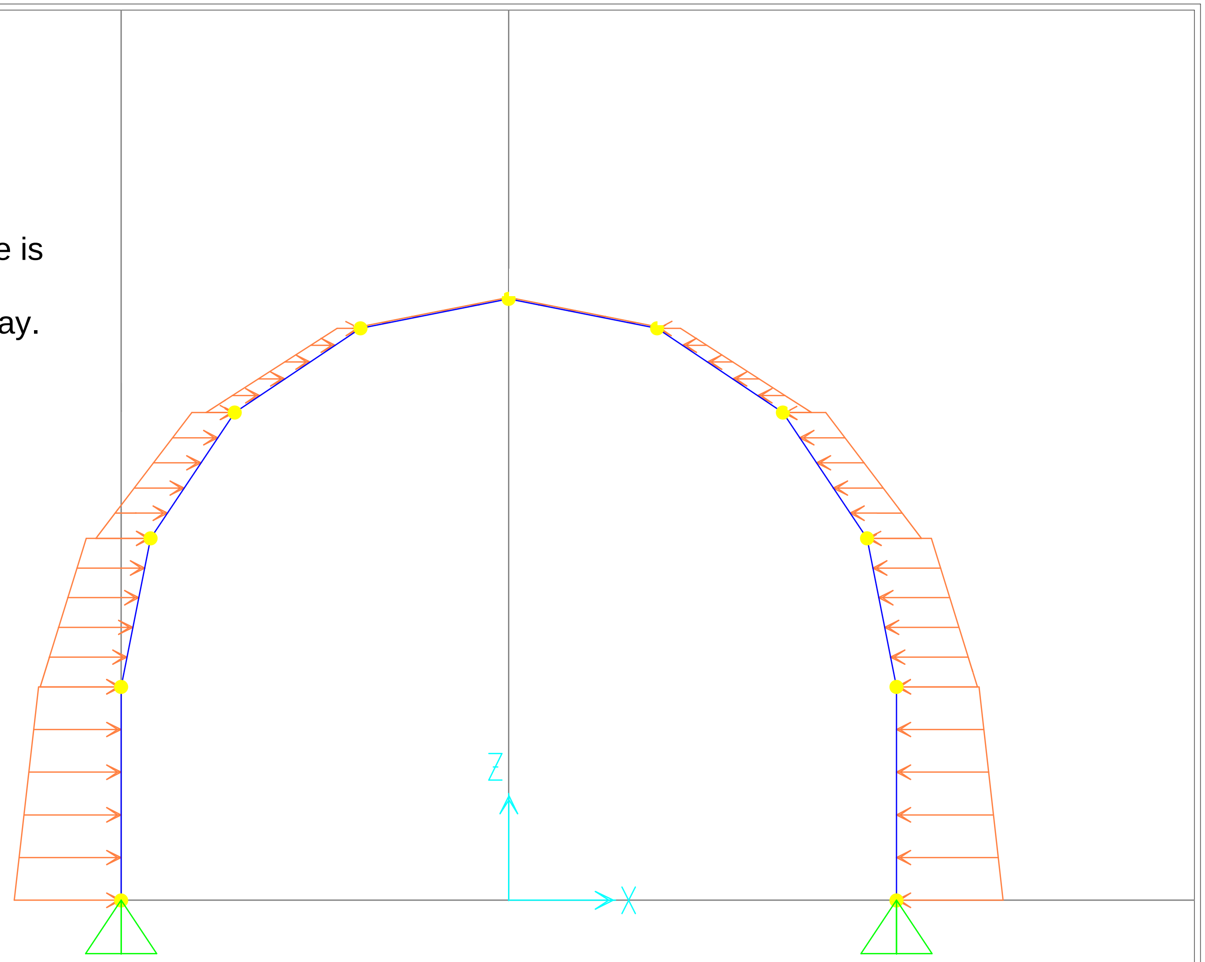
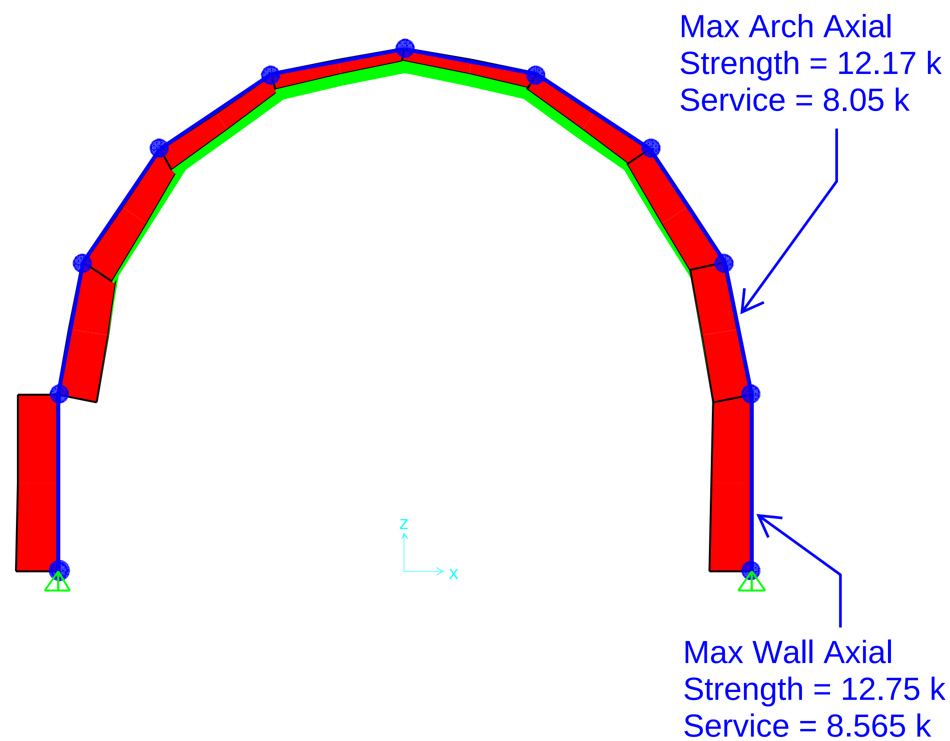
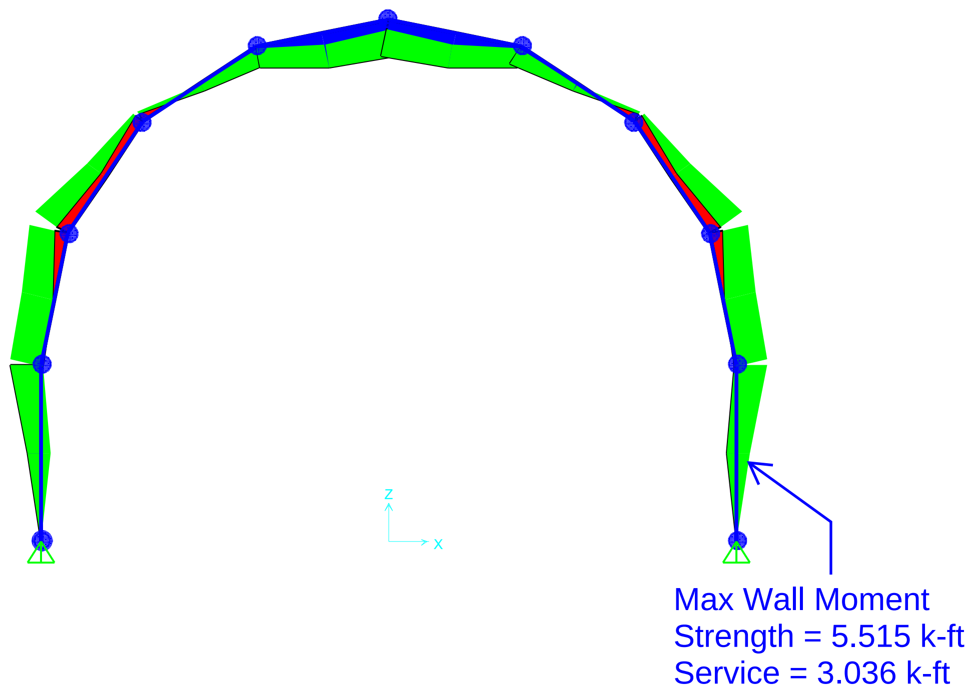
Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.



Section 3 - Frame Span Loads (EHMin) - Kip, ft, F Units


Max Arch Axial
Strength = 12.17 k
Service = 8.05 k
Z
X
Max Wall Axial
Strength = 12.75 k
Service = 8.565 k


Z
X
Max Wall Moment
Strength = 5.515 k-ft
Service = 3.036 k-ft

SECTION 3 ARCH CULVERT FLEXURE CHECK

Geometry

h =	22.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	11.00	in	(Distance from extreme comp. fiber to center)
I_y =	10648	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	2.980	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.41	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

M_n = $Min[\,5 * \lambda * \sqrt{f'c} * S_m;\;\; 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

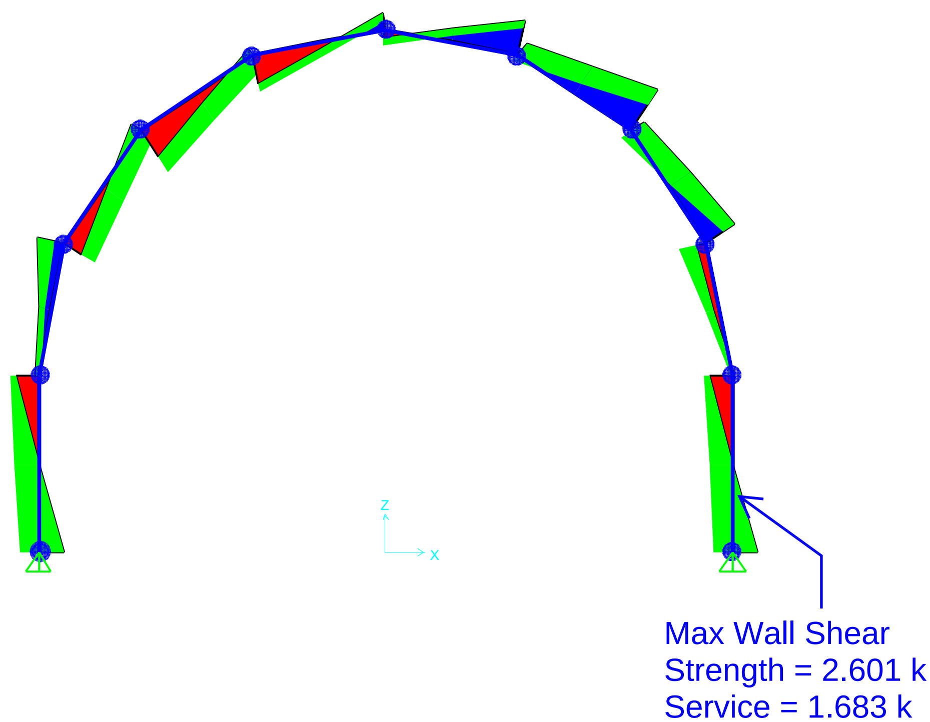
M_n = 22.02 k-ft

Φ = 0.6 (ACI 21.2.1)

ΦM_n = 13.21 k-ft > 5.52 k-ft = Critical Moment from SAP Model **OK**

D/C = 0.42

Flexural capacity is sufficient.


Z
X
Max Wall Shear
Strength = 2.601 k
Service = 1.683 k

SECTION 3 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h = 22.00 in (Height of section)
b_w = 12.00 in (Width of section)
c.c. = N/A in (Clear cover)
A_c = 264.00 in^2 (Area of concrete section)

Materials

f'_c = 2.980 ksi (Concrete compressive strength)
f_y = N/A ksi (Steel tensile strength)
E_c = 3142 ksi (Young's Modulus of Concrete) (AASHTO C5.4.2.4-3)
E_s = N/A ksi (Young's Modulus of Steel)
f_r = 0.41 ksi (Modulus of Rupture) (AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar = #5
n = 0.00 bars /FT
A_s = #N/A in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 2.60 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)

Concrete Shear Capacity

$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$ 19.22 k (ACI 14.5.5.1)

$\phi V_n = V_c > V_U$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 11.53 k > $V_u = V_{crit}$ = 2.60 k **OK** D/C = 0.23

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required

STRAWBERRY CREEK CULVERT
STRUCTURAL ASSESSMENT
BERKELEY, CA

SECTION 4

CSEG

Crown Pressure
Strawberry Creek Culvert Section 4

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	1.263333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 0.176867 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 1.9 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.55 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20
Traffic Driving Parallel to Culvert Span
Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 8.49 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	72	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 4

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 3.82 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 17.82 ft
Per AASHTO 3.6.1.2.6b-6

lw = 3.82 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 5.02 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 11.02 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 5.02 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 1 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - $\boldsymbol{P_L}$

Wheel Load = 16 kips
w_{Lane} = 0.64 klf — Per AASHTO 3.6.1.2.4
Lane Width = 10 ft — Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 1.9 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) — Per AASHTO 3.6.2.2
IM = 1.25 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	3.82	5.02	16	1.315
2	1	3.82	15.02	32	0.761
3	0.85	3.82	25.02	48	0.597
4	0.65	3.82	35.02	64	0.452

Crown Pressure
Strawberry Creek Culvert Section 4

Tire Distribution - Tandem

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft — Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 2.04 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 72 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 3.82 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 7.82 ft
Per AASHTO 3.6.1.2.6b-6

lw = 3.82 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 5.02 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 11.02 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 5.02 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 1 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 4

Determine the Crown Pressure - $\boldsymbol{P_L}$

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 1.9 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.25 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7)

$$A_{LL} = L_w * W_w$$

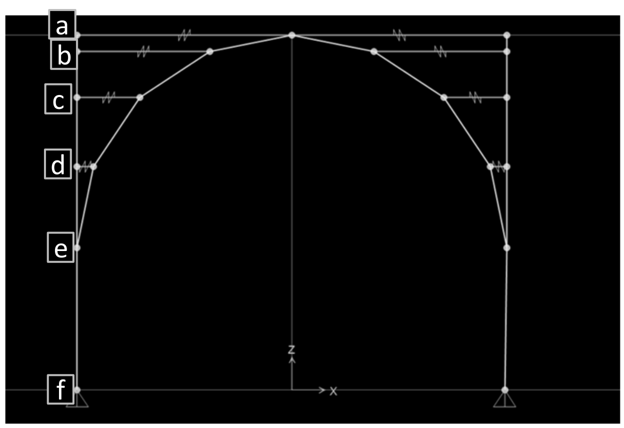
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	3.82	5.02	12.5	1.041
2	1	3.82	15.02	25	0.608
3	0.85	3.82	25.02	37.5	0.481
4	0.65	3.82	35.02	50	0.367

Max pressure is from HL-93 truck = 1.315 ksf

Crown Pressure
Strawberry Creek Culvert Section 4

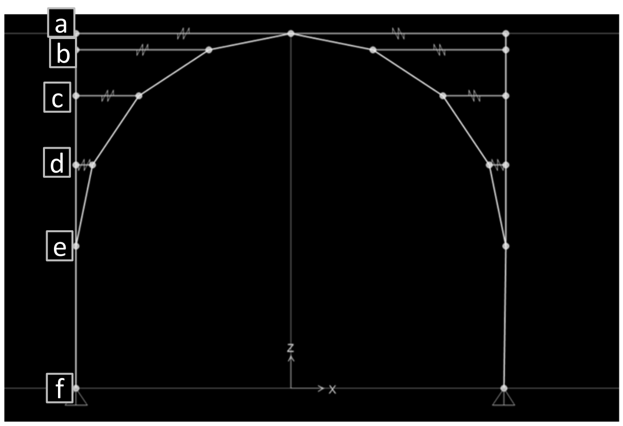
5.) Horizontal Earth Pressure - EH Minimum

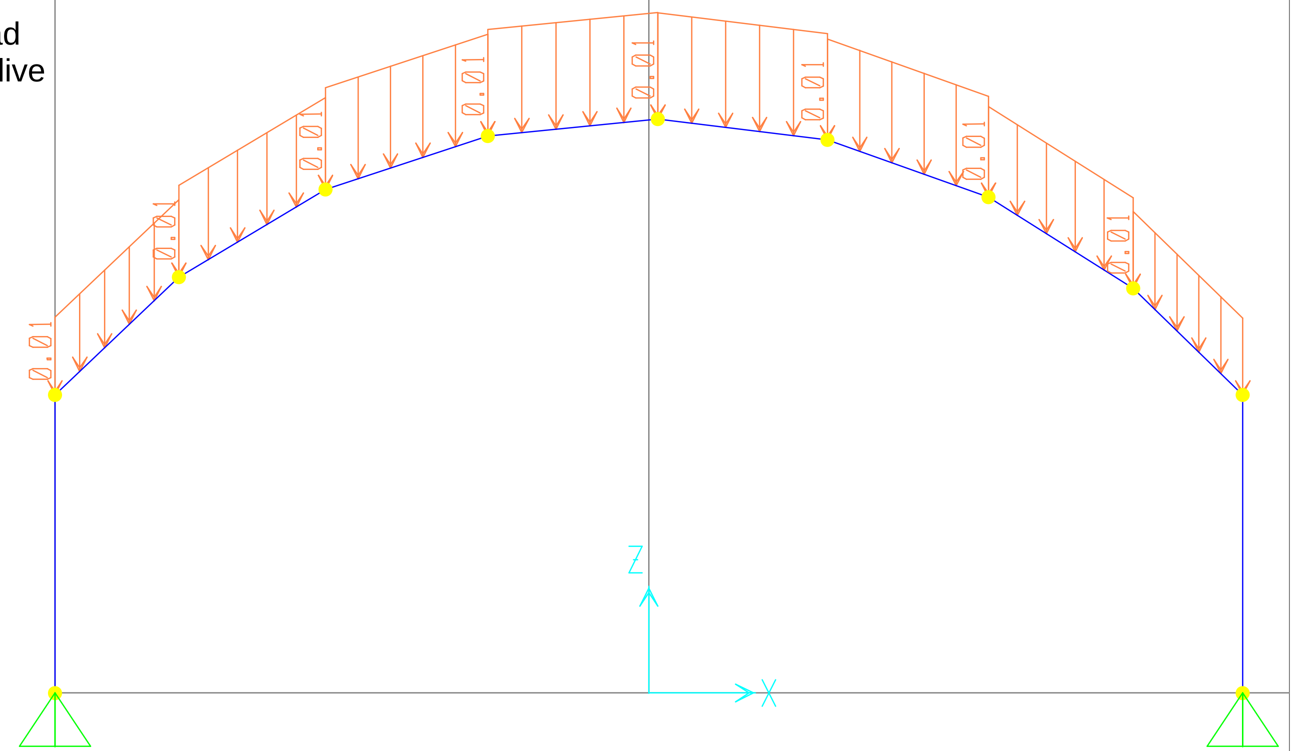
Depth =	1.263333	ft	(Soil Above a)
a =	5.034	ft	(Top of Culvert Arch Height, Height at a)
b =	4.869	ft	(Height at b)
c =	4.383	ft	(Height at c)
d =	3.599	ft	(Height at d)
e =	2.615	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	45.5	plf	(Trap. EH Value at a)
EH_b =	51.4	plf	(Trap. EH Value at b)
EH_c =	68.9	plf	(Trap. EH Value at c)
EH_d =	97.1	plf	(Trap. EH Value at d)
EH_e =	132.6	plf	(Trap. EH Value at e)
EH_f =	226.7	plf	(Trap. EH Value at f)



6.) Horizontal Earth Pressure - EH Maximum

Depth =	1.263333	ft	(Soil Above a)
a =	5.034	ft	(Top of Culvert Arch Height, Height at a)
b =	4.869	ft	(Height at b)
c =	4.383	ft	(Height at c)
d =	3.599	ft	(Height at d)
e =	2.615	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	151.6	plf	(Trap. EH Value at a)
EH_b =	171.4	plf	(Trap. EH Value at b)
EH_c =	229.7	plf	(Trap. EH Value at c)
EH_d =	323.8	plf	(Trap. EH Value at d)
EH_e =	441.9	plf	(Trap. EH Value at e)
EH_f =	755.7	plf	(Trap. EH Value at f)



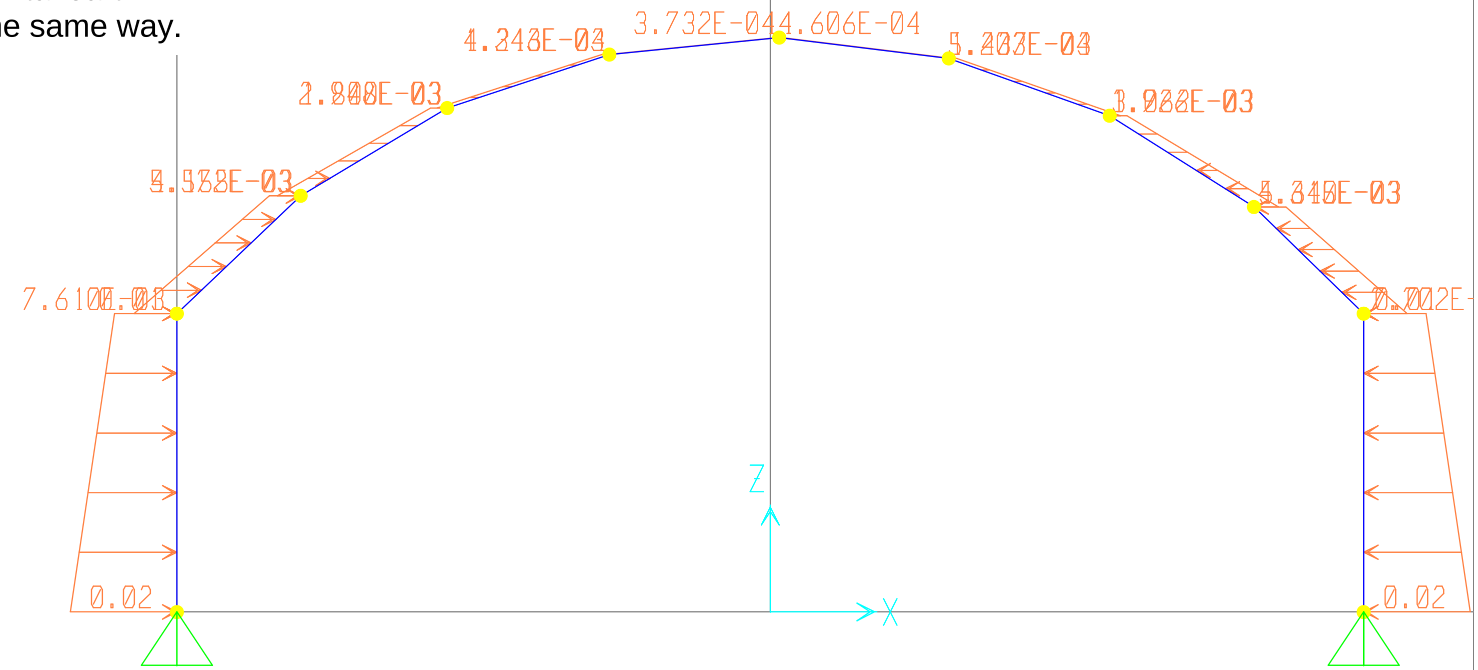


Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.

Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.



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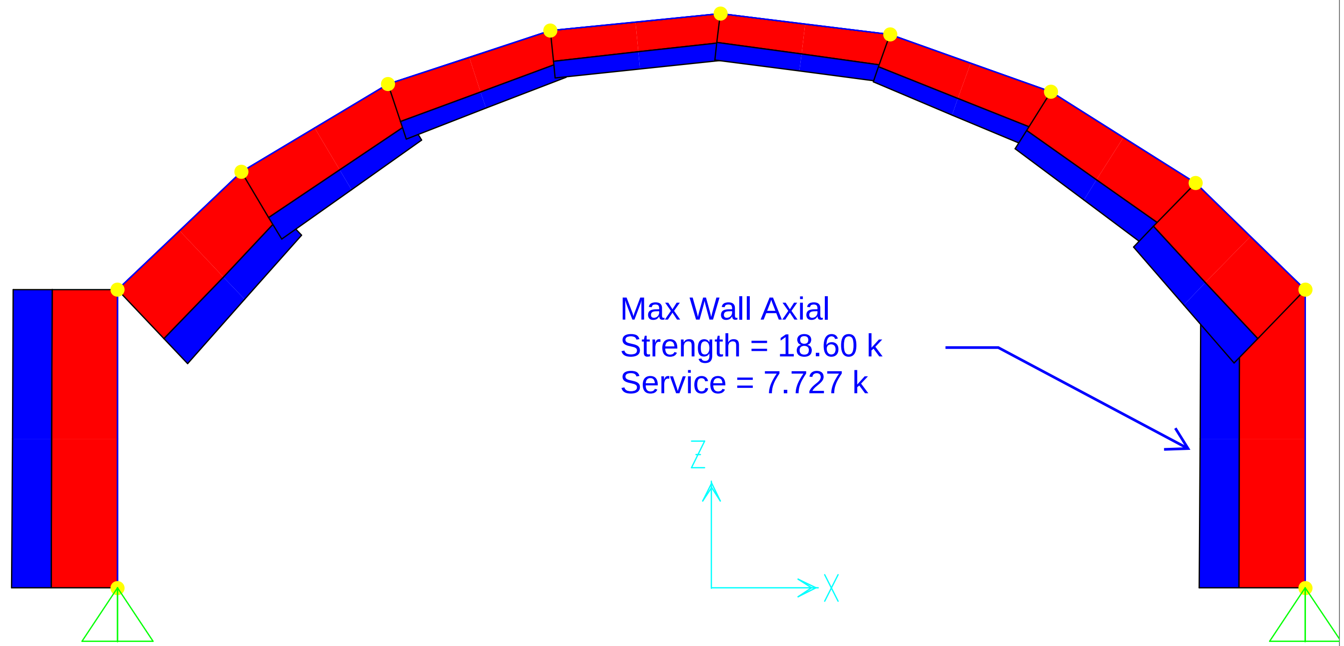

SAP2000 v8.3.0 - File:Section 4 - Wide Round Top, Flat Bottom (STA 8+60) - Axial Force Diagram (Strength) - Kip, ft, F Units

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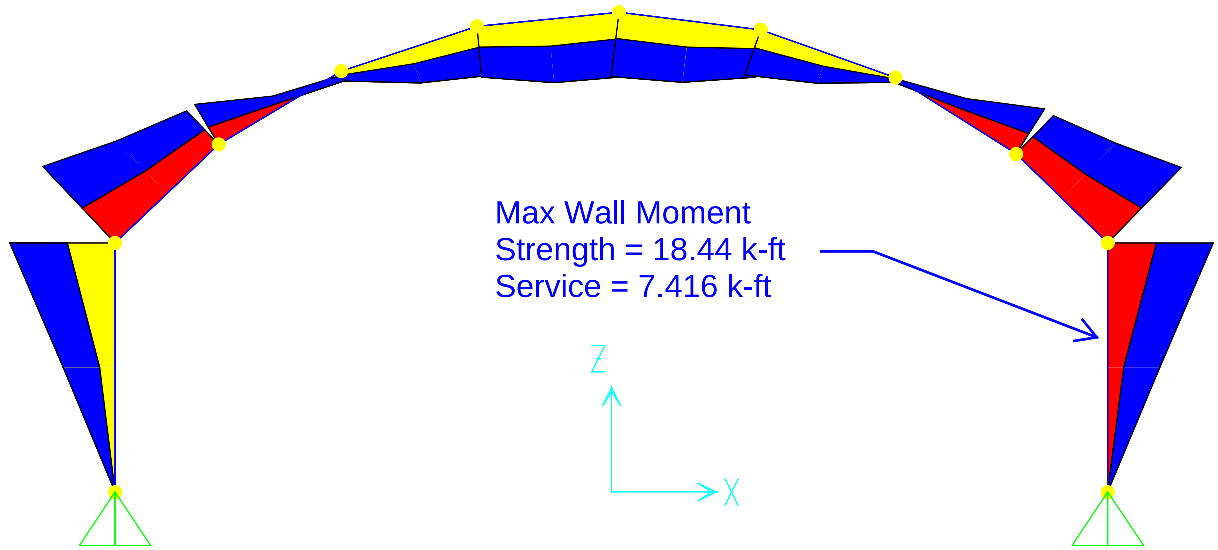

SAP2000 v8.3.0 - File:Section 4 - Wide Round Top, Flat Bottom (STA 8+60) - Moment 3-3 Diagram (Strength) - Kip, ft, F Units

SECTION 4 CULVERT - FLEXURE DESIGN

Input:

M_u=	18.4	k-ft
f'c=	4000	psi
fy=	40000	psi
φ =	0.9	
b_1=	0.85	
h=	10	in.
b=	12	in.

No. of Bars = 0.7 Bars

Area of Main Bar = #5 0.306 in^2

d = h / 2 = 5.00 in.

$$S_c = \frac{bh^2}{6} = 200\ in^3$$

$$f_r = 0.24\sqrt{f'_c} = 480\ psi$$

$M_{u(min)}$= 9.6 K-FT

$$M_{CR} = \gamma_3\left[(\gamma_1 f_r + \gamma_2 f_{cpe})S_c - M_{dnc}\left(\frac{S_c}{S_{nc}} - 1\right)\right]$$ [AASHTO 5.6.3.3-1]

γ_1 =	1.6	
γ_2 =	1	
γ_3 =	0.75	
f_r =	480	psi
f_{cpe} =	0	psi
S_c =	200	in^3
S_{nc} =	200	in^3
M_{dnc}	0	k-ft
M_{CR} =	9.6	k-ft

Design Ultimate Moment; M_u= 18.4 K-FT (Minimum of 1.33M_u or M_{CR})

$$a = \frac{A_s f_y}{0.85 f'_c b} = 0.20\ in.$$

$$c = \frac{a}{b_1} = 0.235\ in.$$

ε = 0.061 in/in. *Therefore tension controlled*

$A_{s,provided}$ = 0.204 in^2 $\phi M_n = \phi A_s f_y\left(d - \frac{a}{2}\right)$ = 3.0 k-ft > M_u= 18.4 k-ft

#5 at 8" Spacing is Inadequate D/C: 6.15 **NG**

Note:

The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

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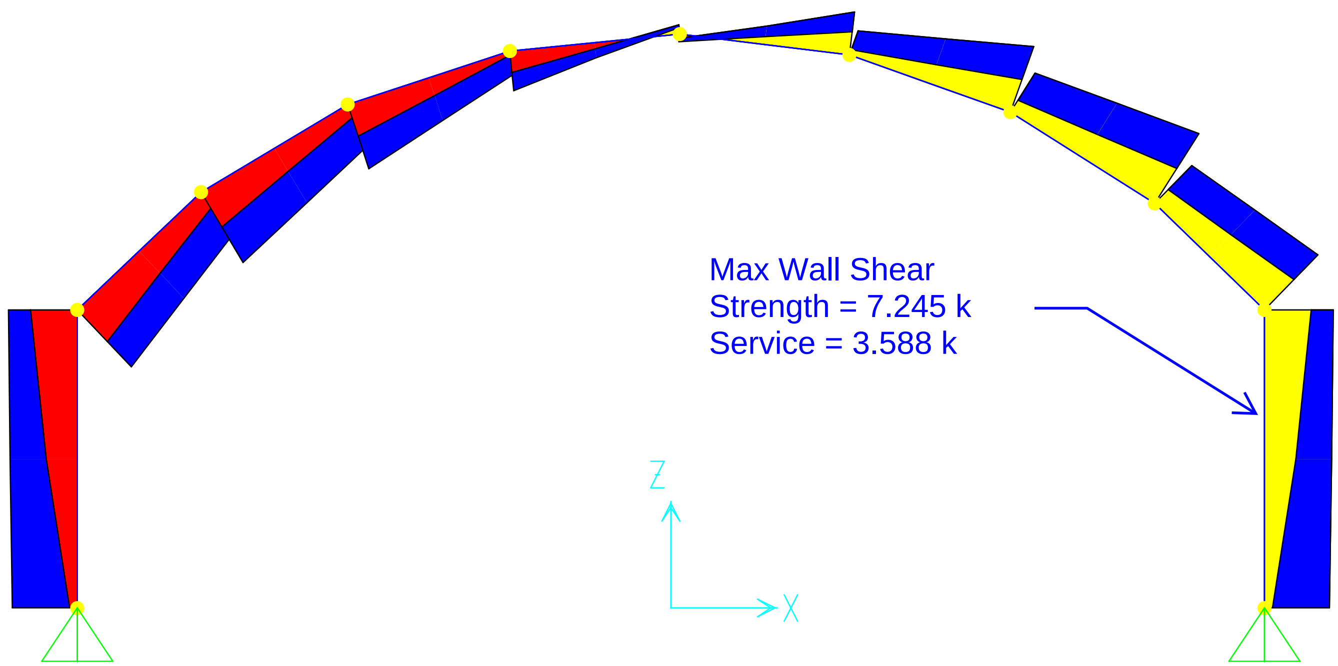


SAP2000 v8.3.0 - File:Section 4 - Wide Round Top, Flat Bottom (STA 8+60) - Shear Force 2-2 Diagram (Strength) - Kip, ft, F Units

SECTION 4 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the Simplified Procedure for Nonprestressed Sections per AASHTO 5.7.3.4.1.

Geometry

h =	5.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	60.00	in^2	(Area of concrete section)

Materials

f'_c =	4.000	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	3640	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.48	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)
B_1 =	0.85		(Stress Block Factor)	(AASHTO 5.6.2.2)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	0.00	in^2 / FT

Loading

Φ = 0.90 (AASHTO 5.5.4.2)

Forces at Critical Section

V_{crit} = 7.25 k/ft (shear) (Values per SAP Model)

Determine Effective Area of Concrete:

Assume the d_v is 0.72h according to the AASHTO LRFD 5.7.2.8.

d_v = 3.6 in

Simplified Procedure for Nonprestressed Sections

Since the member in question is described by the requirements set forth in AASHTO LRFD Section 5.7.3.4.1, simplified method can be used to determine the values of β and θ as opposed to using Appendix B5

Therefore:

β = 2.0
θ = 45 °

Concrete Shear Capacity

$V_c = 0.0316\beta\sqrt{f'_c}\,b_w d_v =$ 5.46 k (AASHTO LRFD 5.7.3.3-3)

$0.5\phi V_n = 0.5\phi V_c > V_U$ (AASHTO LRFD 5.7.2.3-1)

0.5ϕVn = 0.5ϕVc = 2.46 k < $V_u = V_{crit}$ = 7.25 k **NG** D/C = 2.95

Concrete shear capacity is not adequate for shear demand at critical section of concrete. Transverse reinforcement required

Note:

The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT
BERKELEY, CA

SECTION 5

Crown Pressure
Strawberry Creek Culvert Section 5

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	3.223333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 0.451267 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 3.9 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.55 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{S_a - \frac{l_t}{12}}{LLDF}$ = 8.49 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	72	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{S_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 5

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 6.86 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 20.86 ft
Per AASHTO 3.6.1.2.6b-6

lw = 6.86 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 8.06 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 14.06 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 14.06 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 2 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - P_L

Wheel Load = 16 kips
w_{Lane} = 0.64 klf — Per AASHTO 3.6.1.2.4
Lane Width = 10 ft — Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 3.9 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) — Per AASHTO 3.6.2.2
IM = 1.17 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b–7) $$A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	6.86	14.06	32	0.530
2	1	6.86	24.06	64	0.517
3	0.85	6.86	34.06	96	0.472
4	0.65	6.86	44.06	128	0.386

Crown Pressure
Strawberry Creek Culvert Section 5

Tire Distribution - Tandem

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 2.04 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 72 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 6.86 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 10.86 ft
Per AASHTO 3.6.1.2.6b-6

lw = 10.86 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 8.06 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 14.06 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 14.06 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 5

Determine the Crown Pressure - P_L

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 3.9 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.17 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	10.86	14.06	50	0.524
2	1	10.86	24.06	100	0.512
3	0.85	10.86	34.06	150	0.467
4	0.65	10.86	44.06	200	0.382

Max pressure is from HL-93 truck = 0.530 ksf

Strawberry Creek Culvert
Section 5 -RCP Analysis

Reinforced Concrete Pipe Structural Analysis:

Determine Pipe Structural Demands:

**Assume Type 4 Installation

Moment:	Mi = Cmi * Wi * Dm / 2	(Nebraska Department of Roads)
Thrust:	Ni = Cni * Wi	(Nebraska Department of Roads)
Shear:	Vi = Cvi * Wi	(Nebraska Department of Roads)

Crown Pressures

Pipe Diameter = Dm =	84	in	
Unfactored DC Crown Pressure =	0.093	ksf	(Per Crown Pressure Calculations)
Unfactored EV Crown Pressure =	0.45	ksf	(Per Crown Pressure Calculations)
Unfactored DW Crown Pressure =	0.035	ksf	(Per Crown Pressure Calculations)
Unfactored LL Crown Pressure =	0.53	ksf	(Per Crown Pressure Calculations)

Invert Demands:

DC:	Cmi =	0.235		Cni =	0.077	(Nebraska Department of Roads)
	M_{DC} =	0.076493	k-ft/ft	N_{DC} =	0.007161	kip/ft
EV:	Cmi =	0.191		Cni =	0.128	(Nebraska Department of Roads)
	M_{EV} =	0.300825	k-ft/ft	N_{EV} =	0.0576	kip/ft
DW:	Cmi =	0.235		Cni =	0.077	(Nebraska Department of Roads)
	M_{DW} =	0.028788	k-ft/ft	N_{DW} =	0.002695	kip/ft
LL:	Cmi =	0.237		Cni =	0.152	(Nebraska Department of Roads)
	M_{LL} =	0.439635	k-ft/ft	N_{LL} =	0.08056	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Mu =	1.359396	k-ft/ft	Nu =	0.240374	k/ft
$M_{Service}$ =	0.84574	k-ft/ft	$N_{Service}$ =	0.148016	k/ft

Crown Demands:

DC:	Cmi =	0.079		Cni =	-0.077	(Nebraska Department of Roads)
	M_{DC} =	0.025715	k-ft/ft	N_{DC} =	-0.00716	kip/ft
EV:	Cmi =	0.118		Cni =	0.079	(Nebraska Department of Roads)
	M_{EV} =	0.18585	k-ft/ft	N_{EV} =	0.03555	kip/ft
DW:	Cmi =	0.079		Cni =	-0.077	(Nebraska Department of Roads)
	M_{DW} =	0.009678	k-ft/ft	N_{DW} =	-0.0027	kip/ft
LL:	Cmi =	0.255		Cni =	0.114	(Nebraska Department of Roads)
	M_{LL} =	0.473025	k-ft/ft	N_{LL} =	0.06042	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Mu =	1.15	k-ft/ft	Nu =	0.15	k/ft
$M_{Service}$ =	0.69	k-ft/ft	$N_{Service}$ =	0.09	k/ft

Reinforced Concrete Pipe Structural Analysis:
Determine Pipe Structural Demands:

Springline Demands:

DC:	Cmi =	-0.101		Cni =	0.287	(Nebraska Department of Roads)
	M_{DC} =	-0.033	k-ft/ft	N_{DC} =	0.027	kip/ft
EV:	Cmi =	-0.127		Cni =	0.504	(Nebraska Department of Roads)
	M_{EV} =	-0.200	k-ft/ft	N_{EV} =	0.227	kip/ft
DW:	Cmi =	-0.101		Cni =	0.287	(Nebraska Department of Roads)
	M_{DW} =	-0.012	k-ft/ft	N_{DW} =	0.010	kip/ft
LL:	Cmi =	-0.168		Cni =	0.495	(Nebraska Department of Roads)
	M_{LL} =	-0.312	k-ft/ft	N_{LL} =	0.262	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Mu =	-0.91	k-ft/ft	Nu =	0.85	k/ft
$M_{Service}$ =	-0.56	k-ft/ft	$N_{Service}$ =	0.53	k/ft

Critical Shear Invert Demands:

DC:	Cni =	0.188		Cvi =	0.431	(Nebraska Department of Roads)
	N_{DC} =	0.061	k-ft/ft	V_{DC} =	0.040	kip/ft
EV:	Cni =	0.211		Cvi =	0.309	(Nebraska Department of Roads)
	N_{EV} =	0.332	k-ft/ft	V_{EV} =	0.139	kip/ft
DW:	Cni =	0.188		Cvi =	0.431	(Nebraska Department of Roads)
	N_{DW} =	0.023	k-ft/ft	V_{DW} =	0.015	kip/ft
LL:	Cni =	0.229		Cvi =	0.305	(Nebraska Department of Roads)
	N_{LL} =	0.425	k-ft/ft	V_{LL} =	0.162	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Nu =	1.35	k/ft	Vu =	0.56	k/ft
$N_{Service}$ =	0.84	k/ft	$V_{Service}$ =	0.36	k/ft

Reinforced Concrete Pipe Structural Analysis:

Determine Flexural Resistance - Circumferential Reinforcement

As Required = $A_s \geq \frac{g\phi d - N_u - \sqrt{g\left[g(\phi d)^2 - N_u(2\phi d - h) - 2M_u\right]}}{f_y}$ (AASHTO LRFD 12.10.4.2.4a-1)

g = 0.85 * b * f'c =	29.48	k/in	(AASHTO LRFD 12.10.4.2.4a-2)
b =	12	in	
f'c =	2.89	ksi	
Nu =	1.35	k/ft	
Mu =	16.31	k-in/ft	
d =	4.5	in	
h =	9	in	
fy =	40	ksi	
As Provided =	0.53	in^2/ft	(#5 @ 7")
Phi =	0.9		

As Required = 0.065 in^2/ft < As Provided = 0.53 in^2/ft

Determine Minimum Inside Layer Reinforcement

$A_s \geq \frac{(S_i + h)^2}{1{,}000 f_y} \geq 0.07$ = 0.216 in^2/ft (AASHTO LRFD 12.10.4.2.4b-1)

Si =	84	in
h =	9	in
fy =	40	ksi
As Provided =	0.53	in^2/ft

As Required = 0.216 in^2/ft < As Provided = 0.53 in^2/ft

Determine Minimum Outside Layer Reinforcement

$A_s \geq 0.60\frac{(S_i + h)^2}{1{,}000 f_y} \geq 0.07$ = 0.130 in^2/ft (AASHTO LRFD 12.10.4.2.4b-1)

Si =	84	in
h =	9	in
fy =	40	ksi
As Provided =	0.531	in^2/ft

As Required = 0.130 in^2/ft < As Provided = 0.53 in^2/ft

Reinforced Concrete Pipe Structural Analysis:
Check Crack Width Control

If N_s is compressive, it is taken as positive and:

$$F_{cr} = \frac{B_1}{30\phi d A_s}\left[\frac{M_s + N_s\left(d - \frac{h}{2}\right)}{ij} - 0.0316 C_1 b h^2 \sqrt{f'_c}\right] = -2.50138$$ (AASHTO LRFD 12.10.4.2.4d-1)

If N_s is tensile, it is taken as negative and:

$$F_{cr} = \frac{B_1}{30 d A_s \phi}\left(1.1 M_s - 0.6 N_s d - 0.0316 C_1 b h^2 \sqrt{f'_c}\right) = 0$$ (AASHTO LRFD 12.10.4.2.4d-2)

$M_{Service}$ =	10.15	k-in/ft
$N_{Service}$ + =	0.84	k/ft
$N_{Service}$ - =	0.09	k/ft
d =	4.5	in
h =	9	in
f'c =	2.89	ksi
As Provided =	0.531	in^2/ft
Phi =	0.9	
C_1 =	1.9	

Compression:

$$e = \frac{M_s}{N_s} + d - \frac{h}{2} = 12.06 \text{ in}$$

$$j = 0.74 + 0.1\frac{e}{d} \leq 0.9 = 1.01$$

$$i = \frac{1}{\left(1 - \frac{jd}{e}\right)} = 1.60$$

$$B_1 = \left(\frac{t_b S_\ell}{2n}\right)^{\frac{1}{3}} = 1.74$$

t_b =	1.5	in
S_L =	7	in
n =	1	

Fcr = -2.50 < 1

Average cracking width NOT expected to exceed 0.01in.

Reinforced Concrete Pipe Structural Analysis:

Determine Shear Resistance without Stirrups

$$V_n = 0.0316bdF_{vp}\sqrt{f_c'}(1.1+63\rho)\left(\frac{F_dF_n}{F_c}\right) = \quad 5.53 \text{ k/ft}$$ (AASHTO LRFD 12.10.4.2.5-2)

Rho = As / (b*d) =	0.0098		(AASHTO LRFD 12.10.4.2.5-3)
b =	12	in	
d =	4.5	in	
As =	0.531	in^2/ft	
Fd = 0.8 + (1.6/d) =	1.16		(AASHTO LRFD 12.10.4.2.5-4)
If Nu is compressive, Fn = 1 + (Nu/24h) =	1.006		(AASHTO LRFD 12.10.4.2.5-6)
If Nu is tensile, Fn = 1 + (Nu/6h) =	1.025		(AASHTO LRFD 12.10.4.2.5-7)
Fn =	1.006		
Fc = 1 + (d/2r) =	1.05		(AASHTO LRFD 12.10.4.2.5-8)
Radius = r =	46.5	in	
Fvp =	1.0		(AASHTO LRFD 12.10.4.2.3)
Phi Vn =	4.98	k/ft	
Phi =	0.9		
Vu =	0.56	k/ft	
D/C =	**0.11**		

Determine Shear Resistance With Stirrups

Radial Tension

$$A_{vr} = \frac{1.1s_v(M_u - 0.45N_u\phi_r d)}{f_y r_s \phi_r d} = \quad 0.006142 \text{ in}^2\text{/ft}$$ (AASHTO LRFD 12.10.4.2.6-1)

Mu =	16.31	k-in/ft	
Nu =	1.35	k/ft	
d =	4.5	in	
fy =	40	ksi	
rs =	46.5	in	
Phir =	0.9		
sv provided =	7	in	
sv = min(0.75Phird ; sv Provided) =	3.04	in	
Av Provided =	0.53	in^2/ft	(#5 @ 6")

Av Required = 0.006 in^2/ft < Av Provided = 0.53 in^2/ft

Reinforced Concrete Pipe Structural Analysis:

Determine Shear Resistance With Stirrups

Shear Resistance

$$A_{vs} = \frac{1.1 s_v}{f_y \phi_v d}\left(V_u F_c - V_c\right) + A_{vr}$$ = -0.058794 in^2/ft (AASHTO LRFD 12.10.4.2.6-1)

Vu =	0.56	k/ft	
sv = min(0.75Phivd ; sv Provided) =	3.04	in	
d =	4.5	in	
Avr =	0.006	in^2/ft	
Fc =	1.05		
Phiv =	0.9		
Av Provided =	0.53	in^2/ft	(#5 @ 6")

$$V_c = \frac{4V_r}{\frac{M_{nu}}{V_u d} + 1} \le 0.0633 \phi_v b d \sqrt{f_c'}$$ = 3.74 k/ft (AASHTO LRFD 12.10.4.2.6-1)

$$M_{nu} = M_u - N_u\left[\frac{(4h-d)}{8}\right]$$ = 10.99 k-in/ft (AASHTO LRFD 12.10.4.2.5-9)

Vr = 4.98 k/ft

Av Required = -0.059 in^2/ft < Av Provided = 0.53 in^2/ft

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 6

CSEG

Crown Pressure
Strawberry Creek Culvert Section 6

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	2.763333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 0.386867 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 3.4 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.55 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 8.49 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	72	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 6

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 6.15 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 20.15 ft
Per AASHTO 3.6.1.2.6b-6

lw = 6.15 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 7.34 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 13.34 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 13.34 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 2 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - P_L

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 3.4 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.19 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b–7) $$A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	6.15	13.34	32	0.620
2	1	6.15	23.34	64	0.594
3	0.85	6.15	33.34	96	0.537
4	0.65	6.15	43.34	128	0.435

Crown Pressure
Strawberry Creek Culvert Section 6

Tire Distribution - Tandem
Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft — Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 2.04 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 72 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 6.15 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 10.15 ft
Per AASHTO 3.6.1.2.6b-6

lw = 10.15 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 7.34 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 13.34 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 13.34 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 6

Determine the Crown Pressure - $\boldsymbol{P_L}$

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 3.4 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.19 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

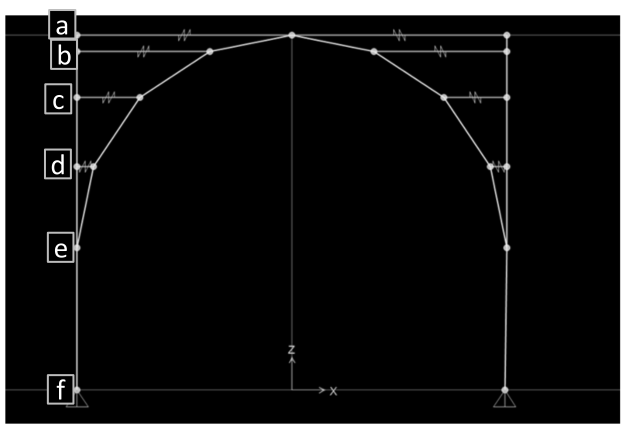
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	10.15	13.34	50	0.591
2	1	10.15	23.34	100	0.566
3	0.85	10.15	33.34	150	0.512
4	0.65	10.15	43.34	200	0.415

Max pressure is from HL-93 truck = 0.620 ksf

Crown Pressure
Strawberry Creek Culvert Section 6

5.) Horizontal Earth Pressure - EH Minimum

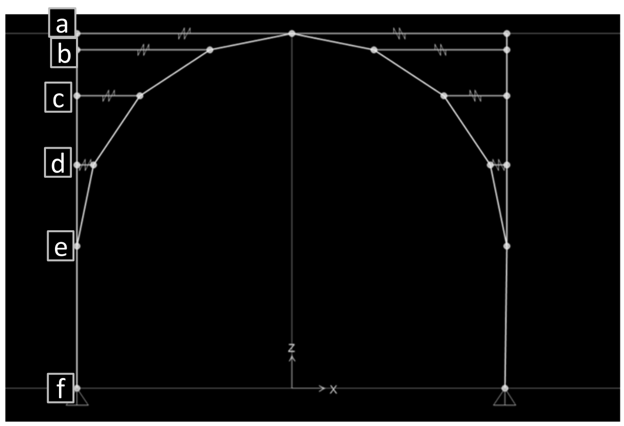
Depth =	2.763333	ft	(Soil Above a)
a =	6.792	ft	(Top of Culvert Arch Height, Height at a)
b =	6.547	ft	(Height at b)
c =	5.852	ft	(Height at c)
d =	4.811	ft	(Height at d)
e =	3.583	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	99.5	plf	(Trap. EH Value at a)
EH_b =	108.3	plf	(Trap. EH Value at b)
EH_c =	133.3	plf	(Trap. EH Value at c)
EH_d =	170.8	plf	(Trap. EH Value at d)
EH_e =	215.0	plf	(Trap. EH Value at e)
EH_f =	344.0	plf	(Trap. EH Value at f)

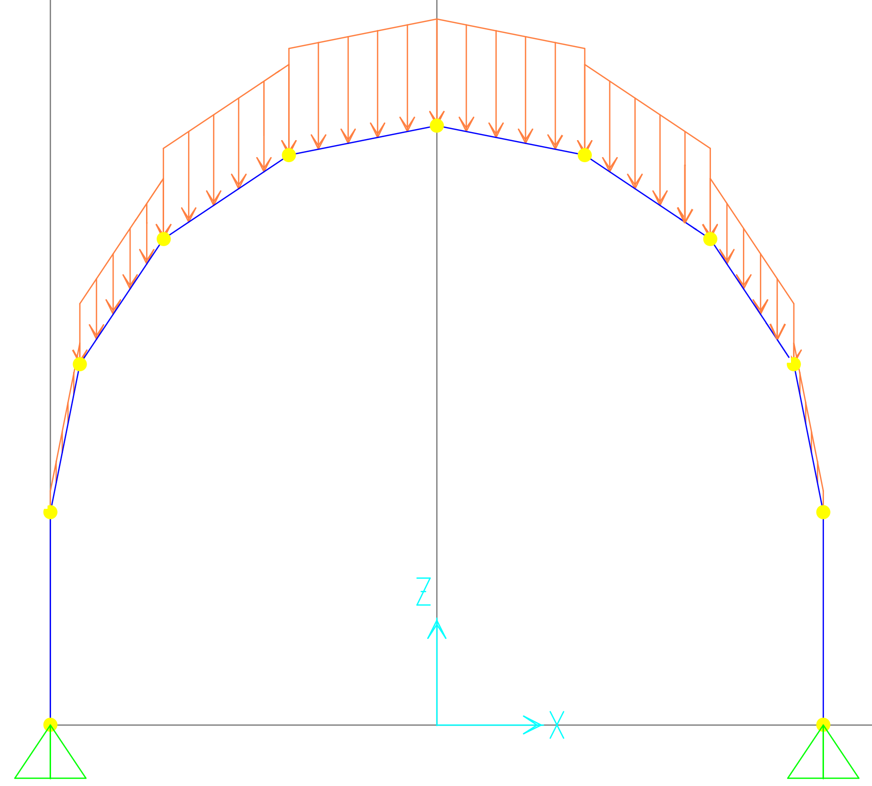


Crown Pressure
Strawberry Creek Culvert Section 6

6.) Horizontal Earth Pressure - EH Maximum

Depth =	2.763333	ft	(Soil Above a)
a =	6.792	ft	(Top of Culvert Arch Height, Height at a)
b =	6.547	ft	(Height at b)
c =	5.852	ft	(Height at c)
d =	4.811	ft	(Height at d)
e =	3.583	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	331.6	plf	(Trap. EH Value at a)
EH_b =	361.0	plf	(Trap. EH Value at b)
EH_c =	444.4	plf	(Trap. EH Value at c)
EH_d =	569.3	plf	(Trap. EH Value at d)
EH_e =	716.7	plf	(Trap. EH Value at e)
EH_f =	1146.6	plf	(Trap. EH Value at f)





Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.

Section 6 - Frame Span Loads (EV) - Kip, ft, F Units

SAP2000

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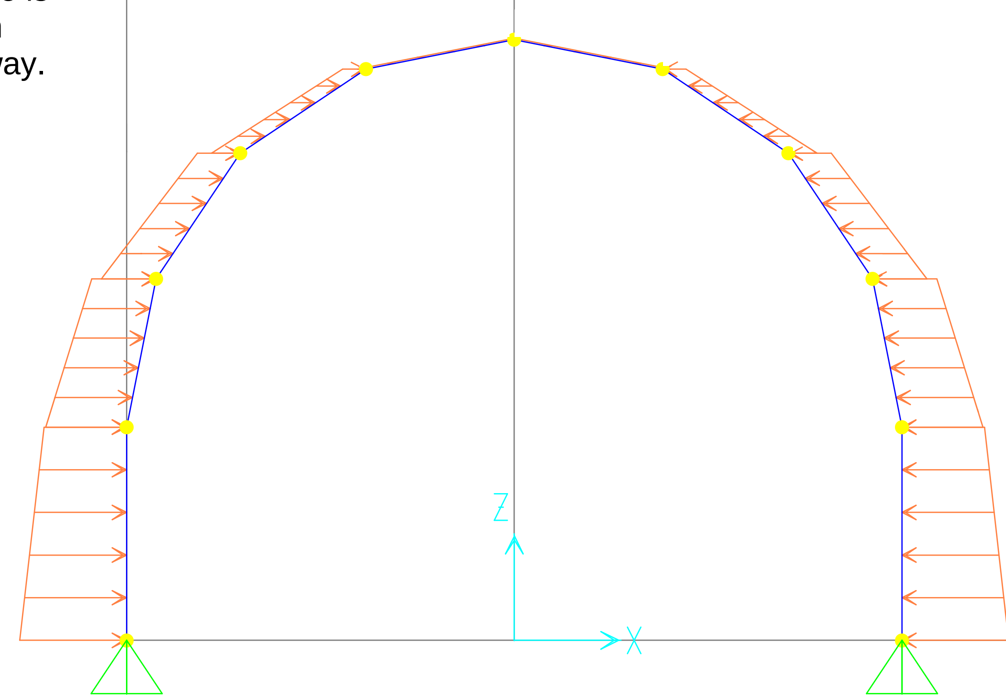
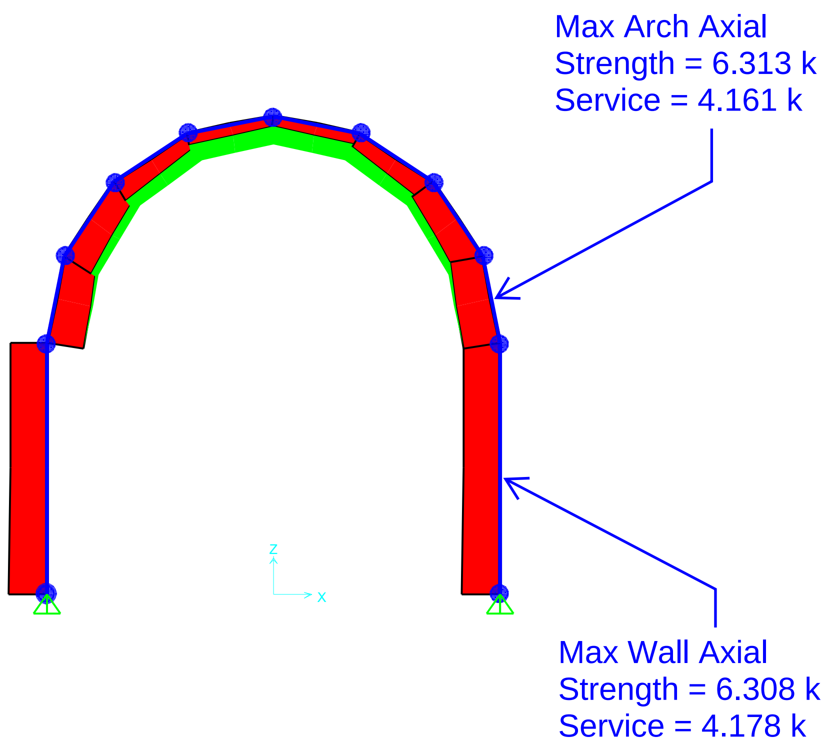
Horizontal Input

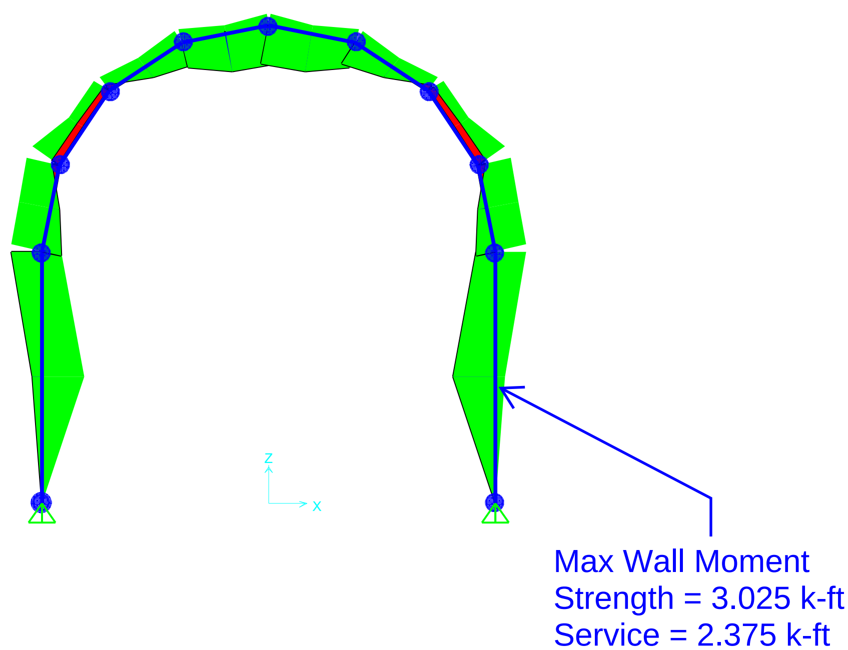
The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.



Section 6 - Frame Span Loads (EHMin) - Kip, ft, F Units



 Axial Force Diagram (Strength Envelope - Max/Min) lb, ft, F



z
x
Max Wall Moment
Strength = 3.025 k-ft
Service = 2.375 k-ft

BY HAK DATE 10/4/2023 Strawberry Creek Culvert SHEET NO __________ OF __________
Structural Calculations
CHKD BY __________ DATE ______________ JOB NO. 2023025

SECTION 6 ARCH CULVERT FLEXURE CHECK

Geometry

h =	5.00 in	(Height of section)
b_w =	12.00 in	(Width of section)
y =	2.50 in	(Distance from extreme comp. fiber to center)
I_y =	125 in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	1.740 ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0 ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.32 ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

M_n = $Min[\,5 * \lambda * \sqrt{f'c} * S_m;\;\; 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 0.87 k-ft

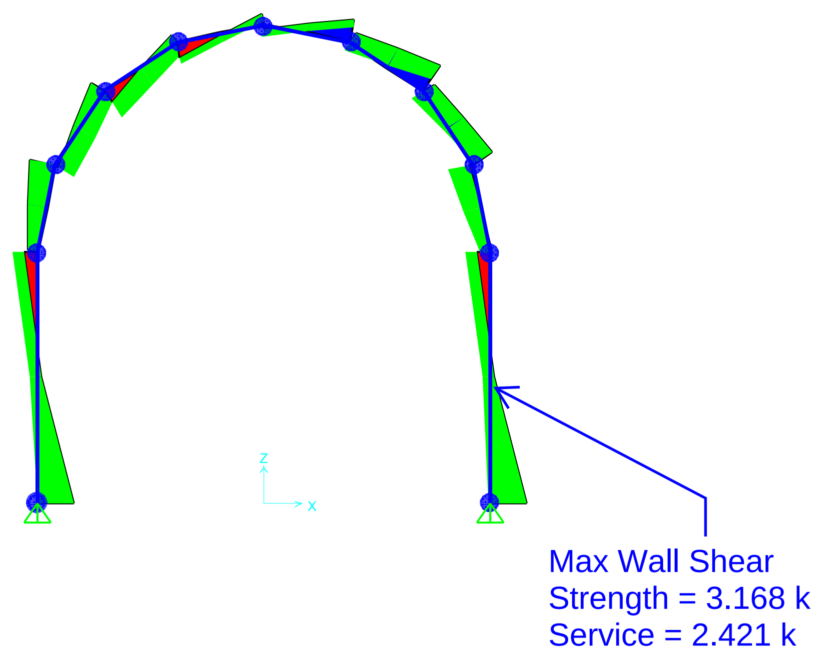
Φ = 0.6 (ACI 21.2.1)

ΦM_n = 0.52 k-ft < 3.03 k-ft = Critical Moment from SAP Model **NG**

D/C = 5.80

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.



Shear Force 2-2 Diagram (Strength Envelope - Max/Min)
lb, ft, F

SECTION 6 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h =	5.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	60.00	in^2	(Area of concrete section)

Materials

f'_c =	1.740	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	2401	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.32	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 3.17 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)
Concrete Shear Capacity

$$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$$ 3.34 k (ACI 14.5.5.1)

$$\phi V_n = V_c > V_U$$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 2.00 k < $V_u = V_{crit}$ = 3.17 k **NG** D/C = 1.58

Concrete shear capacity is not adequate for shear demand at critical section of concrete. Transverse reinforcement required.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 7

Crown Pressure
Strawberry Creek Culvert Section 7

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	6.933333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 0.970667 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 7.6 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.55 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) =
Per AASHTO 3.6.1.2.6b-4

$$H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF} = 8.49 \text{ ft}$$

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	72	in

Wheel Interaction Depth Transverse to Culvert (H int-t) =
Per AASHTO 3.6.1.2.6b-1

$$H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF} = 2.56 \text{ ft}$$

Crown Pressure
Strawberry Creek Culvert Section 7

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 12.61 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 26.61 ft
Per AASHTO 3.6.1.2.6b-6

lw = 12.61 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 13.81 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 19.81 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 19.81 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 2 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - $\boldsymbol{P_L}$

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 7.6 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.02 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$P_L = \frac{P(1 + \frac{IM}{100})(m)}{A_{LL}} + \# Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$ (AASHTO 3.6.1.2.6b−7) $A_{LL} = L_w * W_w$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	12.61	19.81	32	0.220
2	1	12.61	29.81	64	0.237
3	0.85	12.61	39.81	96	0.229
4	0.65	12.61	49.81	128	0.199

Crown Pressure
Strawberry Creek Culvert Section 7

Tire Distribution - Tandem

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft — Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 2.04 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 72 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 12.61 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 16.61 ft
Per AASHTO 3.6.1.2.6b-6

lw = 16.61 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 13.81 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 19.81 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 19.81 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 7

Determine the Crown Pressure - P_L

Wheel Load = 12.5 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 7.6 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.02 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	16.61	19.81	50	0.249
2	1	16.61	29.81	100	0.269
3	0.85	16.61	39.81	150	0.260
4	0.65	16.61	49.81	200	0.224

Max pressure is from tandem truck = 0.269 ksf

Strawberry Creek Culvert
Section 7 -RCP Analysis

Reinforced Concrete Pipe Structural Analysis:
Determine Pipe Structural Demands:

**Assume Type 4 Installation

Moment:	Mi = Cmi * Wi * Dm / 2	(Nebraska Department of Roads)
Thrust:	Ni = Cni * Wi	(Nebraska Department of Roads)
Shear:	Vi = Cvi * Wi	(Nebraska Department of Roads)

Crown Pressures

Pipe Diameter = Dm =	78	in	
Unfactored DC Crown Pressure =	0.093	ksf	(Per Crown Pressure Calculations)
Unfactored EV Crown Pressure =	0.971	ksf	(Per Crown Pressure Calculations)
Unfactored DW Crown Pressure =	0.035	ksf	(Per Crown Pressure Calculations)
Unfactored LL Crown Pressure =	0.269	ksf	(Per Crown Pressure Calculations)

Invert Demands:

DC:	Cmi =	0.235		Cni =	0.077	(Nebraska Department of Roads)
	M_{DC} =	0.071029	k-ft/ft	N_{DC} =	0.007161	kip/ft
EV:	Cmi =	0.191		Cni =	0.128	(Nebraska Department of Roads)
	M_{EV} =	0.602748	k-ft/ft	N_{EV} =	0.124288	kip/ft
DW:	Cmi =	0.235		Cni =	0.077	(Nebraska Department of Roads)
	M_{DW} =	0.026731	k-ft/ft	N_{DW} =	0.002695	kip/ft
LL:	Cmi =	0.237		Cni =	0.152	(Nebraska Department of Roads)
	M_{LL} =	0.207197	k-ft/ft	N_{LL} =	0.040888	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Mu =	1.3956	k-ft/ft	Nu =	0.27098	k/ft
$M_{Service}$ =	0.907706	k-ft/ft	$N_{Service}$ =	0.175032	k/ft

Crown Demands:

DC:	Cmi =	0.079		Cni =	-0.077	(Nebraska Department of Roads)
	M_{DC} =	0.023878	k-ft/ft	N_{DC} =	-0.00716	kip/ft
EV:	Cmi =	0.118		Cni =	0.079	(Nebraska Department of Roads)
	M_{EV} =	0.372379	k-ft/ft	N_{EV} =	0.076709	kip/ft
DW:	Cmi =	0.079		Cni =	-0.077	(Nebraska Department of Roads)
	M_{DW} =	0.008986	k-ft/ft	N_{DW} =	-0.0027	kip/ft
LL:	Cmi =	0.255		Cni =	0.114	(Nebraska Department of Roads)
	M_{LL} =	0.222934	k-ft/ft	N_{LL} =	0.030666	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Mu =	0.99	k-ft/ft	Nu =	0.16	k/ft
$M_{Service}$ =	0.63	k-ft/ft	$N_{Service}$ =	0.10	k/ft

Reinforced Concrete Pipe Structural Analysis:
Determine Pipe Structural Demands:

Springline Demands:

DC:	Cmi =	-0.101		Cni =	0.287	(Nebraska Department of Roads)
	M_{DC} =	-0.031	k-ft/ft	N_{DC} =	0.027	kip/ft
EV:	Cmi =	-0.127		Cni =	0.504	(Nebraska Department of Roads)
	M_{EV} =	-0.401	k-ft/ft	N_{EV} =	0.489	kip/ft
DW:	Cmi =	-0.101		Cni =	0.287	(Nebraska Department of Roads)
	M_{DW} =	-0.011	k-ft/ft	N_{DW} =	0.010	kip/ft
LL:	Cmi =	-0.168		Cni =	0.495	(Nebraska Department of Roads)
	M_{LL} =	-0.147	k-ft/ft	N_{LL} =	0.133	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Mu =	-0.91	k-ft/ft	Nu =	1.02	k/ft
$M_{Service}$ =	-0.59	k-ft/ft	$N_{Service}$ =	0.66	k/ft

Critical Shear Invert Demands:

DC:	Cni =	0.188		Cvi =	0.431	(Nebraska Department of Roads)
	N_{DC} =	0.057	k-ft/ft	V_{DC} =	0.040	kip/ft
EV:	Cni =	0.211		Cvi =	0.309	(Nebraska Department of Roads)
	N_{EV} =	0.666	k-ft/ft	V_{EV} =	0.300	kip/ft
DW:	Cni =	0.188		Cvi =	0.431	(Nebraska Department of Roads)
	N_{DW} =	0.021	k-ft/ft	V_{DW} =	0.015	kip/ft
LL:	Cni =	0.229		Cvi =	0.305	(Nebraska Department of Roads)
	N_{LL} =	0.200	k-ft/ft	V_{LL} =	0.082	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Nu =	1.45	k/ft	Vu =	0.67	k/ft
$N_{Service}$ =	0.94	k/ft	$V_{Service}$ =	0.44	k/ft

Reinforced Concrete Pipe Structural Analysis:
Determine Flexural Resistance - Circumferential Reinforcement

As Required = $A_s \geq \frac{g\phi d - N_u - \sqrt{g\left[g(\phi d)^2 - N_u(2\phi d - h) - 2M_u\right]}}{f_y}$ (AASHTO LRFD 12.10.4.2.4a-1)

g = 0.85 * b * f'c =	40.80	k/in	(AASHTO LRFD 12.10.4.2.4a-2)
b =	12	in	
f'c =	4	ksi	
Nu =	1.45	k/ft	
Mu =	16.75	k-in/ft	
d =	3	in	
h =	6	in	
fy =	40	ksi	
As Provided =	0.12	in^2/ft	(#5 @ 30")
Phi =	0.9		

As Required = 0.119 in^2/ft < As Provided = 0.12 in^2/ft

Determine Minimum Inside Layer Reinforcement

$A_s \geq \frac{(S_i + h)^2}{1{,}000 f_y} \geq 0.07$ = 0.176 in^2/ft (AASHTO LRFD 12.10.4.2.4b-1)

Si =	78	in
h =	6	in
fy =	40	ksi
As Provided =	0.12	in^2/ft

As Required = 0.176 in^2/ft > As Provided = 0.12 in^2/ft

Determine Minimum Outside Layer Reinforcement

$A_s \geq 0.60\frac{(S_i + h)^2}{1{,}000 f_y} \geq 0.07$ = 0.106 in^2/ft (AASHTO LRFD 12.10.4.2.4b-1)

Si =	78	in
h =	6	in
fy =	40	ksi
As Provided =	0.124	in^2/ft

As Required = 0.106 in^2/ft < As Provided = 0.12 in^2/ft

Reinforced Concrete Pipe Structural Analysis:
Check Crack Width Control

If N_s is compressive, it is taken as positive and:

$$F_{cr} = \frac{B_1}{30\phi d A_s}\left[\frac{M_s + N_s\left(d - \frac{h}{2}\right)}{ij} - 0.0316 C_1 b h^2 \sqrt{f'_c}\right]$$ = -12.6542 (AASHTO LRFD 12.10.4.2.4d-1)

If N_s is tensile, it is taken as negative and:

$$F_{cr} = \frac{B_1}{30 d A_s \phi}\left(1.1 M_s - 0.6 N_s d - 0.0316 C_1 b h^2 \sqrt{f'_c}\right)$$ = 0 (AASHTO LRFD 12.10.4.2.4d-2)

$M_{Service}$ =	10.89	k-in/ft
$N_{Service}$ + =	0.94	k/ft
$N_{Service}$ - =	0.10	k/ft
d =	3	in
h =	6	in
f'c =	4	ksi
As Provided =	0.124	in^2/ft
Phi =	0.9	
C_1 =	1.9	

Compression:

$$e = \frac{M_s}{N_s} + d - \frac{h}{2}$$ = 11.54 in

$$j = 0.74 + 0.1\frac{e}{d} \leq 0.9$$ = 1.12

$$i = \frac{1}{\left(1 - \frac{jd}{e}\right)}$$ = 1.41

$$B_1 = \left(\frac{t_b S_\ell}{2n}\right)^{\frac{1}{3}}$$ = 2.82

t_b =	1.5	in
S_L =	30	in
n =	1	

Fcr = -12.65 < 1

Average cracking width NOT expected to exceed 0.01in.

Reinforced Concrete Pipe Structural Analysis:

Determine Shear Resistance without Stirrups

$$V_n = 0.0316bdF_{vp}\sqrt{f_c'}(1.1+63\rho)\left(\frac{F_d F_n}{F_c}\right)$$ = 3.80 k/ft (AASHTO LRFD 12.10.4.2.5-2)

Rho = As / (b*d) =	0.0034		(AASHTO LRFD 12.10.4.2.5-3)
b =	12	in	
d =	3	in	
As =	0.124	in^2/ft	
Fd = 0.8 + (1.6/d) =	1.30		(AASHTO LRFD 12.10.4.2.5-4)
If Nu is compressive, Fn = 1 + (Nu/24h) =	1.010		(AASHTO LRFD 12.10.4.2.5-6)
If Nu is tensile, Fn = 1 + (Nu/6h) =	1.040		(AASHTO LRFD 12.10.4.2.5-7)
Fn =	1.010		
Fc = 1 + (d/2r) =	1.04		(AASHTO LRFD 12.10.4.2.5-8)
Radius = r =	42	in	
Fvp =	1.0		(AASHTO LRFD 12.10.4.2.3)
Phi Vn =	3.42	k/ft	
Phi =	0.9		
Vu =	0.67	k/ft	
D/C =	**0.19**		

Determine Shear Resistance With Stirrups

Radial Tension

$$A_{vr} = \frac{1.1 s_v (M_u - 0.45 N_u \phi_r d)}{f_y r_s \phi_r d}$$ = 0.007358 in^2/ft (AASHTO LRFD 12.10.4.2.6-1)

Mu =	16.75	k-in/ft	
Nu =	1.45	k/ft	
d =	3	in	
fy =	40	ksi	
rs =	42	in	
Phir =	0.9		
sv provided =	30	in	
sv = min(0.75Phird ; sv Provided) =	2.03	in	
Av Provided =	0.12	in^2/ft	(#5 @ 30")

Av Required = 0.007 in^2/ft < **Av Provided = 0.12 in^2/ft**

Reinforced Concrete Pipe Structural Analysis:

Determine Shear Resistance With Stirrups

Shear Resistance

$$A_{vs} = \frac{1.1s_v}{f_y \phi_v d}\left(V_u F_c - V_c\right) + A_{vr}$$ = -0.016167 in^2/ft (AASHTO LRFD 12.10.4.2.6-1)

Vu =	0.67	k/ft	
sv = min(0.75Phivd ; sv Provided) =	2.03	in	
d =	3	in	
Avr =	0.007	in^2/ft	
Fc =	1.04		
Phiv =	0.9		
Av Provided =	0.12	in^2/ft	(#5 @ 30")

$$V_c = \frac{4V_r}{\frac{M_{nu}}{V_u d} + 1} \le 0.0633\phi_v bd\sqrt{f_c'}$$ = 1.83 k/ft (AASHTO LRFD 12.10.4.2.6-1)

$$M_{nu} = M_u - N_u\left[\frac{(4h-d)}{8}\right]$$ = 12.94 k-in/ft (AASHTO LRFD 12.10.4.2.5-9)

Vr = 3.42 k/ft

Av Required = -0.016 in^2/ft < Av Provided = 0.12 in^2/ft

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 8

Crown Pressure
Strawberry Creek Culvert Section 8

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	9.463333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 1.324867 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 10.1 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.55 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20
Traffic Driving Parallel to Culvert Span
Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 8.49 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	72	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 8

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 16.53 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 30.53 ft
Per AASHTO 3.6.1.2.6b-6

lw = 30.53 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 17.73 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 23.73 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 23.73 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 4 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - $\boldsymbol{P_L}$

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 10.1 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 0.91 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$ (AASHTO 3.6.1.2.6b−7) $A_{LL} = L_w * W_w$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	30.53	23.73	64	0.161
2	1	30.53	33.73	128	0.177
3	0.85	30.53	43.73	192	0.175
4	0.65	30.53	53.73	256	0.157

Crown Pressure
Strawberry Creek Culvert Section 8

Tire Distribution - Tandem

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft — Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 2.04 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 72 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 16.53 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 20.53 ft
Per AASHTO 3.6.1.2.6b-6

lw = 20.53 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 17.73 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 23.73 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 23.73 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 8

Determine the Crown Pressure - $\boldsymbol{P_L}$

Wheel Load =	12.5 kips	
w_{Lane} =	0.64 klf	Per AASHTO 3.6.1.2.4
Lane Width =	10 ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 10.1 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 0.91 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

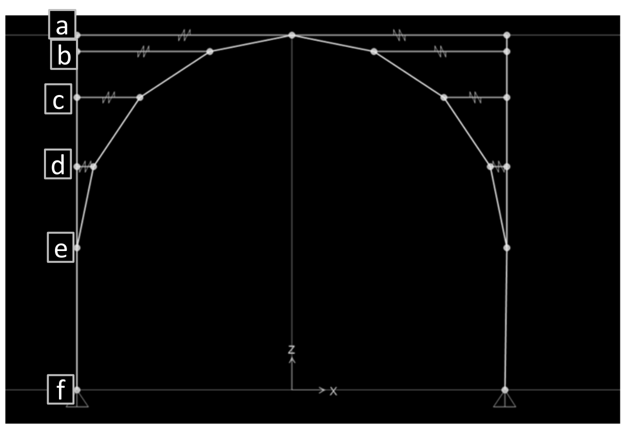
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	20.53	23.73	50	0.176
2	1	20.53	33.73	100	0.196
3	0.85	20.53	43.73	150	0.194
4	0.65	20.53	53.73	200	0.171

Max pressure is from tandem truck = 0.196 ksf

Crown Pressure
Strawberry Creek Culvert Section 8

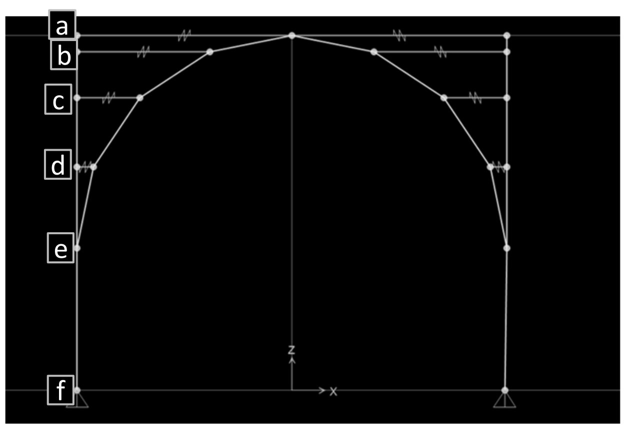
5.) Horizontal Earth Pressure - EH Minimum

Depth =	9.463333	ft	(Soil Above a)
a =	5.875	ft	(Top of Culvert Arch Height, Height at a)
b =	5.618	ft	(Height at b)
c =	4.886	ft	(Height at c)
d =	3.792	ft	(Height at d)
e =	2.500	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	340.7	plf	(Trap. EH Value at a)
EH_b =	349.9	plf	(Trap. EH Value at b)
EH_c =	376.3	plf	(Trap. EH Value at c)
EH_d =	415.7	plf	(Trap. EH Value at d)
EH_e =	462.2	plf	(Trap. EH Value at e)
EH_f =	552.2	plf	(Trap. EH Value at f)



6.) Horizontal Earth Pressure - EH Maximum

Depth =	9.463333	ft	(Soil Above a)
a =	5.875	ft	(Top of Culvert Arch Height, Height at a)
b =	5.618	ft	(Height at b)
c =	4.886	ft	(Height at c)
d =	3.792	ft	(Height at d)
e =	2.5	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	1135.6	plf	(Trap. EH Value at a)
EH_b =	1166.4	plf	(Trap. EH Value at b)
EH_c =	1254.3	plf	(Trap. EH Value at c)
EH_d =	1385.6	plf	(Trap. EH Value at d)
EH_e =	1540.6	plf	(Trap. EH Value at e)
EH_f =	1840.6	plf	(Trap. EH Value at f)



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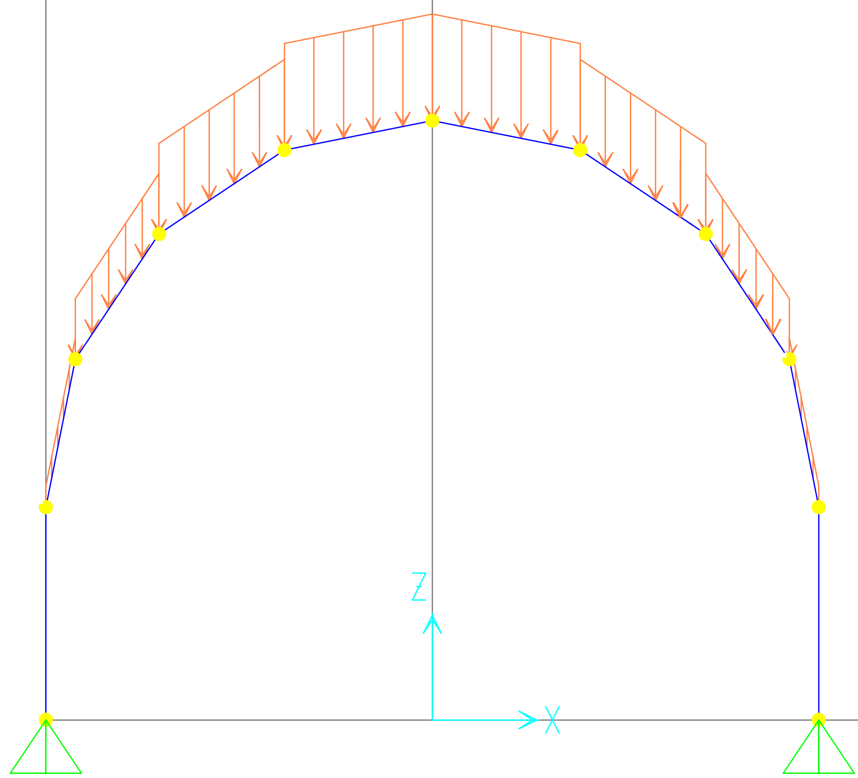
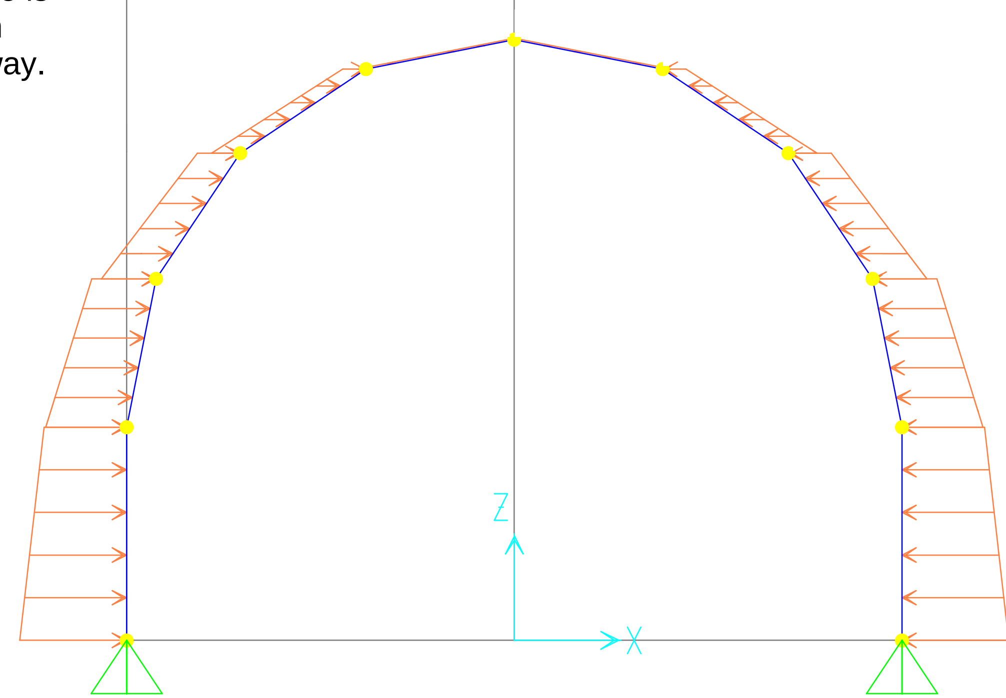
Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.



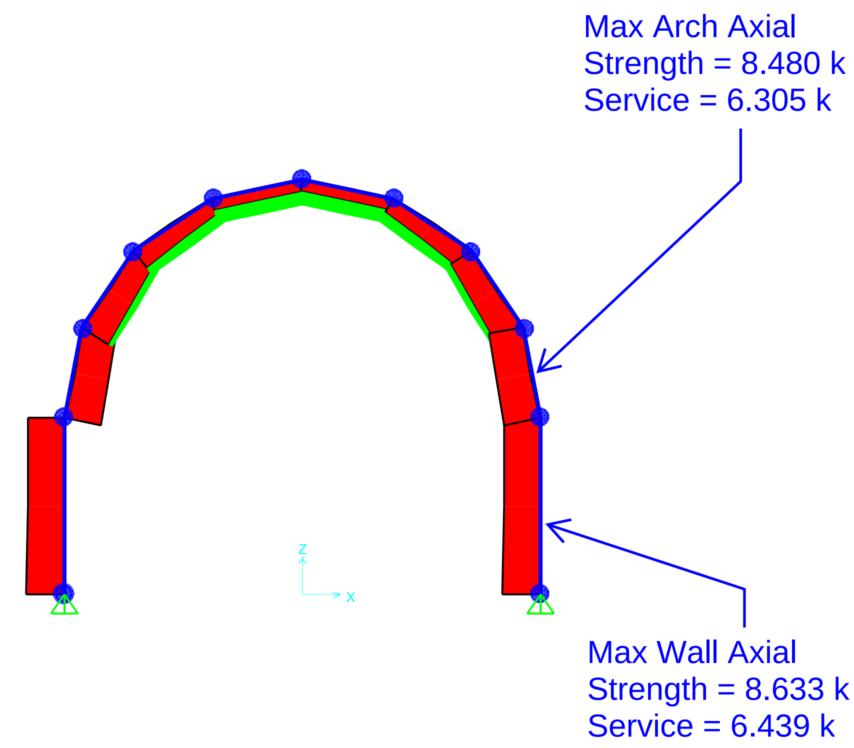
Section 8 - Frame Span Loads (EV) - Kip, ft, F Units

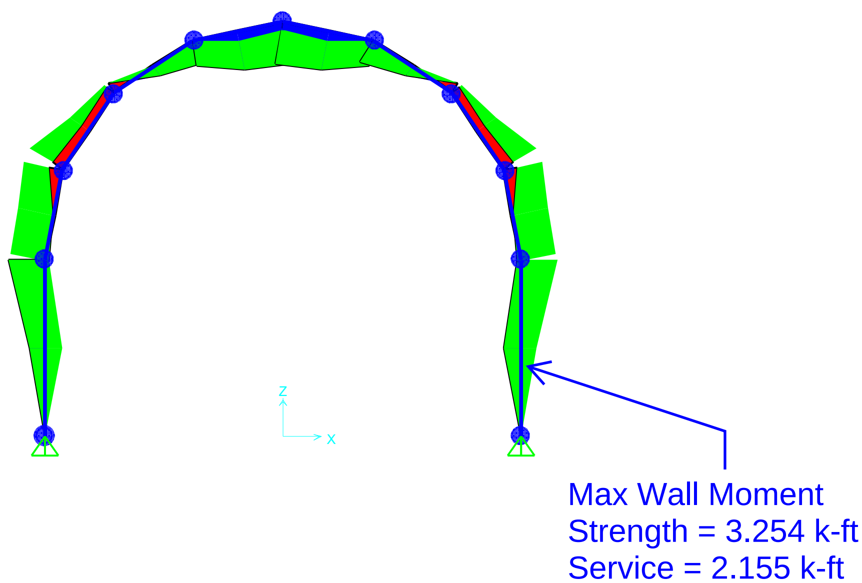


Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.

Section 8 - Frame Span Loads (EHMin) - Kip, ft, F Units


Max Arch Axial
Strength = 8.480 k
Service = 6.305 k
Z
X
Max Wall Axial
Strength = 8.633 k
Service = 6.439 k


Z
X
Max Wall Moment
Strength = 3.254 k-ft
Service = 2.155 k-ft

SECTION 8 ARCH CULVERT FLEXURE CHECK

Geometry

h =	11.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	5.50	in	(Distance from extreme comp. fiber to center)
I_y =	1331	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	3.190	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.43	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

$M_n = Min[\, 5 * \lambda * \sqrt{f'c} * S_m ;\ \ 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 5.70 k-ft

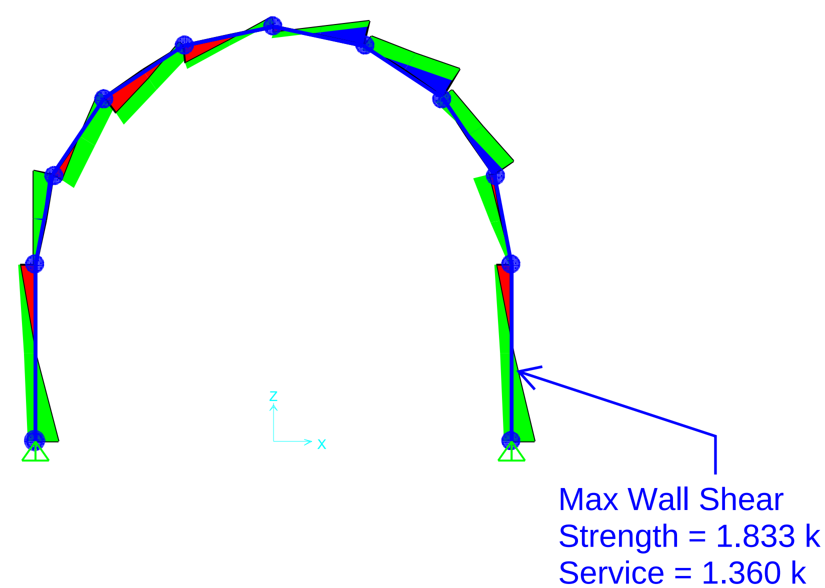
Φ = 0.6 (ACI 21.2.1)

ΦM_n = 3.42 k-ft < 5.75 k-ft = Critical Moment from SAP Model **NG**

D/C = 1.68

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.


Z
X
Max Wall Shear
Strength = 1.833 k
Service = 1.360 k

SECTION 8 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h =	9.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	108.00	in^2	(Area of concrete section)

Materials

f'_c =	3.190	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	3251	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.43	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 1.83 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)
Concrete Shear Capacity

$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$ 8.13 k (ACI 14.5.5.1)

$\phi V_n = V_c > V_U$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 4.88 k > $V_u = V_{crit}$ = 1.83 k **OK** D/C = 0.38

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 9

Crown Pressure
Strawberry Creek Culvert Section 9

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	10.31333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 1.443867 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 11.0 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.75 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 7.52 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	96	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 9

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 20.05 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 34.05 ft
Per AASHTO 3.6.1.2.6b-6

lw = 34.05 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 21.36 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 27.36 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 27.36 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 4 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - P_L

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 11.0 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 0.88 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$P_L = \frac{P(1 + \frac{IM}{100})(m)}{A_{LL}} + \# Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$ (AASHTO 3.6.1.2.6b–7) $A_{LL} = L_w * W_w$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	34.05	27.36	64	0.136
2	1	34.05	37.36	128	0.152
3	0.85	34.05	47.36	192	0.153
4	0.65	34.05	57.36	256	0.139

Crown Pressure
Strawberry Creek Culvert Section 9

Tire Distribution - Tandem

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft   Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 1.81 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 20.05 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 24.05 ft
Per AASHTO 3.6.1.2.6b-6

lw = 24.05 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 21.36 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 27.36 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 27.36 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels

If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 9

Determine the Crown Pressure - P_L

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 11.0 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 0.88 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

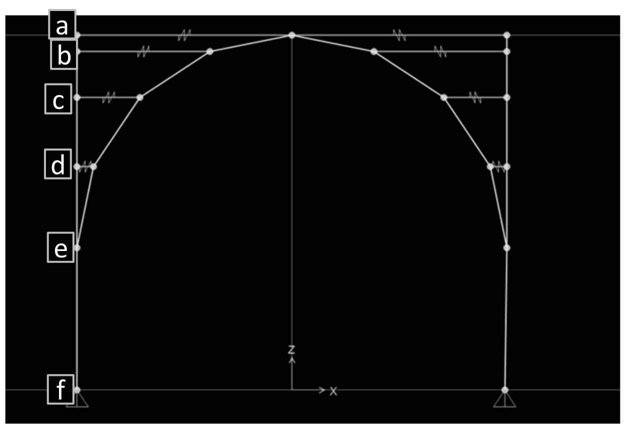
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	24.05	27.36	50	0.144
2	1	24.05	37.36	100	0.162
3	0.85	24.05	47.36	150	0.162
4	0.65	24.05	57.36	200	0.147

Max pressure is from tandem truck = 0.162 ksf

Crown Pressure
Strawberry Creek Culvert Section 9

5.) Horizontal Earth Pressure - EH Minimum

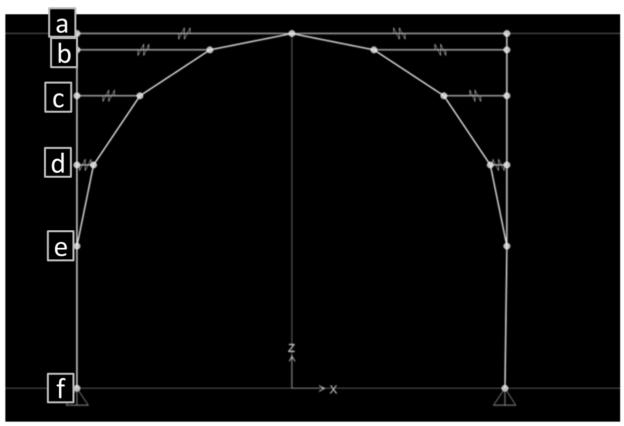
Depth =	10.31333	ft	(Soil Above a)
a =	7.458	ft	(Top of Culvert Arch Height, Height at a)
b =	7.120	ft	(Height at b)
c =	6.153	ft	(Height at c)
d =	4.706	ft	(Height at d)
e =	3.000	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	371.3	plf	(Trap. EH Value at a)
EH_b =	383.5	plf	(Trap. EH Value at b)
EH_c =	418.3	plf	(Trap. EH Value at c)
EH_d =	470.4	plf	(Trap. EH Value at d)
EH_e =	531.8	plf	(Trap. EH Value at e)
EH_f =	639.8	plf	(Trap. EH Value at f)



Crown Pressure
Strawberry Creek Culvert Section 9

6.) Horizontal Earth Pressure - EH Maximum

Depth =	10.31333	ft	(Soil Above a)
a =	7.4583	ft	(Top of Culvert Arch Height, Height at a)
b =	7.12	ft	(Height at b)
c =	6.153	ft	(Height at c)
d =	4.706	ft	(Height at d)
e =	3	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	1237.6	plf	(Trap. EH Value at a)
EH_b =	1278.2	plf	(Trap. EH Value at b)
EH_c =	1394.2	plf	(Trap. EH Value at c)
EH_d =	1567.9	plf	(Trap. EH Value at d)
EH_e =	1772.6	plf	(Trap. EH Value at e)
EH_f =	2132.6	plf	(Trap. EH Value at f)



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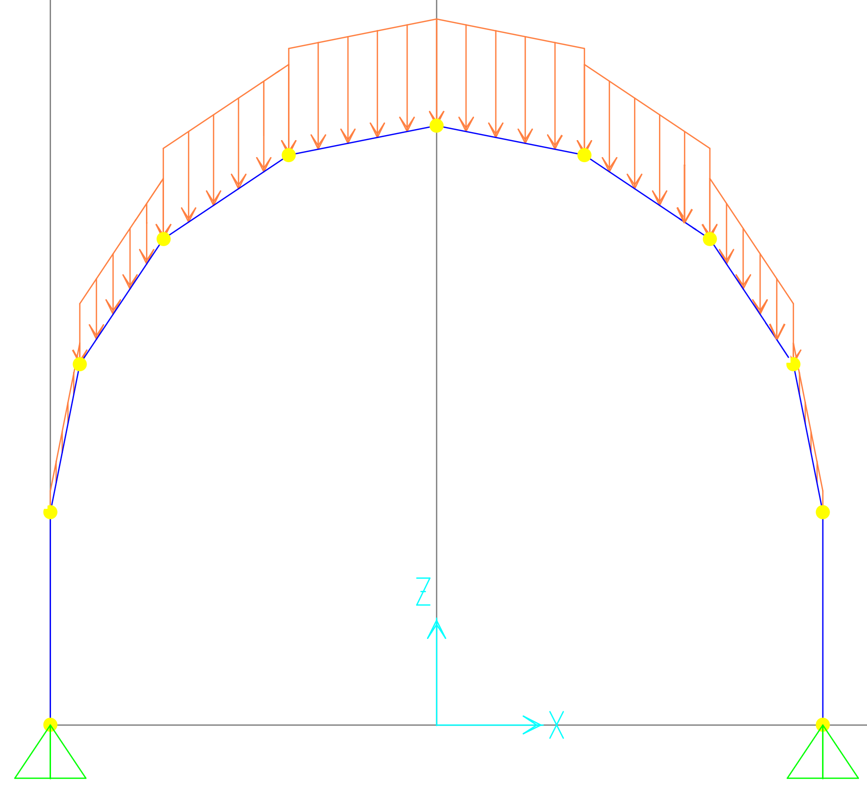
Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.



Section 9 - Frame Span Loads (EV) - Kip, ft, F Units

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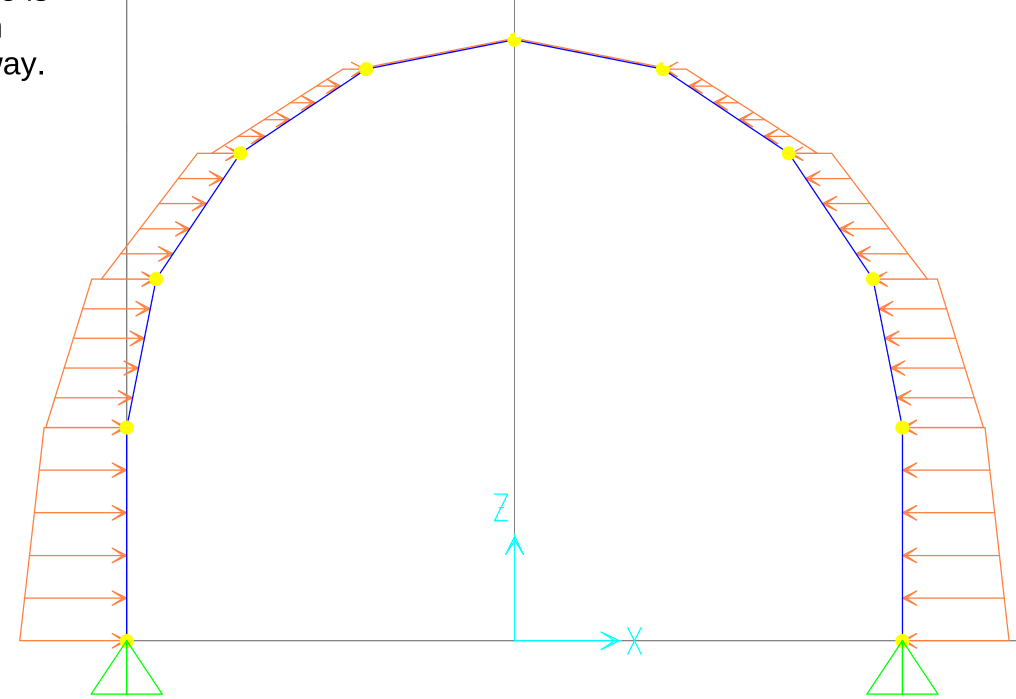
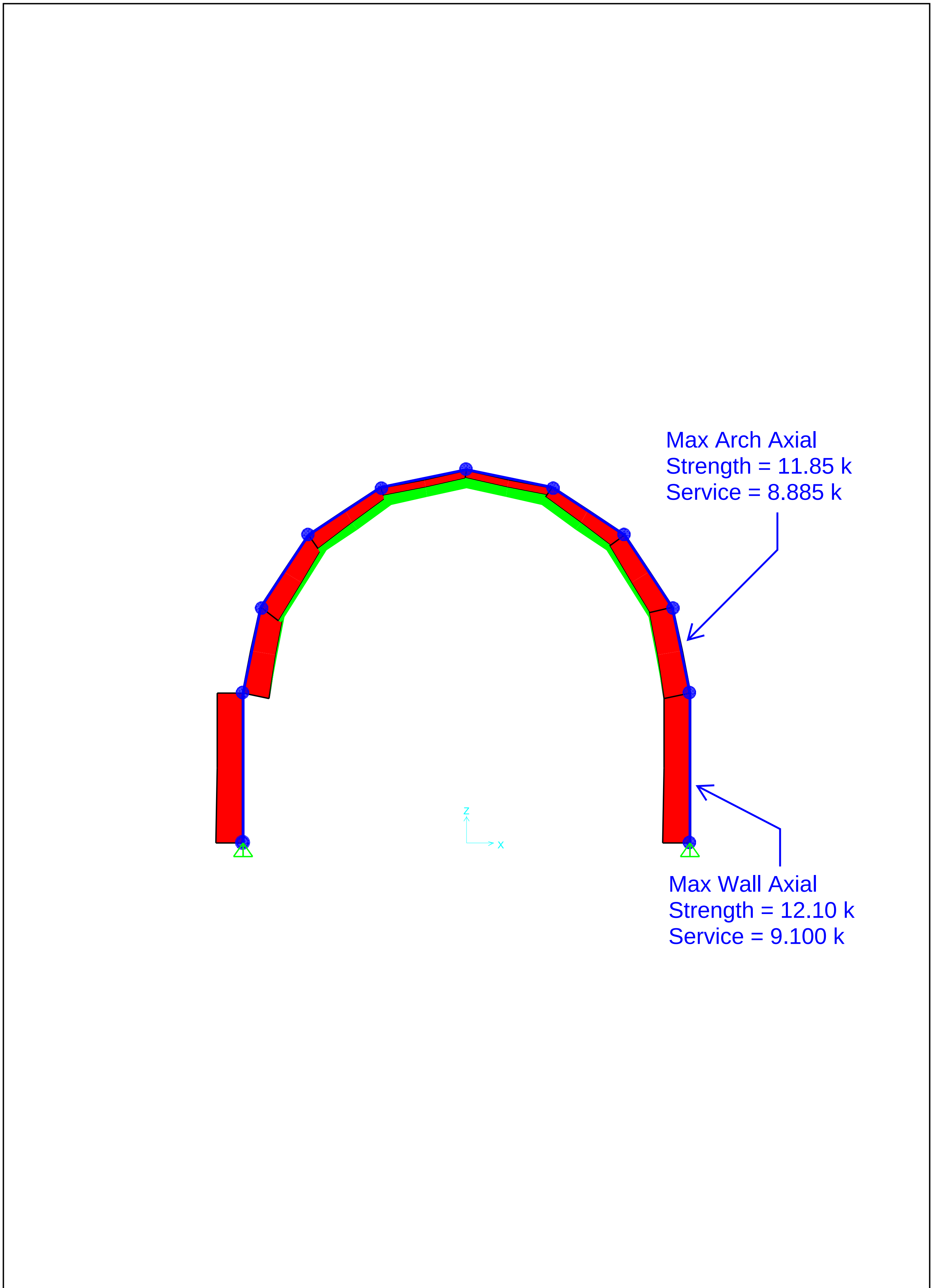
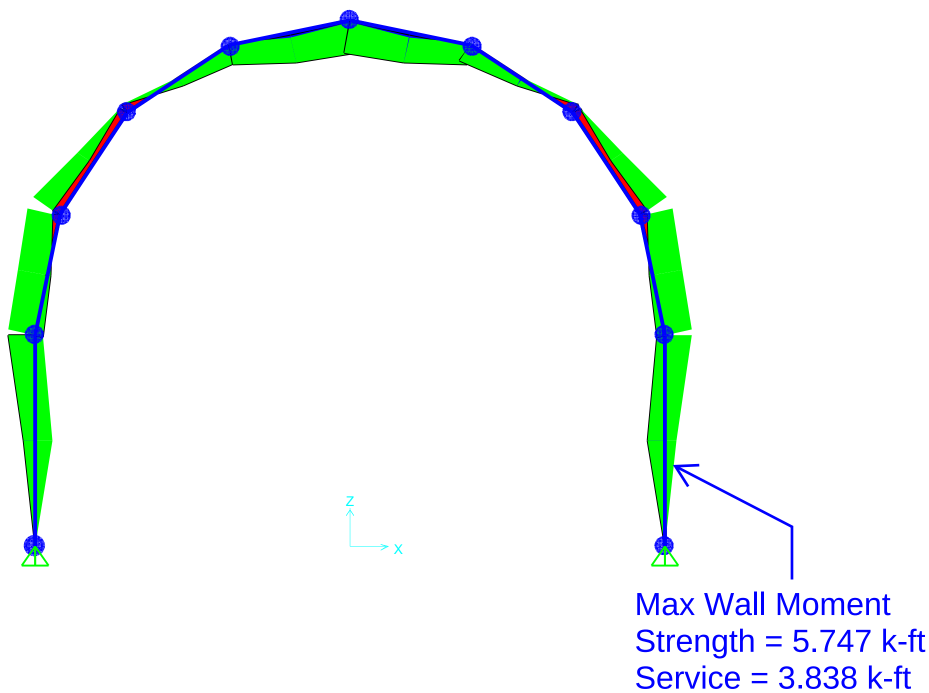
Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.



Section 9 - Frame Span Loads (EHMin) - Kip, ft, F Units


Max Arch Axial
Strength = 11.85 k
Service = 8.885 k
Max Wall Axial
Strength = 12.10 k
Service = 9.100 k
Z
X


Z
X
Max Wall Moment
Strength = 5.747 k-ft
Service = 3.838 k-ft

SECTION 9 ARCH CULVERT FLEXURE CHECK

Geometry

h =	11.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	5.50	in	(Distance from extreme comp. fiber to center)
I_y =	1331	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	3.010	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.42	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

$M_n = Min[\,5 * \lambda * \sqrt{f'c} * S_m;\;\; 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 5.53 k-ft

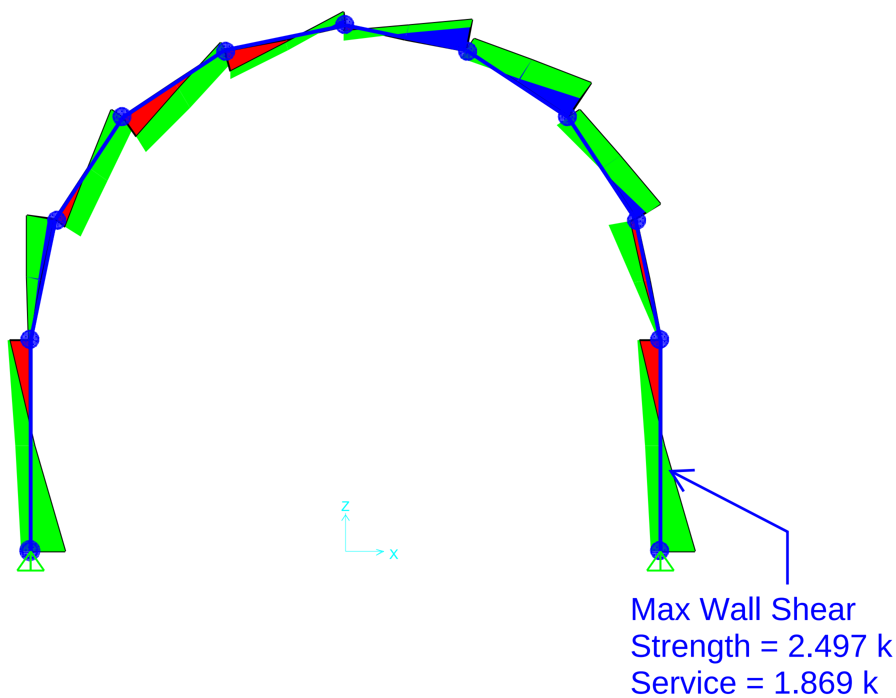
Φ = 0.6 (ACI 21.2.1)

ΦM_n = 3.32 k-ft < 5.75 k-ft = Critical Moment from SAP Model **NG**

D/C = 1.73

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.


Z
X
Max Wall Shear
Strength = 2.497 k
Service = 1.869 k

SECTION 9 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h =	11.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	132.00	in^2	(Area of concrete section)

Materials

f'_c =	3.010	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	3158	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.42	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 2.50 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)

Concrete Shear Capacity

$$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h = $$ 9.66 k (ACI 14.5.5.1)

$$\phi V_n = V_c > V_U$$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 5.79 k > $V_u = V_{crit}$ = 2.50 k **OK** D/C = 0.43

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 10

Crown Pressure
Strawberry Creek Culvert Section 10

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	9.183333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 1.285667 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 9.9 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.75 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20
Traffic Driving Parallel to Culvert Span
Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{S_a - \frac{l_t}{12}}{LLDF}$ = 7.52 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	96	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{S_W - \frac{W_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 10

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 18.07 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 32.07 ft
Per AASHTO 3.6.1.2.6b-6

lw = 32.07 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 19.38 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 25.38 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 25.38 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 4 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - $\boldsymbol{P_L}$

Wheel Load = 16 kips
w_{Lane} = 0.64 klf — Per AASHTO 3.6.1.2.4
Lane Width = 10 ft — Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 9.9 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) — Per AASHTO 3.6.2.2
IM = 0.92 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \# Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$ (AASHTO 3.6.1.2.6b–7) $A_{LL} = L_w * W_w$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	32.07	25.38	64	0.151
2	1	32.07	35.38	128	0.168
3	0.85	32.07	45.38	192	0.168
4	0.65	32.07	55.38	256	0.151

Crown Pressure
Strawberry Creek Culvert Section 10

Tire Distribution - Tandem

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft — Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 1.81 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 18.07 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 22.07 ft
Per AASHTO 3.6.1.2.6b-6

lw = 22.07 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 19.38 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 25.38 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 25.38 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 10

Determine the Crown Pressure - P_L

Wheel Load = 12.5 kips
w_{Lane} = 0.64 klf — Per AASHTO 3.6.1.2.4
Lane Width = 10 ft — Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 9.9 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) — Per AASHTO 3.6.2.2
IM = 0.92 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

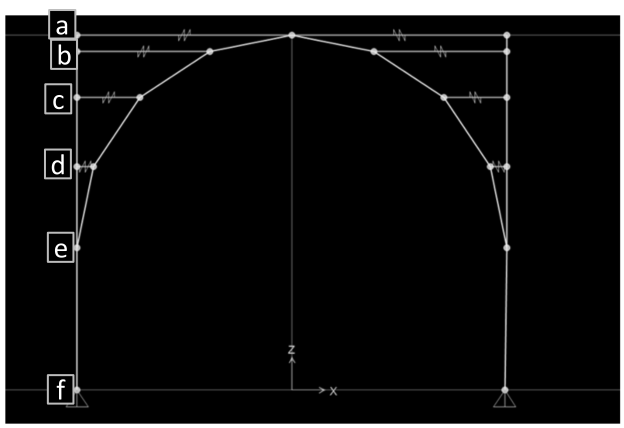
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	22.07	25.38	50	0.163
2	1	22.07	35.38	100	0.182
3	0.85	22.07	45.38	150	0.182
4	0.65	22.07	55.38	200	0.162

Max pressure is from tandem truck = 0.182 ksf

Crown Pressure
Strawberry Creek Culvert Section 10

5.) Horizontal Earth Pressure - EH Minimum

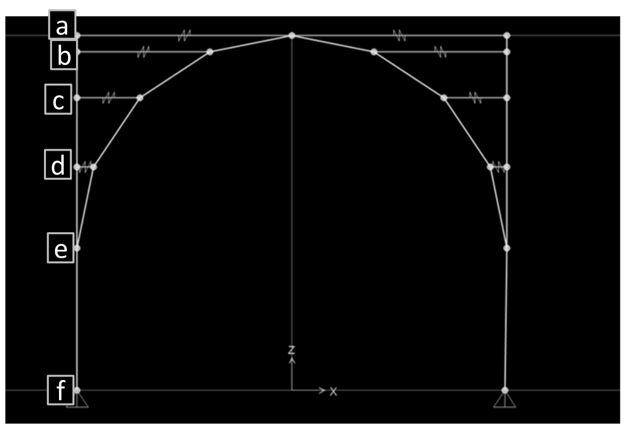
Depth =	9.183333	ft	(Soil Above a)
a =	7.042	ft	(Top of Culvert Arch Height, Height at a)
b =	6.696	ft	(Height at b)
c =	5.711	ft	(Height at c)
d =	4.238	ft	(Height at d)
e =	2.500	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	330.6	plf	(Trap. EH Value at a)
EH_b =	343.1	plf	(Trap. EH Value at b)
EH_c =	378.5	plf	(Trap. EH Value at c)
EH_d =	431.5	plf	(Trap. EH Value at d)
EH_e =	494.1	plf	(Trap. EH Value at e)
EH_f =	584.1	plf	(Trap. EH Value at f)



Crown Pressure
Strawberry Creek Culvert Section 10

6.) Horizontal Earth Pressure - EH Maximum

Depth =	9.183333	ft	(Soil Above a)
a =	7.042	ft	(Top of Culvert Arch Height, Height at a)
b =	6.696	ft	(Height at b)
c =	5.711	ft	(Height at c)
d =	4.238	ft	(Height at d)
e =	2.5	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	1102.0	plf	(Trap. EH Value at a)
EH_b =	1143.5	plf	(Trap. EH Value at b)
EH_c =	1261.7	plf	(Trap. EH Value at c)
EH_d =	1438.5	plf	(Trap. EH Value at d)
EH_e =	1647.0	plf	(Trap. EH Value at e)
EH_f =	1947.0	plf	(Trap. EH Value at f)



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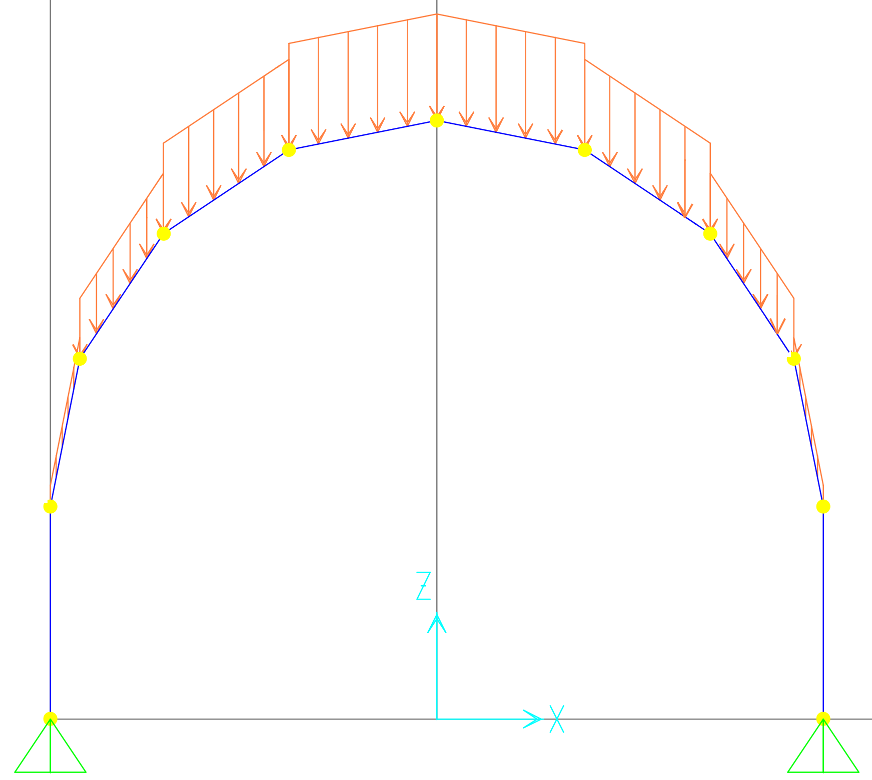
Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.



Section 10 - Frame Span Loads (EV) - Kip, ft, F Units

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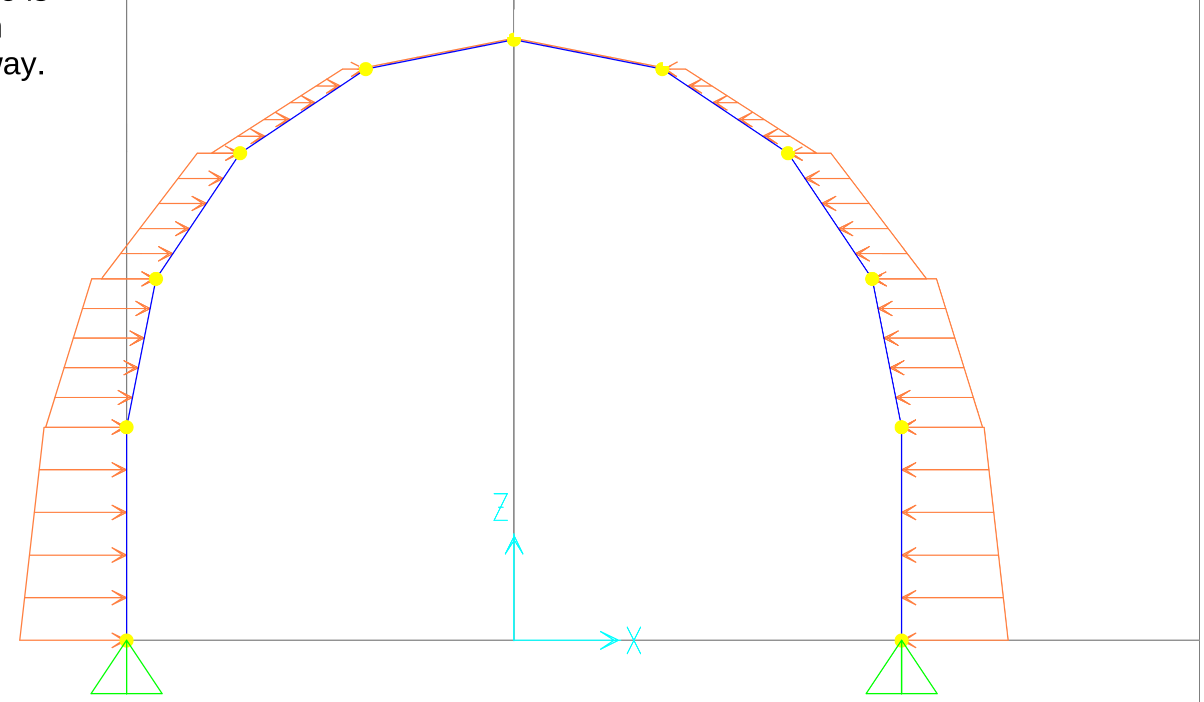
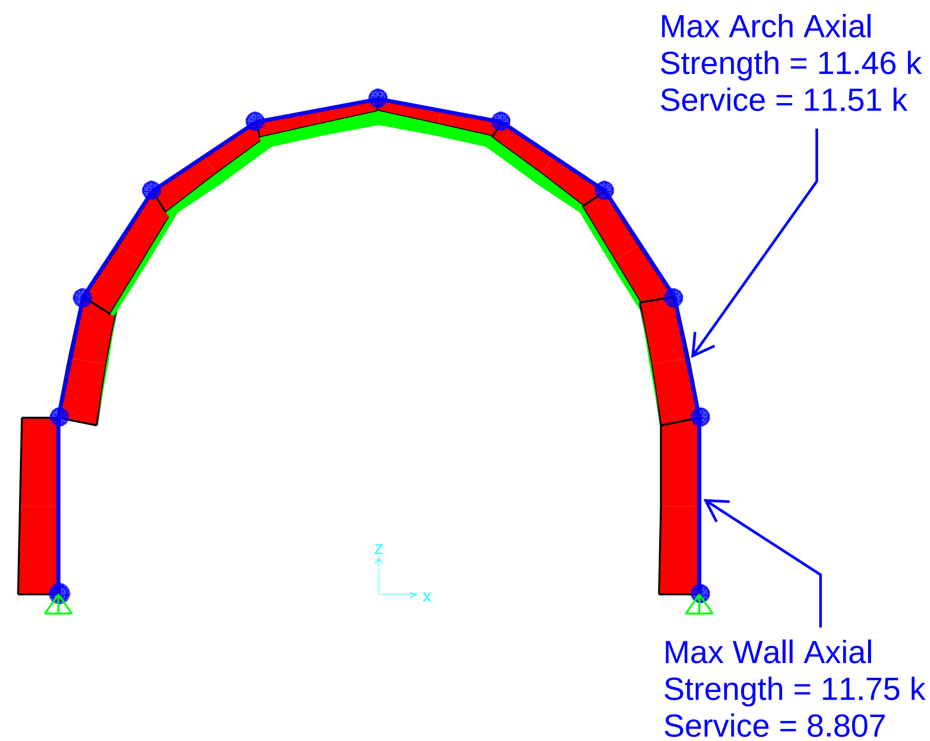
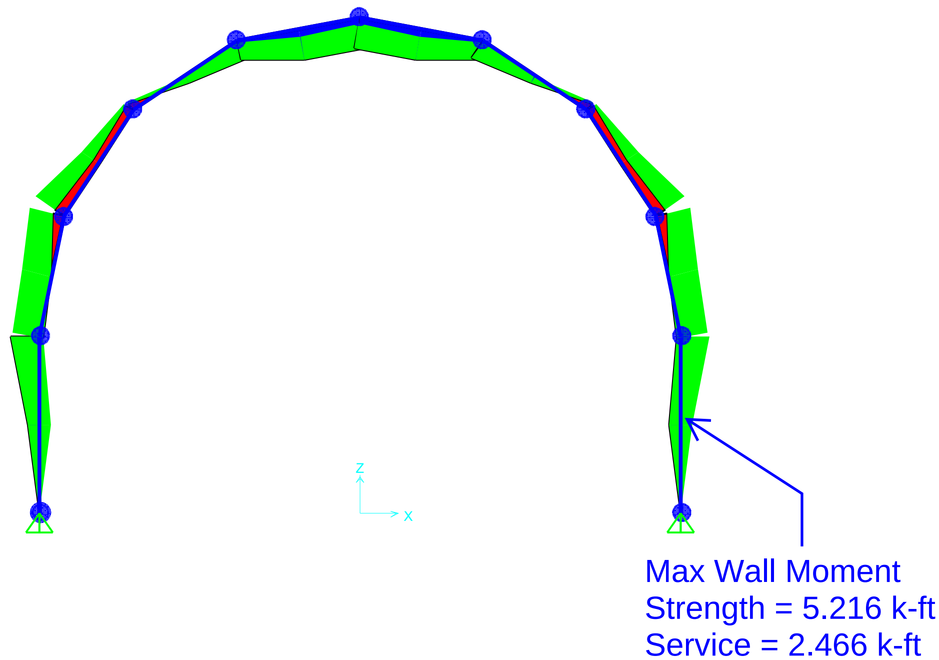


Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.

Section 10 - Frame Span Loads (EHMin) - Kip, ft, F Units


Max Arch Axial
Strength = 11.46 k
Service = 11.51 k
Z
X
Max Wall Axial
Strength = 11.75 k
Service = 8.807


Z
X
Max Wall Moment
Strength = 5.216 k-ft
Service = 2.466 k-ft

SECTION 10 ARCH CULVERT FLEXURE CHECK

Geometry

h =	13.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	6.50	in	(Distance from extreme comp. fiber to center)
I_y =	2197	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	3.230	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.43	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

$M_n = Min[\,5 * \lambda * \sqrt{f'c} * S_m;\;\; 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 8.00 k-ft

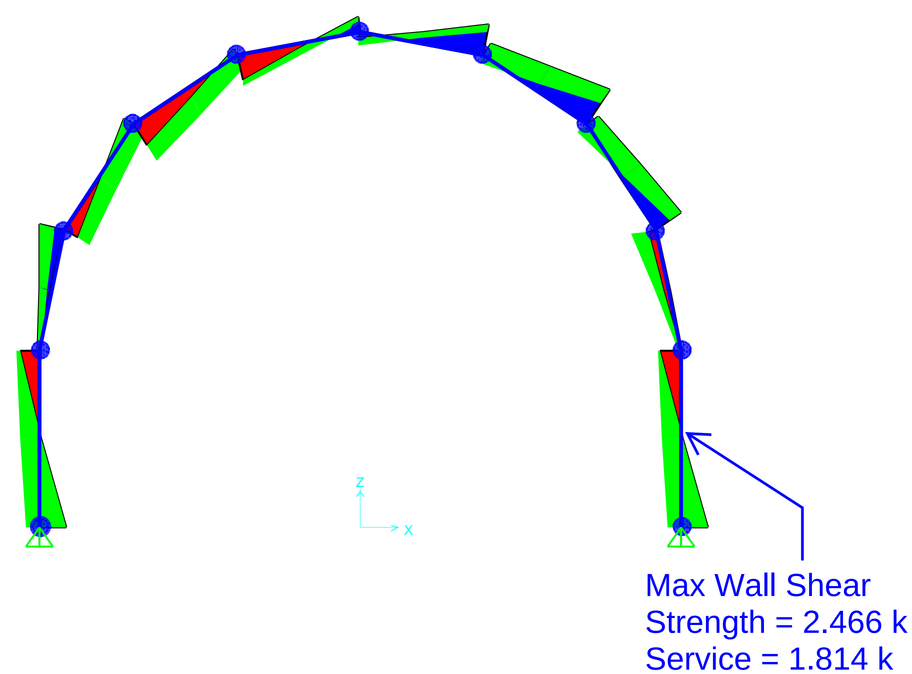
Φ = 0.6 (ACI 21.2.1)

ΦM_n = 4.80 k-ft < 5.22 k-ft = Critical Moment from SAP Model **NG**

D/C = 1.09

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.


Z
X
Max Wall Shear
Strength = 2.466 k
Service = 1.814 k

SECTION 10 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h =	13.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	156.00	in^2	(Area of concrete section)

Materials

f'_c =	3.230	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	3271	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.43	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 2.47 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)
Concrete Shear Capacity

$$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$$ 11.82 k (ACI 14.5.5.1)

$$\phi V_n = V_c > V_U$$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 7.09 k > $V_u = V_{crit}$ = 2.47 k **OK** D/C = 0.35

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 12

Crown Pressure
Strawberry Creek Culvert Section 12

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	6.033333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 0.844667 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 6.7 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.75 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20
Traffic Driving Parallel to Culvert Span
Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 7.52 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	96	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 12

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 12.56 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 26.56 ft
Per AASHTO 3.6.1.2.6b-6

lw = 12.56 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 13.87 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 19.87 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 19.87 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 2 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - $\boldsymbol{P_L}$

Wheel Load = 16 kips
w_{Lane} = 0.64 klf — Per AASHTO 3.6.1.2.4
Lane Width = 10 ft — Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 6.7 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) — Per AASHTO 3.6.2.2
IM = 1.05 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$$P_L = \frac{P(1 + \frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b–7) $$A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	12.56	19.87	32	0.226
2	1	12.56	29.87	64	0.244
3	0.85	12.56	39.87	96	0.236
4	0.65	12.56	49.87	128	0.204

Crown Pressure
Strawberry Creek Culvert Section 12

Tire Distribution - Tandem

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 1.81 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 12.56 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 16.56 ft
Per AASHTO 3.6.1.2.6b-6

lw = 16.56 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 13.87 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 19.87 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 19.87 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels

If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 12

Determine the Crown Pressure - P_L

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 6.7 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.05 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

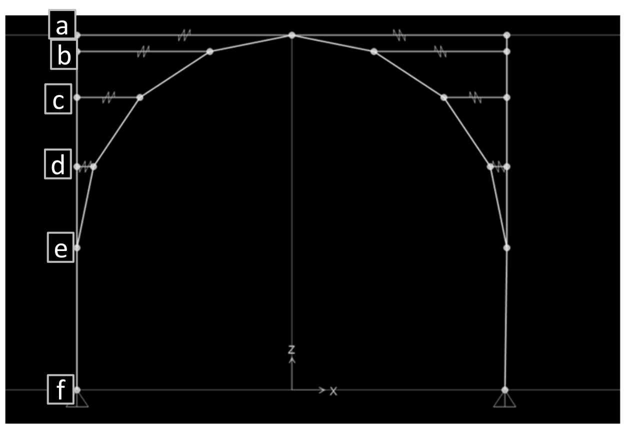
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	16.56	19.87	50	0.256
2	1	16.56	29.87	100	0.277
3	0.85	16.56	39.87	150	0.267
4	0.65	16.56	49.87	200	0.230

Max pressure is from tandem truck = 0.277 ksf

Crown Pressure
Strawberry Creek Culvert Section 12

5.) Horizontal Earth Pressure - EH Minimum

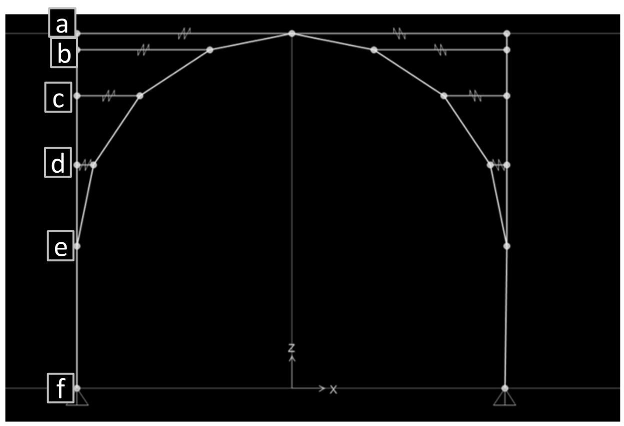
Depth =	6.033333	ft	(Soil Above a)
a =	7.042	ft	(Top of Culvert Arch Height, Height at a)
b =	6.696	ft	(Height at b)
c =	5.711	ft	(Height at c)
d =	4.238	ft	(Height at d)
e =	2.500	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	217.2	plf	(Trap. EH Value at a)
EH_b =	229.7	plf	(Trap. EH Value at b)
EH_c =	265.1	plf	(Trap. EH Value at c)
EH_d =	318.1	plf	(Trap. EH Value at d)
EH_e =	380.7	plf	(Trap. EH Value at e)
EH_f =	470.7	plf	(Trap. EH Value at f)



Crown Pressure
Strawberry Creek Culvert Section 12

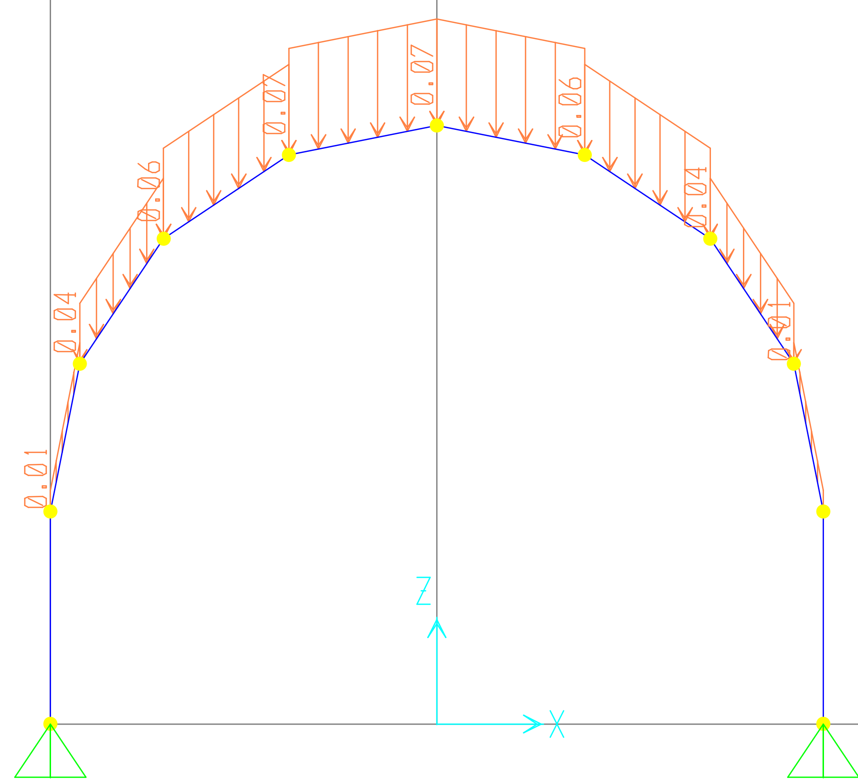
6.) Horizontal Earth Pressure - EH Maximum

Depth =	6.033333	ft	(Soil Above a)
a =	7.042	ft	(Top of Culvert Arch Height, Height at a)
b =	6.696	ft	(Height at b)
c =	5.711	ft	(Height at c)
d =	4.238	ft	(Height at d)
e =	2.5	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	724.0	plf	(Trap. EH Value at a)
EH_b =	765.5	plf	(Trap. EH Value at b)
EH_c =	883.7	plf	(Trap. EH Value at c)
EH_d =	1060.5	plf	(Trap. EH Value at d)
EH_e =	1269.0	plf	(Trap. EH Value at e)
EH_f =	1569.0	plf	(Trap. EH Value at f)



Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.



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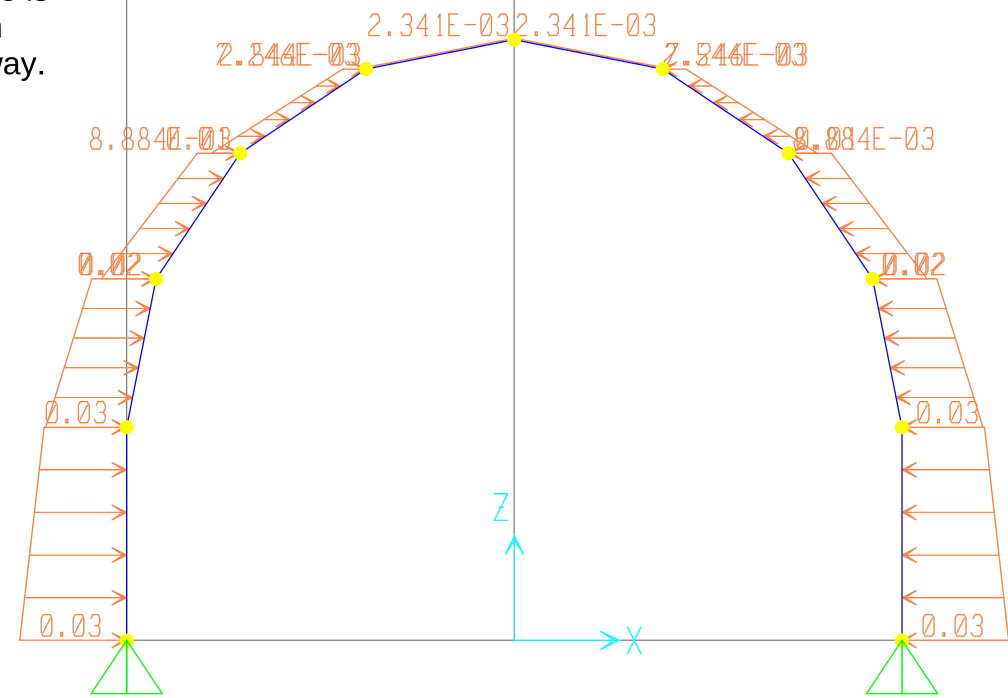
Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.



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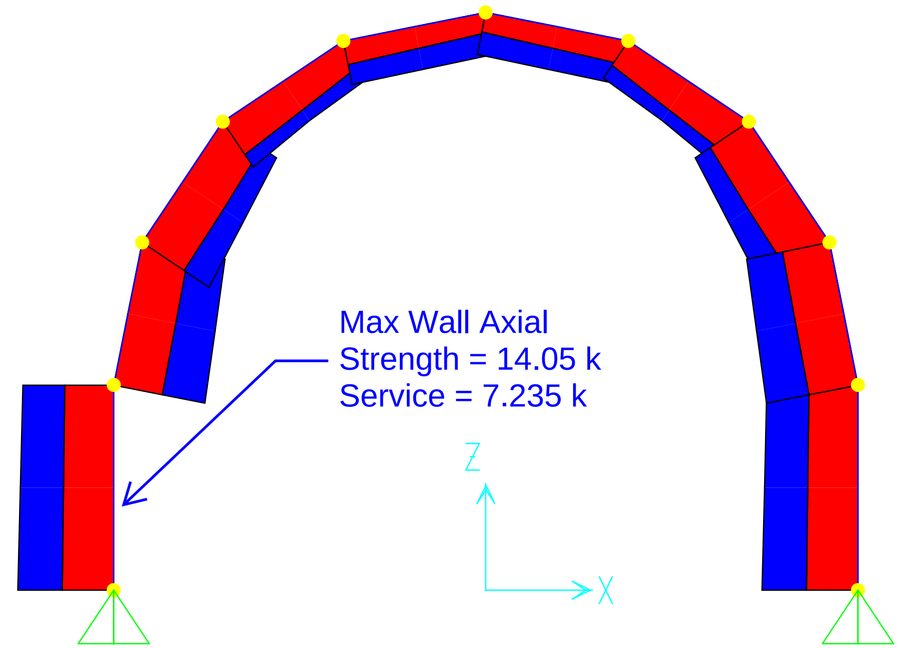

SAP2000 v8.3.0 - File:Section 12 - Round Top, Flat Bottom (STA 28+50) - Axial Force Diagram (Strength) - Kip, ft, F Units

SAP2000

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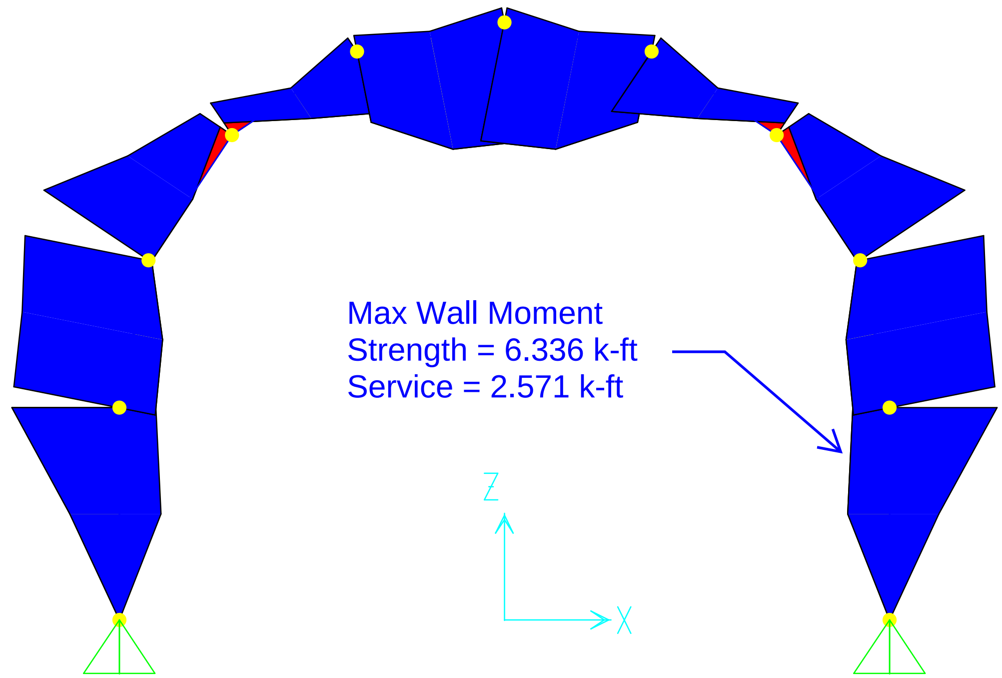

SAP2000 v8.3.0 - File:Section 12 - Round Top, Flat Bottom (STA 28+50) - Moment 3-3 Diagram (Strength) - Kip, ft, F Units

SECTION 12 ARCH CULVERT FLEXURE CHECK

Geometry

h =	13.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	6.50	in	(Distance from extreme comp. fiber to center)
I_y =	2197	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	2.580	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.39	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

M_n = $Min[\,5 * \lambda * \sqrt{f'c} * S_m;\ \ 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 7.15 k-ft

Φ = 0.6 (ACI 21.2.1)

ΦM_n = 4.29 k-ft < 6.34 k-ft = Critical Moment from SAP Model **NG**

D/C = 1.48

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

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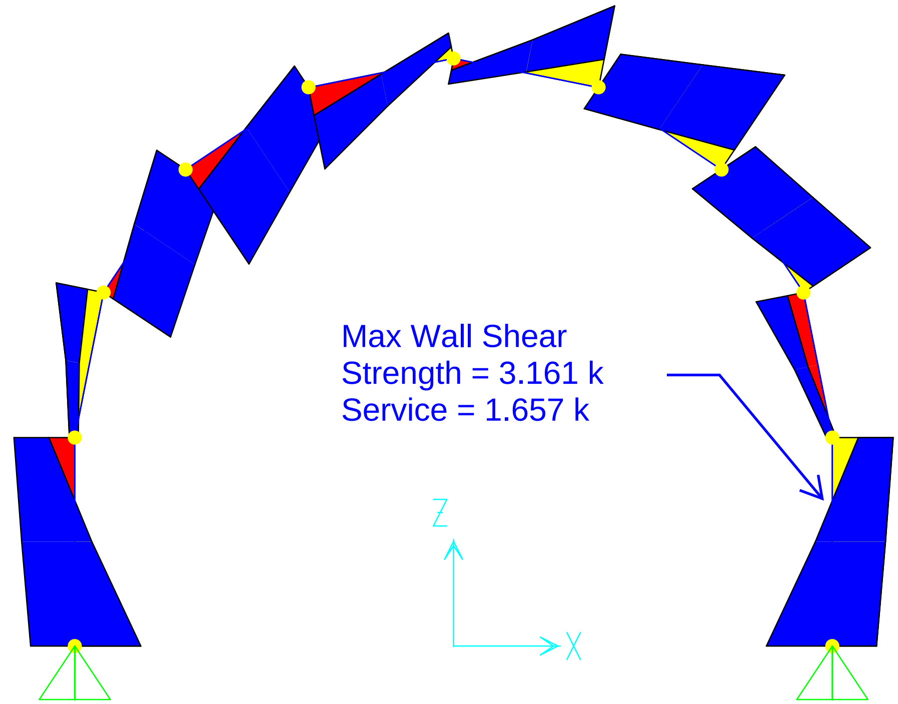


SAP2000 v8.3.0 - File:Section 12 - Round Top, Flat Bottom (STA 28+50) - Shear Force 2-2 Diagram (Strength) - Kip, ft, F Units

SECTION 12 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h =	13.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	156.00	in^2	(Area of concrete section)

Materials

f'_c =	2.580	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	2923	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.39	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 3.16 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)
Concrete Shear Capacity

$$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$$ 10.57 k (ACI 14.5.5.1)

$$\phi V_n = V_c > V_U$$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 6.34 k > $V_u = V_{crit}$ = 3.16 k **OK** D/C = 0.50

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 13

Crown Pressure
Strawberry Creek Culvert Section 13

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	5.643333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 0.790067 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 6.3 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.75 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 7.52 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	96	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 13

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H) =$ 11.88 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 25.88 ft
Per AASHTO 3.6.1.2.6b-6

lw = 11.88 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 13.19 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 19.19 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 19.19 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 2 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - P_L

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 6.3 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.07 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width} \quad \text{(AASHTO 3.6.1.2.6b–7)} \qquad A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	11.88	19.19	32	0.244
2	1	11.88	29.19	64	0.261
3	0.85	11.88	39.19	96	0.252
4	0.65	11.88	49.19	128	0.216

Crown Pressure
Strawberry Creek Culvert Section 13

Tire Distribution - Tandem
Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft   Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 1.81 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 11.88 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 15.88 ft
Per AASHTO 3.6.1.2.6b-6

lw = 15.88 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 13.19 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 19.19 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 19.19 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 13

Determine the Crown Pressure - P_L

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 6.3 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.07 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

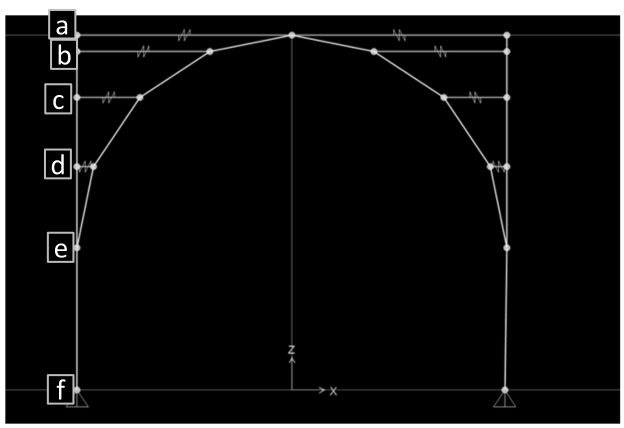
Number of Design Lanes	**Multiple Presence**	**Lw (ft)**	**Ww (ft)**	**P (kip)**	**PL (ksf)**
1	1.2	15.88	19.19	50	0.275
2	1	15.88	29.19	100	0.295
3	0.85	15.88	39.19	150	0.283
4	0.65	15.88	49.19	200	0.242

Max pressure is from tandem truck = 0.295 ksf

Crown Pressure
Strawberry Creek Culvert Section 13

5.) Horizontal Earth Pressure - EH Minimum

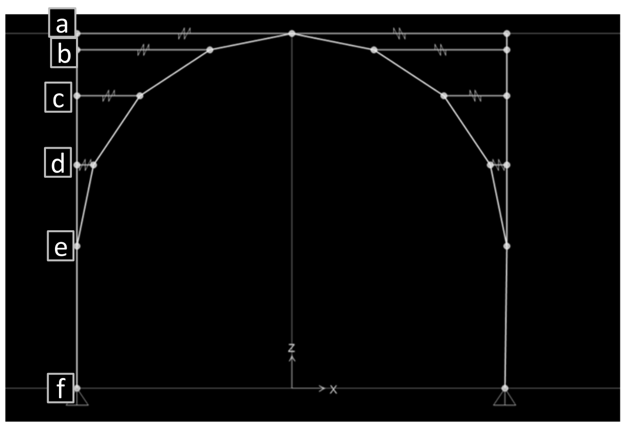
Depth =	5.643333	ft	(Soil Above a)
a =	5.917	ft	(Top of Culvert Arch Height, Height at a)
b =	5.587	ft	(Height at b)
c =	4.647	ft	(Height at c)
d =	3.242	ft	(Height at d)
e =	1.583	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	203.2	plf	(Trap. EH Value at a)
EH_b =	215.0	plf	(Trap. EH Value at b)
EH_c =	248.9	plf	(Trap. EH Value at c)
EH_d =	299.5	plf	(Trap. EH Value at d)
EH_e =	359.2	plf	(Trap. EH Value at e)
EH_f =	416.2	plf	(Trap. EH Value at f)



Crown Pressure
Strawberry Creek Culvert Section 13

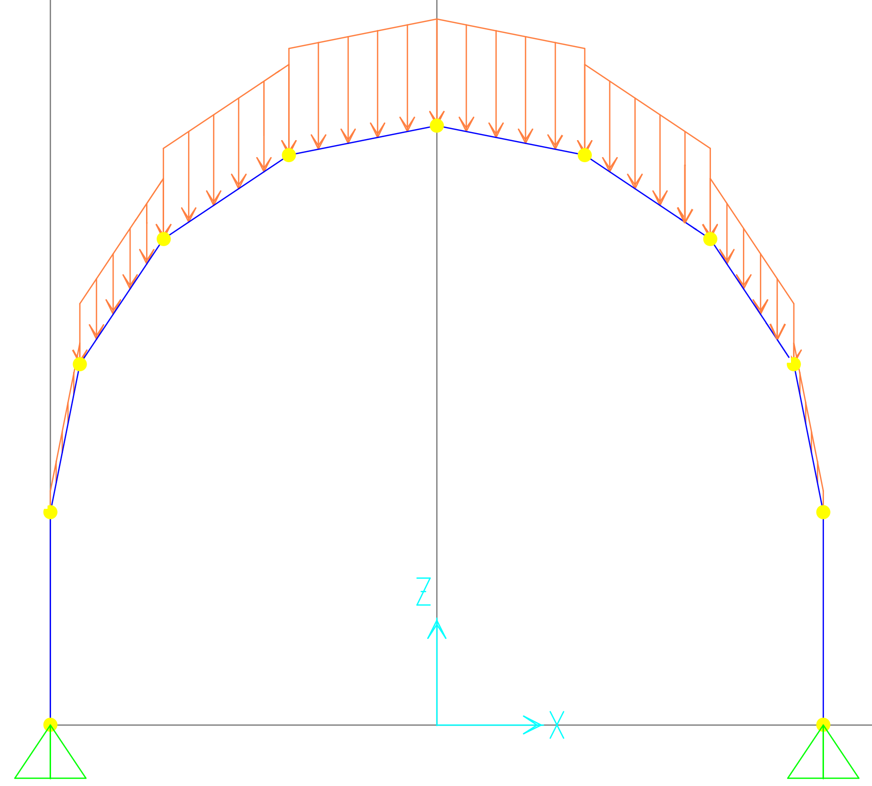
6.) Horizontal Earth Pressure - EH Maximum

Depth =	5.643333	ft	(Soil Above a)
a =	5.917	ft	(Top of Culvert Arch Height, Height at a)
b =	5.587	ft	(Height at b)
c =	4.647	ft	(Height at c)
d =	3.242	ft	(Height at d)
e =	1.583	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	677.2	plf	(Trap. EH Value at a)
EH_b =	716.8	plf	(Trap. EH Value at b)
EH_c =	829.6	plf	(Trap. EH Value at c)
EH_d =	998.2	plf	(Trap. EH Value at d)
EH_e =	1197.3	plf	(Trap. EH Value at e)
EH_f =	1387.2	plf	(Trap. EH Value at f)



Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.



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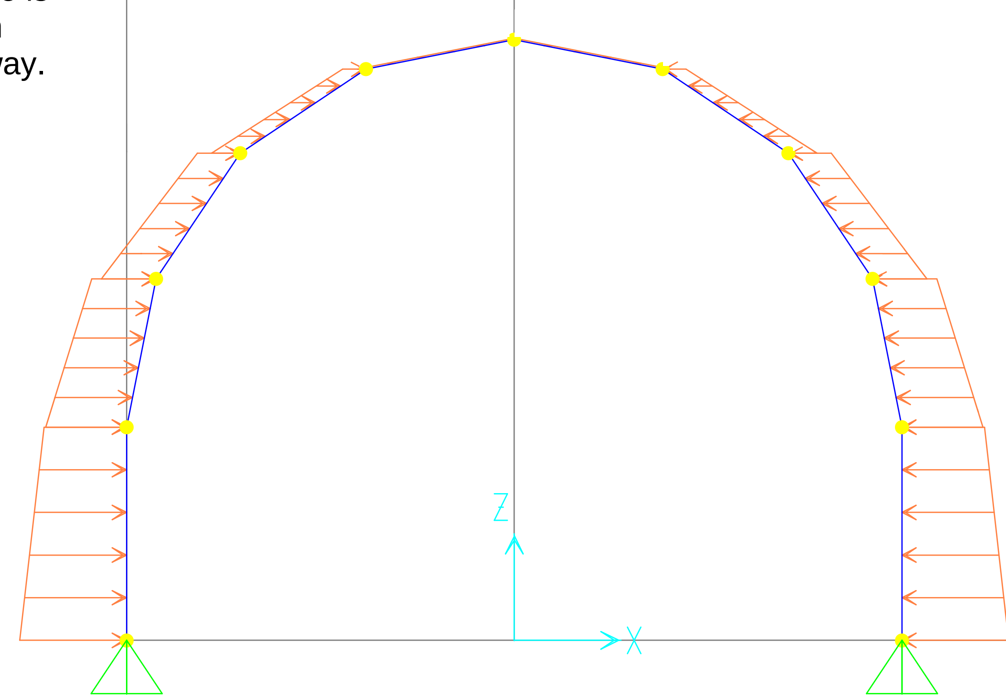
Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.



Section 13 - Frame Span Loads (EHMin) - Kip, ft, F Units

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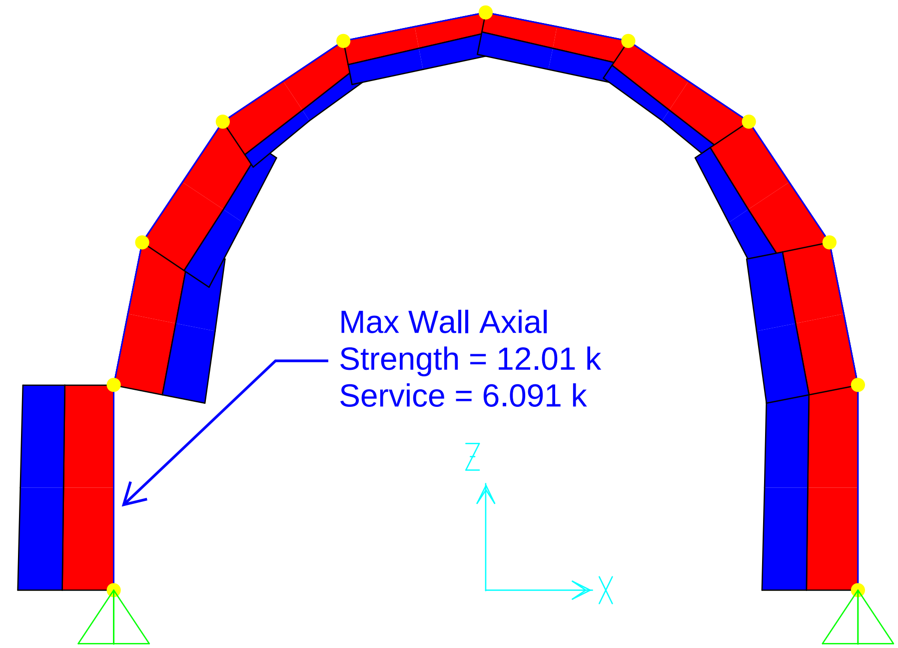

Section 13 - Axial Force Diagram

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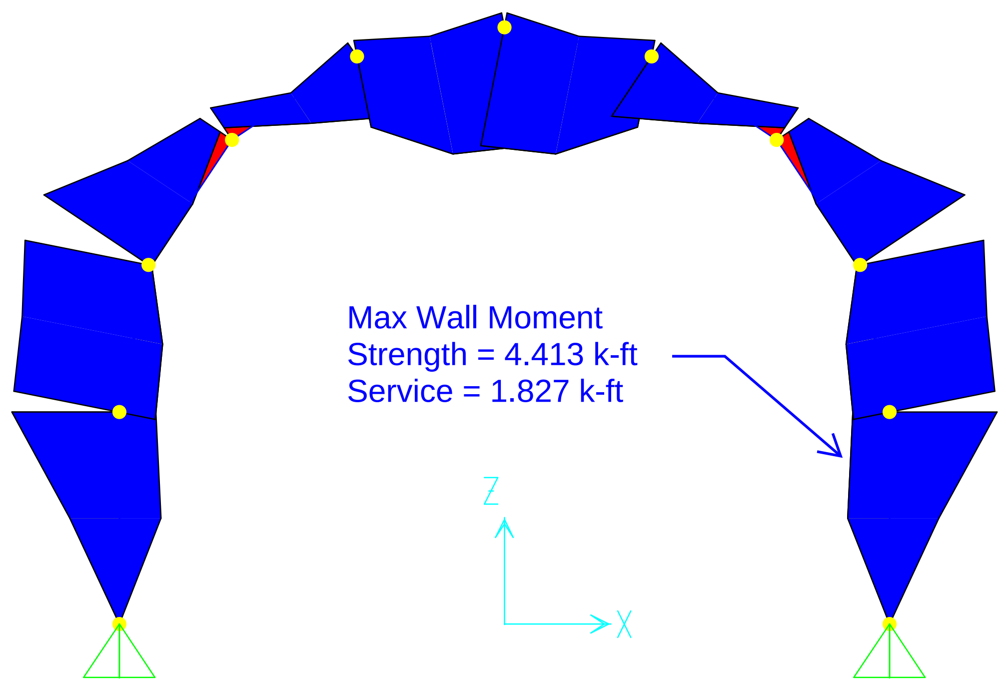

Section 13 - Moment 3-3 Diagram

BY HAK DATE 10/4/2023 — Strawberry Creek Culvert Structural Calculations — SHEET NO ______ OF ______

CHKD BY ______ DATE ______ — JOB NO. 2023025

SECTION 13 ARCH CULVERT FLEXURE CHECK

Geometry

h =	8.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	4.00	in	(Distance from extreme comp. fiber to center)
I_y =	512	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	4.000	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.48	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

$M_n = Min[\,5 * \lambda * \sqrt{f'c} * S_m;\ \ 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 3.37 k-ft

Φ = 0.6 (ACI 21.2.1)

ΦM_n = 2.02 k-ft < 4.41 k-ft = Critical Moment from SAP Model **NG**

D/C = 2.18

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

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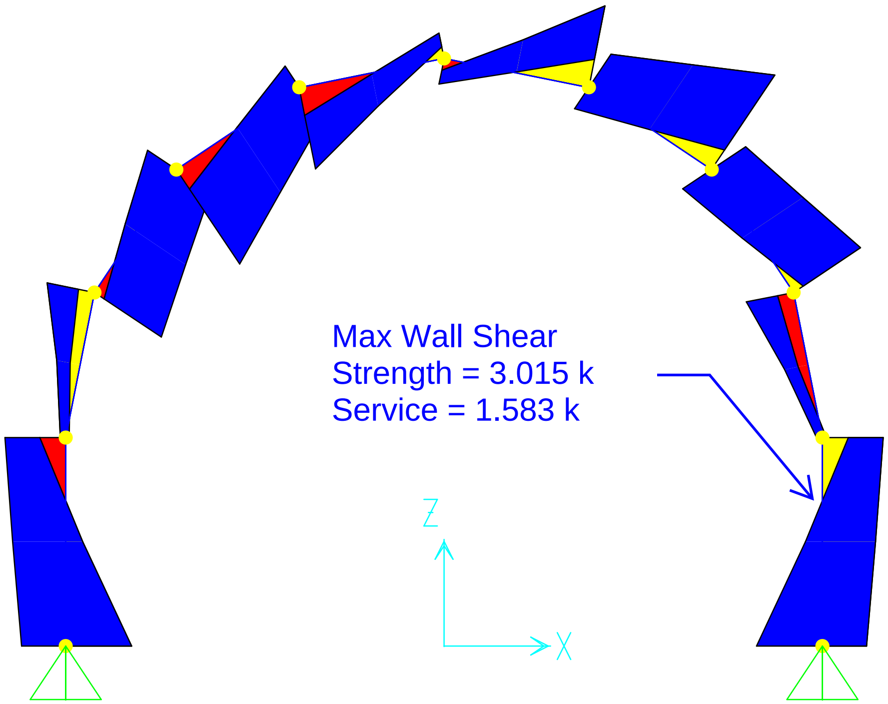


Section 13 - Shear 2-2 Diagram

SECTION 13 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

$h =$	8.00	in	(Height of section)
$b_w =$	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
$A_c =$	96.00	in^2	(Area of concrete section)

Materials

$f'_c =$	4.000	ksi	(Concrete compressive strength)	
$f_y =$	N/A	ksi	(Steel tensile strength)	
$E_c =$	3640	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
$E_s =$	N/A	ksi	(Young's Modulus of Steel)	
$f_r =$	0.48	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
$A_s =$	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

$V_{crit} =$ 3.02 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)
Concrete Shear Capacity

$$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$$ 8.10 k (ACI 14.5.5.1)

$$\phi V_n = V_c > V_U$$ (ACI 14.5.1.1)

$\phi V_n = V_c =$ 4.86 k > $V_u = V_{crit} =$ 3.02 k **OK** D/C = 0.62

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 14

CSEG

Crown Pressure
Strawberry Creek Culvert Section 14

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	7.513333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 1.051867 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 8.2 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.75 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 7.52 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 14

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 15.15 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 29.15 ft
Per AASHTO 3.6.1.2.6b-6

lw = 29.15 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 16.46 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 22.46 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 22.46 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 4 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - $\boldsymbol{P_L}$

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 8.2 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 0.99 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$ (AASHTO 3.6.1.2.6b–7) $A_{LL} = L_w * W_w$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	29.15	22.46	64	0.180
2	1	29.15	32.46	128	0.198
3	0.85	29.15	42.46	192	0.195
4	0.65	29.15	52.46	256	0.172

Crown Pressure
Strawberry Creek Culvert Section 14

Tire Distribution - Tandem

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 1.81 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 15.15 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 19.15 ft
Per AASHTO 3.6.1.2.6b-6

lw = 19.15 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 16.46 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 22.46 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 22.46 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 14

Determine the Crown Pressure - P_L

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 8.2 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 0.99 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

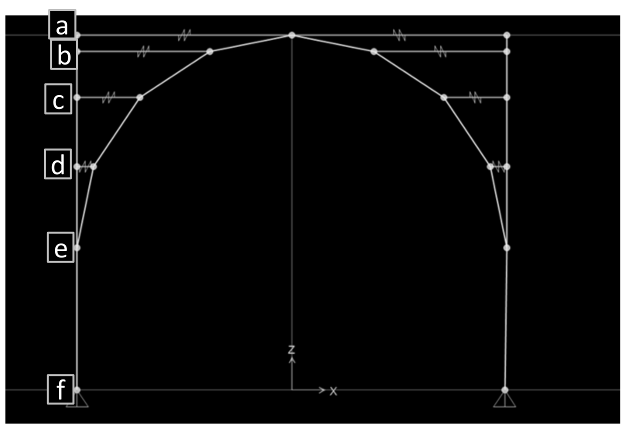
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	19.15	22.46	50	0.202
2	1	19.15	32.46	100	0.224
3	0.85	19.15	42.46	150	0.220
4	0.65	19.15	52.46	200	0.192

Max pressure is from tandem truck = 0.224 ksf

Crown Pressure
Strawberry Creek Culvert Section 14

5.) Horizontal Earth Pressure - EH Minimum

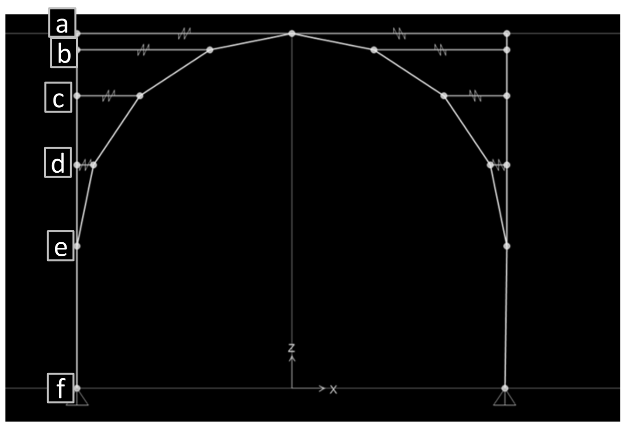
Depth =	7.513333	ft	(Soil Above a)
a =	5.292	ft	(Top of Culvert Arch Height, Height at a)
b =	4.965	ft	(Height at b)
c =	4.035	ft	(Height at c)
d =	2.642	ft	(Height at d)
e =	1.000	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	270.5	plf	(Trap. EH Value at a)
EH_b =	282.3	plf	(Trap. EH Value at b)
EH_c =	315.7	plf	(Trap. EH Value at c)
EH_d =	365.9	plf	(Trap. EH Value at d)
EH_e =	425.0	plf	(Trap. EH Value at e)
EH_f =	461.0	plf	(Trap. EH Value at f)



Crown Pressure
Strawberry Creek Culvert Section 14

6.) Horizontal Earth Pressure - EH Maximum

Depth =	7.513333	ft	(Soil Above a)
a =	5.292	ft	(Top of Culvert Arch Height, Height at a)
b =	4.965	ft	(Height at b)
c =	4.035	ft	(Height at c)
d =	2.642	ft	(Height at d)
e =	1	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	901.6	plf	(Trap. EH Value at a)
EH_b =	940.8	plf	(Trap. EH Value at b)
EH_c =	1052.4	plf	(Trap. EH Value at c)
EH_d =	1219.6	plf	(Trap. EH Value at d)
EH_e =	1416.6	plf	(Trap. EH Value at e)
EH_f =	1536.6	plf	(Trap. EH Value at f)



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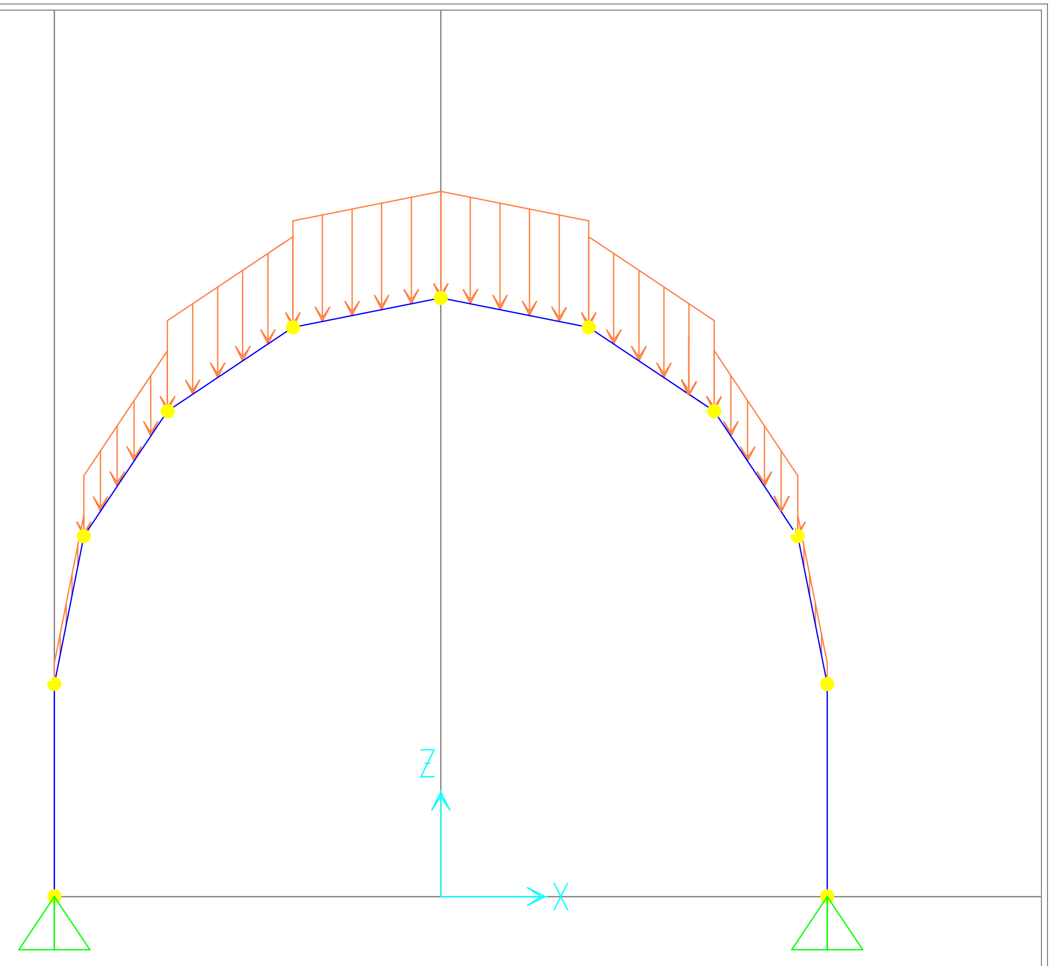
Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.



Section 14 - Frame Span Loads (EV) - Kip, ft, F Units

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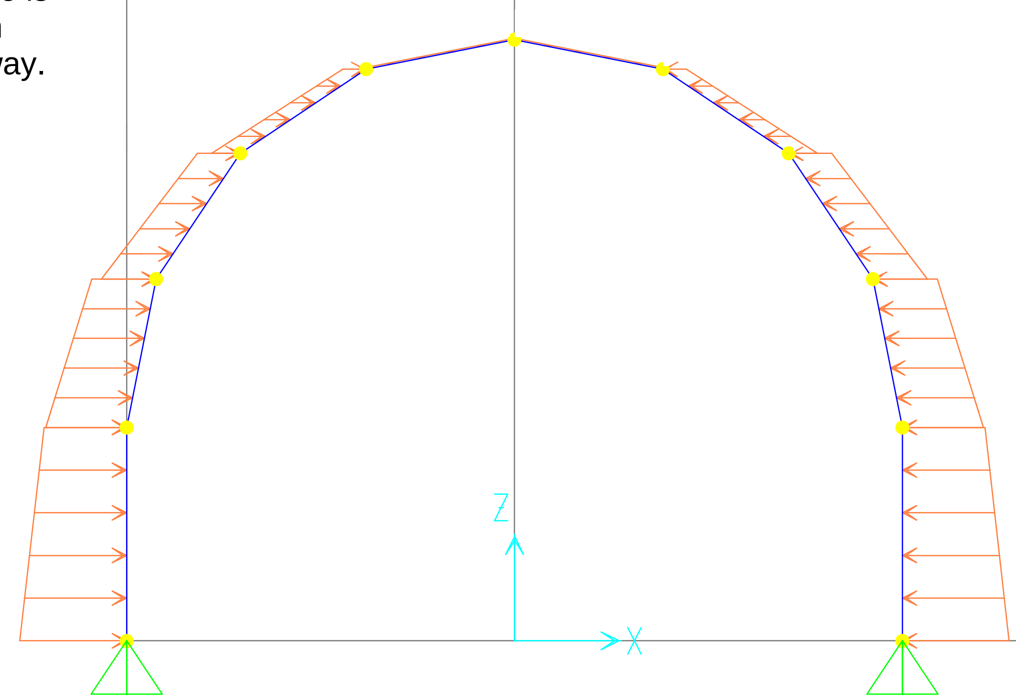

Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.

Section 14 - Frame Span Loads (EHMin) - Kip, ft, F Units

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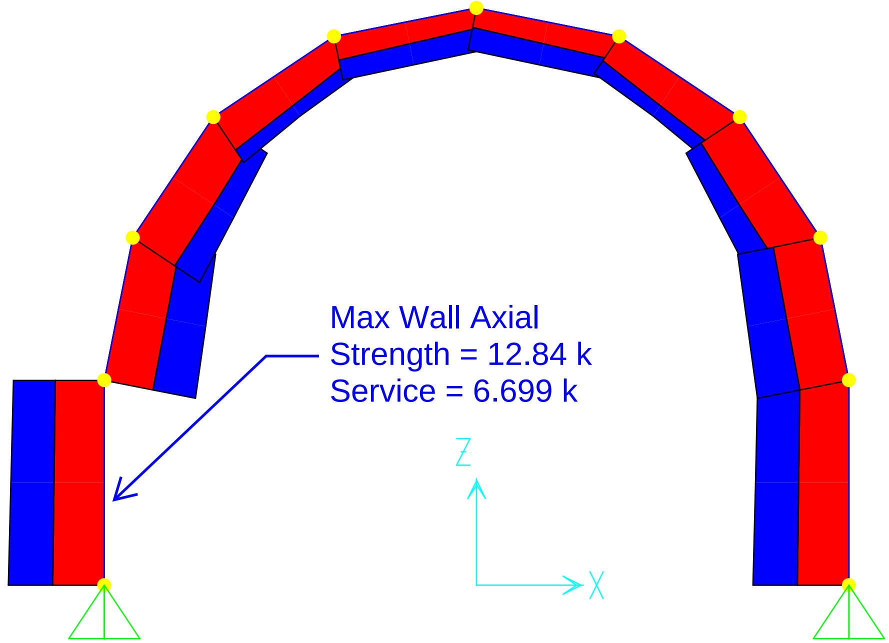

Section 14 - Axial Force Diagram

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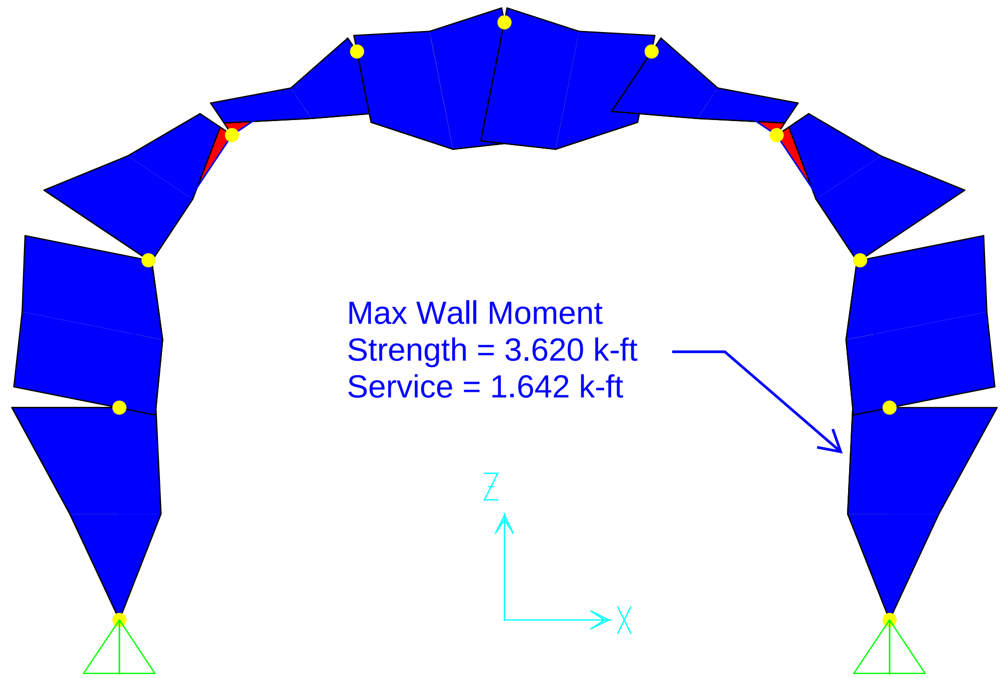

Section 14 - Moment 3-3 Diagram

SECTION 14 ARCH CULVERT FLEXURE CHECK

Geometry

h =	7.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	3.50	in	(Distance from extreme comp. fiber to center)
I_y =	343	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	4.000	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.48	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

$M_n = Min[\, 5 * \lambda * \sqrt{f'c} * S_m;\;\; 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 2.58 k-ft

Φ = 0.6 (ACI 21.2.1)

ΦM_n = 1.55 k-ft < 3.62 k-ft = Critical Moment from SAP Model **NG**

D/C = 2.34

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

SAP2000

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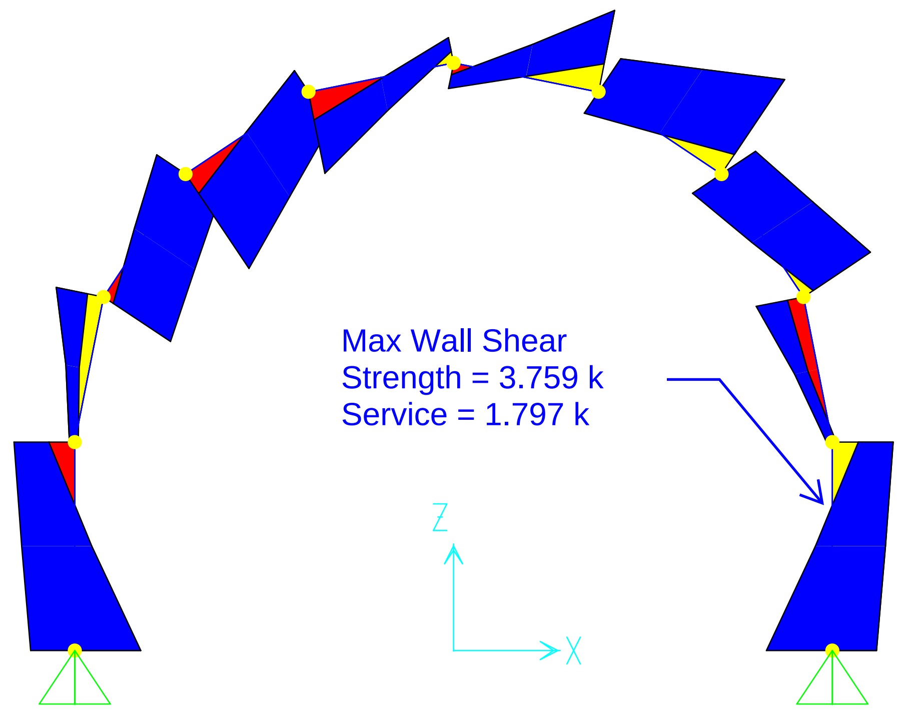


Section 14 - Shear 2-2 Diagram

BY DJF DATE 9/14/2023 | Strawberry Creek Culvert Structural Calculations | SHEET NO ____ OF ____

CHKD BY ____ DATE ____ | JOB NO. 2023025

SECTION 14 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h = 7.00 in (Height of section)
b_w = 12.00 in (Width of section)
c.c. = N/A in (Clear cover)
A_c = 84.00 in^2 (Area of concrete section)

Materials

f'_c = 4.000 ksi (Concrete compressive strength)
f_y = N/A ksi (Steel tensile strength)
E_c = 3640 ksi (Young's Modulus of Concrete) (AASHTO C5.4.2.4-3)
E_s = N/A ksi (Young's Modulus of Steel)
f_r = 0.48 ksi (Modulus of Rupture) (AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar = #5
n = 0.00 bars /FT
A_s = #N/A in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 3.76 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)
Concrete Shear Capacity

$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$ 7.08 k (ACI 14.5.5.1)

$\phi V_n = V_c > V_U$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 4.25 k > $V_u = V_{crit}$ = 3.76 k **OK** D/C = 0.88

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 17

Crown Pressure
Strawberry Creek Culvert Section 17

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	1.863333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 0.260867 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 2.5 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.55 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) =
Per AASHTO 3.6.1.2.6b-4

$$H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF} = \quad 8.49 \text{ ft}$$

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	72	in

Wheel Interaction Depth Transverse to Culvert (H int-t) =
Per AASHTO 3.6.1.2.6b-1

$$H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF} = \quad 2.56 \text{ ft}$$

Crown Pressure
Strawberry Creek Culvert Section 17

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 4.75 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 18.75 ft
Per AASHTO 3.6.1.2.6b-6
lw = 4.75 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 5.95 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 11.95 ft
Per AASHTO 3.6.1.2.6b-3
Ww = 5.95 ft

Determine Number of Wheel Loads per Lane:
Number of Wheel Loads = 1 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - $\boldsymbol{P_L}$

Wheel Load = 16 kips
w_{Lane} = 0.64 klf — Per AASHTO 3.6.1.2.4
Lane Width = 10 ft — Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 2.5 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) — Per AASHTO 3.6.2.2
IM = 1.23 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b–7) $$A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	4.75	5.95	16	0.896
2	1	4.75	15.95	32	0.581
3	0.85	4.75	25.95	48	0.469
4	0.65	4.75	35.95	64	0.362

Crown Pressure
Strawberry Creek Culvert Section 17

<u>Tire Distribution - Tandem</u>
Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft — Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 2.04 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 72 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.56 ft
Per AASHTO 3.6.1.2.6b-1

<u>Determine Live Load Patch Length at Depth H - lw</u>

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 4.75 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 8.75 ft
Per AASHTO 3.6.1.2.6b-6

lw = 8.75 ft

<u>Determine Live Load Patch Width at Depth H - Ww</u>

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 5.95 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 11.95 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 5.95 ft

<u>Determine Number of Wheel Loads</u>

Number of Wheel Loads = 2 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 17

Determine the Crown Pressure - $\boldsymbol{P_L}$

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 2.5 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.23 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b–7) $$A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	8.75	5.95	25	0.770
2	1	8.75	15.95	50	0.503
3	0.85	8.75	25.95	75	0.408
4	0.65	8.75	35.95	100	0.317

Max pressure is from HL-93 truck = 0.896 ksf

Strawberry Creek Culvert
Section 17 -RCP Analysis

Reinforced Concrete Pipe Structural Analysis:
Determine Pipe Structural Demands:

**Assume Type 4 Installation

Moment:	Mi = Cmi * Wi * Dm / 2	(Nebraska Department of Roads)
Thrust:	Ni = Cni * Wi	(Nebraska Department of Roads)
Shear:	Vi = Cvi * Wi	(Nebraska Department of Roads)

Crown Pressures

Pipe Diameter = Dm =	90	in	
Unfactored DC Crown Pressure =	0.093	ksf	(Per Crown Pressure Calculations)
Unfactored EV Crown Pressure =	0.27	ksf	(Per Crown Pressure Calculations)
Unfactored DW Crown Pressure =	0.035	ksf	(Per Crown Pressure Calculations)
Unfactored LL Crown Pressure =	0.896	ksf	(Per Crown Pressure Calculations)

Invert Demands:

DC:	Cmi =	0.235		Cni =	0.077	(Nebraska Department of Roads)
	M_{DC} =	0.081956	k-ft/ft	N_{DC} =	0.007161	kip/ft
EV:	Cmi =	0.191		Cni =	0.128	(Nebraska Department of Roads)
	M_{EV} =	0.193388	k-ft/ft	N_{EV} =	0.03456	kip/ft
DW:	Cmi =	0.235		Cni =	0.077	(Nebraska Department of Roads)
	M_{DW} =	0.030844	k-ft/ft	N_{DW} =	0.002695	kip/ft
LL:	Cmi =	0.237		Cni =	0.152	(Nebraska Department of Roads)
	M_{LL} =	0.79632	k-ft/ft	N_{LL} =	0.136192	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Mu =	1.832352	k-ft/ft	Nu =	0.30317 k/ft
$M_{Service}$ =	1.102508	k-ft/ft	$N_{Service}$ =	0.180608 k/ft

Crown Demands:

DC:	Cmi =	0.079		Cni =	-0.077	(Nebraska Department of Roads)
	M_{DC} =	0.027551	k-ft/ft	N_{DC} =	-0.00716	kip/ft
EV:	Cmi =	0.118		Cni =	0.079	(Nebraska Department of Roads)
	M_{EV} =	0.119475	k-ft/ft	N_{EV} =	0.02133	kip/ft
DW:	Cmi =	0.079		Cni =	-0.077	(Nebraska Department of Roads)
	M_{DW} =	0.010369	k-ft/ft	N_{DW} =	-0.0027	kip/ft
LL:	Cmi =	0.255		Cni =	0.114	(Nebraska Department of Roads)
	M_{LL} =	0.8568	k-ft/ft	N_{LL} =	0.102144	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Mu =	1.73	k-ft/ft	Nu =	0.20 k/ft
$M_{Service}$ =	1.01	k-ft/ft	$N_{Service}$ =	0.11 k/ft

Strawberry Creek Culvert
Section 17 -RCP Analysis

Reinforced Concrete Pipe Structural Analysis:
Determine Pipe Structural Demands:

Springline Demands:

DC:	Cmi =	-0.101		Cni =	0.287	(Nebraska Department of Roads)
	M_{DC} =	-0.035	k-ft/ft	N_{DC} =	0.027	kip/ft
EV:	Cmi =	-0.127		Cni =	0.504	(Nebraska Department of Roads)
	M_{EV} =	-0.129	k-ft/ft	N_{EV} =	0.136	kip/ft
DW:	Cmi =	-0.101		Cni =	0.287	(Nebraska Department of Roads)
	M_{DW} =	-0.013	k-ft/ft	N_{DW} =	0.010	kip/ft
LL:	Cmi =	-0.168		Cni =	0.495	(Nebraska Department of Roads)
	M_{LL} =	-0.564	k-ft/ft	N_{LL} =	0.444	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Mu =	-1.24	k-ft/ft	Nu =	1.03	k/ft
$M_{Service}$ =	-0.74	k-ft/ft	$N_{Service}$ =	0.62	k/ft

Critical Shear Invert Demands:

DC:	Cni =	0.188		Cvi =	0.431	(Nebraska Department of Roads)
	N_{DC} =	0.066	k-ft/ft	V_{DC} =	0.040	kip/ft
EV:	Cni =	0.211		Cvi =	0.309	(Nebraska Department of Roads)
	N_{EV} =	0.214	k-ft/ft	V_{EV} =	0.083	kip/ft
DW:	Cni =	0.188		Cvi =	0.431	(Nebraska Department of Roads)
	N_{DW} =	0.025	k-ft/ft	V_{DW} =	0.015	kip/ft
LL:	Cni =	0.229		Cvi =	0.305	(Nebraska Department of Roads)
	N_{LL} =	0.769	k-ft/ft	V_{LL} =	0.273	kip/ft

Factored Demands: (Strength = 1.25DC + 1.5DW + 1.5EV + 1.75LL; Service = 1.0(DC + DW + EV + LL)

Nu =	1.79	k/ft	Vu =	0.68	k/ft
$N_{Service}$ =	1.07	k/ft	$V_{Service}$ =	0.41	k/ft

Strawberry Creek Culvert
Section 17 -RCP Analysis

Reinforced Concrete Pipe Structural Analysis:

Determine Flexural Resistance - Circumferential Reinforcement

As Required = $A_s \geq \frac{g\phi d - N_u - \sqrt{g\left[g(\phi d)^2 - N_u(2\phi d - h) - 2M_u\right]}}{f_y}$ (AASHTO LRFD 12.10.4.2.4a-1)

g = 0.85 * b * f'c =	101.59	k/in	(AASHTO LRFD 12.10.4.2.4a-2)
b =	12	in	
f'c =	9.96	ksi	
Nu =	1.79	k/ft	
Mu =	21.99	k-in/ft	
d =	5	in	
h =	10	in	
fy =	40	ksi	
As Provided =	0.31	in^2/ft	(#5 @ 12")
Phi =	0.9		

As Required = 0.073 in^2/ft < As Provided = 0.31 in^2/ft

Determine Minimum Inside Layer Reinforcement

$A_s \geq \frac{(S_i + h)^2}{1{,}000 f_y} \geq 0.07$ = 0.250 in^2/ft (AASHTO LRFD 12.10.4.2.4b-1)

Si =	90	in
h =	10	in
fy =	40	ksi
As Provided =	0.31	in^2/ft

As Required = 0.250 in^2/ft < As Provided = 0.31 in^2/ft

Determine Minimum Outside Layer Reinforcement

$A_s \geq 0.60\frac{(S_i + h)^2}{1{,}000 f_y} \geq 0.07$ = 0.150 in^2/ft (AASHTO LRFD 12.10.4.2.4b-1)

Si =	90	in
h =	10	in
fy =	40	ksi
As Provided =	0.310	in^2/ft

As Required = 0.150 in^2/ft < As Provided = 0.31 in^2/ft

Strawberry Creek Culvert
Section 17 -RCP Analysis

Reinforced Concrete Pipe Structural Analysis:
Check Crack Width Control

If N_s is compressive, it is taken as positive and:

$$F_{cr} = \frac{B_1}{30\phi d A_s}\left[\frac{M_s + N_s\left(d - \frac{h}{2}\right)}{ij} - 0.0316 C_1 b h^2 \sqrt{f'_c}\right]$$ = -10.9017 (AASHTO LRFD 12.10.4.2.4d-1)

If N_s is tensile, it is taken as negative and:

$$F_{cr} = \frac{B_1}{30 d A_s \phi}\left(1.1 M_s - 0.6 N_s d - 0.0316 C_1 b h^2 \sqrt{f'_c}\right)$$ = 0 (AASHTO LRFD 12.10.4.2.4d-2)

$M_{Service}$ =	13.23	k-in/ft
$N_{Service}$ + =	1.07	k/ft
$N_{Service}$ - =	0.11	k/ft
d =	5	in
h =	10	in
f'c =	9.96	ksi
As Provided =	0.310	in^2/ft
Phi =	0.9	
C_1 =	1.9	

Compression:

$$e = \frac{M_s}{N_s} + d - \frac{h}{2}$$ = 12.33 in

$$j = 0.74 + 0.1\frac{e}{d} \le 0.9$$ = 0.99

$$i = \frac{1}{\left(1 - \frac{jd}{e}\right)}$$ = 1.67

$$B_1 = \left(\frac{t_b S_\ell}{2n}\right)^{\frac{1}{3}}$$ = 2.08

t_b =	1.5	in
S_L =	12	in
n =	1	

Fcr = -10.90 < 1

Average cracking width NOT expected to exceed 0.01in.

Strawberry Creek Culvert
Section 17 -RCP Analysis

Reinforced Concrete Pipe Structural Analysis:

Determine Shear Resistance without Stirrups

$$V_n = 0.0316bdF_{vp}\sqrt{f'_c}(1.1+63\rho)\left(\frac{F_d F_n}{F_c}\right)$$ = 9.17 k/ft (AASHTO LRFD 12.10.4.2.5-2)

Rho = As / (b*d) =	0.0052		(AASHTO LRFD 12.10.4.2.5-3)
b =	12	in	
d =	5	in	
As =	0.310	in^2/ft	
Fd = 0.8 + (1.6/d) =	1.12		(AASHTO LRFD 12.10.4.2.5-4)
If Nu is compressive, Fn = 1 + (Nu/24h) =	1.007		(AASHTO LRFD 12.10.4.2.5-6)
If Nu is tensile, Fn = 1 + (Nu/6h) =	1.030		(AASHTO LRFD 12.10.4.2.5-7)
Fn =	1.007		
Fc = 1 + (d/2r) =	1.05		(AASHTO LRFD 12.10.4.2.5-8)
Radius = r =	50	in	
Fvp =	1.0		(AASHTO LRFD 12.10.4.2.3)
Phi Vn =	8.25	k/ft	
Phi =	0.9		
Vu =	0.68	k/ft	
D/C =	**0.08**		

Determine Shear Resistance With Stirrups

Radial Tension

$$A_{vr} = \frac{1.1s_v(M_u - 0.45N_u\phi_r d)}{f_y r_s \phi_r d}$$ = 0.007578 in^2/ft (AASHTO LRFD 12.10.4.2.6-1)

Mu =	21.99	k-in/ft	
Nu =	1.79	k/ft	
d =	5	in	
fy =	40	ksi	
rs =	50	in	
Phir =	0.9		
sv provided =	12	in	
sv = min(0.75Phird ; sv Provided) =	3.38	in	
Av Provided =	0.31	in^2/ft	(#5 @ 12")

Av Required = 0.008 in^2/ft < Av Provided = 0.31 in^2/ft

Reinforced Concrete Pipe Structural Analysis:

Determine Shear Resistance With Stirrups

Shear Resistance

$$A_{vs} = \frac{1.1 s_v}{f_y \phi_v d}\left(V_u F_c - V_c\right) + A_{vr}$$ = -0.108837 in²/ft (AASHTO LRFD 12.10.4.2.6-1)

Vu =	0.68	k/ft	
sv = min(0.75Phivd ; sv Provided) =	3.38	in	
d =	5	in	
Avr =	0.008	in^2/ft	
Fc =	1.05		
Phiv =	0.9		
Av Provided =	0.31	in^2/ft	(#5 @ 12")

$$V_c = \frac{4V_r}{\frac{M_{nu}}{V_u d} + 1} \le 0.0633\phi_v b d\sqrt{f_c'}$$ = 6.35 k/ft (AASHTO LRFD 12.10.4.2.6-1)

$$M_{nu} = M_u - N_u\left[\frac{(4h - d)}{8}\right]$$ = 14.17 k-in/ft (AASHTO LRFD 12.10.4.2.5-9)

Vr = 8.25 k/ft

Av Required = -0.109 in^2/ft < Av Provided = 0.31 in^2/ft

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 18

Crown Pressure
Strawberry Creek Culvert Section 18

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight= 140 pcf
AC Pavement Depth= 8 in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight= 140 pcf
Repavement Depth= 3 in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert= 5.313333 ft
Soil Pressure = 140 pcf

EV = Soil Cover Above Culvert * Soil Pressure = 0.743867 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 6.0 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.75 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 7.52 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 18

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 11.30 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then , $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 25.30 ft
Per AASHTO 3.6.1.2.6b-6

lw = 11.30 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 12.61 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 18.61 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 18.61 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 2 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - $\boldsymbol{P_L}$

Wheel Load = 16 kips
w_{Lane} = 0.64 klf — Per AASHTO 3.6.1.2.4
Lane Width = 10 ft — Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 6.0 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) — Per AASHTO 3.6.2.2
IM = 1.08 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b–7) $$A_{LL} = L_w * W_w$$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	11.30	18.61	32	0.262
2	1	11.30	28.61	64	0.278
3	0.85	11.30	38.61	96	0.267
4	0.65	11.30	48.61	128	0.228

Crown Pressure
Strawberry Creek Culvert Section 18

Tire Distribution - Tandem

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 1.81 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 11.30 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 15.30 ft
Per AASHTO 3.6.1.2.6b-6

lw = 15.30 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 12.61 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 18.61 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 18.61 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:
$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 18

Determine the Crown Pressure - P_L

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 6.0 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.08 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

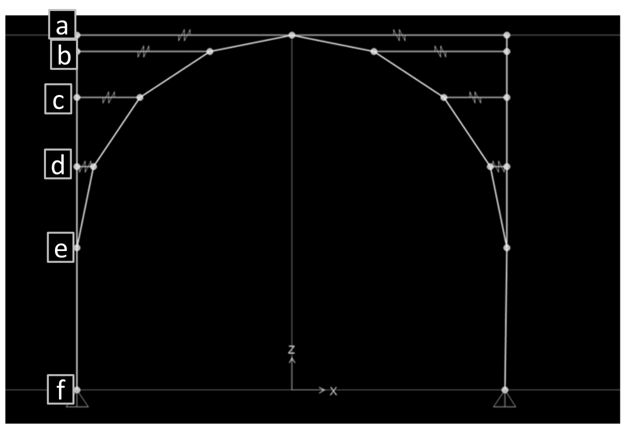
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	15.30	18.61	50	0.292
2	1	15.30	28.61	100	0.311
3	0.85	15.30	38.61	150	0.298
4	0.65	15.30	48.61	200	0.253

Max pressure is from tandem truck = 0.311 ksf

Crown Pressure
Strawberry Creek Culvert Section 18

5.) Horizontal Earth Pressure - EH Minimum

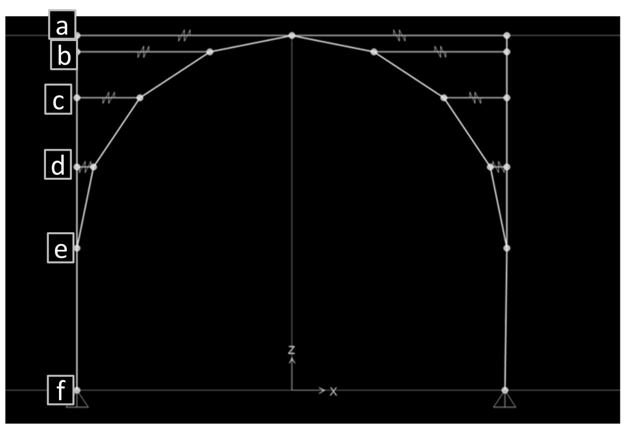
Depth =	5.313333	ft	(Soil Above a)
a =	6.000	ft	(Top of Culvert Arch Height, Height at a)
b =	5.664	ft	(Height at b)
c =	4.706	ft	(Height at c)
d =	3.274	ft	(Height at d)
e =	1.583	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	191.3	plf	(Trap. EH Value at a)
EH_b =	203.4	plf	(Trap. EH Value at b)
EH_c =	237.9	plf	(Trap. EH Value at c)
EH_d =	289.4	plf	(Trap. EH Value at d)
EH_e =	350.3	plf	(Trap. EH Value at e)
EH_f =	407.3	plf	(Trap. EH Value at f)



Crown Pressure
Strawberry Creek Culvert Section 18

6.) Horizontal Earth Pressure - EH Maximum

Depth =	5.313333	ft	(Soil Above a)
a =	6	ft	(Top of Culvert Arch Height, Height at a)
b =	5.664	ft	(Height at b)
c =	4.706	ft	(Height at c)
d =	3.274	ft	(Height at d)
e =	1.583	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	637.6	plf	(Trap. EH Value at a)
EH_b =	677.9	plf	(Trap. EH Value at b)
EH_c =	792.9	plf	(Trap. EH Value at c)
EH_d =	964.7	plf	(Trap. EH Value at d)
EH_e =	1167.6	plf	(Trap. EH Value at e)
EH_f =	1357.6	plf	(Trap. EH Value at f)



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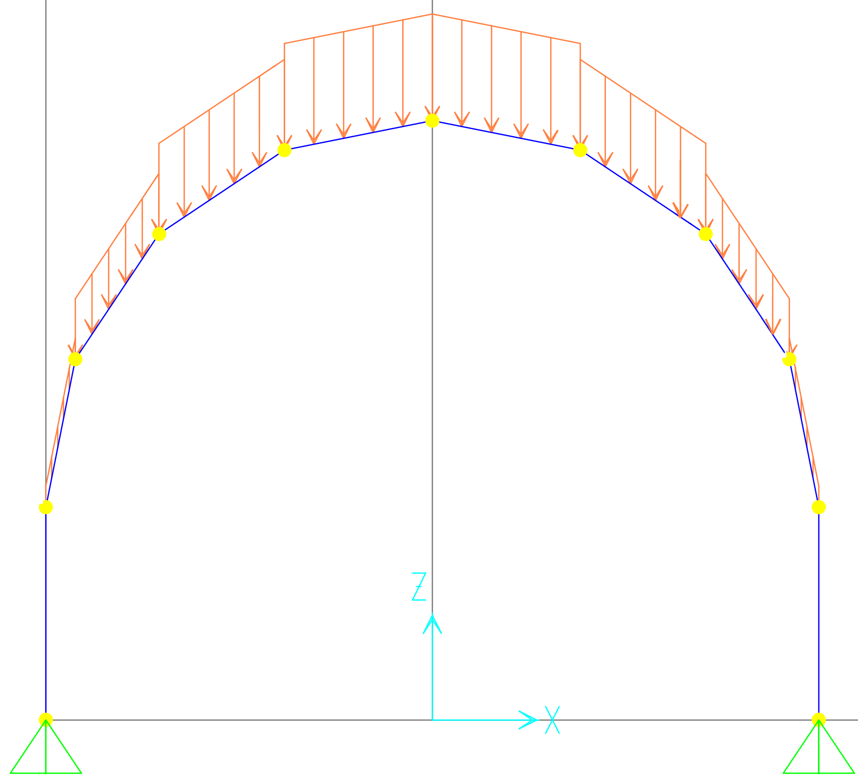
Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.



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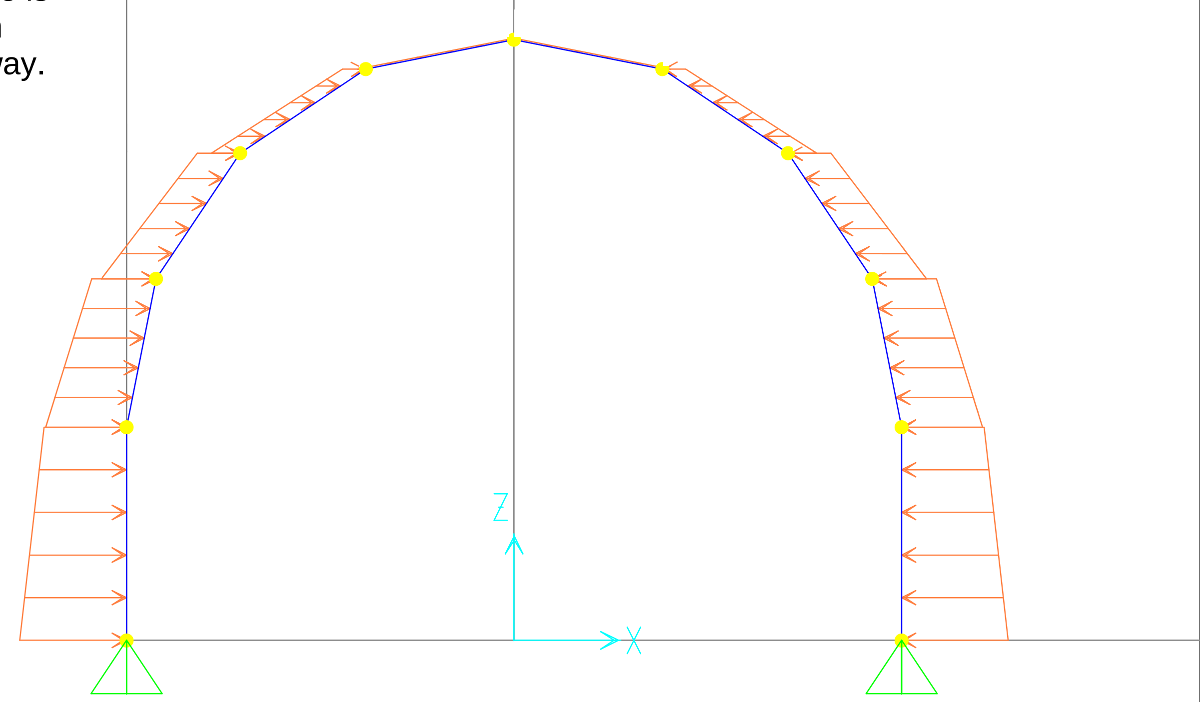

Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.

Section 18 - Frame Span Loads (EHMin) - Kip, ft, F Units

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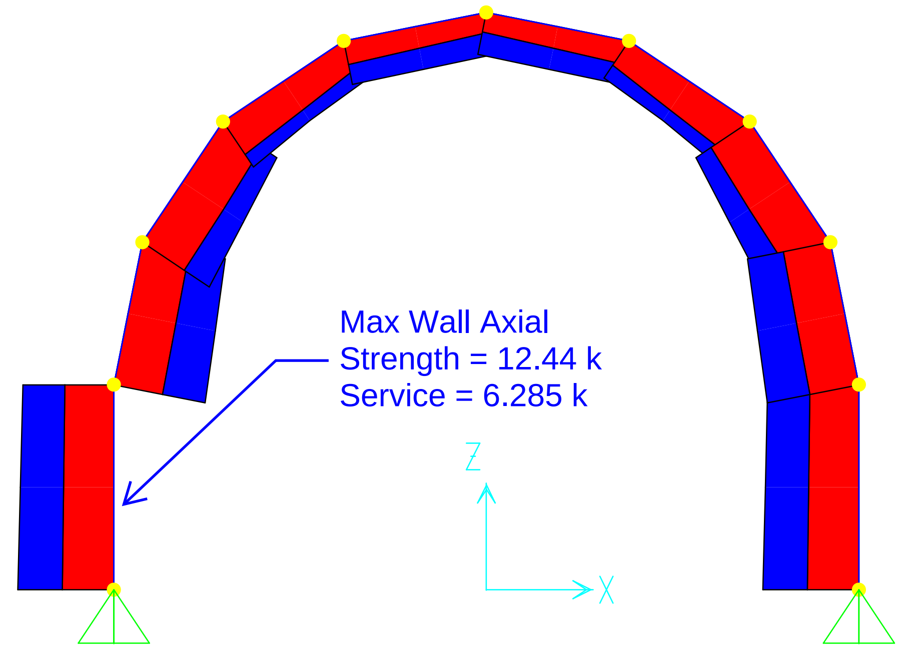

Section 18 - Axial Force Diagram

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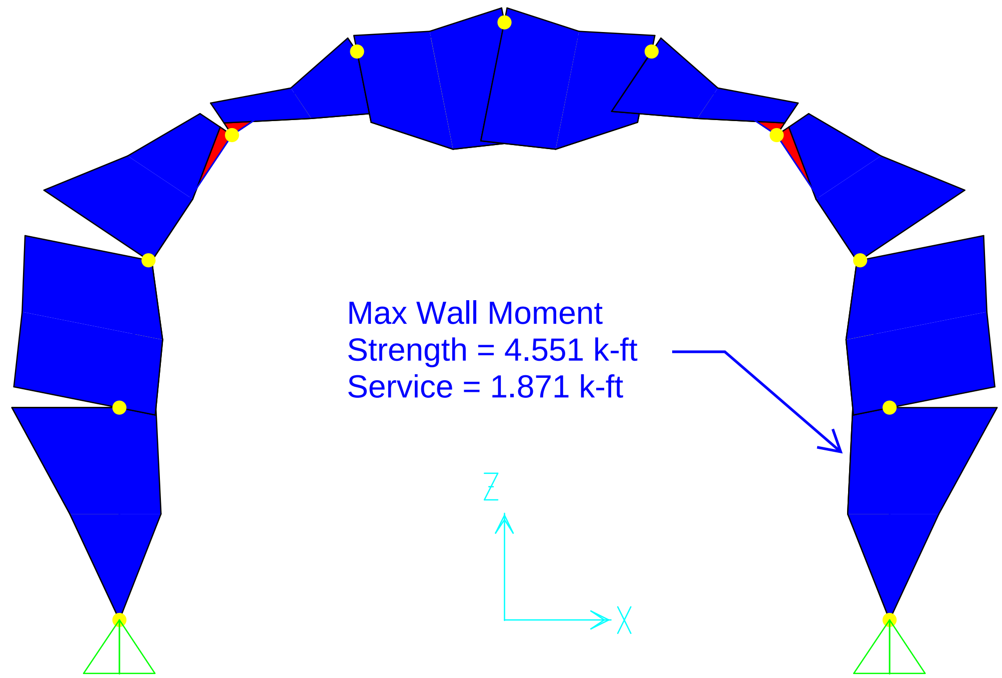

Section 18 - Moment 3-3 Diagram

SECTION 18 ARCH CULVERT FLEXURE CHECK

Geometry

h =	10.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	5.00	in	(Distance from extreme comp. fiber to center)
I_y =	1000	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	2.180	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.35	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

M_n = $Min[\,5 * \lambda * \sqrt{f'c} * S_m;\;\; 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 3.89 k-ft

Φ = 0.6 (ACI 21.2.1)

ΦM_n = 2.33 k-ft < 4.55 k-ft = Critical Moment from SAP Model **NG**

D/C = 1.95

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

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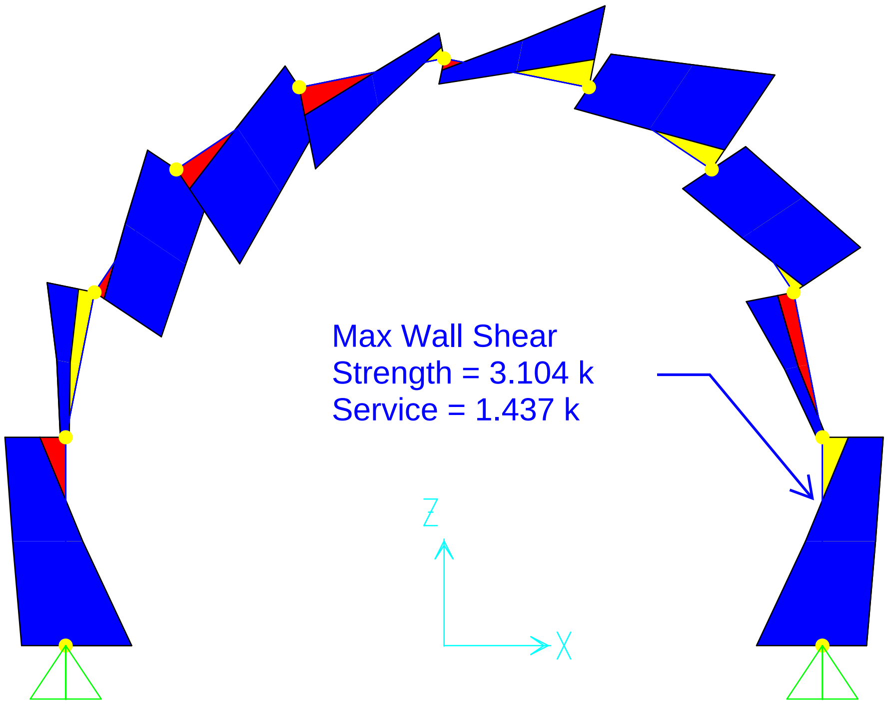


Section 18 - Shear 2-2 Diagram

SECTION 18 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h =	10.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	120.00	in^2	(Area of concrete section)

Materials

f'_c =	2.180	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	2687	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.35	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 3.10 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)
Concrete Shear Capacity

$$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$$ 7.47 k (ACI 14.5.5.1)

$$\phi V_n = V_c > V_U$$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 4.48 k > $V_u = V_{crit}$ = 3.10 k **OK** D/C = 0.69

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 19

CSEG

Crown Pressure
Strawberry Creek Culvert Section 19

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	5.063333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 0.708867 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 5.7 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.75 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) =
Per AASHTO 3.6.1.2.6b-4

$$H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF} = 7.52 \text{ ft}$$

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	96	in

Wheel Interaction Depth Transverse to Culvert (H int-t) =
Per AASHTO 3.6.1.2.6b-1

$$H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF} = 2.20 \text{ ft}$$

Crown Pressure
Strawberry Creek Culvert Section 19

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 10.86 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 24.86 ft
Per AASHTO 3.6.1.2.6b-6

lw = 10.86 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 12.17 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 18.17 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 18.17 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 2 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - P_L

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 5.7 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 1.09 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$P_L = \frac{P(1 + \frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$ (AASHTO 3.6.1.2.6b–7) $A_{LL} = L_w * W_w$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	10.86	18.17	32	0.277
2	1	10.86	28.17	64	0.293
3	0.85	10.86	38.17	96	0.279
4	0.65	10.86	48.17	128	0.238

Crown Pressure
Strawberry Creek Culvert Section 19

<u>Tire Distribution - Tandem</u>

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft — Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 1.81 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

<u>Determine Live Load Patch Length at Depth H - lw</u>

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 10.86 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 14.86 ft
Per AASHTO 3.6.1.2.6b-6

lw = 14.86 ft

<u>Determine Live Load Patch Width at Depth H - Ww</u>

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 12.17 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 18.17 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 18.17 ft

<u>Determine Number of Wheel Loads</u>

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 19

Determine the Crown Pressure - P_L

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 5.7 ft

Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2

IM = 1.09 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

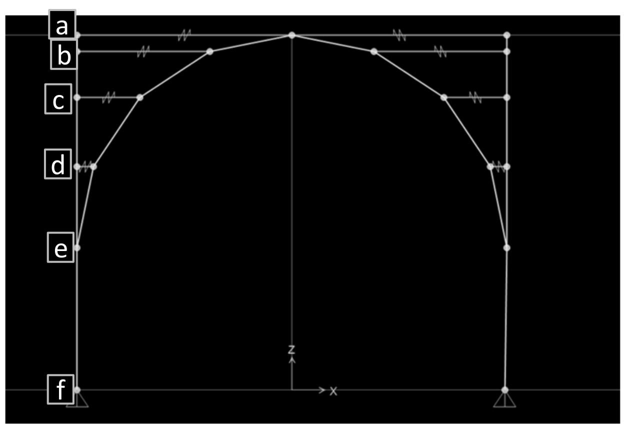
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	14.86	18.17	50	0.307
2	1	14.86	28.17	100	0.325
3	0.85	14.86	38.17	150	0.310
4	0.65	14.86	48.17	200	0.263

Max pressure is from tandem truck = 0.325 ksf

Crown Pressure
Strawberry Creek Culvert Section 19

5.) Horizontal Earth Pressure - EH Minimum

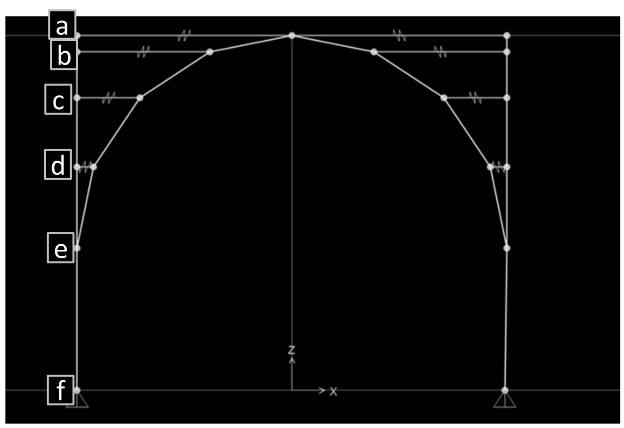
Depth =	5.063333	ft	(Soil Above a)
a =	6.979	ft	(Top of Culvert Arch Height, Height at a)
b =	6.643	ft	(Height at b)
c =	5.686	ft	(Height at c)
d =	4.253	ft	(Height at d)
e =	2.563	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	182.3	plf	(Trap. EH Value at a)
EH_b =	194.4	plf	(Trap. EH Value at b)
EH_c =	228.8	plf	(Trap. EH Value at c)
EH_d =	280.4	plf	(Trap. EH Value at d)
EH_e =	341.3	plf	(Trap. EH Value at e)
EH_f =	433.5	plf	(Trap. EH Value at f)



Crown Pressure
Strawberry Creek Culvert Section 19

6.) Horizontal Earth Pressure - EH Maximum

Depth =	5.063333	ft	(Soil Above a)
a =	6.979	ft	(Top of Culvert Arch Height, Height at a)
b =	6.643	ft	(Height at b)
c =	5.686	ft	(Height at c)
d =	4.253	ft	(Height at d)
e =	2.563	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	607.6	plf	(Trap. EH Value at a)
EH_b =	647.9	plf	(Trap. EH Value at b)
EH_c =	762.8	plf	(Trap. EH Value at c)
EH_d =	934.7	plf	(Trap. EH Value at d)
EH_e =	1137.5	plf	(Trap. EH Value at e)
EH_f =	1445.1	plf	(Trap. EH Value at f)



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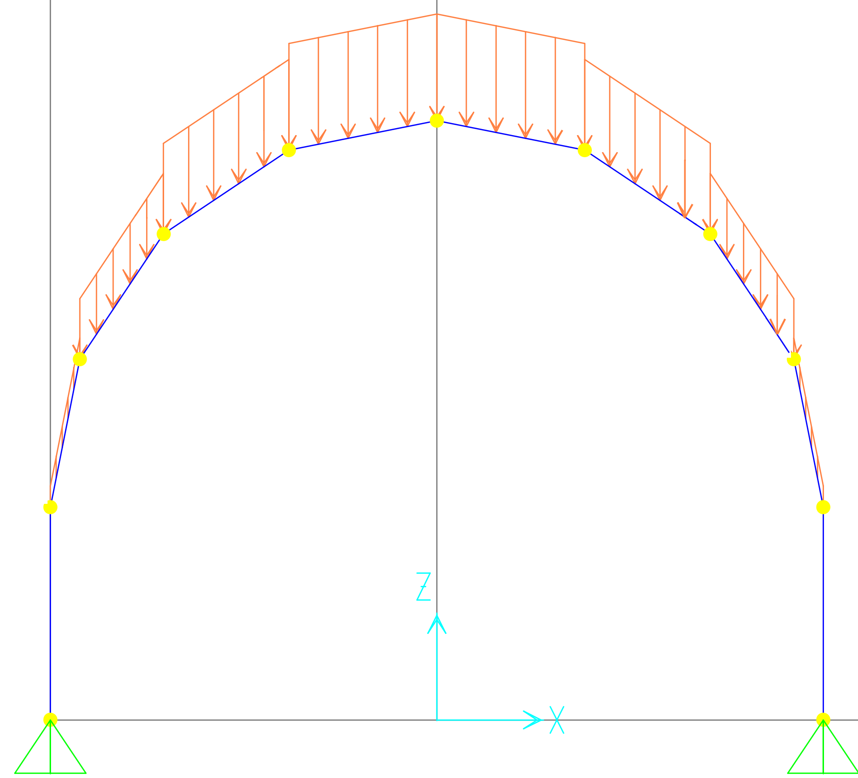

Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.

Section 19 - Frame Span Loads (EV) - Kip, ft, F Units

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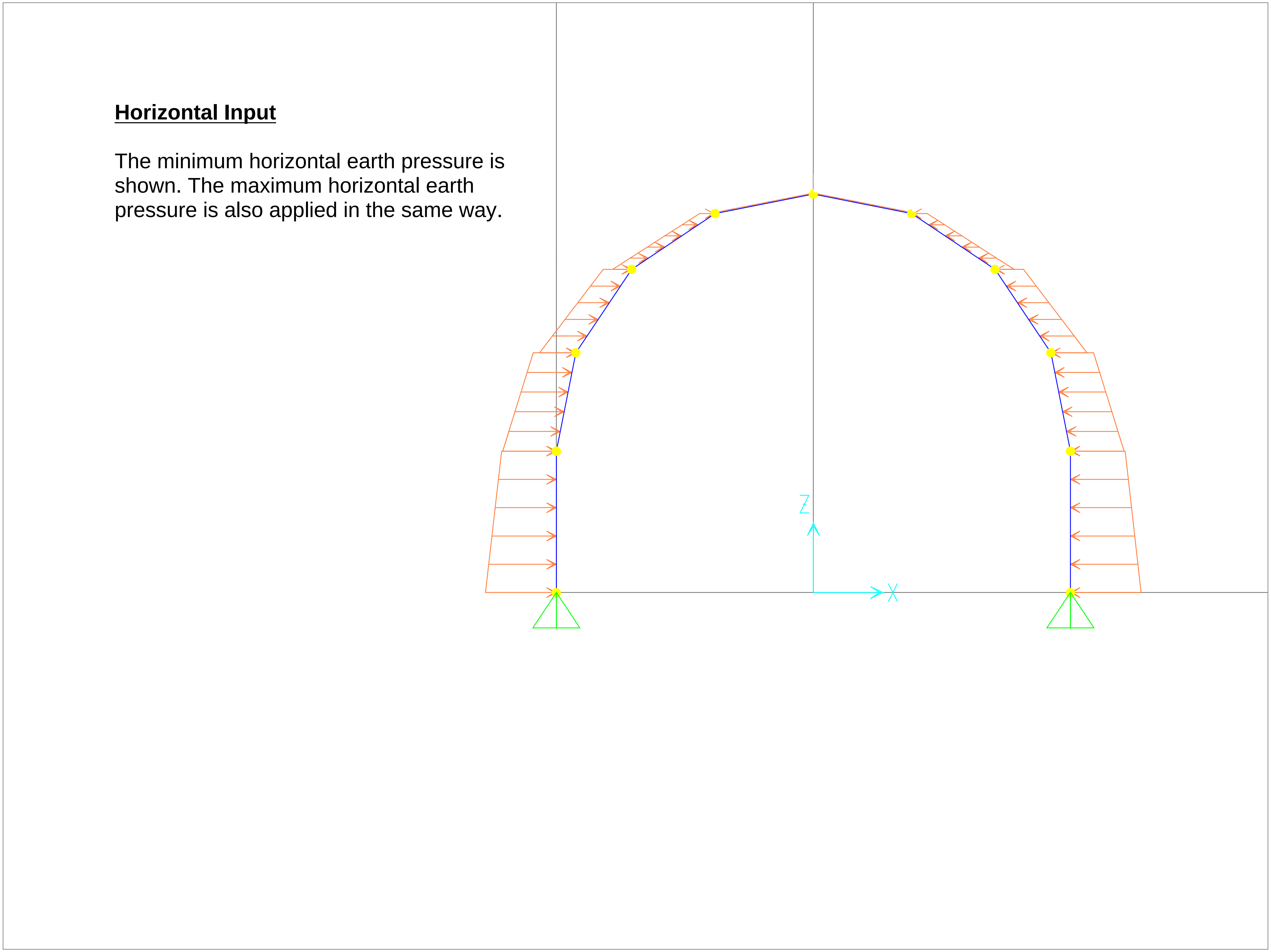

Section 19 - Frame Span Loads (EHMin) - Kip, ft, F Units

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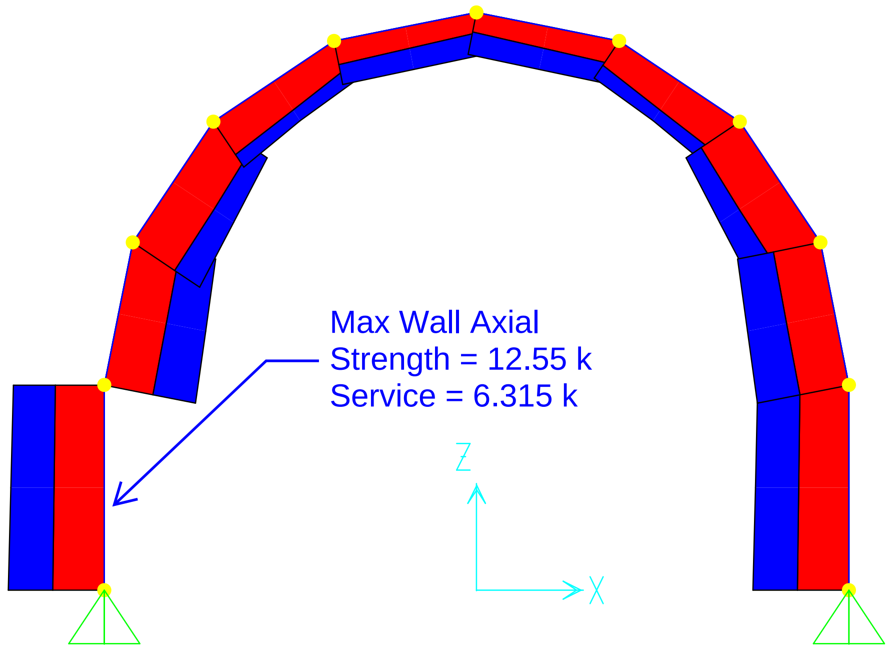

Section 19 - Axial Force Diagram

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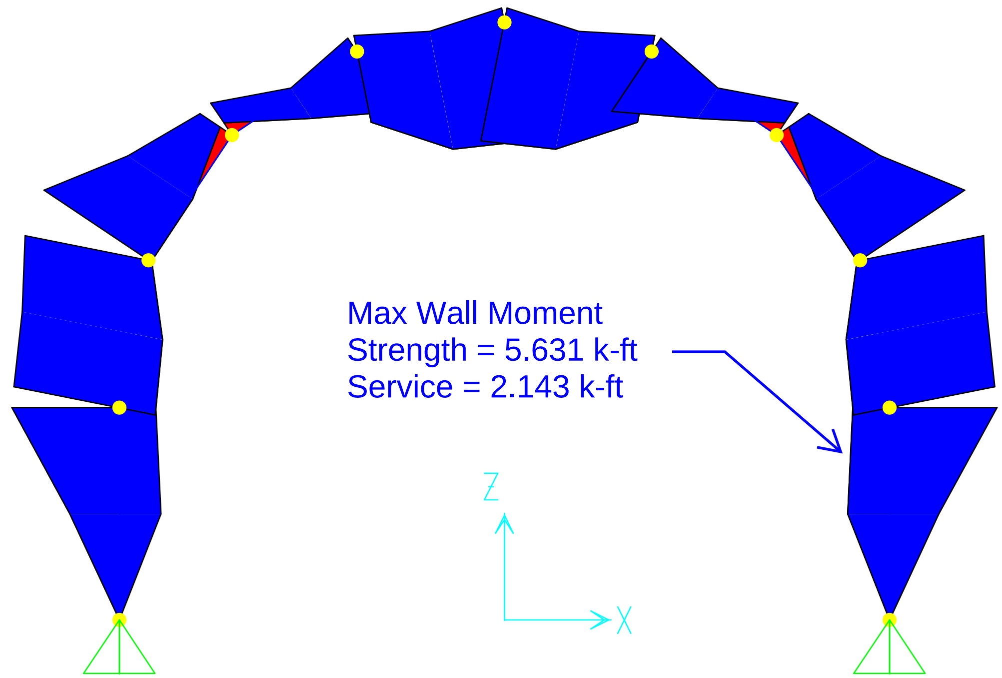


Section 19 - Moment 3-3 Diagram

BY HAK DATE 10/4/2023 | Strawberry Creek Culvert Structural Calculations | SHEET NO ______ OF ______

CHKD BY ______ DATE ______ | JOB NO. 2023025

SECTION 19 ARCH CULVERT FLEXURE CHECK

Geometry

h =	10.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	5.00	in	(Distance from extreme comp. fiber to center)
I_y =	1000	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	1.950	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.34	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

M_n = $Min[\, 5 * \lambda * \sqrt{f'c} * S_m;\;\; 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 3.68 k-ft

Φ = 0.6 (ACI 21.2.1)

ΦM_n = 2.21 k-ft < 5.63 k-ft = Critical Moment from SAP Model **NG**

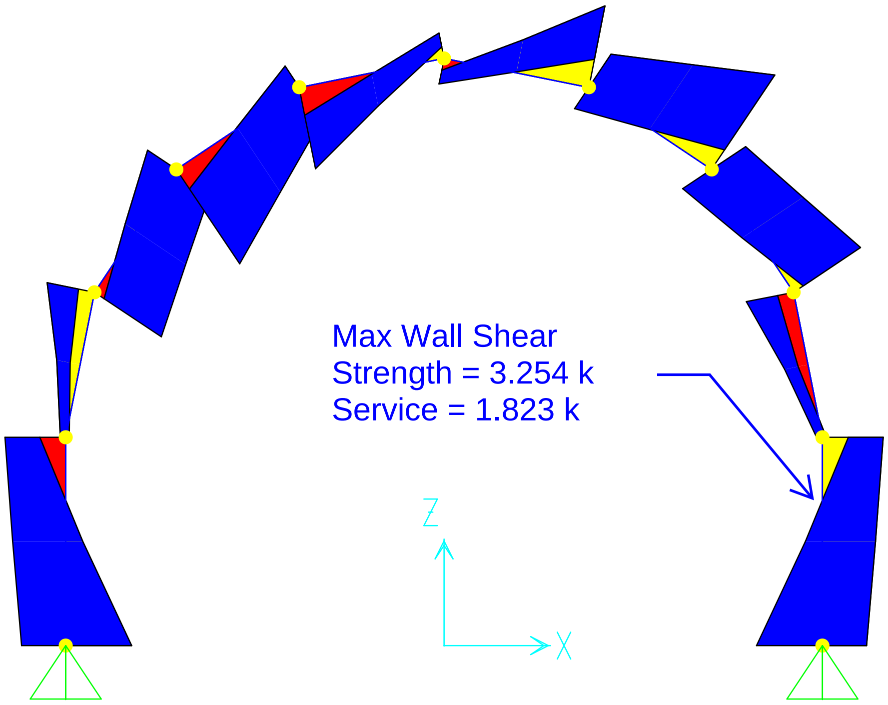
D/C = 2.55

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

SAP2000

9/21/23 13:56:40



Section 19 - Shear 2-2 Diagram

SECTION 19 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h =	10.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	120.00	in^2	(Area of concrete section)

Materials

f'_c =	1.950	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	2541	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.34	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 2.58 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)
Concrete Shear Capacity

$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$ 7.07 k (ACI 14.5.5.1)

$\phi V_n = V_c > V_U$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 4.24 k > $V_u = V_{crit}$ = 2.58 k **OK** D/C = 0.61

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 20

CSEG

Crown Pressure
Strawberry Creek Culvert Section 20

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	7.913333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 1.107867 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 8.6 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.75 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20
Traffic Driving Parallel to Culvert Span
Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 7.52 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	96	in

Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Crown Pressure
Strawberry Creek Culvert Section 20

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 15.85 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 29.85 ft
Per AASHTO 3.6.1.2.6b-6

lw = 29.85 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 17.16 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 23.16 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 23.16 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 4 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - $\boldsymbol{P_L}$

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 8.6 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 0.98 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$P_L = \frac{P(1 + \frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$ (AASHTO 3.6.1.2.6b–7) $A_{LL} = L_w * W_w$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	29.85	23.16	64	0.172
2	1	29.85	33.16	128	0.190
3	0.85	29.85	43.16	192	0.188
4	0.65	29.85	53.16	256	0.166

Crown Pressure
Strawberry Creek Culvert Section 20

Tire Distribution - Tandem
Traffic Driving Parallel to Culvert Span
Axle Spacing (Sa) = 4 ft Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 1.81 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span
Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw
When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 15.85 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 19.85 ft
Per AASHTO 3.6.1.2.6b-6

lw = 19.85 ft

Determine Live Load Patch Width at Depth H - Ww
When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 17.16 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 23.16 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 23.16 ft

Determine Number of Wheel Loads
Number of Wheel Loads = 4 wheels
If:
$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 20

Determine the Crown Pressure - $\boldsymbol{P_L}$

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 8.6 ft

Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2

IM = 0.98 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

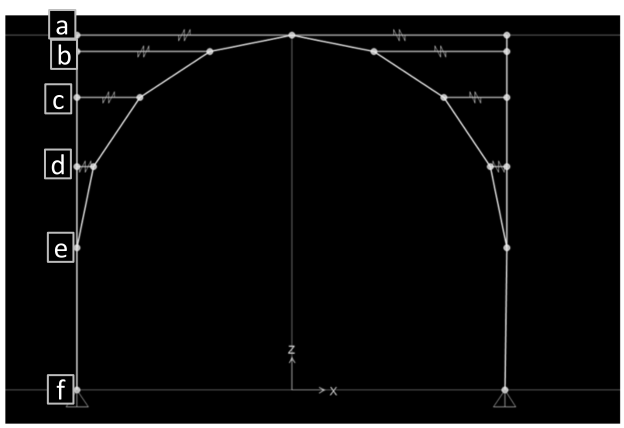
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	19.85	23.16	50	0.191
2	1	19.85	33.16	100	0.212
3	0.85	19.85	43.16	150	0.209
4	0.65	19.85	53.16	200	0.184

Max pressure is from tandem truck = 0.212 ksf

Crown Pressure
Strawberry Creek Culvert Section 20

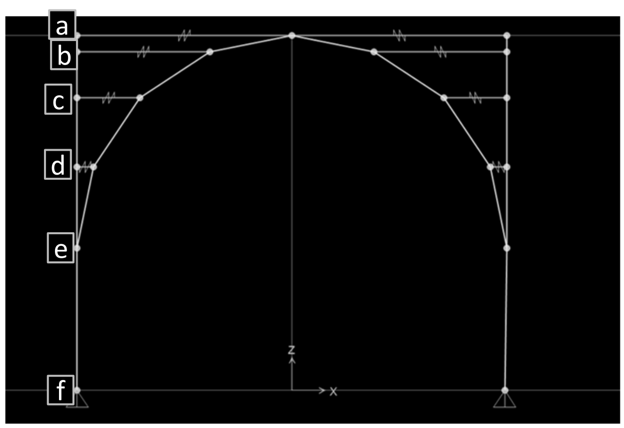
5.) Horizontal Earth Pressure - EH Minimum

Depth =	7.913333	ft	(Soil Above a)
a =	6.771	ft	(Top of Culvert Arch Height, Height at a)
b =	6.446	ft	(Height at b)
c =	5.520	ft	(Height at c)
d =	4.134	ft	(Height at d)
e =	2.500	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	284.9	plf	(Trap. EH Value at a)
EH_b =	296.6	plf	(Trap. EH Value at b)
EH_c =	329.9	plf	(Trap. EH Value at c)
EH_d =	379.8	plf	(Trap. EH Value at d)
EH_e =	438.6	plf	(Trap. EH Value at e)
EH_f =	528.6	plf	(Trap. EH Value at f)



6.) Horizontal Earth Pressure - EH Maximum

Depth =	7.913333	ft	(Soil Above a)
a =	6.771	ft	(Top of Culvert Arch Height, Height at a)
b =	6.446	ft	(Height at b)
c =	5.52	ft	(Height at c)
d =	4.134	ft	(Height at d)
e =	2.5	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	949.6	plf	(Trap. EH Value at a)
EH_b =	988.6	plf	(Trap. EH Value at b)
EH_c =	1099.7	plf	(Trap. EH Value at c)
EH_d =	1266.0	plf	(Trap. EH Value at d)
EH_e =	1462.1	plf	(Trap. EH Value at e)
EH_f =	1762.1	plf	(Trap. EH Value at f)



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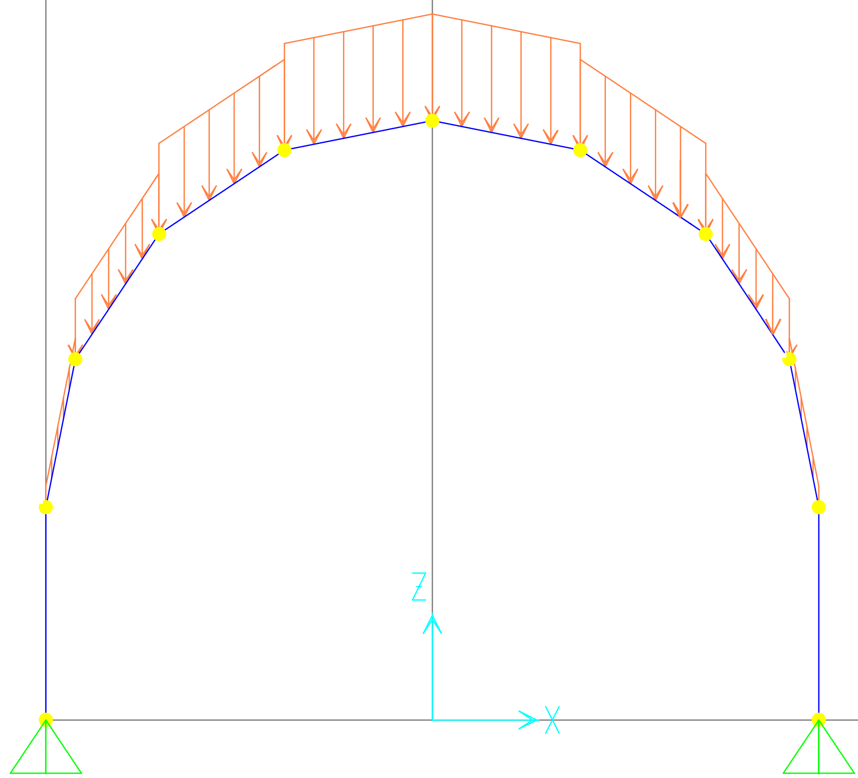

Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.

Section 20 - Frame Span Loads (EV) - Kip, ft, F Units

SAP2000

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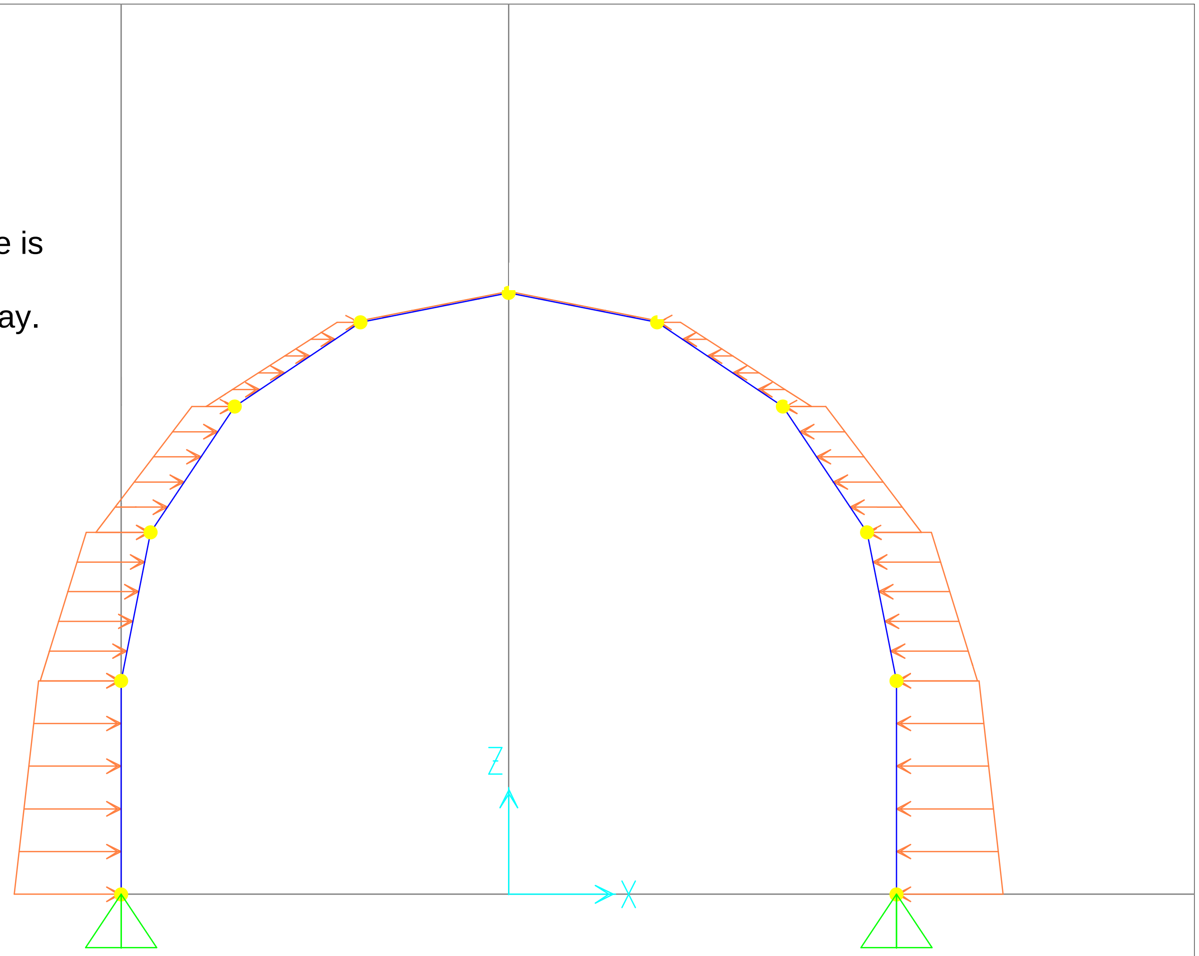

Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.

Section 20 - Frame Span Loads (EHMin) - Kip, ft, F Units

SAP2000

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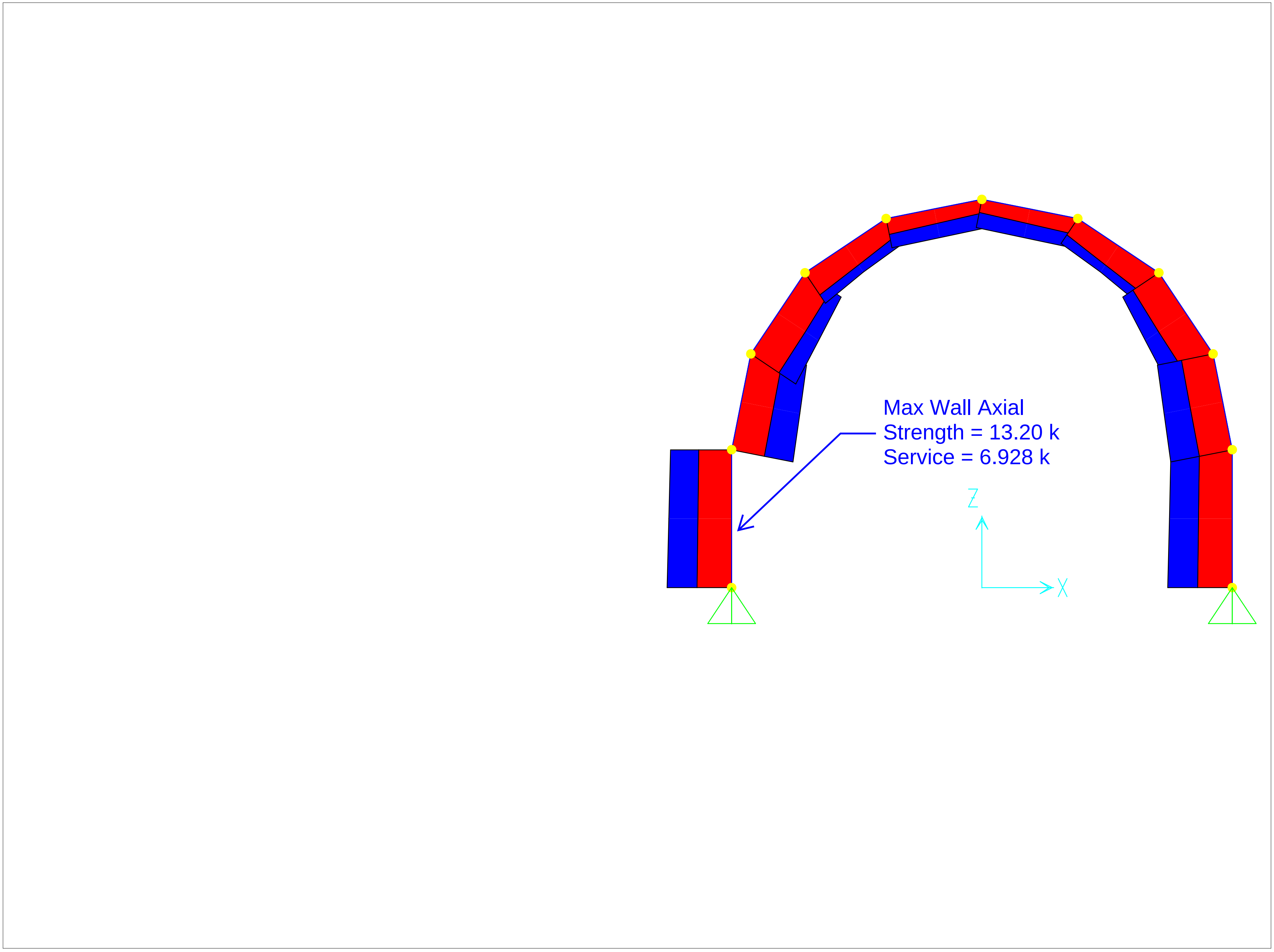

Section 20 - Axial Force Diagram

SAP2000

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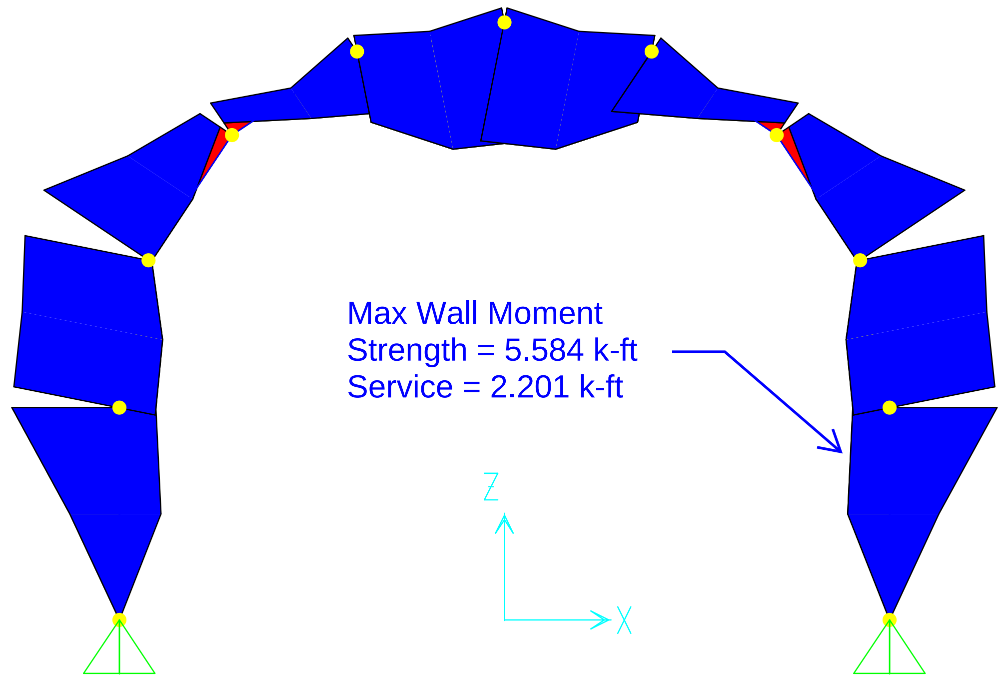

Section 20 - Moment 3-3 Diagram

BY HAK DATE 10/4/2023 | Strawberry Creek Culvert Structural Calculations | SHEET NO ____ OF ____

CHKD BY ____ DATE ____ | JOB NO. 2023025

SECTION 20 ARCH CULVERT FLEXURE CHECK

Geometry

h =	6.50	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	3.25	in	(Distance from extreme comp. fiber to center)
I_y =	275	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	4.000	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.48	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

$M_n = Min[5 * \lambda * \sqrt{f'c} * S_m;\ 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 2.23 k-ft

Φ = 0.6 (ACI 21.2.1)

ΦM_n = 1.34 k-ft < 5.58 k-ft = Critical Moment from SAP Model **NG**

D/C = 4.18

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

SAP2000

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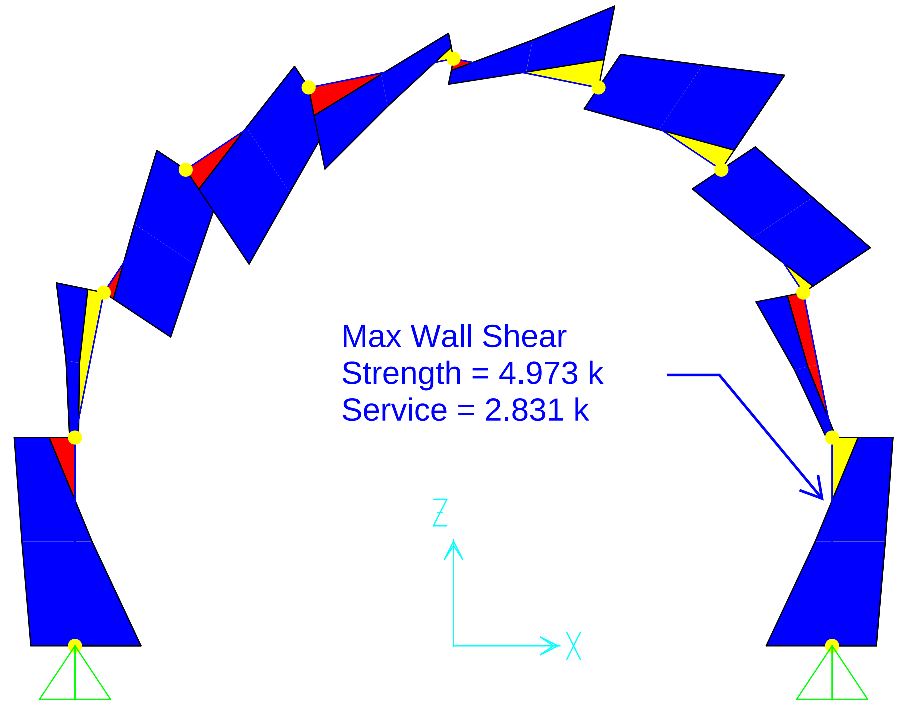


Section 20 - Shear 2-2 Diagram

BY DJF DATE 9/14/2023 | Strawberry Creek Culvert Structural Calculations | SHEET NO ____ OF ____

CHKD BY ____ DATE ____ | JOB NO. 2023025

SECTION 20 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h =	6.50	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	78.00	in^2	(Area of concrete section)

Materials

f'_c =	4.000	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	3640	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.48	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 4.97 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)
Concrete Shear Capacity

$$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h =$$ 6.58 k (ACI 14.5.5.1)

$$\phi V_n = V_c > V_U$$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 3.95 k < $V_u = V_{crit}$ = 4.97 k **NG** D/C = 1.26

Concrete shear capacity is not adequate for shear demand at critical section of concrete. Transverse reinforcement required.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

STRAWBERRY CREEK CULVERT STRUCTURAL ASSESSMENT

BERKELEY, CA

SECTION 21

Crown Pressure
Strawberry Creek Culvert Section 21

Crown Pressure Vertical Loading on Culvert

1.) Dead Load - DC

AC Pavement Weight=	140	pcf
AC Pavement Depth=	8	in

DC = AC Pavement Weight * AC Pavement Depth = 0.093 ksf

2.) Future Wearing Surface - DW

AC Pavement Weight=	140	pcf
Repavement Depth=	3	in

DW = AC Pavement Weight * Repavement Depth = 0.035 ksf

3.) Vertical Earth Pressure - EV

Soil Cover Above Culvert=	10.03333	ft
Soil Pressure =	140	pcf

EV = Soil Cover Above Culvert * Soil Pressure = 1.404667 ksf

4.) Live Load

Height of Fill Above Culvert (H) = 10.7 ft

Tire Contact Area

Length of Tire Patch (Lt) =	10	in	Per AASHTO 3.6.1.2.5
Width of Tire Path (Wt) =	20	in	Per AASHTO 3.6.1.2.5

Live Load Distribution Factor (LLDF) = 1.75 Per AASHTO Table 3.6.1.2.6a-1

Tire Distribution - HS20

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 14 ft Per AASHTO 3.6.1.2.2

Axle Interaction Depth Parallel to Culvert Span (H int-p) =
Per AASHTO 3.6.1.2.6b-4

$$H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF} = \quad 7.52 \text{ ft}$$

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) =	6	ft
Span of the Culvert (Di) =	96	in

Wheel Interaction Depth Transverse to Culvert (H int-t) =
Per AASHTO 3.6.1.2.6b-1

$$H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF} = \quad 2.20 \text{ ft}$$

Crown Pressure
Strawberry Creek Culvert Section 21

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 19.56 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 33.56 ft
Per AASHTO 3.6.1.2.6b-6

lw = 33.56 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 20.87 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 26.87 ft
Per AASHTO 3.6.1.2.6b-3

Ww = 26.87 ft

Determine Number of Wheel Loads per Lane:

Number of Wheel Loads = 4 wheels per lane

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel per lane
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels per lane
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels per lane
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels per lane

Determine Crown Pressure - P_L

Wheel Load = 16 kips
w_{Lane} = 0.64 klf Per AASHTO 3.6.1.2.4
Lane Width = 10 ft Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 10.7 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 0.89 %

Multiple Presence Factor (m) = Per AASHTO 3.6.1.1.2

$P_L = \frac{P(1 + \frac{IM}{100})(m)}{A_{LL}} + \# \, Lanes * \frac{w_{Lane}}{Total \; Lane \; Width}$ (AASHTO 3.6.1.2.6b–7) $A_{LL} = L_w * W_w$

Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	33.56	26.87	64	0.140
2	1	33.56	36.87	128	0.156
3	0.85	33.56	46.87	192	0.156
4	0.65	33.56	56.87	256	0.141

Crown Pressure
Strawberry Creek Culvert Section 21

Tire Distribution - Tandem

Traffic Driving Parallel to Culvert Span

Axle Spacing (Sa) = 4 ft Per AASHTO 3.6.1.2.3

Axle Interaction Depth Parallel to Culvert Span (H int-p) = $H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$ = 1.81 ft
Per AASHTO 3.6.1.2.6b-4

Traffic Driving Perpendicular to Culvert Span

Wheel Spacing (Sw) = 6 ft
Span of the Culvert (Di) = 96 in
Wheel Interaction Depth Transverse to Culvert (H int-t) = $H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06Di}{12}}{LLDF}$ = 2.20 ft
Per AASHTO 3.6.1.2.6b-1

Determine Live Load Patch Length at Depth H - lw

When $H < H_{int-p}$ then, $l_w = \frac{l_t}{12} + LLDF(H)$ = 19.56 ft
Per AASHTO 3.6.1.2.6b-5

When $H \geq H_{int-p}$ then, $l_w = \frac{l_t}{12} + s_a + LLDF(H) =$ 23.56 ft
Per AASHTO 3.6.1.2.6b-6

lw = 23.56 ft

Determine Live Load Patch Width at Depth H - Ww

When $H < H_{int-t}$ then, $w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12} =$ 20.87 ft
Per AASHTO 3.6.1.2.6b-2

When $H \geq H_{int-t}$ then, $w_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\frac{D_i}{12} =$ 26.87 ft
Per AASHTO 3.6.1.2.6b-3

Ww= 26.87 ft

Determine Number of Wheel Loads

Number of Wheel Loads = 4 wheels
If:

$H < H_{int-p}$ & $H < H_{int-t}$, then only 1 wheel
$H > H_{int-p}$ & $H < H_{int-t}$, then only 2 wheels
$H < H_{int-p}$ & $H > H_{int-t}$, then only 2 wheels
$H > H_{int-p}$ & $H > H_{int-t}$, then only 4 wheels

Crown Pressure
Strawberry Creek Culvert Section 21

Determine the Crown Pressure - P_L

Wheel Load =	12.5	kips	
w_{Lane} =	0.64	klf	Per AASHTO 3.6.1.2.4
Lane Width =	10	ft	Per AASHTO 3.6.1.2.5

Minimum Depth of Earth Cover Above Structure (De) = 10.7 ft
Dynamic Load Allowance (IM) = 1+ 0.33(1.0 - 0.125De) Per AASHTO 3.6.2.2
IM = 0.89 %

Multiple Presence Factor (m) = Per AASHTO 3.6.11.2

$$P_L = \frac{P(1+\frac{IM}{100})(m)}{A_{LL}} + \#\,Lanes * \frac{w_{Lane}}{Total\ Lane\ Width}$$ (AASHTO 3.6.1.2.6b−7) $$A_{LL} = L_w * W_w$$

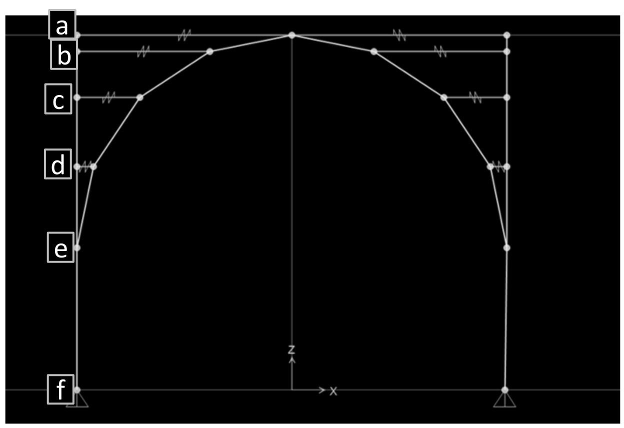
Number of Design Lanes	Multiple Presence	Lw (ft)	Ww (ft)	P (kip)	PL (ksf)
1	1.2	23.56	26.87	50	0.148
2	1	23.56	36.87	100	0.166
3	0.85	23.56	46.87	150	0.167
4	0.65	23.56	56.87	200	0.150

Max pressure is from tandem truck = 0.167 ksf

Crown Pressure
Strawberry Creek Culvert Section 21

5.) Horizontal Earth Pressure - EH Minimum

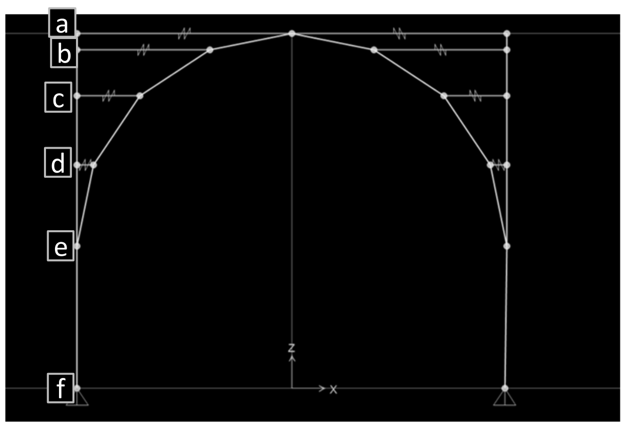
Depth =	10.03333	ft	(Soil Above a)
a =	6.750	ft	(Top of Culvert Arch Height, Height at a)
b =	6.426	ft	(Height at b)
c =	5.505	ft	(Height at c)
d =	4.126	ft	(Height at d)
e =	2.500	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	36	pcf	(Horizontal Earth Pressure)
EH_a =	361.2	plf	(Trap. EH Value at a)
EH_b =	372.9	plf	(Trap. EH Value at b)
EH_c =	406.0	plf	(Trap. EH Value at c)
EH_d =	455.7	plf	(Trap. EH Value at d)
EH_e =	514.2	plf	(Trap. EH Value at e)
EH_f =	604.2	plf	(Trap. EH Value at f)



Crown Pressure
Strawberry Creek Culvert Section 21

6.) Horizontal Earth Pressure - EH Maximum

Depth =	10.03333	ft	(Soil Above a)
a =	6.75	ft	(Top of Culvert Arch Height, Height at a)
b =	6.426	ft	(Height at b)
c =	5.505	ft	(Height at c)
d =	4.126	ft	(Height at d)
e =	2.5	ft	(Height at e)
f =	0	ft	(Bottom of Culvert Height, Height at f)
γ =	120	pcf	(Horizontal Earth Pressure)
EH_a =	1204.0	plf	(Trap. EH Value at a)
EH_b =	1242.9	plf	(Trap. EH Value at b)
EH_c =	1353.4	plf	(Trap. EH Value at c)
EH_d =	1518.9	plf	(Trap. EH Value at d)
EH_e =	1714.0	plf	(Trap. EH Value at e)
EH_f =	2014.0	plf	(Trap. EH Value at f)



SAP2000

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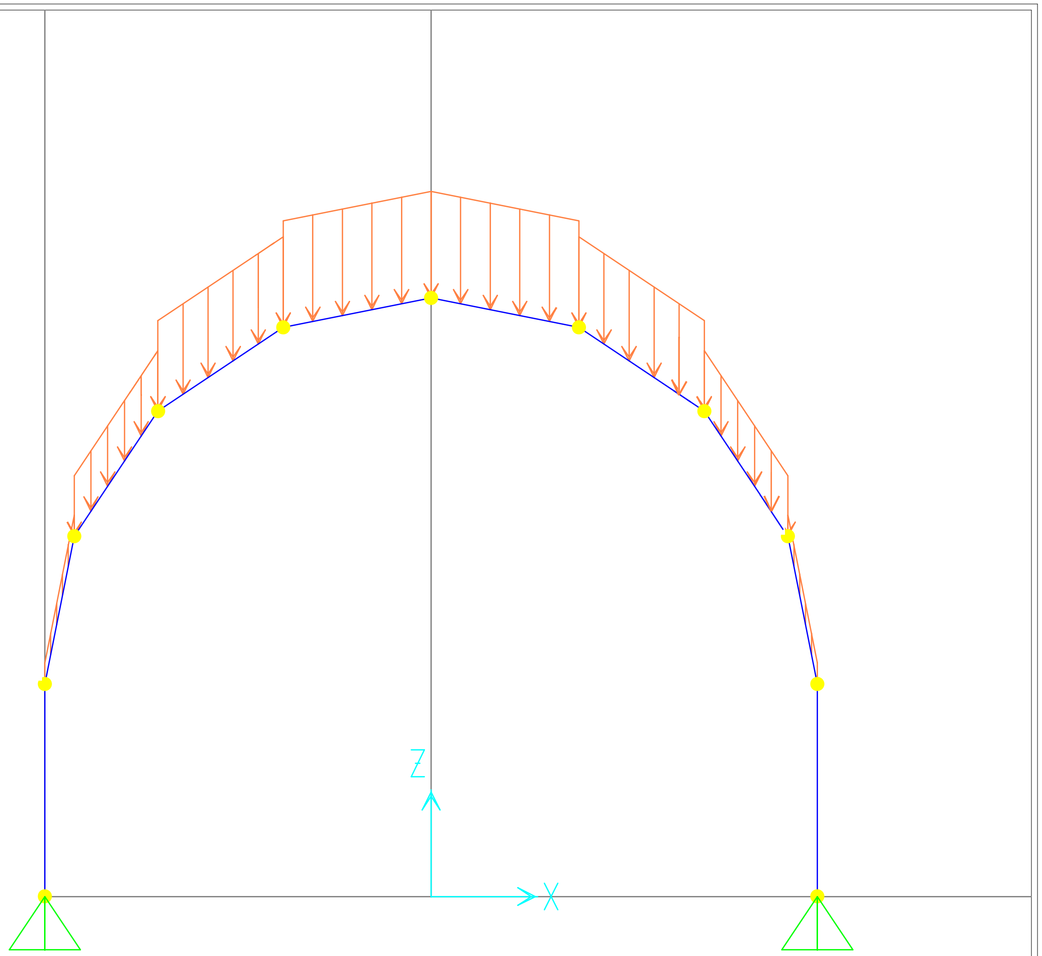
Vertical Input

The vertical earth pressure is shown. Dead loads, wearing surfaces and utilities, and live loads are also applied in the same way.



Section 21 - Frame Span Loads (EV) - Kip, ft, F Units

SAP2000

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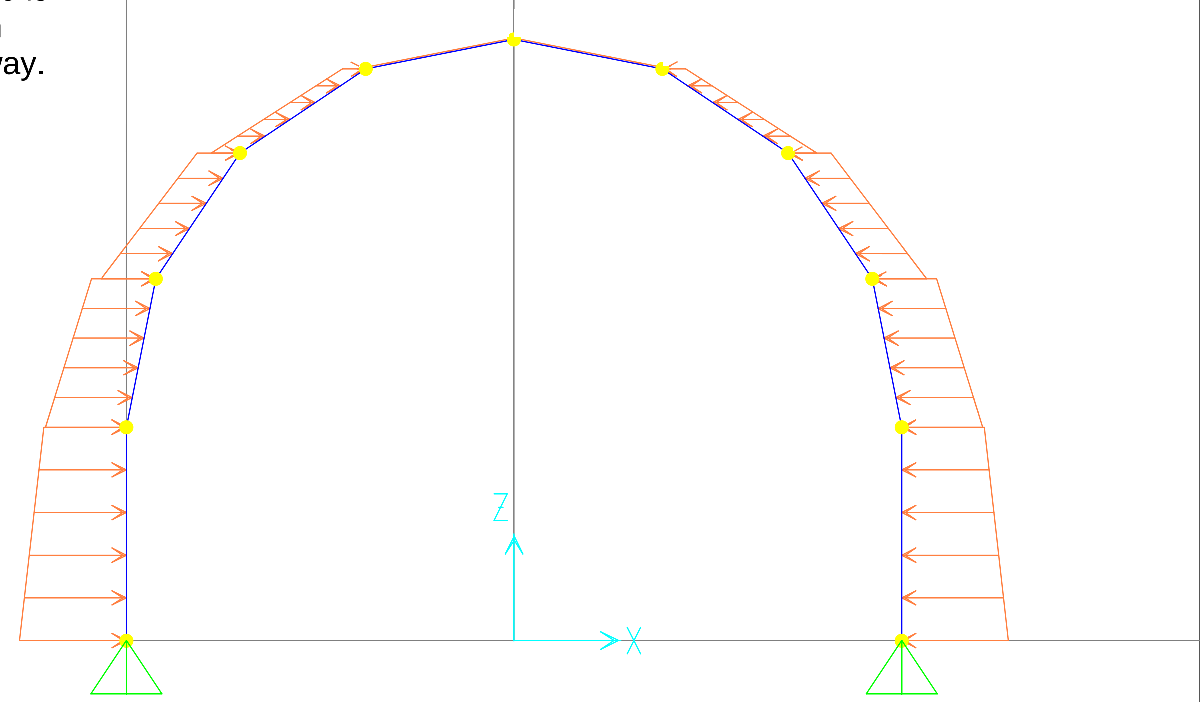
Horizontal Input

The minimum horizontal earth pressure is shown. The maximum horizontal earth pressure is also applied in the same way.



Section 21 - Frame Span Loads (EHMin) - Kip, ft, F Units

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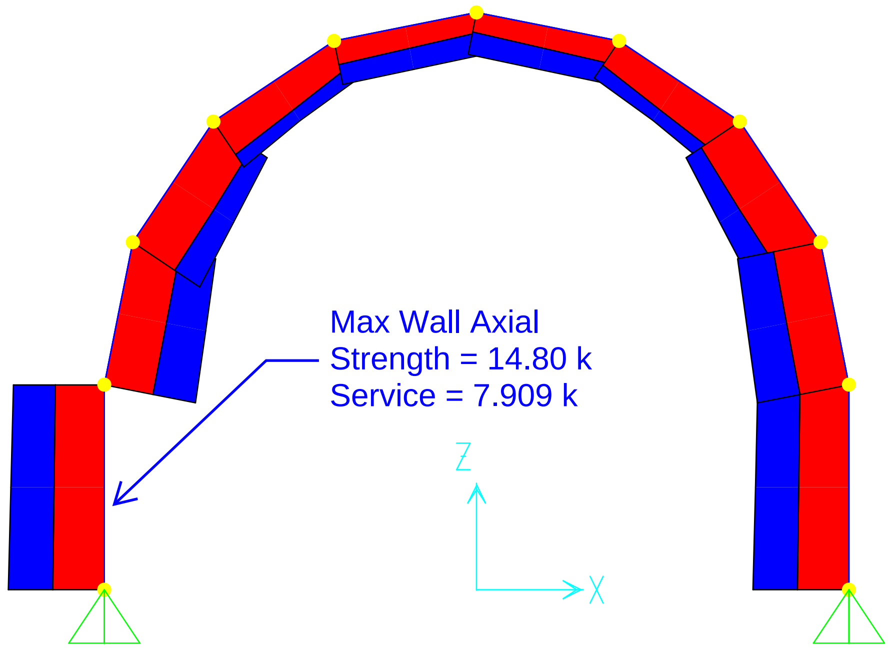

Section 21 - Axial Force Diagram

SAP2000

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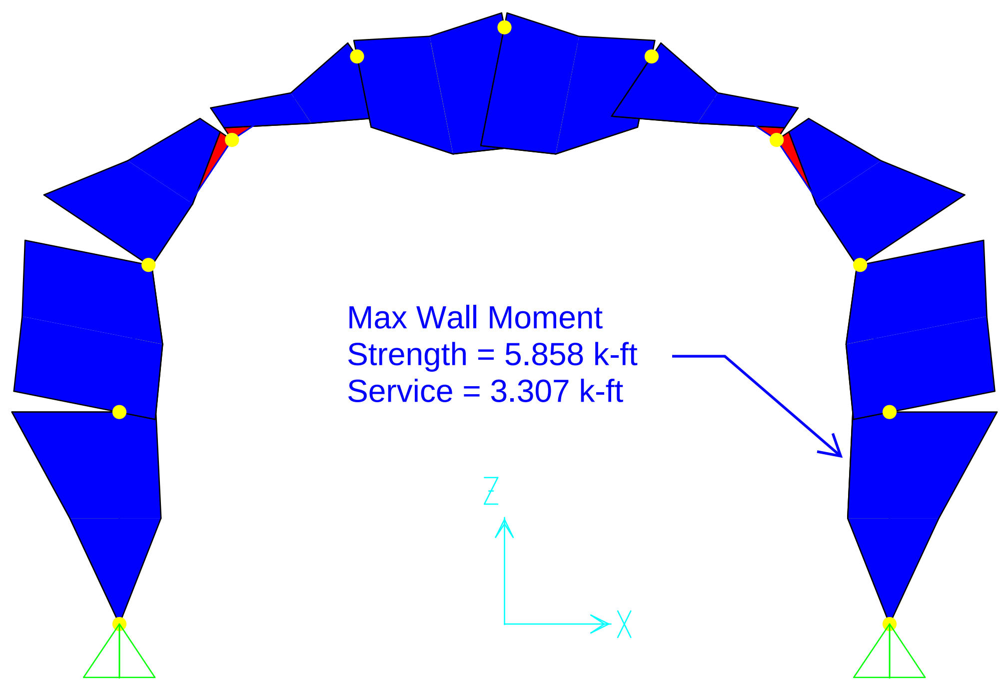

Section 21 - Moment 3-3 Diagram

BY HAK DATE 10/4/2023 — Strawberry Creek Culvert Structural Calculations — SHEET NO ________ OF ________

CHKD BY ________ DATE ________ — JOB NO. 2023025

SECTION 21 ARCH CULVERT FLEXURE CHECK

Geometry

h =	6.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
y =	3.00	in	(Distance from extreme comp. fiber to center)
I_y =	216	in^4	(Moment of Inertia of concrete section)

Materials

f'_c =	1.950	ksi	(Concrete compressive strength)	(Per ISI Report)
λ =	1.0	ksi	(Concrete Density Modification Factor)	(AASHTO 5.4.2.8)
f_r =	0.34	ksi	(Modulus of Rupture of Concrete)	(AASHTO 5.4.2.6)

Moment Capacity (ACI Calculation)

$M_n = Min[\,5 * \lambda * \sqrt{f'c} * S_m;\ \ 0.85 * f'c * S_m]$ (ACI 14.5.2.1)

M_n = 1.32 k-ft

Φ = 0.6 (ACI 21.2.1)

ΦM_n = 0.79 k-ft < 5.86 k-ft = Critical Moment from SAP Model **NG**

D/C = 7.37

Flexural Capacity is exceeded and concrete will fail in flexure.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

SAP2000

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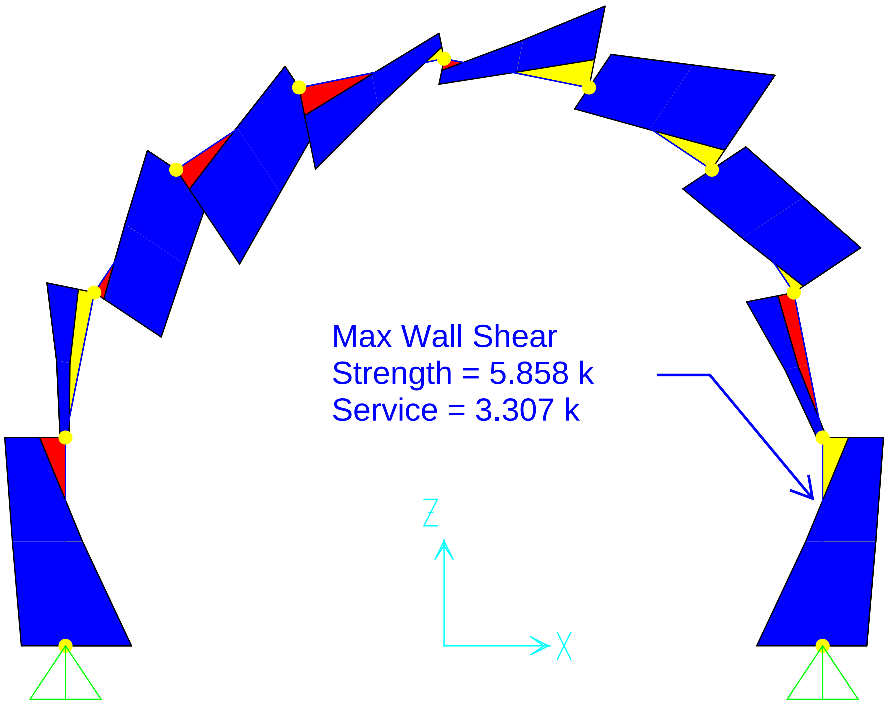

Section 21 - Shear 2-2 Diagram

SECTION 21 ARCH CULVERT SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the shear capacity methodology for plain concrete as outlined in Section 14.5.5.1 of ACI 318-14.

Geometry

h =	6.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	N/A	in	(Clear cover)
A_c =	72.00	in^2	(Area of concrete section)

Materials

f'_c =	1.950	ksi	(Concrete compressive strength)	
f_y =	N/A	ksi	(Steel tensile strength)	
E_c =	2541	ksi	(Young's Modulus of Concrete)	(AASHTO C5.4.2.4-3)
E_s =	N/A	ksi	(Young's Modulus of Steel)	
f_r =	0.34	ksi	(Modulus of Rupture)	(AASHTO 5.4.2.6)

Longitudinal Reinforcement

Rebar =	#5	
n =	0.00	bars /FT
A_s =	#N/A	in^2 / FT

Loading

Φ = 0.60 (ACI 21.2.1)

Forces at Critical Section

V_{crit} = 5.86 k/ft (shear) (Values per SAP Model)

Shear Capacity (ACI Calculation)
Concrete Shear Capacity

$$V_c = \frac{4}{3} * \lambda * \sqrt{f'c} * b * h = \quad 4.24 \text{ k}$$ (ACI 14.5.5.1)

$$\phi V_n = V_c > V_U$$ (ACI 14.5.1.1)

$\phi V_n = V_c$ = 2.54 k < $V_u = V_{crit}$ = 5.86 k **NG** D/C = 2.30

Concrete shear capacity is not adequate for shear demand at critical section of concrete. Transverse reinforcement required.

Note:
The MBE states that the simplified modeling approach for buried structures described in the preceding paragraph tends to produce conservative force demands (AASHTO 2018). The MBE goes on to state that buried structures carry vertical load through a combination of internal capacity as well as soil arching around the structure termed soil-structure interaction (AASHTO 2018). Since we do not have a geotechnical engineer aboard to provide more refined load demands on the buried culvert segments, we have conservatively neglected soil-structure interaction effects in our analysis. Lastly, the MBE notes that due to soil-structure interaction often being neglected in the load rating evaluation of buried structures, it is not uncommon to observe satisfactory performance of in-service culverts even when the analysis results would indicate insufficient structural capacity. As further discussed in the Analysis Results section of this report, most culvert sections analyzed as part of this study have been performing satisfactorily since being constructed even though the analysis results neglecting soil-structure interaction would indicate differently.

Appendix H
Structural Analysis of Rehabilitated Culvert Sections

GEOTREE PRELIMINARY CALCULATIONS:

GEOTREE

Todays Date	
Project Name	
GeoTree Project Number	
Project Asset Owner	
Contact phone and email of person providing initial design assumptions pulled from draft or final plans and Specs	
Installation Contractor -Contact responsible for confirming design input geometry assumptions	
Initial Draft Design Done by	

Design Pipe Number	1	2	3	4	5	6	7
Structure Location (ie MH 1 to MH 4)	00+00 to 00+76±	00+76± to 07+80±	07+80± to 08+07±	08+07± to 08+55±	08+55± to 10+26±	10+26± to 15+92±	15+92± + 22+39±
Description	7' Wide by 5.5' Tall Reinforced Concrete Box Shaped	6' Wide by 5.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	10' Wide Reinforced Concrete Wide Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	7' Wide by 7' Tall Reinforced Concrete Tubular, Flat Bottom	6' Wide by 7' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 4.0 ft tall)	6.5' Diameter Reinforced Concrete Tubular
Pipe Shape: Round, Egg / Oval, Horseshoe, Arch, Box, Other	Box	Arch or Horseshoe	Arch or Horseshoe	Arch or Horseshoe	Round	Arch or horseshoe	Round
Average Daily Dry Weather Flow (MGD)	NA	NA	NA	NA	NA	NA	NA
Length (ft.)	40	550	30	50	170	360	630
Largest Horizontal Dimension -X Axis (used in liner design) (in)	84	72	96	120	84	72	78
Typical Height Dimension - Y Axis (in)	66	66	78	60	84	84	78
Estimated Original Pipe size or theoretical avgerage ID or box side dimension (in)							78
Design Evaluation - External Soil Water & Live Load	Y	Y	Y	Y	Y	Y	Y
Ovality % (Mean ID -Min ID)/ Mean ID per ASTM F1216	0	0	0	0	0	0	0
Min. Cover Depth above crown; Not Applicable (NA) if over 8' (ft)							
Max Cover Depth above crown (ft)	1.60	7.90	2.50	1.90	3.90	3.40	7.60
Does Min or Max cover depth govern design	MAX	max	max	max	max	max	max
Water Table depth measured down from the surface (ft)	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Material Type ie Brick, RCP, Stone, CMP, PCCP, Steel Other	RC	URC	URC	RC	RC	URC	RC
Pipe Function: ie Storm (ST), Sanitary Sewer (SS), Combined Sewer (CS), Potable (P)	ST	ST	ST	ST	ST	ST	ST
Live Load: ie None, HS20, HS25, HL93, E80 Railroad, Airport, Building, Other, Unknown	HS25	HS25	HS25	HS25	HS25	HS25	HS25
What is above the pipe? Ie Road pavement, woods, building	Road	Road	Road	Road	Road	Road	Road
Level of deterioration- partially or fully	Fully	Fully	Fully	Fully	Fully	Fully	Fully
Safety Factor	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Direction of pipe with respect to traffic, ie perpendicular or parallel	Perp	Perp	Perp	Perp	Perp	Perp	Perp
Assume Soil Arching: No or Yes (If "Yes" Height of Soil used to calculate soil load on pipe will be capped at 3X the pipe diameter)	No	No	No	No	No	No	No
Soil Density (pcf)	140	140	140	140	140	140	140
Soil Type	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any
Compressive Strength -28 Day ASTM C39 (not used in design) (psi)	8000	8000	8000	8000	8000	8000	8000
Tensile Strength -28 Day ASTM C496 (used in pressure design)(psi)	800	800	800	800	800	800	800
Flex Strength (FS) -28 Day ASTM C78 (used in gravity design) (psi)	1500	1500	1500	1500	1500	1500	1500
Tmin as required by project specifications if any	NA	NA	NA	NA	NA	NA	NA
Global Suggested Tmin using distibuted beam model per flex listed above (in)	2.00	1.15	0.80	0.82	0.90	0.70	1.10
Global Tmin propose for construction to nearest .05" (in)	**2.00**	**1.50**	**1.50**	**1.50**	**1.50**	**1.50**	**1.50**
Global Tmin propose for construction to nearest .05" * Note: per the Distributed Beam Design Method, Thickness Minimum (Tmin) (for pipe not MH) is correlated to the ASTM C78 - 28 day Flexural Strength (FS) in psi for the specific Geopolymer strength used. (in)	**2.00"** x $(1500/FS)^{0.5}$	**1.50"** x $(1500/FS)^{0.5}$	**1.5"** x $(1500/FS)^{0.5}$	**1.50"** x $(1500/FS)^{0.5}$	**1.5"** x $(1500/FS)^{0.5}$	**1.5"** x $(1500/FS)^{0.5}$	**1.5"** x $(1500/FS)^{0.5}$
Design Notes: * Distributed beam model is not applicable for pressure pipes, box sewer & MH. For a structural enhancement, use the project specified thickness, or if none is given, consider 1/2" min for potable water, 1 to 2" for box pipe & 1" for MH							

GEOTREE PRELIMINARY CALCULATIONS:

Strawberry Creek Culvert Rehabilitation

10/9/2023

Strawberry Creek Culvert Rehabilitation

City of Berkeley

Darren Fagundes, PE, Cornerstone Structural Engineering Group

Kurt Chirbas, PE; Western Region Manager, GeoTree Solutions
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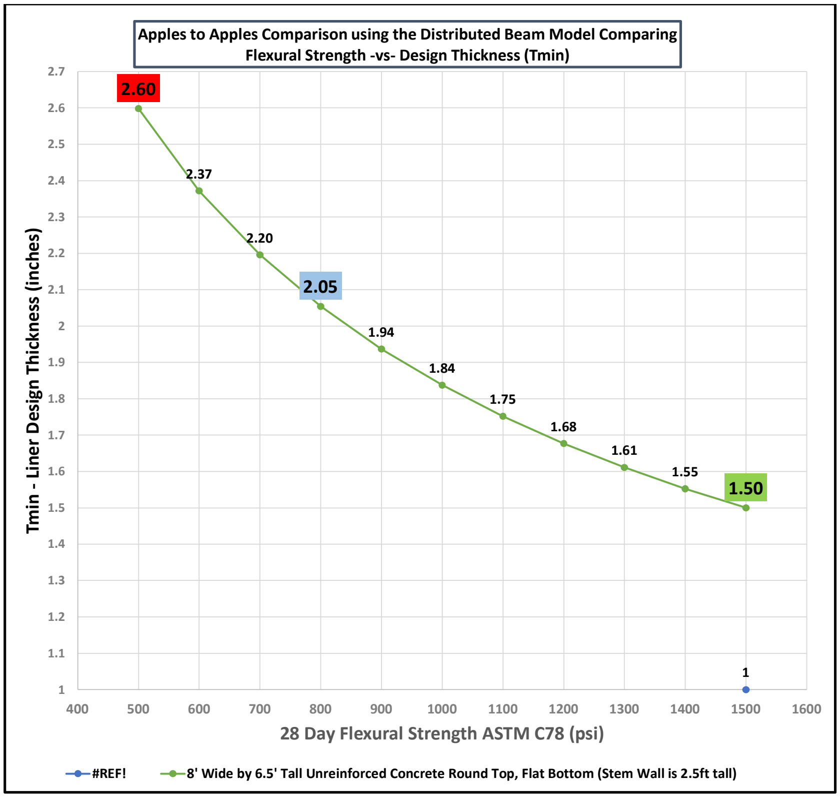
Jon Babson, Inside Sales Engineer, GeoTree Solutions
C: 518-225-1840 E: jbabson@CS-NRI.com

8	9	10	12	14	17	18	19	20	21	TOTALS
22+39± to 22+92±	**22+92± to 26+18±**	**26+18± to 27+80±**	**28+62± to 34+88±**	**36+89± to 38+25±**	**41+32± to 44+52±**	**44+52± to 45+19±**	**45+19± to 53+37±**	**00+00 to 01+22±**	**00+00 to 01+12±**	
6' Wide by 5.5' Tall Reinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)	**8' Wide by 7' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 3.0 ft tall)**	**8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	**8' Wide by 6.5' Tall Reinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	**8' Wide by 5' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 1.0ft tall)**	**7.5' Diameter Reinforced Concrete Tubular**	**8' Wide by 6' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 2.0 ft tall)**	**8' Wide by 7' Tall Unreinforced Concrete Round Top, V-Channel Bottom (Stem Wall is 3.0 ft tall)**	**8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	**8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall)**	
Arch or Horseshoe	Arch or Horseshoe	Arch or Horseshoe	Arch or Horseshoe	Arch or Horseshoe	Round	Arch or Horseshoe	Arch or horseshoe	Arch or Horshoe	Arch or Horseshoe	
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
55	330	90	145	70	40	70	810	70	65	**3575**
72	96	96	96	96	90	96	96	96	96	
66	84	78	78	60	90	72	84	78	78	
				78						
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
0	0	0	0	0	0	0	0	0	0	
10.10	11.00	9.90	6.70	8.20	4.50	6.00	5.70	8.60	10.70	
max	max	max	max	max	max	max	max	max	max	
6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	
RC	URC	URC	RC	URC	RCP	URC	URC	URC	URC	
ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	
HS25	HS25	HS25	HS25	HS25	HS25	HS25	HS25	HS25	HS25	
Road	Road	Road	Road	Road	Road	Road	Road	Road	Road	
Fully	Fully	Fully	Fully	Fully	Fully	Fully	Fully	Fully	Fully	
2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
Perp	Perp	Perp	Perp	Perp	Perp	Perp	Perp	Perp	Perp	
No	No	No	No	No	No	No	No	No	No	
140	140	140	140	140	140	140	140	140	140	
LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	LRFD Any	
8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	
800	800	800	800	800	800	800	800	800	800	
1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1.20	1.60	1.60	1.30	1.40	1.00	1.20	1.20	1.40	1.60	
1.50	**1.60**	**1.60**	**1.50**	**1.50**	**1.50**	**1.50**	**1.50**	**1.50**	**1.60**	
1.5" x $(1500/FS)^{0.5}$	**1.6" x $(1500/FS)^{0.5}$**	**1.6" x $(1500/FS)^{0.5}$**	**1.5" x $(1500/FS)^{0.5}$**	**1.50" x $(1500/FS)^{0.5}$**	**1.50" x $(1500/FS)^{0.5}$**	**1.5" x $(1500/FS)^{0.5}$**	**1.5" x $(1500/FS)^{0.5}$**	**1.5" x $(1500/FS)^{0.5}$**	**1.6" x $(1500/FS)^{0.5}$**	

GEOTREE PRELIMINARY CALCULATIONS:

TABLE 1	10/9/2023	
Apples to Apples Comparison of GeoSpray Geopolymer and Ordinary Portland Cement (OPC) Minimum Liner Design Thickness (Tmin) Examples		
Material	*28 day Flexural Strength (FS) per ASTM C78 (psi)	8' Wide by 6.5' Tall Unreinforced Concrete Round Top, Flat Bottom (Stem Wall is 2.5ft tall) $T\,min = 1.50''\,x\sqrt{\frac{1500}{Fs}}$ OR $T\,min = 2.60''\,x\sqrt{\frac{500}{Fs}}$ (in.)
GeoTree's GeoSpray Geopolymer	1500	1.50
	1400	1.55
	1300	1.61
	1200	1.68
	1100	1.75
	1000	1.84
	900	1.94
Lower End Alternative Spray on Material	800	2.05
	700	2.20
	600	2.37
Ordinary Portland Cement (OPC)	500	2.60
% (OPC-GeoSpray)	-67%	73%

When all dead load geometry and live load values are held constant, the distributed beam model can be simplified per the formula above. This shows how the 28 day Flexural Strength (FS) per ASTM C78 has a direct correlation to liner thickness that is almost linear. OPC has 67% less flexural strength, however an equal load bearing capacity design would require 73% more thickness. In addition, typically wire mesh would be added to the OPC because the flexural strength is so low. For questions



CORNERSTONE
structural
engineering
group

www.cseg.com

Strawberry Creek Culvert Structural Assessment

Job No. 2023025

PRELIMINARY STRUCTURAL CALCULATIONS

November 29, 2023

986 W. Alluvial, Ste. 201
Fresno, CA 93711

tel. (415)369-9100
fax. (415) 369-9101

SHOTCRETE REHABILATION STRUCTURAL CALCULATIONS

Shotcrete rehabilitation will be analyzed by determining the maximum flexural and shear demands computed from the analysis of the existing arch culvert sections for Section 12 as an example. The required shotcrete section will be determined to resist the maximum load computed from the existing arch culvert analysis. The loading is conservative due to neglecting the soil arching effect. If the shotcrete alternative is considered for Final Design, refined soil pressures will need to be provided by the Geotechnical Engineer for each culvert Section.

Maximum Moment Demand = 6.3 k-ft/ft (Per Section 12 SAP2000 Output)

Maximum Shear Demand = 3.2 k/ft (Per Section 12 SAP2000 Output)

Required Shotcrete Section:

Use 8" Thick 4,000psi Shotcrete Section with #5 Grade 60 Rebar Spaced at 8" Each Way.

(See Following Flexural and Shear Capacity Calculations)

ARCH CULVERT WALL - SHOTCRETE FLEXURE DESIGN

Input:

M_u= 6.3 k-ft/ft (Per Section 12)
f'c= 4000 psi
fy= 60000 psi
φ = 0.9
b_1= 0.85
h= 8 in.
b= 12 in.
Clear Cover = 0.00 in.
Spacing = 8.0 in.
Dia. of Main Bar = #5 0.625 in.
Area of Main Bar = #5 0.306 in^2

$$d = h - \text{Clr Cover} - \frac{\text{Bar dia}}{2} = 4.00 \text{ in.}$$

$$S_c = \frac{bh^2}{6} = 128 \text{ in}^3$$

$$f_r = 0.24\sqrt{f'_c} = 480 \text{ psi}$$

Bar Size	Dia	Bar Size	Area
#4	0.5	#4	0.2
#5	0.625	#5	0.306
#6	0.75	#6	0.44
#7	0.875	#7	0.6
#8	1	#8	0.785
#9	1.128	#9	1
#10	1.27	#10	1.27
#11	1.41	#11	1.56
#14	1.693	#14	2.25

$M_{u(min)}$= 6.1 K-FT/FT

$$M_{CR} = \gamma_3\left[(\gamma_1 f_r + \gamma_2 f_{cpe})S_c - M_{dnc}\left(\frac{S_c}{S_{nc}} - 1\right)\right]$$ [AASHTO 5.6.3.3-1]

γ_1 = 1.6
γ_2 = 1
γ_3 = 0.75
f_r = 480 psi
f_{cpe} = 0 psi
S_c = 128 in^3
S_{nc} = 128 in^3
M_{dnc} 0 k-ft
M_{CR} = 6.1 k-ft

Design Ultimate Moment; M_u= 6.3 K-FT/FT (Minimum of 1.33M_u or M_{CR})

$$a = \frac{A_s f_y}{0.85 f'_c b} = 0.68 \text{ in.}$$

$$c = \frac{a}{b_1} = 0.794 \text{ in.}$$

ε = 0.012 in/in. *Therefore tension controlled*

$A_{s,provided}$ = 0.459 in^2 $\phi M_n = \phi A_s f_y\left(d - \frac{a}{2}\right)$ = 7.6 k-ft > M_u= 6.3 k-ft

USE #5 @ 8"

D/C: 0.84 **OK**

CULVERT SUPPLEMENTAL SHOTCRETE SHEAR DESIGN

Reinforcement Spacing Generator

Note: This spreadsheet uses the Simplified Procedure for Nonprestressed Sections per AASHTO 5.7.3.4.1

Geometry

h =	8.00	in	(Height of section)
b_w =	12.00	in	(Width of section)
c.c. =	0.00	in	(Clear cover)
d =	4.00	in	(Distance from extreme comp. fiber to tensile reinf.)
A_c =	96.00	in^2	(Area of concrete section)

Materials

f'_c =	4.0	ksi	(Concrete compressive strength)	
f_y =	60.0	ksi	(Steel tensile strength)	
E_c =	3640	ksi	(Youngs Modulus of Concrete)	(AASHTO 5.4.x)
E_s =	29000	ksi	(Youngs Modulus of Steel)	

Longitudinal Reinforcement

Rebar =	#5	
n =	1.00	bars /FT
A_s =	0.31	in^2 / FT

Loading

Φ = 0.90 (AASHTO 5.5.4.2.1)

Forces at Critical Section

Critical section for abutment is defined as the critical depth away from support/pile location. Assumptions are conservative.

N_{crit} =	0.00	k	(axial)
V_{crit} =	3.20	k/ft	(shear)
M_{crit} =	6.34	k-ft/ft	(moment)

(Values per Footing Demand Calculations)

Shear Stress on Concrete at Critical Section (AASHTO LRFD 5.8.2.9)

$Vu = \frac{|V_{crit}|}{\phi b_w d} =$ 0.074 ksi where $d_v = \max(0.9d, 0.72h,) =$ 5.76 in

Simplified Procedure for Nonprestressed Sections

Since the member in question is described by the requirements set forth in AASHTO LRFD Section 5.7.3.4.1, simplified method can be used to determine the values of β and θ as opposed to using Appendix B5

Therefore:

β = 2.0

θ = 45 °

Concrete Shear Capacity

$V_c = 0.0316\beta\sqrt{f_c'}b_w d_v =$ 8.74 k

$0.5\phi V_n = 0.5\phi V_c > V_U$ (AASHTO LRFD 5.8.2.4)

0.5ϕVn = 0.5ϕVc = 3.93 k > $V_u = V_{crit}$ = 3.20 k **OK** D/C = 0.81

Concrete shear capacity adequate for shear demand at critical section of concrete. Transverse reinforcement not required.

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