3-7 EXAMPLE OF EVALUATION PROCESS

The purpose of this example is to illustrate the type of information to be recorded and transmitted in the design phase, as well as how structural adequacy of a defective shaft is checked. The bridge superstructure is a prestressed reinforced concrete box girder and is supported by two Type-II shafts as shown in Figure 1. The site is prone to scour and the soil may liquefy under seismic excitations. The maximum factored axial force of the column considering the overturning effect of seismic forces is 1790 kips, and the plastic moment of the column at this point is 9173 kip-ft. The corresponding overstrength moment and associated shear force are calculated as $M_o = 1.2\ M_p = 11008$ kip-ft, and $V_o = 900$ kips, respectively. The shaft is eight feet in diameter with 40 - #14 main reinforcing bars and #8 confining hoops @ 7.5″ spacing along the shaft, $f_y = 60$ ksi ($f_{ye} = 68$ ksi) and $f'_c = 4$ ksi ($f'_{ce} = 5.2$ ksi). The concrete cover to shaft reinforcement is six inches.

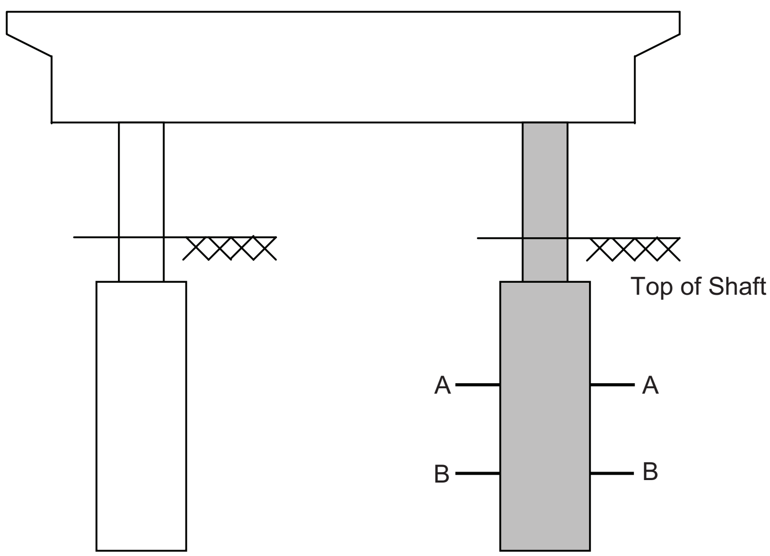
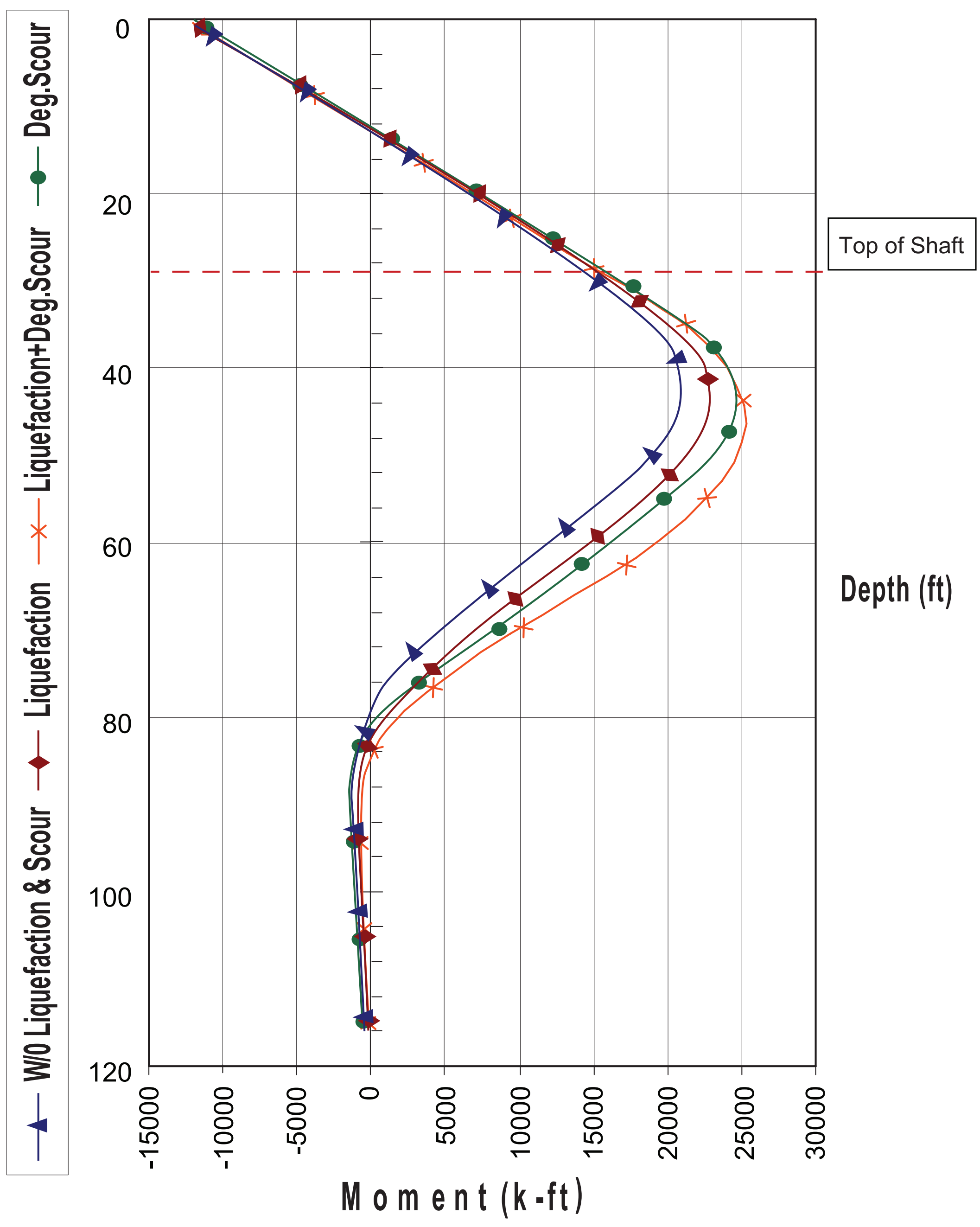


Figure 1 Elevation of the Column Shaft.

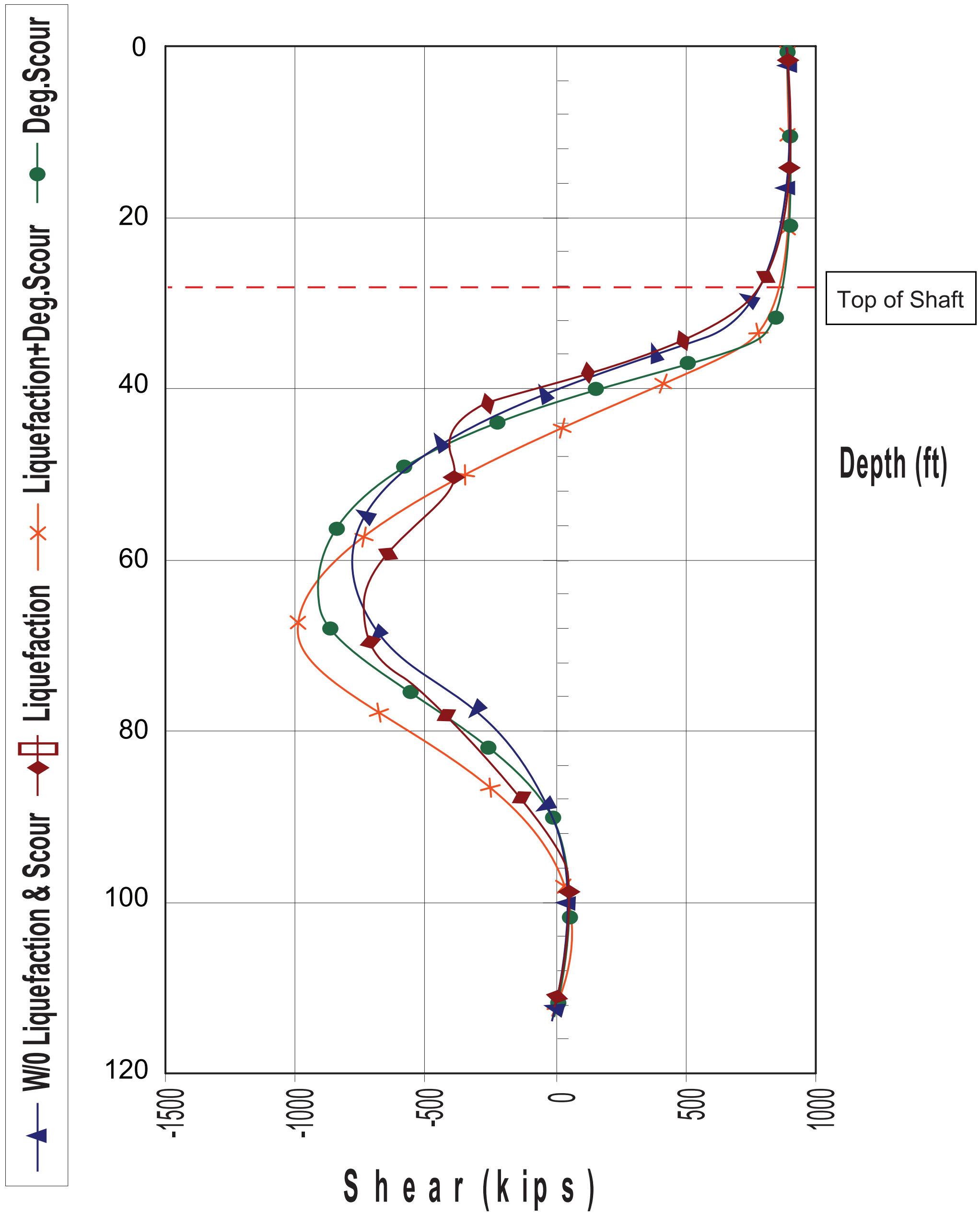
Design Data to be Recorded and Transmitted

Since the site is prone to scour and also the soil may liquefy during seismic excitations, the designer analyzed the shaft under column overstrength moment and shear for all possible combinations of scour and liquefaction. The soil springs down to scour depth were eliminated for the 100% scour effect. The effect of liquefaction was also considered by reducing the stiffness of the soil springs. The moment and shear diagrams for all possible combinations of the scour and liquefaction were reported by the designer and are shown in Figures 2 and 3, respectively. The information was saved in the bridge design branch to be used for construction support.



Note: Depth is measured from the deck.

Figure 2 Seismic Moment Demand in the Shaft.



Note: Depth is measured from the deck.

Figure 3 Seismic Shear Demand in the Shaft.

Evaluation for GGL Results

During construction of the shaft, the result of the GGL showed one pipe (out of eight) with low reading at the depth of 32- 34 ft. that is 3-5 ft. below top of shaft (Section A-A), and two pipe (out of eight) with low readings at a depth of 65 - 67 feet, that is 36-38 ft., below top of shaft (Section B-B) as shown in Figure 4. Attachment 3 shows the PDDF for this example with information from GGL regarding location and size of the anomaly.

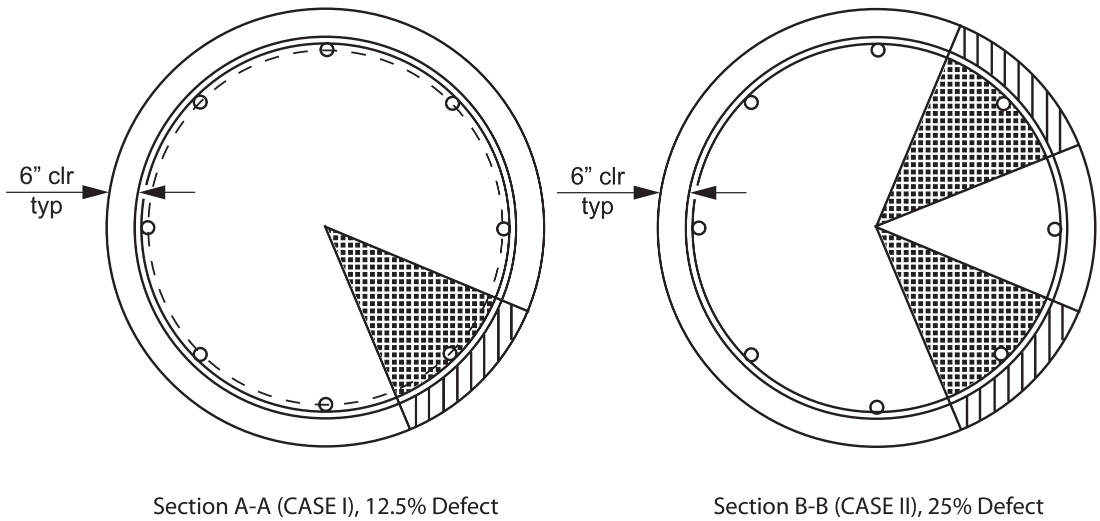


Figure 4 Modeling of Shaft with Anomalies Detected by GGL.

Capacity of Defective Shaft

Sectional analysis tool (such as the X-Section Program) is used to calculate the reduced flexural capacity of the defective shaft. In this example the compression steel rebars in the defected area have been ignored. If requested, FTB may provide information on the nature of the anomalous material that would help the designer to decide if rebars in the defected area can be included in the sectional analysis. For a single anomaly Section A-A is rotated to place the defective area under compression to capture the minimum flexural capacity value. However, in the case of two or more non-adjacent tubes with low readings (anomalies) in the shaft, the cross section is rotated in 30 degree increments to locate the lowest flexural capacity of the reduced section.

The capacity calculation is different for Types I and II shafts. For Type II shafts (capacity protected component) the reduced expected nominal moment (M_{ne}^{R}) is used in evaluation and that moment is calculated at concrete compressive strain of 0.003. For Type I shaft (ductile component) hinging of the shaft is allowed and therefore the plastic capacity of the reduced section of the shaft (M_{p}^{R}) is calculated.

In this example, the expected nominal moment of the reduced section for Section A-A was calculated as 18,725 kip-ft. For Section B-B the capacities of the reduced section at various angles of rotation were calculated and are listed in Table 1.

Angle of Rotation (degrees)	M_{ne} **@** ε_c **= 0.003 (k-ft)**
30	17014
60	15776
90	17955
120	18344
150	17911
180	17945
210	18448
240	17025
270	15871
300	18337
330	21744
360	21030

Table 1 Type II Shaft with Low Readings at Two Tubes.

Evaluation for Bending (Seismic)

The moment demand at Section A-A is 21,500 kip-ft for the most critical condition, when liquefaction and scour are considered. The reduced capacity of the section (M_{ne}^{R}) was calculated as 18,725 kip-ft; therefore, the pile anomaly at this location is not acceptable. The governing moment demand at Section B-B is 13,700 kip-ft and the minimum capacity of the reduced section was calculated as 15,776 kip-ft (see Table 1); therefore, the shaft capacity at this location is acceptable.

Evaluation for Shear (Seismic)

The shear capacity of the shaft at Sections A-A and B-B is calculated as 1,272 kips and 1,198 kips, respectively. Shear demands at these two points are 813 and 913 kips (Figure 3), respectively. Therefore, the shaft is acceptable for shear.

Evaluation for Axial Force (LRFD)

The factored nominal compression resistance of the shaft without anomaly is calculated as 18,938 kips. The reduced factored resistance of defective shaft at Section B-B (largest reduction) is 18,938 (1-0.25) = 14,204 kips, where 25% reduction accounts for two tubes out of eight (2/8) with low readings. In general, interaction of the axial force and bending moment should be considered when evaluating the shaft for LRFD strength limit state load combinations. However, factored axial resistance is much higher than maximum factored axial load of 3,120 kips, and such analysis is not necessary in this example. Attachment 3 shows completed PDDF for this example. The completed form is then forwarded to the FTB.

Evaluation for CSL Results

Further CSL testing showed that the single anomaly at Section A-A is equivalent to 9% of the cross section, and Section B-B anomalies are equivalent to 8.0% of the cross section as shown in Figure 5. Analytical (X-Section) models of Sections A-A and B-B modeling anomalies as void, are shown in Figure 5. For Section A-A the lowest flexural capacity is calculated as M_{ne}^{R} = 18,848 kip-ft, and 0.8 M_{ne}^{R} = 15,078 kip-ft, at an orientation that applied bending moment develops compression in the defective area. For Section B-B the variation of flexural capacity with angle of rotation is given in Table 2.

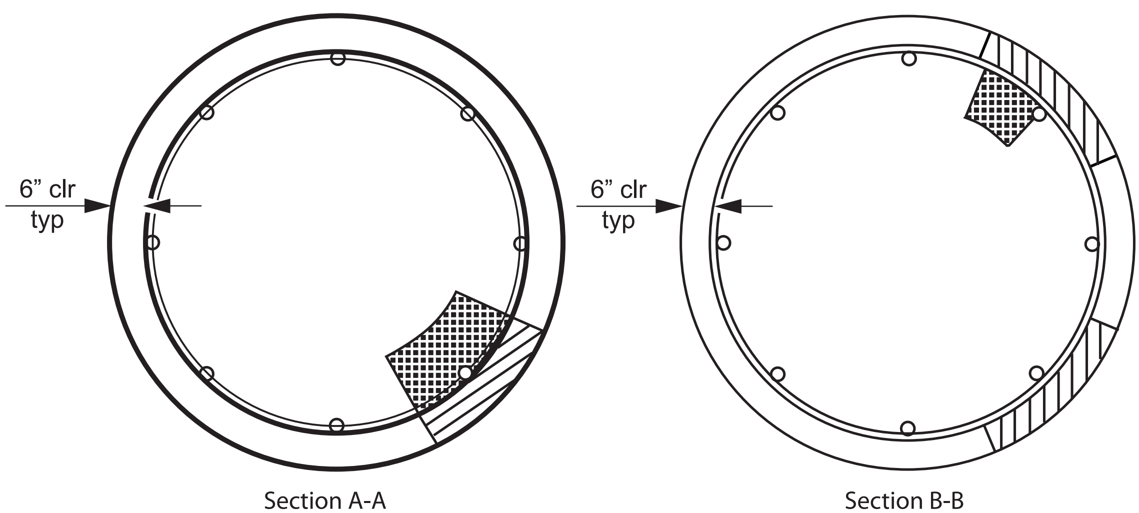


Figure 5 Schematics of Defects in the Shaft Detected by CSL.

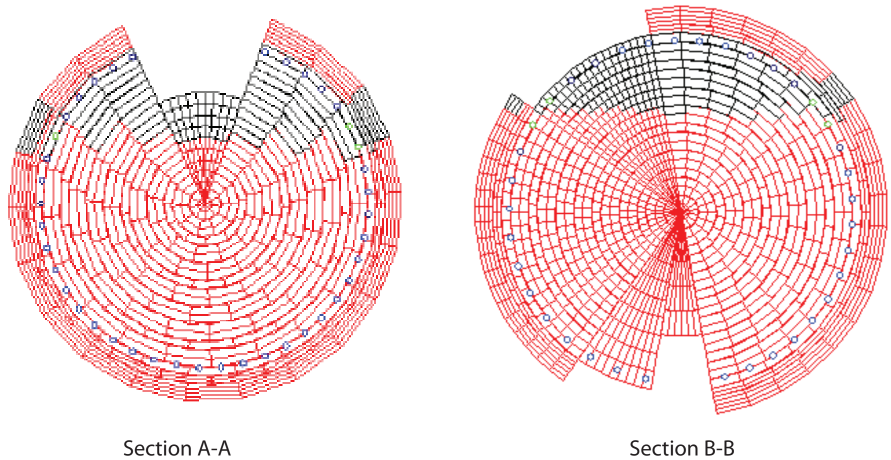


Figure 6 Analytical Modeling of Shaft with Anomalies Detected by CSL.

Angle of Rotation (degrees)	M_{ne} @ $\varepsilon_c = 0.003$ (k-ft)
30	21177
60	20352
90	21502
120	22329
150	21611
180	21151
210	20902
240	20168
270	20360
300	20908
330	22506
360	22795

Table 2 Capacity of Type II Shaft with Two Anomalies Detected by CSL.

Evaluation for Bending (Seismic)

The moment demand at Section A-A is 21,500 kip-ft for the most critical condition when liquefaction and scour are considered. The reduced capacity of the section was calculated as M_{ne}^{R} = 18,848 kip-ft; and 0.8 M_{ne}^{R} = 15,078 kip-ft; therefore, the shaft at this location is rejected.

The governing moment demand at Section B-B is 13,700 kip-ft and the minimum capacity of the reduced section was calculated as M_{ne}^{R} = 20,168 kip-ft (see Table 2), and 0.8 M_{ne}^{R} = 16,134 kip-ft; therefore, the shaft capacity at this location is acceptable. Attachment 4 shows completed PDDF for this example (evaluation based on CSL results).

Evaluation for Shear (Seismic)

The reduced shear capacity of the shaft (φV_n^R) at Sections A-A and B-B is calculated as 1305 kips and 1,307 kips, respectively. Shear demands at these two points are 813 and 913 kips (Figure 3); therefore, the shaft is acceptable for shear.

Evaluation for Axial Force (LRFD)

The reduced factored axial resistance of defective shaft at Section A-A (largest reduction) is 18,938 (1-0.086) = 17,309 kips. In general, interaction of the axial force and bending moment should be considered when evaluating the shaft for LRFD strength limit state load combinations. However, factored axial resistance is much higher than maximum factored axial load of 3,120 kips, and such analysis is not necessary in this example.