AEA Appendix 3

Scour Analysis

PACE
Advanced Water Engineering

Technical Memorandum

Date: September 30, 2016

To: Sam Rojas and Matt Carpenter – Newhall Land

From: Mark Krebs, PE and Jose Cruz, PE

Re: Pier Scour Analysis - Newhall Ranch RMDP Permanent Bridges #8238E

Purpose and Background

The purpose of this memorandum is to provide additional context to the issue of bridge pier scour as it relates to the potential for stranding of fish in scour holes that may result from large storm events. This memorandum provides an analysis of pier scour at the proposed permanent bridges of the Newhall Ranch RMDP: the Commerce Center Drive and Long Canyon Road Bridges. Specifically, the memorandum describes pier scour during two different "reset" storm events – the first where peak flow corresponds to a 10-year storm, and second where peak flow corresponds to a 25-year storm. PACE ran the HEC-RAS[1] model to establish the river hydraulics for the 10-year and 25-year storms, using hydrologic data that PACE had previously prepared for the Santa Clara River watershed. For the Commerce Center Drive Bridge (located upstream of Castaic Creek confluence), flow rates are 11,700-cubic feet per second (cfs) (10-year) and 23,000 cfs (25-year), respectively. For the Long Canyon Road Bridge location (downstream of Castaic Creek confluence), the flow rates are 14,300-cfs (10-year) and 28,100-cfs (25-year), respectively. A separate memorandum, following the same methodologies contained herein, has been prepared by PACE to provide an analysis of pier scour related to the Newhall Ranch RMDP temporary haul route bridge piles (steel HP).

The relationship between rainfall and river-flow over time is typically illustrated in a storm hydrograph. Peak flood flows recede back to, or near, pre-storm flow levels on the falling limb of the discharge curve, as illustrated on **Figure 1** below. The analysis provided herein reports on the maximum local pier scour expected at the peak flow of each modeled event and then presents a methodology to estimate the aerial extent and depth of local residual scour pools that might be expected to persist as flood flows from these events abate. Therefore, this analysis is only applicable to the period immediately after such events and does not consider or analyze conditions from multiple storm events nor does it provide information on what scour hole conditions may be expected at the end of the winter storm season. As the flow velocity is diminished, entrained sediment and fluvial bed movement settle, resulting in a residual scour hole that is smaller in aerial extent and shallower than the maximum scour that occurs during the peak discharge. Furthermore, subsequent storm events may interrupt the falling limb of the hydrograph, resulting in a new peak discharge curve and/or a new elevated base river flow.

[1] Hydrologic Engineering Center's (CEIWR-HEC) River Analysis System (HEC-RAS), US Army Corps of Engineers (USACE).

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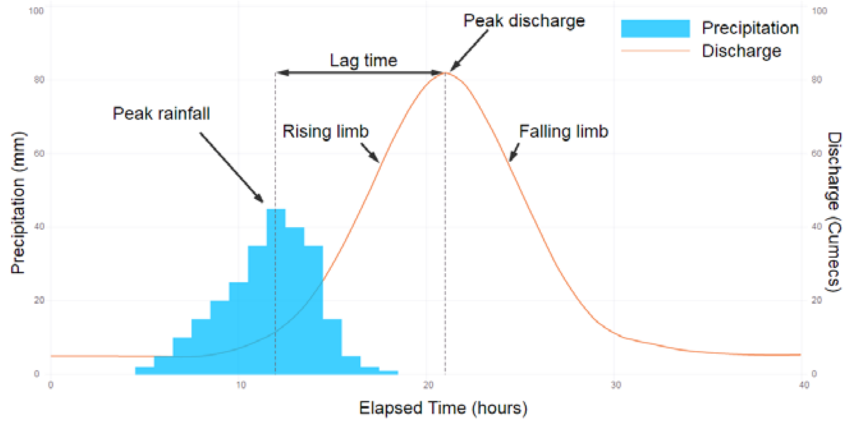

https://geographyas.info/rivers/discharge-and-hydrographs/

Figure 1 – Example Storm Hydrograph

The US Geological Survey (USGS) defines scour as the hole left behind when sediment (sand and gravel) is washed away from the bottom of a river. Although scour may occur at any time, scour action is especially strong during floods. Swiftly flowing water has more energy than calm water to lift and carry sediment down river. In general, local pier scour is a concern for structural stability of a bridge, however for the RMDP bridges the foundation design extends far below the scour zone, and as such scour is not a structural design concern at the pier locations.

Hydraulic analysis results from the HEC-RAS modeling were used to perform the subsequent scour analysis, which followed the procedures outlined in the Federal Highway Administration (FHWA) Hydraulic Engineering Circular No. 18 (HEC-18), Evaluating Scour at Bridges, 2001. The scour calculations were performed in a module embedded directly in HEC-RAS. Using HEC-18, bridge scour is comprised of three individual components: (1) Contraction scour, (2) Pier scour, and (3) Abutment scour. This memo addresses only the pier scour.

Pier Scour Calculation Methods

Several factors influence the magnitude of pier scour, including pier size, pier shape, bed material characteristics, and orientation and configuration of bridge piers. These elements are considered in the present calculations, and are expressed as form factors (or correction factors) for pier nose shape, angle of attack of flow, bed condition, and bed armoring. Within the HEC-18 module, there are two different options available for calculating pier scour: (1) using local hydraulic conditions in the vicinity of each bridge pier, herein referred to as the local method, and (2) using maximum hydraulic conditions occurring at any location along the cross-section, herein referred to as the maximum method.

Local Method. The local method calculates scour at each pier using the maximum flow velocity and depth that corresponds to the centerline of each of the pier rows (measured along the cross-section immediately upstream of the bridge).

Maximum Method. The maximum method calculates scour at each pier using the maximum flow velocity and depth calculated at any location along the cross-section immediately upstream of the bridge, regardless of the actual location of the bridge piers. Since the maximum method uses one value for velocity and depth, one value for pier scour is calculated for all pier rows.

It is important to note HEC-18 performs these calculations on the pier located at the upstream end of the bridge for each row of piers (i.e., the pier that makes initial contact with the river flow). The upstream end of the bridge provides the worst-case scenario in terms of impacts to hydraulic performance due to the obstruction created by the piers. Any subsequent impacts caused by the other piers in each pier row would not exceed the impacts caused by the most upstream pier.

Calculations were performed using both the local method and maximum method to obtain an envelope of largest scour anticipated for each of the storm events analyzed. Pier scour calculations were performed using the Colorado State University (CSU) equation, outlined in the FHWA publication. This approach is the default method within the HEC-18 module in HEC-RAS.

Commerce Center Drive (CCD) Bridge Pier Scour

Commerce Center Drive currently ends at its intersection with Henry Mayo Drive, just shy of the Santa Clara River. The proposed CCD Bridge will be constructed as part of the Mission Village development project (TTM No. 61105) with the goal of providing secondary access to the development. Currently, the nearest bridge crossing over the River is 2 miles upstream (I-5 freeway and Old Road bridges), and the main access to the Mission Village development is through Magic Mountain Parkway on the northeastern side of the project boundary. The proposed bridge will vary in width from 120-feet to 129-feet and will carry three lanes of traffic in each direction to and from the development.

Local Method

Results for pier scour at CCD Bridge using the local method are shown in **Table 1** and **Table 2**, below.

Table 1 – Pier Scour for CCD Bridge (10-year storm event)

Pier Number (Pier Row)	Pier Scour (feet)
	Local Method
1 (G)	-
2 (F)	3.0
3 (E)	8.1
4 (D)	8.3
5 (C)	6.3
6 (B)	4.2
7 (A)	2.7

Notes:

1. *Values shown are for pier scour only (excludes contraction & abutment scour)*
2. *Pier #1 is located on the floodplain fringe, therefore no scour at this location*
3. *See Figures 2 and 3 for Plan View Layout of Bridge Piers*

Table 2 – Pier Scour for CCD Bridge (25-year storm event)

Pier Number (Pier Row)	Pier Scour (feet)
	Local Method
1 (G)	-
2 (F)	4.2
3 (E)	9.9
4 (D)	10.0
5 (C)	7.4
6 (B)	5.2
7 (A)	4.6

Notes:

1. *Values shown are for pier scour only (excludes contraction & abutment scour)*
2. *Pier #1 is located on the floodplain fringe, therefore no scour at this location*
3. *See Figures 2 and 3 for Plan View Layout of Bridge Piers*

When the calculations are performed using the local scour method, the pier scour ranges from 2.7-feet to a maximum of 8.3-feet for the 10-year event, and from 4.2-feet to a maximum of 10.0-feet for the 25-year event. Based on the results of the local scour method, the piers located towards the center of the River (piers 3, 4 and 5) have larger values of pier scour, which is likely due to the larger flow depths and higher velocities that occur in this region. Limits of inundation for the 10-year and 25-year storm events are shown on **Figure 2** and **Figure 3**, respectively, as well as the bridge pier configurations and pier rows.

Maximum Method

Using the maximum method, the calculated pier scour (for all CCD Bridge piers) is approximately 8.4-feet for the 10-year event, and 10.0-feet for the 25-year event. See **Table 3** below. As the data show, the maximum method yields slightly larger values for pier scour than does the local method for both storm events. Accordingly, these values represent the maximum pier scour that is expected to occur during the respective storm events. A graphical representation of the pier scour results are also provided in a cross sectional view on **Figure 4**.

Table 3 – Pier Scour for CCD Bridge (Maximum Method)

CCD Bridge	Pier Scour (feet)
	Maximum Method
10-year storm event	8.4
25-year storm event	10.0

Long Canyon Road Bridge Pier Scour

Long Canyon Road is a proposed infrastructure link to connect the Newhall Ranch Landmark Village development (VTTM No. 53108) to the north with the Homestead South development (VTTM No. 60678) to the south. A preliminary layout of the bridge yields an overall length of approximately 1,088 feet. The bridge will carry two lanes of traffic in each direction (for a total of four lanes), resulting in an overall width of 89-feet. Similar to the CCD Bridge, the majority of the structure would consist of two parallel structures separated by an open median.

Local Method

Results for pier scour at Long Canyon Road Bridge using the local method are shown in **Table 4** and **Table 5**, below.

Table 4 – Pier Scour for Long Canyon Road Bridge (10-year storm event)

Pier Number (Pier Row)	Pier Scour (feet)
	Local Method
1 (F)	-
2 (E)	-
3 (D)	-
4 (C)	8.4
5 (B)	8.5
6 (A)	-

Notes:

1. *Values shown are for pier scour only (excludes contraction & abutment scour)*
2. *Pier #1, 2, 3 & 6 are located outside of active flow (no scour at these locations)*
3. *See Figures 5 and 6 for Plan View Layout of Bridge Piers*

Table 5 – Pier Scour for Long Canyon Road Bridge (25-year storm event)

Pier Number (Pier Row)	Pier Scour (feet)
	Local Method
1 (F)	-
2 (E)	3.2
3 (D)	7.1
4 (C)	10.1
5 (B)	10.1
6 (A)	7.5

Notes:

1. *Values shown are for pier scour only (excludes contraction & abutment scour)*
2. *Pier #1 is located on the floodplain fringe, therefore no scour at this location*
3. *See Figures 5 and 6 for Plan View Layout of Bridge Piers*

When the calculations are performed using the local scour method, the pier scour is approximately 8.5-feet for the 10-year event, and ranges from 3.2-feet to a maximum of 10.1-feet for the 25-year event. Based on the results of the local scour method, the piers located towards the center of the River (piers 4 & 5) have larger values of pier scour, which is likely due to the larger flow depths and higher velocities that occur in this region. Limits of inundation for the 10-year and 25-year storm events are shown on **Figure 5** and **Figure 6**, respectively, as well as the bridge pier configurations and pier rows.

Maximum Method

Using the maximum method, the calculated pier scour (for all Long Canyon Road Bridge piers subject to flood flow) is approximately 10.4-feet for the 10-year event, and 11.8-feet for the 25-year event. See **Table 6** below. As the data show, the maximum method yields slightly larger values for pier scour than does the local method for both storm events. Accordingly, these values represent the maximum pier scour that is expected to occur during the respective storm events. A graphical representation of the pier scour results are also provided in a cross sectional view on **Figure 7**.

Table 6 – Pier Scour for Long Canyon Road Bridge (Maximum Method)

Long Canyon Road Bridge	Pier Scour (feet)
	Maximum Method
10-year storm event	10.4
25-year storm event	11.8

Residual Scour

As previously discussed, the values for maximum pier scour represent the maximum scour expected to occur during the peak flow of a specified storm event. Residual scour is an estimate of the resulting depression in the riverbed immediately after a large scour producing storm event has occurred and the river returns to a relatively static flow. Refer to the storm hydrograph discussion above for further information regarding the timing of precipitation and peak flood flows. Residual scour presented herein has assumed that no subsequent storm event occurs, and as such is a limited snap-shot of riverbed conditions, only representing modeled storm event flow velocities. The results are informative as an estimate of the remaining depressional area that might be present until such time as any subsequent storm event occurs or the depression is filled in with additional sediment as deposition occurs if the depression is within the active river flow (i.e., wetted channel).

Residual scour present after the storm flow has ended is expected to be less than the maximum scour presented above, reflecting fill-in of the scour pockets by material transported during the receding leg of the hydrograph. Relying on anecdotal experience and best engineering judgment for the present study, the residual scour is estimated to be approximately one-third of the maximum pier scour calculated using the FHWA procedure.

This presentation of residual scour is not intended to be a complete description of all likely storm flows and resulting scour that the bridge piers and riverbed may experience nor is this intended to be an overall description of the river geomorphology. For an extensive discussion of overall sediment transport and fluvial mechanics of the Santa Clara River, the reader is directed to the RMDP 2010 FEIR, more specifically the geomorphology section and associated appendices. Also note, that laboratory studies have been performed to evaluate scour at bridge piers in an attempt to estimate residual scour, however these studies are typically performed for clear-flow conditions. In alluvial channels such as the Santa Clara River, storm flows carry a substantial sediment load that tends to restore areas of local erosion that occur during peak flow as the flood flow subsides. It is generally not feasible to model a flow that is sediment-laden in a laboratory setting, therefore no standard calculation methods are available to determine residual scour.

Commerce Center Drive (CCD) Bridge Residual Scour

As shown on **Figure 4**, the post-storm (residual) scour is estimated to be 2.8-feet for the 10-year event, and 3.3-feet for the 25-year event. These results are summarized in **Table 7** below.

Long Canyon Road Bridge Residual Scour

As shown on **Figure 7**, the post-storm (residual) scour is estimated to be 3.5-feet for the 10-year event, and 3.9-feet for the 25-year event. These results are summarized in **Table 7** below.

Aerial Extent of Scour Hole

Another component to be considered when evaluating pier scour is the aerial extents (length and width) of the scour hole created during a storm. According to FHWA, the top-width of the scour hole at a pier is dependent on the angle of repose of the bed material, as well as the depth of scour. For practical applications, FHWA suggests using a value equal to twice the scour depth to determine the top-width of a scour hole, as shown on **Figure 8**.

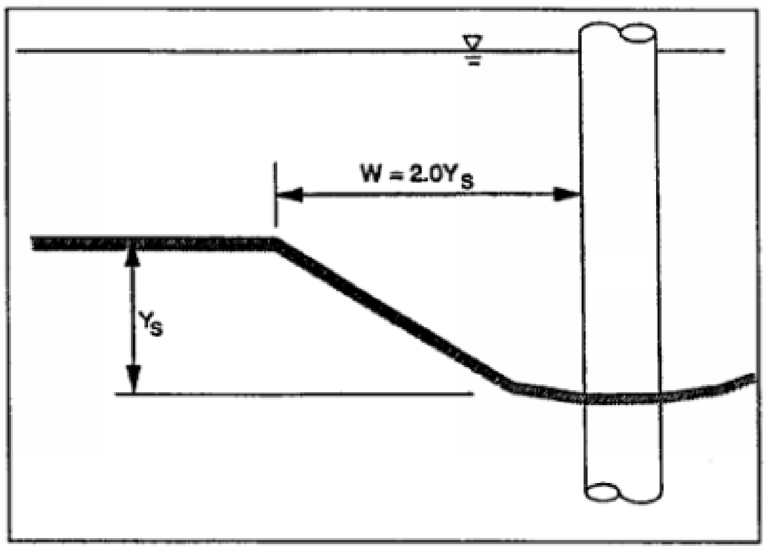

Figure 8 – Top width of Scour Hole (FHWA, 2001)

However, based on research of model studies, there is evidence that indicates the limit of scouring will extend farther downstream due to the existence of vortices created by water flowing around the bridge pier. The basic mechanism that causes pier scour is the formation of a "horseshoe" vortex, as shown in **Figure 9**. The horseshoe vortex is a result of downward movement of flow caused by the flow impingement at the upstream face of the pier. These downward forces create a scour hole at the base of the pier. As the depth of scour increases, the intensity of the vortex decreases and the flow begins to move downstream, creating a horseshoe-like shaped hole around the bridge pier. As flow travels around the pier, the separation of flow caused by the obstruction of the pier forms a "wake" vortex that extends the limits of the scour hole downstream of the pier.

There are currently no published guidelines for determining the extents of the additional scour caused by the wake vortex as this phenomenon is specific to site conditions and flow characteristics. PACE has estimated the horizontal limits at the bottom of the scour hole (downstream of the pier) to be roughly 1.5 times the pier diameter.

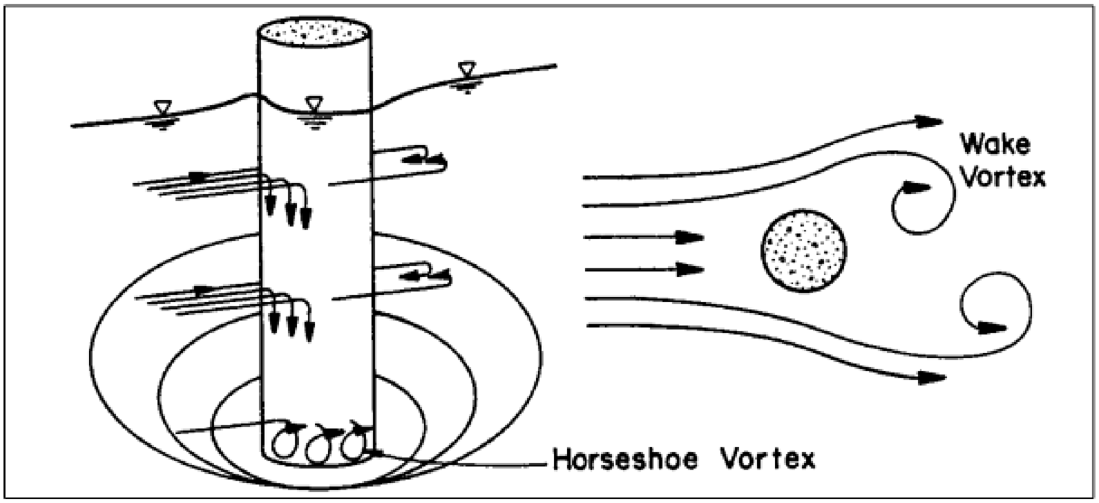

Figure 9 – Schematic Representation of Scour at Cylindrical Pier (FHWA, 2001)

Commerce Center Drive (CCD) Bridge Aerial Extent

Using the approaches outlined above, the top-width of the residual scour hole is estimated to be 5.6-feet for the 10-year event and 6.6-feet for the 25-year event. The length of the scour hole (downstream of the pier) is projected to be 14.6-feet for the 10-year event, and 15.6-feet for the 25-year event. These results are summarized in **Table 7** below.

Long Canyon Road Bridge Aerial Extent

Using the approaches outlined above, the top-width of the residual scour hole is estimated to be 7.0-feet for the 10-year event and 7.8-feet for the 25-year event. The length of the scour hole (downstream of the pier) is projected to be 16.0-feet for the 10-year event, and 16.8-feet for the 25-year event. These results are summarized in **Table 7** below.

Conclusion

The 10-year and 25-year events were presented as they are representative of what is considered major reset events on the Santa Clara River, and in the recent record (post Saint Francis Dam failure), have been observed on a periodic basis.. Based on these modeled 10-year and 25-year storm events, which are reflective of these large “reset events” on the Santa Clara River it is likely that residual scour pools will persist at one or more of the bridge piers at the Commerce Center Drive and Long Canyon Road Bridges. **Table 7** provides a summary of the maximum extent of the 10-year and 25-year residual scour that could be expected. For smaller storm events and as you move upland away from the wetted channel of the Santa Clara River, scour will be less. For larger storm events, greater scour would be expected.

Table 7 – Residual Pier Scour

Storm Event	CCD Bridge			Long Canyon Road Bridge		
	Residual Scour (feet)	Aerial Extent Top Width (feet)	Aerial Extent Length (feet)	Residual Scour (feet)	Aerial Extent Top Width (feet)	Aerial Extent Length (feet)
10-year	2.8	5.6	14.6	3.5	7.0	16.0
25-year	3.3	6.6	15.6	3.9	7.8	16.8

Attachments:

Figures:

Figure 2 – CCD Bridge 10-Year Floodplain Limits
Figure 3 – CCD Bridge 25-Year Floodplain Limits
Figure 4 – CCD Bridge Cross-Sectional View of Pier Scour
Figure 5 – Long Canyon Road Bridge 10-Year Floodplain Limits
Figure 6 – Long Canyon Road Bridge 25-Year Floodplain Limits
Figure 7 – Long Canyon Road Bridge Cross-Sectional View of Pier Scour

Appendix:

Appendix A – CCD Bridge Results of Pier Scour Analyses for 10-year Storm Event

- Local Scour Method
- Maximum Scour Method

Appendix B – CCD Bridge Results of Pier Scour Analyses for 25-year Storm Event

- Local Scour Method
- Maximum Scour Method

Appendix C – Long Canyon Road Bridge Results of Pier Scour Analyses for 10-year Storm Event

- Local Scour Method
- Maximum Scour Method

Appendix D – Long Canyon Road Bridge Results of Pier Scour Analyses for 25-year Storm Event

- Local Scour Method
- Maximum Scour Method

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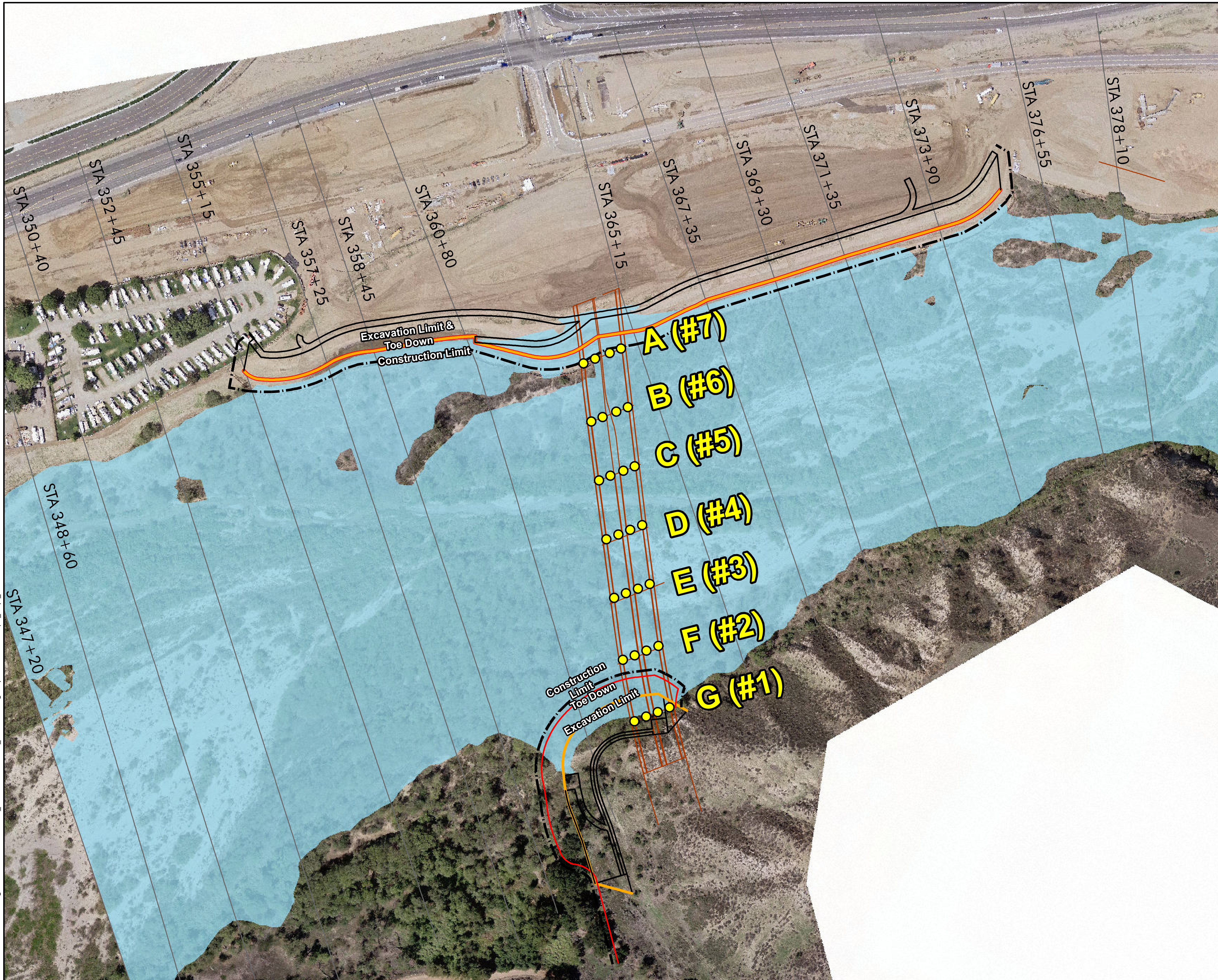
Figures



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NEWHALL RANCH

LA County CA

Legend

Pier Row (Pier # in HEC-RAS model)

10 Year Floodplain

0 125 250 500 Feet

PACE Advanced Water Engineering

Date: 8/12/2016

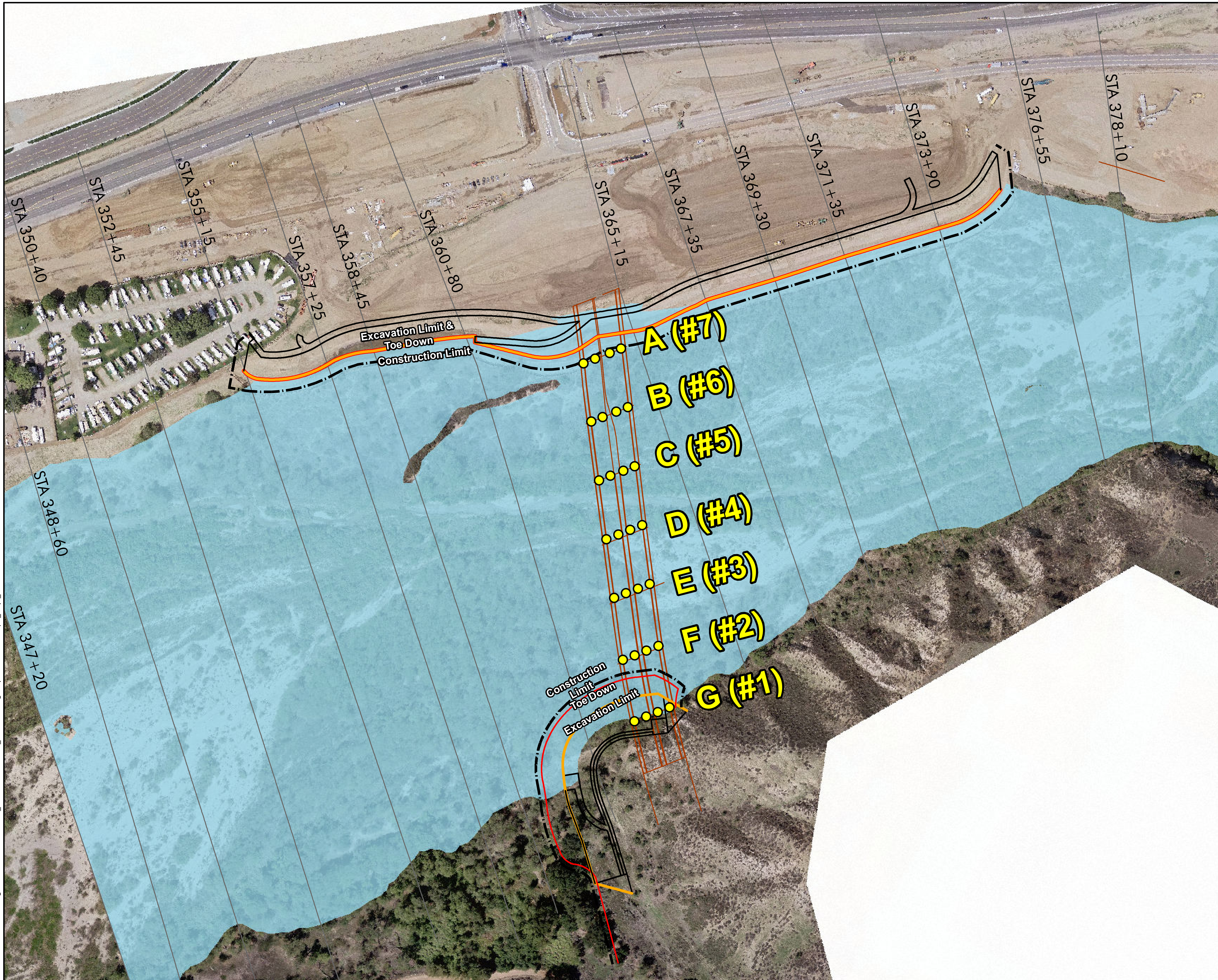
Job Number 8238E

Drawn By thowze

FIGURE 2

COMMERCE CENTER DRIVE BRIDGE 10 YEAR FLOODPLAIN

Aerial Imagery collected in 2014



NEWHALL RANCH

LA County CA

Legend

Pier Row (Pier # in HEC-RAS model)

25 Year Floodplain

0 125 250 500 Feet

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FIGURE 3

COMMERCE CENTER DRIVE BRIDGE 25 YEAR FLOODPLAIN

Aerial Imagery collected in 2014

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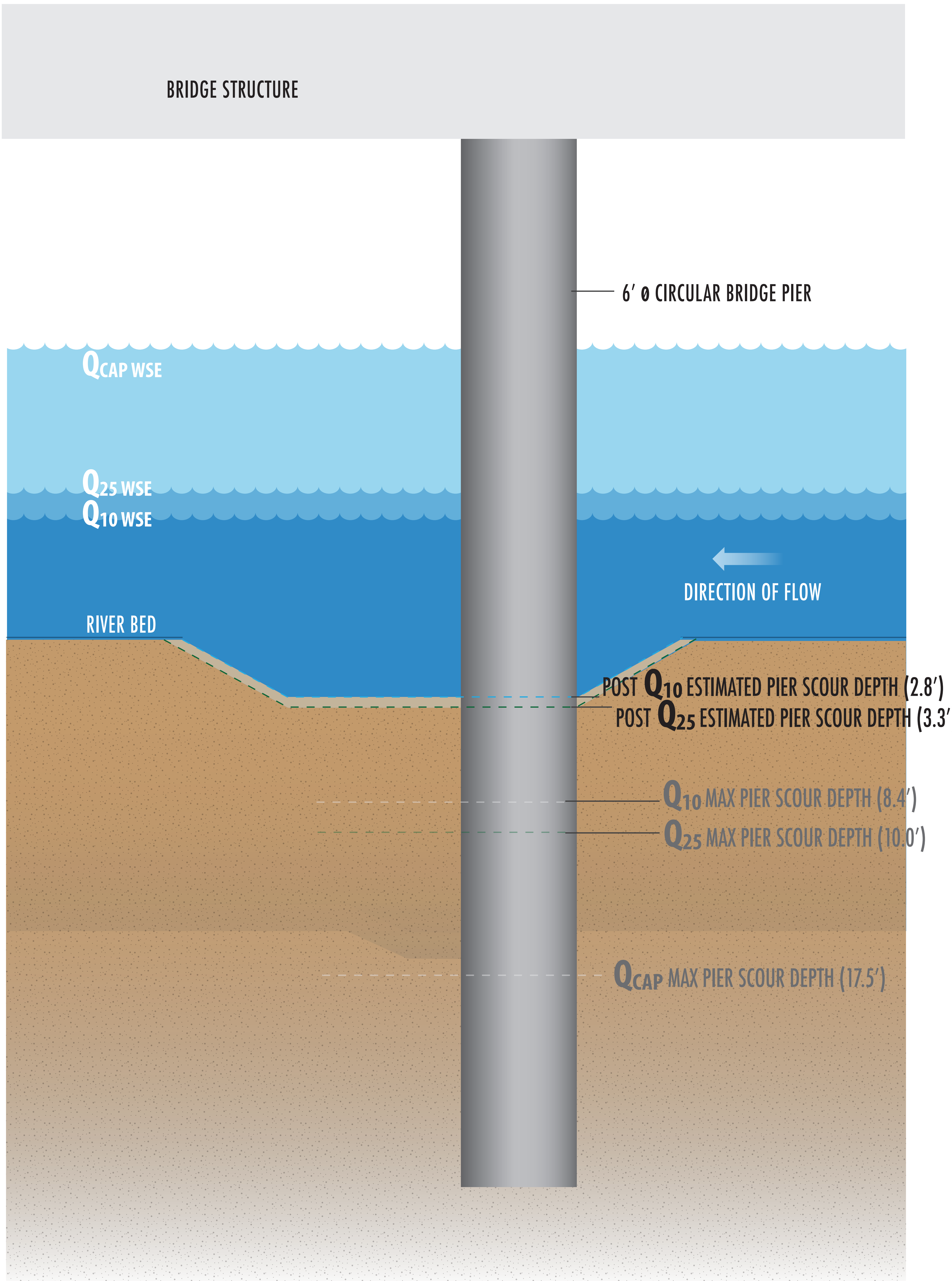
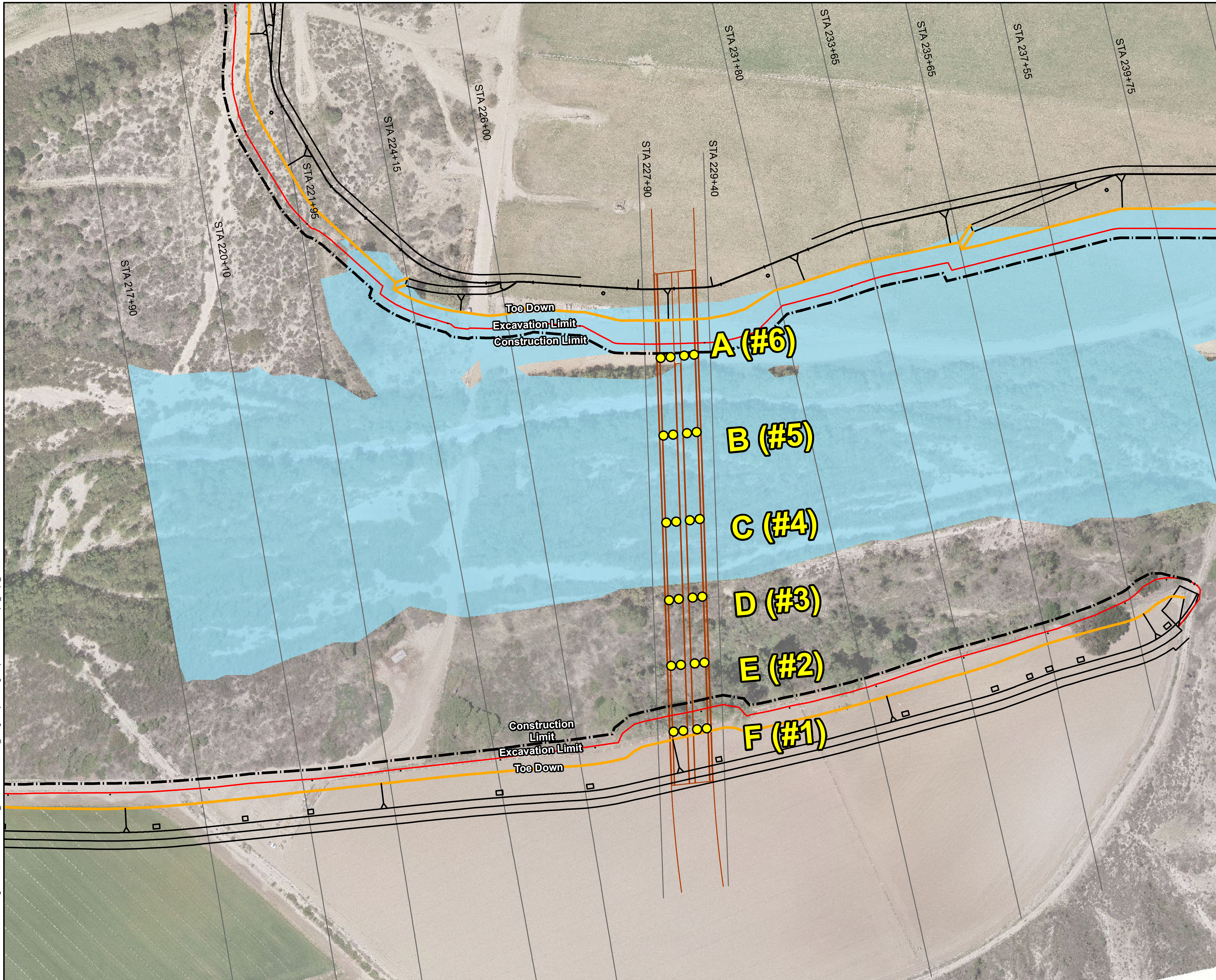


FIGURE 4 – CROSS SECTIONAL VIEW OF PIER SCOUR AT COMMERCE CENTER DRIVE BRIDGE

Q_{CAP} = LOS ANGELES COUNTY CAPITAL STORM EVENT



NEWHALL RANCH

LA County CA

Legend

- Pier Row (Pier # in HEC-RAS model)
- 10 Year Floodplain

0 100 200 400 Feet

PACE Advanced Water Engineering

Date: 9/30/2016

Job Number 8238E

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FIGURE 5

LONG CANYON BRIDGE 10 YEAR FLOODPLAIN

Aerial Imagery collected in 2014

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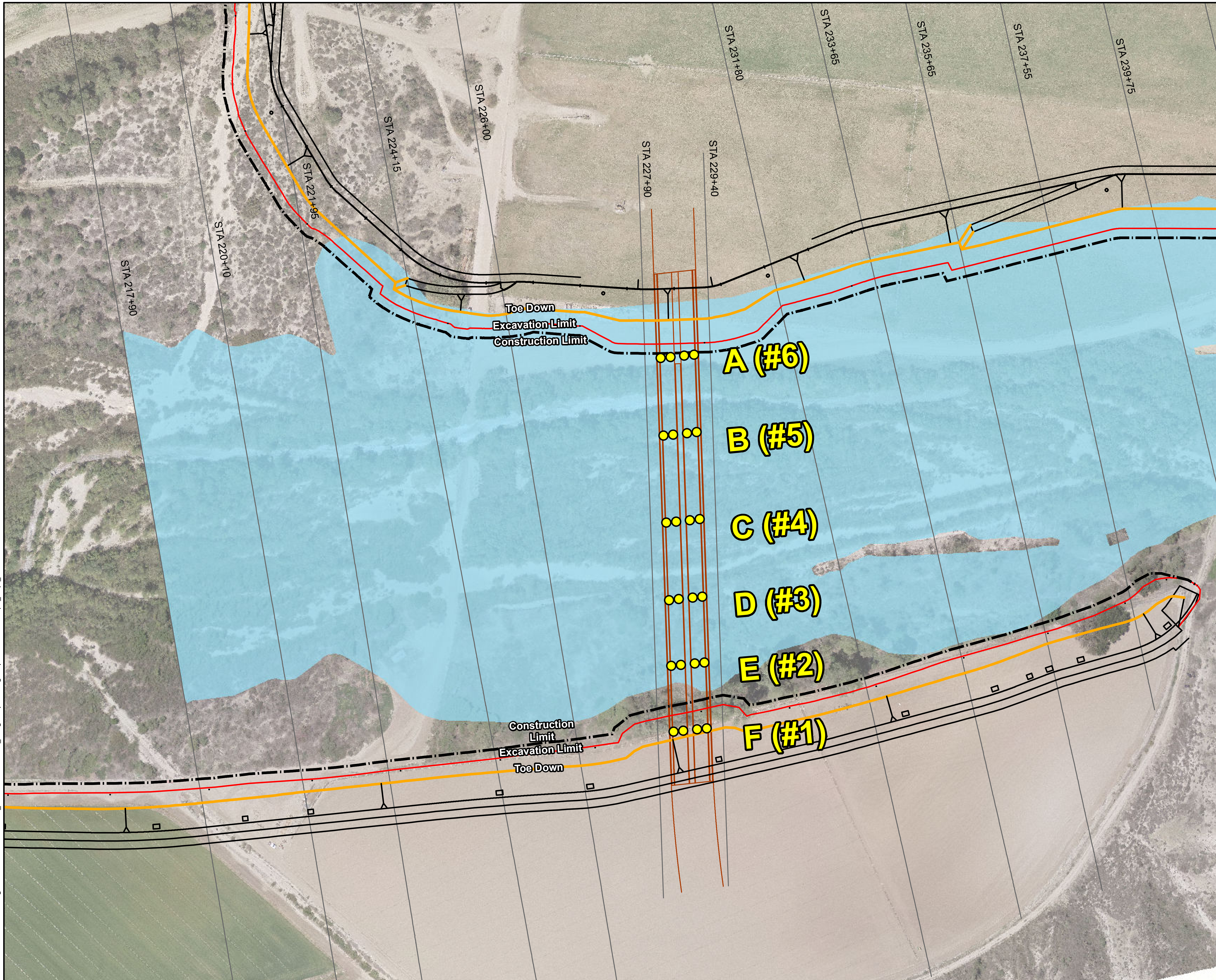
NEWHALL RANCH

LA County CA

Legend

- Pier Row (Pier # in HEC-RAS model)
- 25 Year Floodplain



0 100 200 400 Feet

PACE Advanced Water Engineering

Date: 9/12/2016

Job Number 8238E

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FIGURE 6

LONG CANYON BRIDGE 25 YEAR FLOODPLAIN

Aerial Imagery collected in 2014

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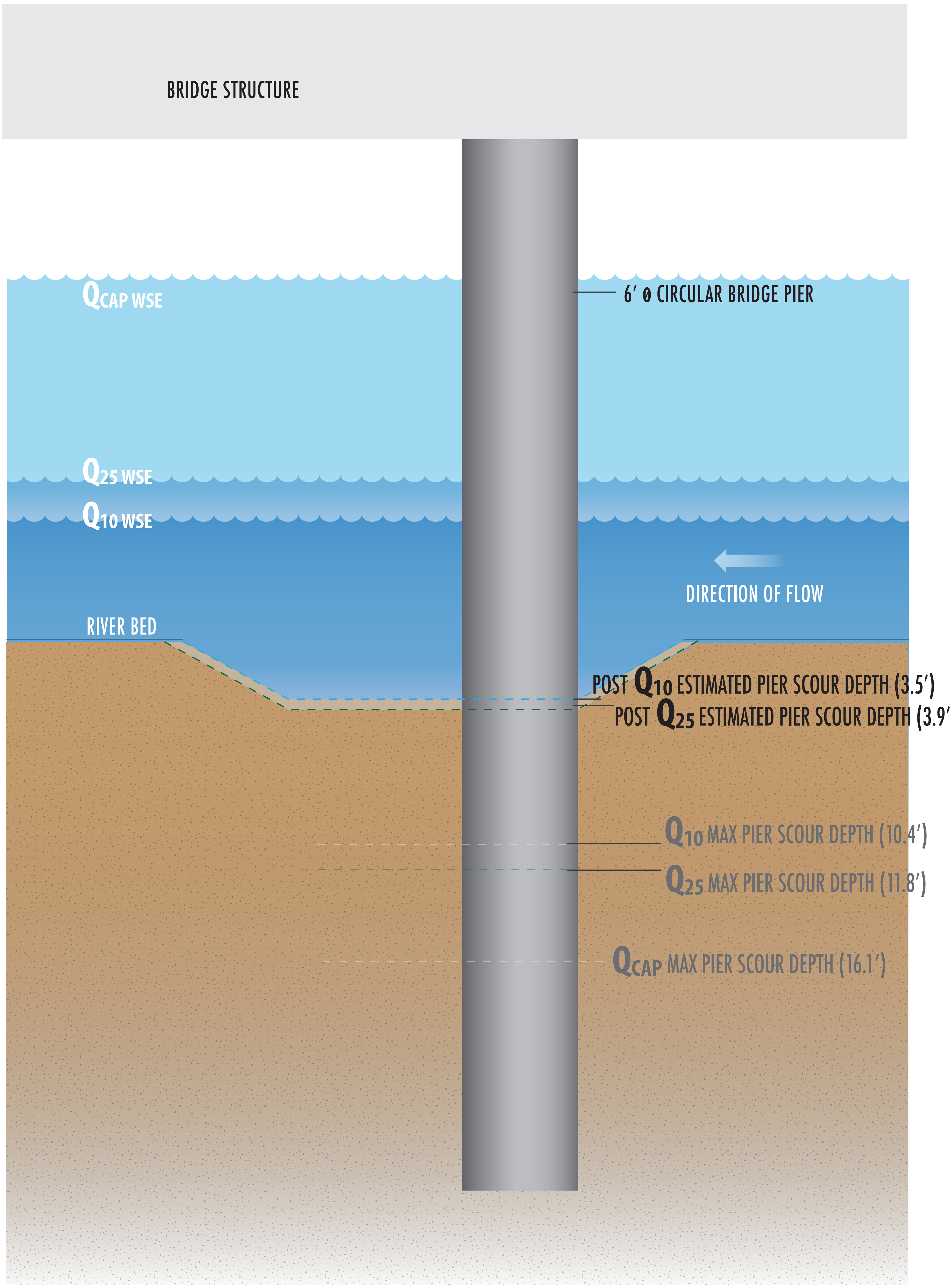
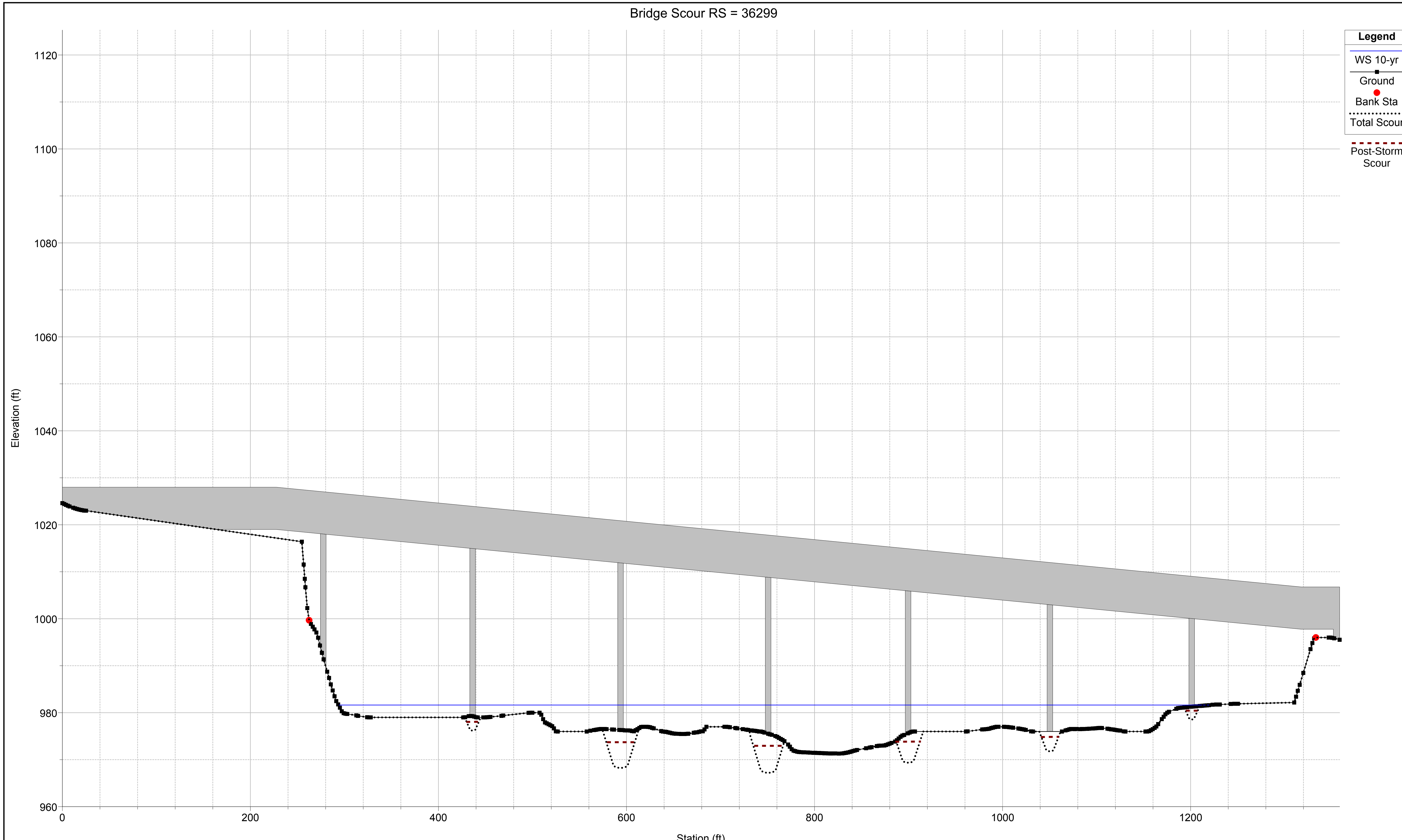


FIGURE 7 - CROSS SECTIONAL VIEW OF PIER SCOUR AT LONG CANYON ROAD BRIDGE

Q_{CAP} = LOS ANGELES COUNTY CAPITAL STORM EVENT

Appendix A

Pier Scour for CCD Bridge - Local Scour Method (10-yr Storm Event)



1 in Horiz. = 100 1 in Vert. = 20

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Hydraulic Design Data

Pier Scour

Pier: #1 (CL = 277.501)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	0.00
Velocity Upstream (ft/s):	0.00
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	
Froude #:	
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Pier: #2 (CL = 436.405)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	2.43
Velocity Upstream (ft/s):	0.61
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	3.0
Froude #:	0.07
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Pier: #3 (CL = 593.677)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	5.35
Velocity Upstream (ft/s):	4.58
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	8.1
Froude #:	0.35
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Pier: #4 (CL = 750.698)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	6.15
Velocity Upstream (ft/s):	4.71
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	8.3
Froude #:	0.33
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Pier: #5 (CL = 899.557)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	6.05
Velocity Upstream (ft/s):	2.45
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	6.3
Froude #:	0.18
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Pier: #6 (CL = 1050.338)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	5.67
Velocity Upstream (ft/s):	0.99
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	4.2
Froude #:	0.07
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

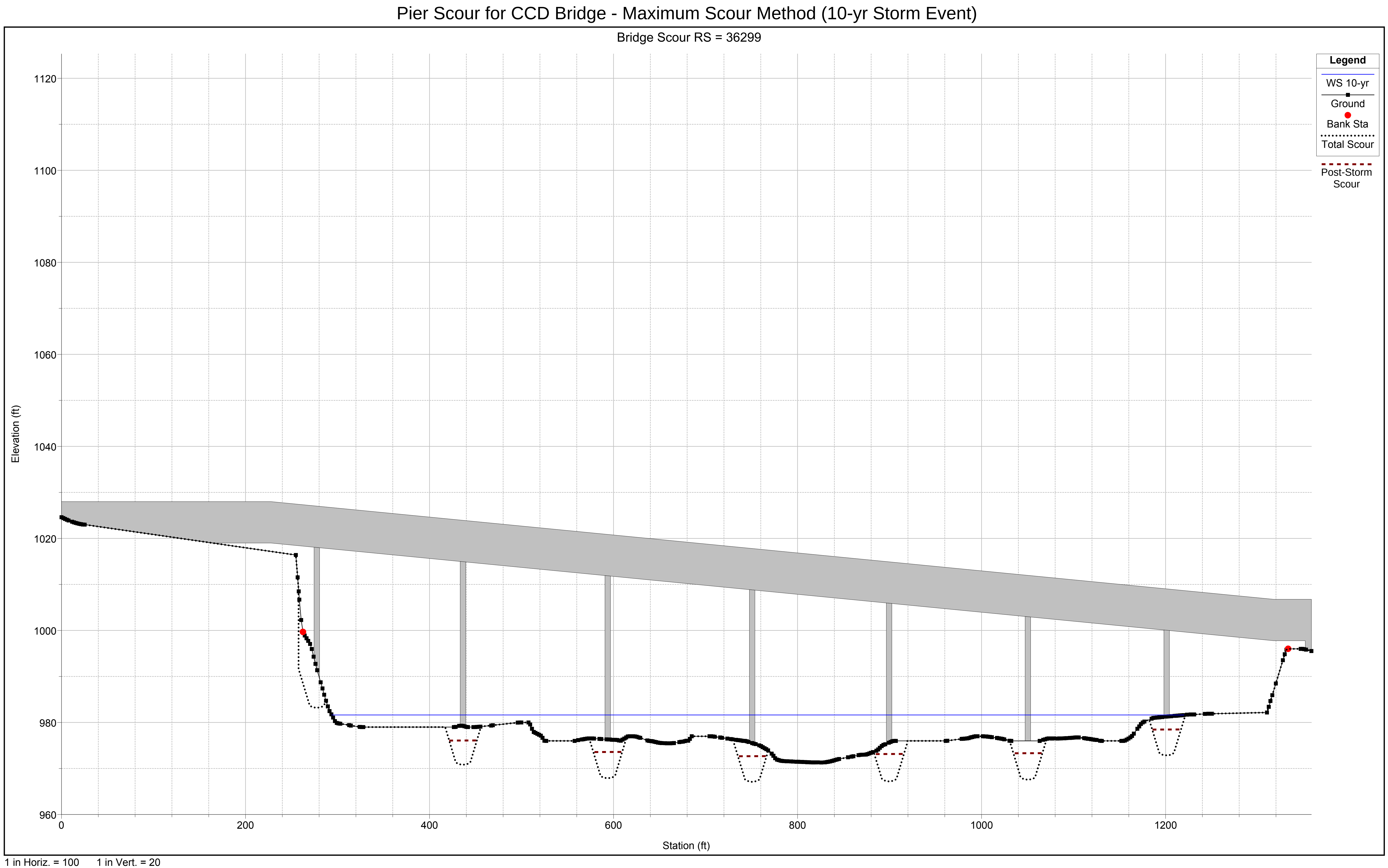
Pier: #7 (CL = 1201.109)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	0.40
Velocity Upstream (ft/s):	0.81
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	2.7
Froude #:	0.23
Equation:	CSU equation


Pier Scour for CCD Bridge - Maximum Scour Method (10-yr Storm Event)
Bridge Scour RS = 36299
Legend
WS 10-yr
Ground
Bank Sta
Total Scour
Post-Storm Scour
Elevation (ft)
1120
1100
1080
1060
1040
1020
1000
980
960
0
200
400
600
800
1000
1200
Station (ft)
1 in Horiz. = 100 1 in Vert. = 20

Results of Pier Scour Analysis - Maximum Scour Method (Q_{10})

Hydraulic Design Data

Pier Scour

All piers have the same scour depth

Input Data

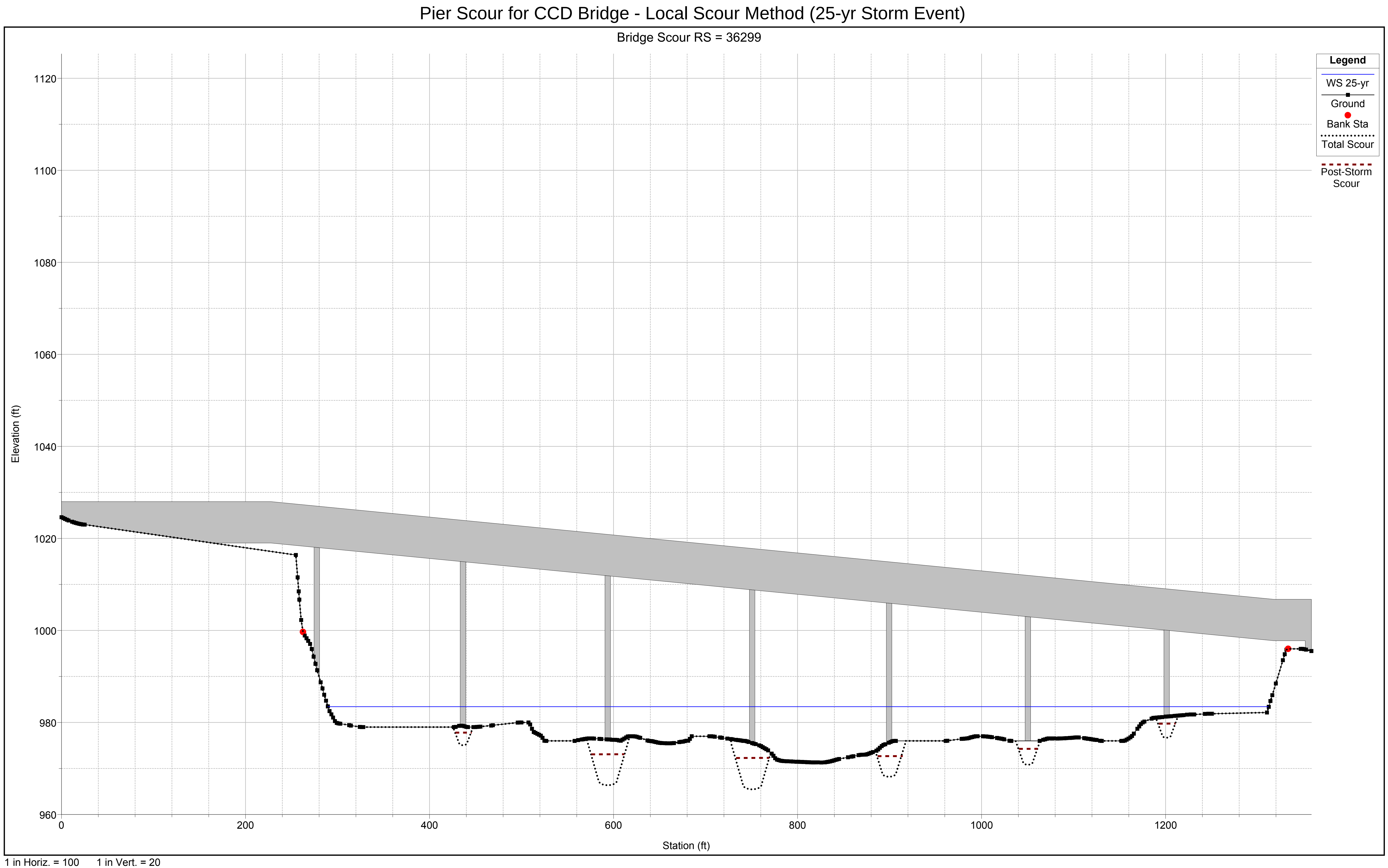
Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	6.67
Velocity Upstream (ft/s):	4.71
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	8.4
Froude #:	0.32
Equation:	CSU equation

PACE Advanced Water Engineering

Appendix B



Pier Scour for CCD Bridge - Local Scour Method (25-yr Storm Event)
Bridge Scour RS = 36299
Legend
WS 25-yr
Ground
Bank Sta
Total Scour
Post-Storm Scour
Elevation (ft)
1120
1100
1080
1060
1040
1020
1000
980
960
0
200
400
600
800
1000
1200
Station (ft)
1 in Horiz. = 100 1 in Vert. = 20

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Hydraulic Design Data

Pier Scour

Pier: #1 (CL = 277.501)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	0.00
Velocity Upstream (ft/s):	0.00
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	
Froude #:	
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Pier: #2 (CL = 436.405)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	4.29
Velocity Upstream (ft/s):	1.06
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	4.2
Froude #:	0.09
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Pier: #3 (CL = 593.677)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	7.21
Velocity Upstream (ft/s):	6.78
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	9.9
Froude #:	0.45
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Pier: #4 (CL = 750.698)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	8.01
Velocity Upstream (ft/s):	6.72
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	10.0
Froude #:	0.42
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Pier: #5 (CL = 899.557)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	7.91
Velocity Upstream (ft/s):	3.32
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	7.4
Froude #:	0.21
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Pier: #6 (CL = 1050.338)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	7.53
Velocity Upstream (ft/s):	1.46
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	5.2
Froude #:	0.09
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

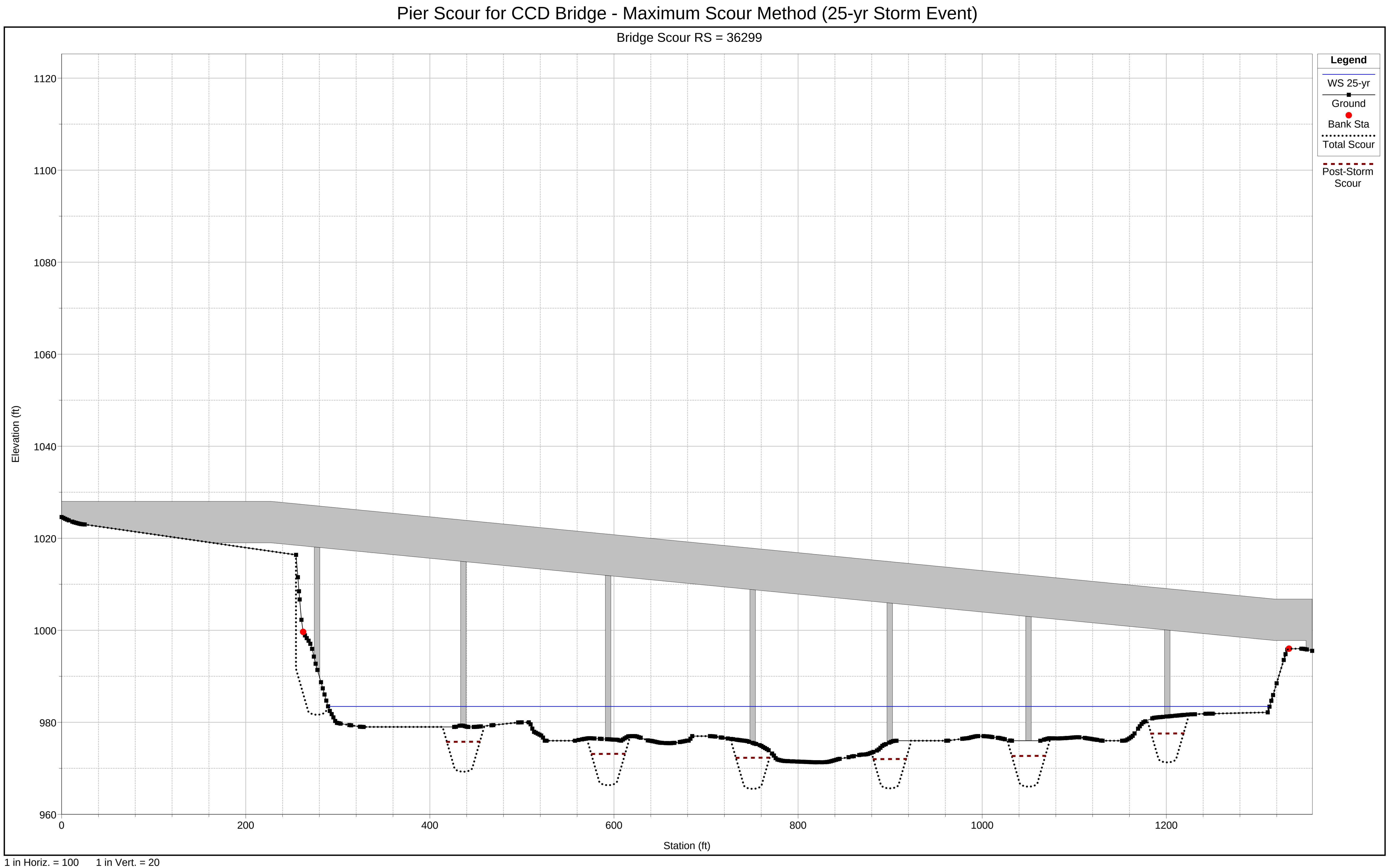
Pier: #7 (CL = 1201.109)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	2.26
Velocity Upstream (ft/s):	1.62
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	4.6
Froude #:	0.19
Equation:	CSU equation


Pier Scour for CCD Bridge - Maximum Scour Method (25-yr Storm Event)
Bridge Scour RS = 36299
Legend
WS 25-yr
Ground
Bank Sta
Total Scour
Post-Storm Scour
Elevation (ft)
1120
1100
1080
1060
1040
1020
1000
980
960
0
200
400
600
800
1000
1200
Station (ft)
1 in Horiz. = 100 1 in Vert. = 20

Results of Pier Scour Analysis - Maximum Scour Method (Q_{25})

Hydraulic Design Data

Pier Scour

All piers have the same scour depth

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	0.70
Depth Upstream (ft):	7.34
Velocity Upstream (ft/s):	6.78
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	120.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	9.50
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	10.0
Froude #:	0.44
Equation:	CSU equation

Appendix C

Appendix C

Pier Scour for Long Canyon Bridge - Local Scour Method (10-yr Storm Event)

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Hydraulic Design Data

Pier Scour

Pier: #1 (CL = 333.279)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	0.00
Velocity Upstream (ft/s):	0.00
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.33
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	
Froude #:	
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Pier: #2 (CL = 471.152)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	0.00
Velocity Upstream (ft/s):	0.00
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.33
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	
Froude #:	
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Pier: #3 (CL = 609.025)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	0.00
Velocity Upstream (ft/s):	0.00
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.33
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	
Froude #:	
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Pier: #4 (CL = 771.518)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	4.00
Velocity Upstream (ft/s):	5.48
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.33
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	8.4
Froude #:	0.48
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

Pier: #5 (CL = 953.707)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	4.00
Velocity Upstream (ft/s):	5.60
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.33
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	8.5
Froude #:	0.49
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{10})

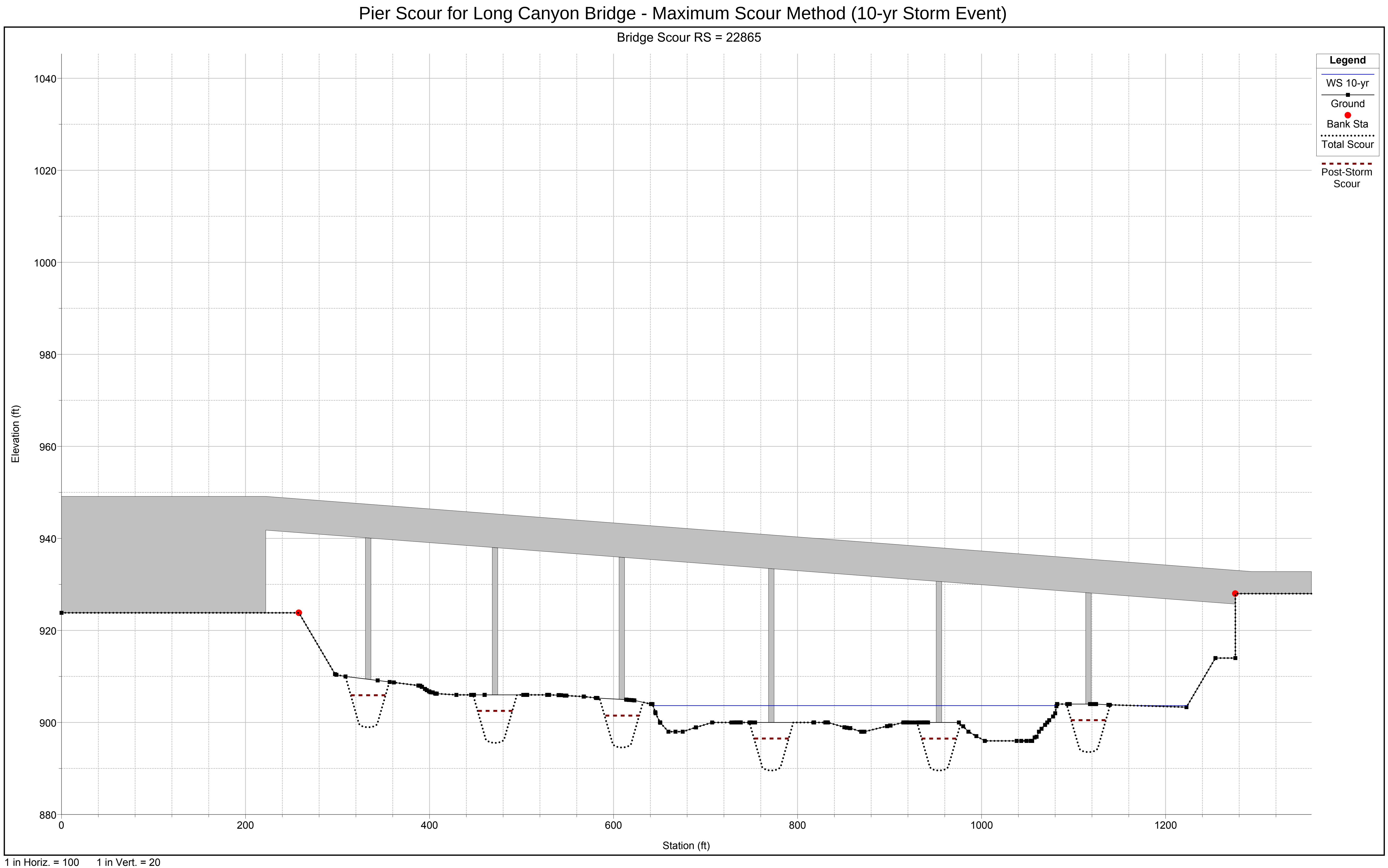
Pier: #6 (CL = 1116.201)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	0.00
Velocity Upstream (ft/s):	2.80
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.33
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	
Froude #:	
Equation:	CSU equation


Pier Scour for Long Canyon Bridge - Maximum Scour Method (10-yr Storm Event)
Bridge Scour RS = 22865
Legend
WS 10-yr
Ground
Bank Sta
Total Scour
Post-Storm Scour
Elevation (ft)
Station (ft)
1040
1020
1000
980
960
940
920
900
880
0
200
400
600
800
1000
1200
1 in Horiz. = 100 1 in Vert. = 20

Results of Pier Scour Analysis - Maximum Scour Method (Q_{10})

Hydraulic Design Data

Pier Scour

All piers have the same scour depth

Input Data

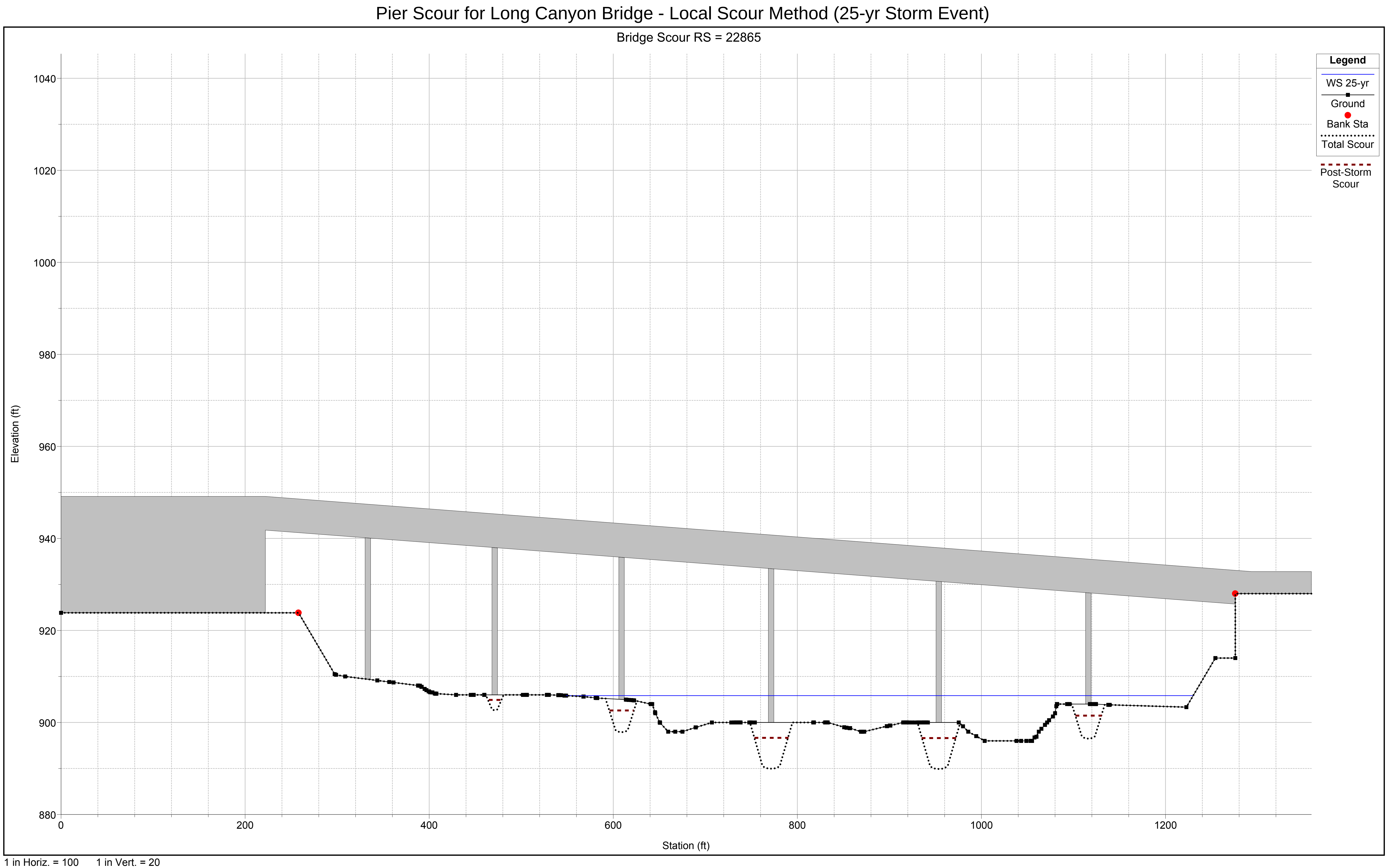
Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	6.96
Velocity Upstream (ft/s):	7.66
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.3
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	10.4
Froude #:	0.51
Equation:	CSU equation

Appendix D

Appendix D


Pier Scour for Long Canyon Bridge - Local Scour Method (25-yr Storm Event)
Bridge Scour RS = 22865
Legend
WS 25-yr
Ground
Bank Sta
Total Scour
Post-Storm Scour
Elevation (ft)
1040
1020
1000
980
960
940
920
900
880
Station (ft)
0
200
400
600
800
1000
1200
1 in Horiz. = 100 1 in Vert. = 20

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Hydraulic Design Data

Pier Scour

Pier: #1 (CL = 333.279)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	0.00
Velocity Upstream (ft/s):	0.00
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.3
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	
Froude #:	
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Pier: #2 (CL = 471.152)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	0.27
Velocity Upstream (ft/s):	1.37
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.3
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	3.2
Froude #:	0.47
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Pier: #3 (CL = 609.025)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	1.27
Velocity Upstream (ft/s):	5.31
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.3
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	7.1
Froude #:	0.83
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Pier: #4 (CL = 771.518)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	6.27
Velocity Upstream (ft/s):	7.28
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.3
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	10.1
Froude #:	0.51
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

Pier: #5 (CL = 953.707)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	6.27
Velocity Upstream (ft/s):	7.39
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.3
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	10.1
Froude #:	0.52
Equation:	CSU equation

Results of Pier Scour Analysis - Local Scour Method (Q_{25})

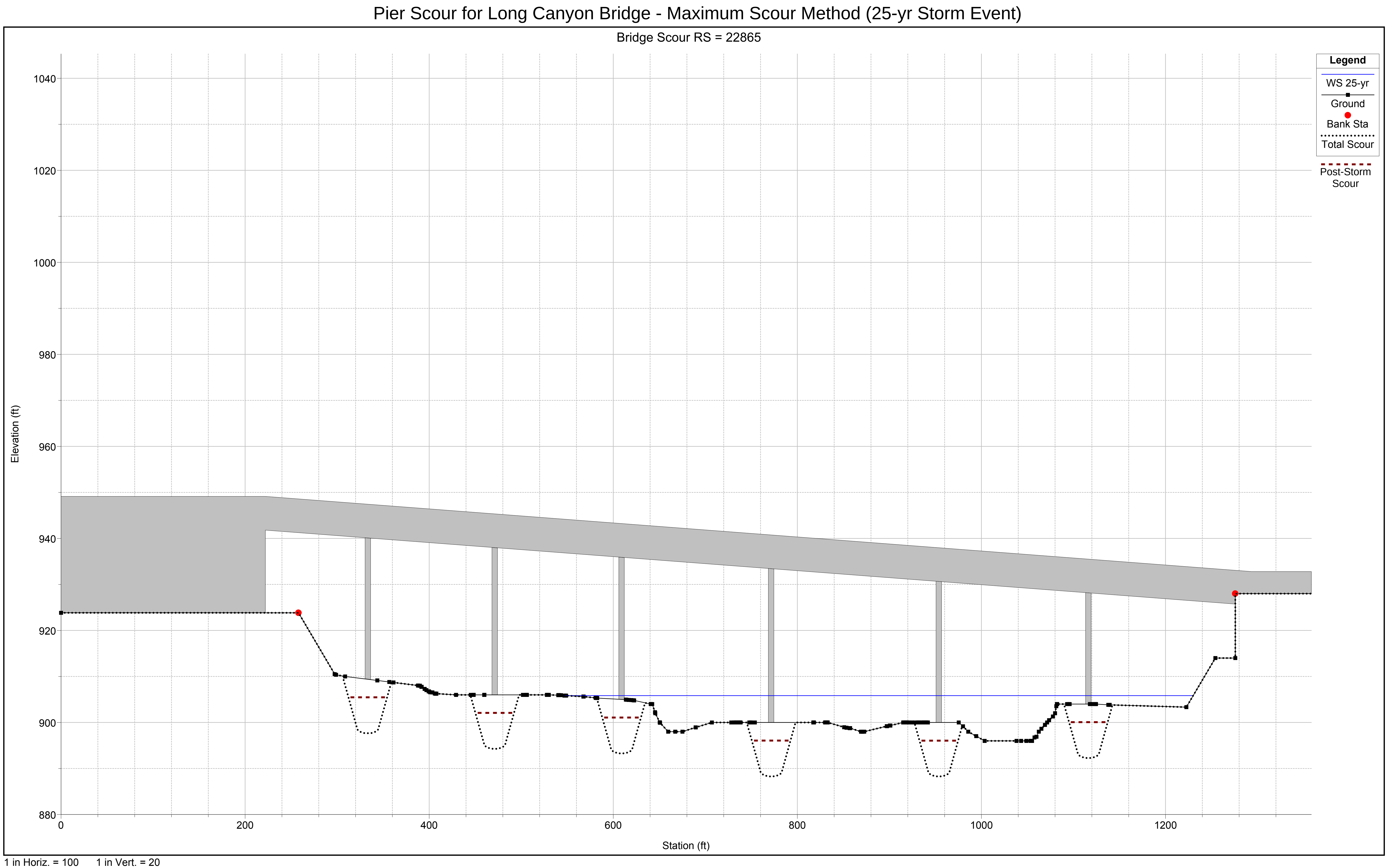
Pier: #6 (CL = 1116.201)

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	2.27
Velocity Upstream (ft/s):	5.06
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.3
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	7.5
Froude #:	0.59
Equation:	CSU equation



Pier Scour for Long Canyon Bridge - Maximum Scour Method (25-yr Storm Event)
Bridge Scour RS = 22865
Legend
WS 25-yr
Ground
Bank Sta
Total Scour
Post-Storm Scour
Elevation (ft)
1040
1020
1000
980
960
940
920
900
880
0
200
400
600
800
1000
1200
Station (ft)
1 in Horiz. = 100 1 in Vert. = 20

Results of Pier Scour Analysis - Maximum Scour Method (Q_{25})

Hydraulic Design Data

Pier Scour

All piers have the same scour depth

Input Data

Pier Shape:	Group of Cylinders
Pier Width (ft):	6.0
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	9.23
Velocity Upstream (ft/s):	9.28
K1 Nose Shape:	1.0
Pier Angle:	0.0
Pier Length (ft):	89.3
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	11.8
Froude #:	0.54
Equation:	CSU equation

PACE
Advanced Water Engineering

Technical Memorandum

Date: October 3, 2016

To: Sam Rojas and Matt Carpenter – Newhall Land

From: Mark Krebs, PE and Jose Cruz, PE

Re: Pier Scour Analysis – Newhall Ranch RMDP Temporary Haul Route Bridge #8238E

Purpose and Background

The purpose of this memorandum is to provide additional context to the issue of bridge pier scour as it relates to the potential for stranding of fish in scour holes that may result from large storm events. This memorandum provides an analysis of pier scour at the proposed Newhall Ranch RMDP temporary haul route bridge piles located near the proposed Long Canyon Bridge. The support piles (steel HP piles) for the temporary bridges will be in place during the winter season (December 1 – April 30), however the bridge decks will not be present. The temporary haul route bridges, including the temporary steel HP piles will be removed once grading operations at Landmark Village have been completed. Specifically, the memorandum describes pier scour for two different "reset" events – the first where peak flow corresponds to a 10-year storm, and second where peak flow corresponds to a 25-year storm. PACE ran the HEC-RAS[1] model to establish the river hydraulics for the 10-year and 25-year storms, using hydrologic data that PACE had previously prepared for the Santa Clara River watershed. For this analysis, the flow rates are 14,300-cubic feet per second (cfs) (10-year) and 28,100 cfs (25-year), respectively. The pier scour has been estimated using the HEC-RAS model as prepared for the September 30, 2016 technical memorandum to determine pier scour for the proposed Newhall Ranch RMDP permanent bridges. The previously prepared HEC-RAS scour model was adjusted to include the proposed temporary bridge with much smaller piers (i.e. 14-inch steel "I" beam versus 6-foot diameter circular concrete columns for the permanent bridge). Additionally, the bridge deck width in the model was set to 20-feet width for the temporary bridge, which corresponds to the width of each pile row of the temporary bridge. It should be noted that the model used in this analysis is specific to the Long Canyon bridge location, including hydraulic effects of the larger bridge and therefore is not reflective of the temporary bridge, which during the storm season will only consist of the piles (no bridge deck). However, pier scour determined in this analysis are representative of conditions for the temporary bridge crossing as it will be located near the proposed Long Canyon Bridge, with similar flow velocities. Therefore, this analysis should be viewed only as an estimate of local scour for the steel HP piles and not as an analysis of a complete bridge with piers and deck. As stated, the bridge deck is not to be present during the winter season, and therefore modeling of such a condition is not applicable.

The relationship between rainfall and river-flow over time is typically illustrated in a storm hydrograph. Peak flood flows recede back to, or near, pre-storm flow levels on the falling limb of the discharge curve, as illustrated on **Figure 1** below. The analysis provided herein reports on the maximum local pier scour expected at the peak flow of each modeled event and then presents a methodology to estimate the aerial extent and depth of local residual scour pools that might be expected to persist as flood flows from these

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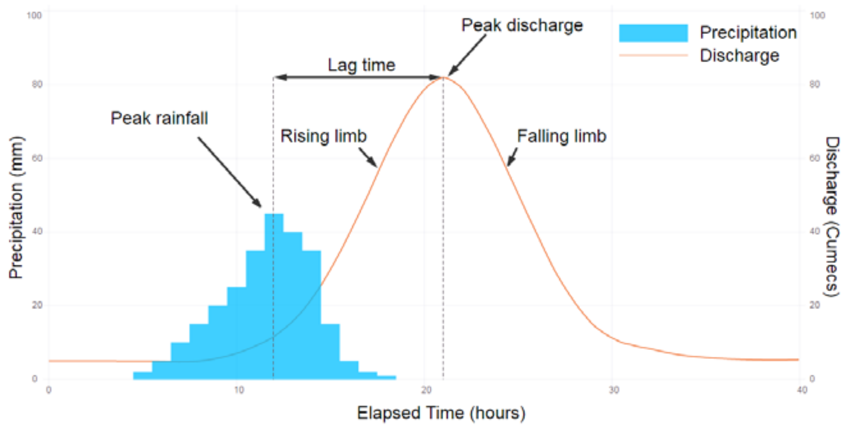
[1] Hydrologic Engineering Center's (CEIWR-HEC) River Analysis System (HEC-RAS), US Army Corps of Engineers (USACE).

events abate. Therefore, this analysis is only applicable to the period immediately after such events and does not consider or analyze conditions from multiple storm events nor does it provide information on what scour hole conditions may be expected at the end of the winter storm season. As the flow velocity is diminished, entrained sediment and fluvial bed movement settle, resulting in a residual scour hole that is smaller in aerial extent and shallower than the maximum scour that occurs during the peak discharge. Furthermore, subsequent storm events may interrupt the falling limb of the hydrograph, resulting in a new peak discharge curve and/or a new elevated base river flow.



https://geographyas.info/rivers/discharge-and-hydrographs/

Figure 1 – Example Storm Hydrograph

The US Geological Survey (USGS) defines scour as the hole left behind when sediment (sand and gravel) is washed away from the bottom of a river. Although scour may occur at any time, scour action is especially strong during floods. Swiftly flowing water has more energy than calm water to lift and carry sediment down river. In general, local pier scour is a concern for structural stability of a bridge. In the case of the temporary steel HP piles, they will be installed to a depth below the Qcap scour zone to ensure they are not damaged during a large storm season. However, as the bridge decks will not be in place, and the bridges will therefore not be in use during the storm season, scour is not a structural design concern at the pier locations.

Hydraulic analysis results from the HEC-RAS modeling were used to perform the subsequent scour analysis, which followed the procedures outlined in the Federal Highway Administration (FHWA) Hydraulic Engineering Circular No. 18 (HEC-18), Evaluating Scour at Bridges, 2001. The scour calculations were performed in a module embedded directly in HEC-RAS. Using HEC-18, bridge scour is comprised of three individual components: (1) Contraction scour, (2) Pier scour, and (3) Abutment scour. This memo addresses only the pier scour. For the reason stated above, the other types of scour are not applicable (the lack of a bridge deck eliminates contraction scour and the temporary bridges do not have abutments).

Pier Scour Calculation Methods

Several factors influence the magnitude of pier scour, including pier size, pier shape, bed material characteristics, and orientation and configuration of bridge piers. These elements are considered in the present calculations, and are expressed as form factors (or correction factors) for pier nose shape, angle of attack of flow, bed condition, and bed armoring. Within the HEC-18 module, there are two different options available for calculating pier scour: (1) using local hydraulic conditions in the vicinity of each bridge pier, herein referred to as the local method, and (2) using maximum hydraulic conditions occurring at any location along the cross-section, herein referred to as the maximum method.

Local Method. The local method calculates scour at each pier using the maximum flow velocity and depth that corresponds to the centerline of each of the pier rows (measured along the cross-section immediately upstream of the bridge).

Maximum Method. The maximum method calculates scour at each pier using the maximum flow velocity and depth calculated at any location along the cross-section immediately upstream of the bridge, regardless of the actual location of the bridge piers. Since the maximum method uses one value for velocity and depth, one value for pier scour is calculated for all pier rows.

As the temporary haul route bridges and associated pier supports are anticipated to be in close proximity to where velocity and depth of flow are expected to be highest, the maximum scour method is recommended. Calculations were performed using the maximum method to determine the largest scour anticipated for each of the storm events analyzed. Pier scour calculations were performed using the Colorado State University (CSU) equation, outlined in the FHWA publication. This approach is the default method within the HEC-18 module in HEC-RAS. It is important to note HEC-18 performs these calculations on the pier located at the upstream end of the bridge for each row of piers (i.e., the pier, or in this case steel HP pile, that makes initial contact with the river flow). The upstream end of the bridge provides the worst-case scenario in terms of impacts to hydraulic performance due to the obstruction created by the piers. Any subsequent impacts caused by the other piers in each pier row would not exceed the impacts caused by the most upstream pier.

Temporary Bridge Pier Scour

The temporary haul routes will include a modular bridge deck section that spans the wetted channel of the Santa Clara River, supported on temporary steel HP piles, and would consist of the following elements:

(i) Support piers made of steel piles;
(ii) Pile cap to support each of the modular temporary bridge deck sections;
(iii) Modular temporary bridge decks; and
(iv) Deck work consisting of K-rail barriers/curbing, cover soil / road surface, and fencing.

Only elements (i) and (ii) above will be in place during the winter season and therefore are the only elements of the temporary haul route bridges that will influence local scour. Elements (iii) and (iv) will be removed prior to the winter season. The temporary steel HP piles will be removed from the riverbed upon completion of construction and it is expected that they may experience up to three winter seasons prior to removal.

Maximum Method

Results for the calculated pier scour for the 10-yr and 25-yr events using maximum method are shown in **Table 1**, below. Accordingly, these values represent the maximum pier scour that is expected to occur during the respective storm events.

Table 1 – Pier Scour for Temporary Bridge (Maximum Method)

RMDP Temporary Haul Route Bridge	Pier Scour (feet)
	Maximum Method
10-year storm event	4.0
25-year storm event	4.4

For perspective, note that maximum pier scour for the permanent bridge (Long Canyon Bridge) calculated for the 10-year and 25-year events are in the neighborhood of 10.4-feet and 11.8-feet, respectively.

Residual Scour

As previously discussed, the values for maximum pier scour represent the maximum scour expected to occur during the peak flow of a specified storm event. Residual scour is an estimate of the resulting depression in the riverbed immediately after a large scour producing storm event has occurred and the river returns to a relatively static flow. Refer to the storm hydrograph discussion above for further information regarding the timing of precipitation and peak flood flows. Residual scour presented herein has assumed that no subsequent storm event occurs, and as such is a limited snap-shot of riverbed conditions, only representing modeled storm event flow velocities. The results are informative as an estimate of the remaining depressional area that might be present until such time as any subsequent storm event occurs or the depression is filled in with additional sediment as deposition occurs if the depression is within the active river flow (i.e., wetted channel).

Residual scour present after the storm flow has ended is expected to be less than the maximum scour presented above, reflecting fill-in of the scour pockets by material transported during the receding leg of the hydrograph. Relying on anecdotal experience and best engineering judgement for the present study, the residual scour is estimated to be approximately one-third of the maximum pier scour calculated using the FHWA procedure.

This presentation of residual scour is not intended to be a complete description of all likely storm flows and resulting scour that the bridge piers and riverbed may experience nor is this intended to be an overall description of the river geomorphology. For an extensive discussion of overall sediment transport and fluvial mechanics of the Santa Clara River, the reader is directed to the RMDP 2010 FEIR, more specifically the geomorphology section and associated appendices. Also note, that laboratory studies have been performed to evaluate scour at bridge piers in an attempt to estimate residual scour, however these studies are typically performed for clear-flow conditions. In alluvial channels such as the Santa Clara River, storm flows carry a substantial sediment load that tends to restore areas of local erosion that occur during peak flow as the flood flow subsides. It is generally not feasible to model a flow that is sediment-laden in a laboratory setting, therefore no standard calculation methods are available to determine residual scour.

The post-storm (residual) scour is estimated to be 1.3-feet for the 10-year event, and 1.5-feet for the 25-year event. These results are summarized in **Table 2** below.

Aerial Extent of Scour Hole

Another component to be considered when evaluating pier scour is the aerial extents (length and width) of the scour hole created during a storm. According to FHWA, the top-width of the scour hole at a pier is dependent on the angle of repose of the bed material, as well as the depth of scour. For practical applications, FHWA suggests using a value equal to twice the scour depth to determine the top-width of a scour hole, as shown on **Figure 2**.

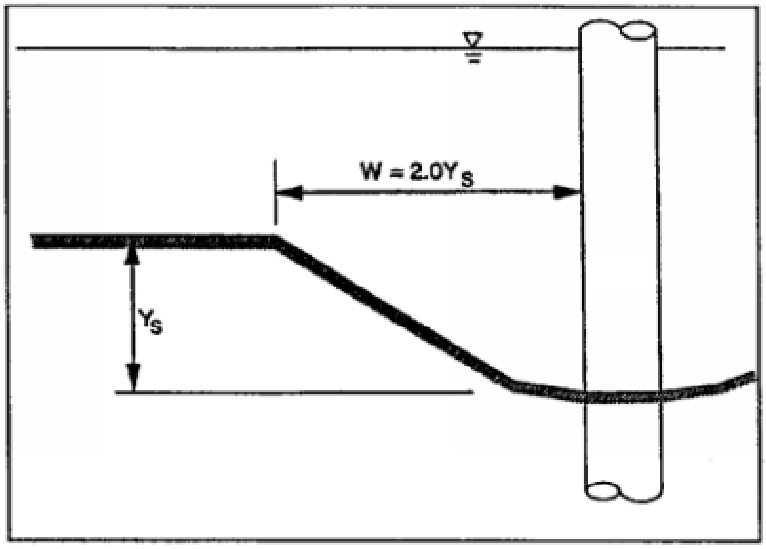


Figure 2 – Top width of Scour Hole (FHWA, 2001)

However, based on research of model studies, there is evidence that indicates the limit of scouring will extend farther downstream due to the existence of vortices created by water flowing around the bridge pier. The basic mechanism that causes pier scour is the formation of a "horseshoe" vortex, as shown in **Figure 3**. The horseshoe vortex is a result of downward movement of flow caused by the flow impingement at the upstream face of the pier. These downward forces create a scour hole at the base of the pier. As the depth of scour increases, the intensity of the vortex decreases and the flow begins to move downstream, creating a horseshoe-like shaped hole around the bridge pier. As flow travels around the pier, the separation of flow caused by the obstruction of the pier forms a "wake" vortex that extends the limits of the scour hole downstream of the pier.

There are currently no published guidelines for determining the extents of the additional scour caused by the wake vortex as this phenomenon is specific to site conditions and flow characteristics. PACE has estimated the horizontal limits at the bottom of the scour hole (downstream of the pier) to be roughly 1.5 times the pier diameter.

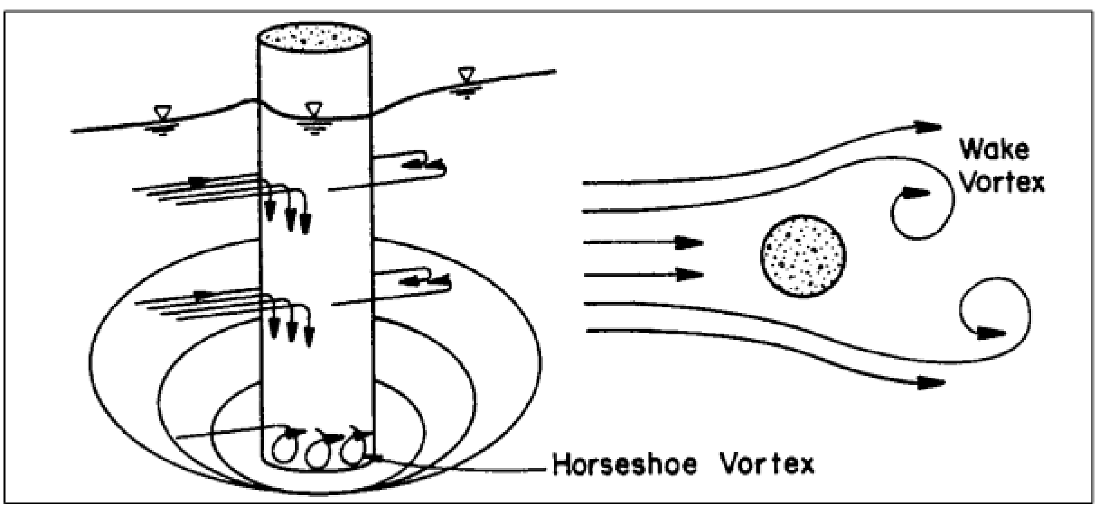


Figure 3 – Schematic Representation of Scour at Cylindrical Pier (FHWA, 2001)

Using the approaches outlined above, the top-width of the residual scour hole is estimated to be 2.6-feet for the 10-year event and 3.0-feet for the 25-year event. The length of the scour hole (downstream of the pier) is projected to be 4.4-feet for the 10-year event, and 4.8-feet for the 25-year event. These results are summarized in **Table 2** below.

Conclusion

The 10-year and 25-year events were presented as they are representative of what is considered major reset events on the Santa Clara River, and in the recent record (post Saint Francis Dam failure), have been observed on a periodic basis. Based on these modeled 10-year and 25-year storm events, which are reflective of these large "reset events" on the Santa Clara River it is suggested that residual scour pools could persist at one or more of the bridge piers at the Newhall Ranch RMDP temporary haul route bridges, however due to the very limited time period that the temporary bridge piles are in place, it is unlikely that such an event would occur. **Table 2** provides a summary of the maximum extent of the 10-year and 25-year residual scour that could be expected, if such an event were to occur. For smaller storm events, scour will be less. For larger storm events, greater scour would be expected.

Table 2 – Residual Pier Scour

Storm Event	RMDP Temporary Haul Route Bridge		
	Residual Scour (feet)	Aerial Extent Top Width (feet)	Aerial Extent Length (feet)
10-year	1.3	2.6	4.4
25-year	1.5	3.0	4.8

Attachments:

Appendix A:

Maximum Scour Method Results of Pier Scour Analyses for 10-yr Storm Event

Maximum Scour Method Results of Pier Scour Analyses for 25-yr Storm Event

Appendix A

Results of Pier Scour Analysis - Maximum Scour Method (10-Year Storm)

Hydraulic Design Data

Pier Scour

All piers have the same scour depth

Input Data

Pier Shape:	Square nose
Pier Width (ft):	1.17
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	7.03
Velocity Upstream (ft/s):	7.58
K1 Nose Shape:	1.1
Pier Angle:	0.0
Pier Length (ft):	20.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	4.0
Froude #:	0.50
Equation:	CSU equation

Results of Pier Scour Analysis - Maximum Scour Method (25-Year Storm)

Hydraulic Design Data

Pier Scour

All piers have the same scour depth

Input Data

Pier Shape:	Square nose
Pier Width (ft):	1.17
Grain Size D50 (mm):	1.60
Depth Upstream (ft):	9.34
Velocity Upstream (ft/s):	9.07
K1 Nose Shape:	1.1
Pier Angle:	0.0
Pier Length (ft):	20.0
K2 Angle Coefficient:	1.0
K3 Bed Cond Coefficient:	1.1
Grain Size D95 (mm):	20.00
K4 Armouring Coefficient:	1.0

Results

Scour Depth Ys (ft):	4.4
Froude #:	0.52
Equation:	CSU equation