Summary of Analytical Assessment of Line 132 Response to Estimated Liquefaction Settlement

October 13, 2011

Background

The existing plan alignment of Line 132 in the vicinity of Redacted and Redacted is located within liquefiable soil deposits that could experience ground settlement in the event of a significant earthquake. Several borings and cone penetrometer test (CPT) soundings that were placed during site investigation for the BART tunnel on the south side of Redacted were reviewed by Kleinfelder. The location of the existing subsurface data was within 50 feet to 800 feet of Line 132. Liquefaction settlement was based upon the same conservative water table elevation established for the design basis of the BART tunnel. Since this water table elevation is approximately 25 feet below the ground surface in the vicinity of Redacted, lateral displacement of the banks of the lined creek from liquefaction can be excluded as a realistic ground failure hazard and only differential ground settlement needs to be considered as credible potential hazard to the pipeline related to liquefaction.

Kleinfelder Estimates of Liquefaction Settlement Hazard

Kleinfelder[1] provided estimates of ground settlement related to liquefaction based upon the following assumptions:

1. The subsurface conditions are consistent with those represented by the investigations performed for the BART SFO Extension Alignment. It is recognized that these subsurface investigations are spaced 300 feet to 500 feet apart and are located at distances less than 50 feet to 850 feet from Line 132.
2. The depth to ground water has been assumed to be the same as the design ground water depths assumed for the BART subsurface investigation and is believed to overestimate the actual elevation of the ground water table. Kleinfelder notes that the design ground water depths for BART are 5 feet to 10 feet higher that the high water measurements from borings and observations wells reported in the 1999 HLA report[2].
3. Liquefaction analyses were performed using the deterministic methods proposed by Seed et al. (2003) and Idriss and Boulanger (2008).
4. Assessment of liquefaction by Kleinfelder assumed an earthquake moment magnitude of 8.0 and a peak ground acceleration of 0.56 g assuming site

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[1] Kleinfelder, 2011. "Geotechnical Evaluation (Update 1), Pacific Gas and Electric Company, Gas Transmission Line 132 Redacted, South San Francisco, California," letter from Redacted and Redacted to Redacted, 29 September, 2011.

[2] Harding Lawson & Associates, 1999. "Final Design Phase Submittal – Geotechnical Engineering Design Report, BART Extension to SFO – Module 2, Contract 12YC-120, San Mateo County, California," prepared for HNTB Corporation, March 5.

conditions consistent with site class D of ASCE 7-10[3].

The most severe earthquake settlement hazard to Line 132 estimated by Kleinfelder was a 4" differential settlement over a distance of 50 ft. Kleinfelder also examined the effect of different peak ground acceleration values on the estimates of ground settlement and found virtually no difference for a peak ground acceleration of 0.4 g. From the USGS website, the annual likelihood of an earthquake producing a peak ground acceleration greater than 0.4 g is approximately 1/485.

Pipeline Response to Liquefaction Settlement

The response of Line 132 to liquefaction settlement was assessed using finite element analysis methods as recommended in industry guidelines[4, 5]. Analysis of pipeline response was carried out using ANSYS, a general-purpose finite element program that is widely used and is well-supported. The pipeline elements used in the analysis were typically one pipe diameter in length except at the elbows where eight elements per 90° angle change where used. A maximum settlement displacement of 12 inches was applied in 120 increments with the maximum longitudinal tension and compression strain at key locations in the model extracted at each displacement increment.

In these analyses, soil restraint is represented by non-linear soil springs based upon soil properties provided by Kleinfelder[2]. The soil in which the pipeline is located is quite variable and Kleinfelder recommended the characterizing the soil as a cohesionless material with an internal friction angle of 30° or a cohesive material with an undrained shear strength of 500 psf. In both cases, the recommended total unit weight of the soil was 125 pcf.

Soil spring properties were computed for both types of soil. Considering that higher soil restraint leads to more concentrated pipeline bending and higher pipeline strains, the largest soil spring restraint for either soil type was used in the analytical model. This approach leads to uplift soil restraint that is comparable to the restraint that would be provided by well-compacted soil that is typically required for pipelines placed within city streets. Therefore, no modifications were made in the modeling to account for the location of the pipeline relative to city streets.

The concrete lining of Redacted increases the vertical uplift restraint on the pipeline compared to what would exist for only soil cover. To account for this higher restraint, the soil restraint against upward pipeline displacement was taken to be the same as the soil restraint against downward pipeline displacement.

As specified in the Kleinfelder report, analyses were performed to assess pipeline response to liquefaction settlement that could develop over a distance of 50 feet. The analysis of pipeline response

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[3] ASCE, 2010. "Minimum Design Loads for Buildings and Other Structures," Standard ASCE 7-10, American Society of Civil Engineers, Reston, VA.

[4] Honegger, D.G. and D.J. Nyman, 2004. "Guidelines for the Seismic Design and Assessment of Natural Gas and Liquid Hydrocarbon Pipelines," Pipeline Research Council International, Inc., Catalog No. L51927.

[5] Pipeline Research Council International, Inc., 2009. "Guidelines for Constructing Natural Gas and Liquid Hydrocarbon Pipelines Through Areas Prone to Landslide and Subsidence Hazards," report prepared for PRCI by D.G. Honegger Consulting, C-CORE, and SSD, Inc., PRCI Catalog No. L52292.

considered settlement displacements as large as 12 inches to provide more complete information on the variation of pipeline strain with ground settlement.

The settlement displacements were applied to two pipeline configurations:

1. A straight pipeline subjected to ground settlement configuration with 350 feet of pipe undergoing settlement with 250 feet of pipe exposed to the maximum specified settlement and a 50-foot transition distance on each end.
2. A zone of settlement encompassing the pipeline overbend at the Redacted and a portion of the pipeline between the Redacted and Redacted as illustrated in Figure 1. The decision to encompass the overbend in the transition zone south of the Redact Redacted was based upon information that the girth weld at the fittings in this location was not considered unacceptable based upon inspection results.

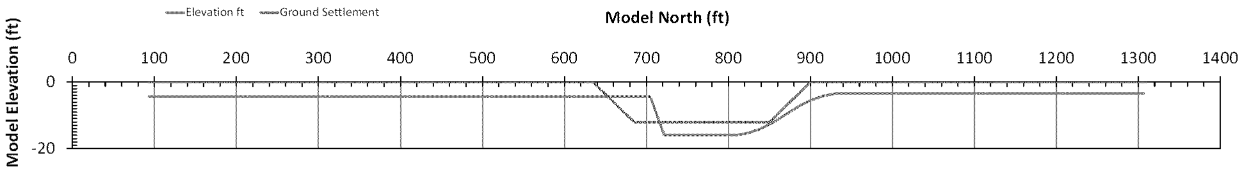

Figure 1: Pipe Profile and Ground Settlement Pattern Used in the Finite Element Analysis

Analysis Results

Plots of longitudinal tension and compression strain versus liquefaction settlement are provided in Figure 2. The computed strains are only considered to be significant to 4 decimal places. The distributed vertical displacement pattern applied on the south side of the Redacted results in maximum strains at the Redacted located near the more deeply buried sections of the pipeline north of the crossing. The maximum tension strain at 4 inches of settlement at the crossing is 0.0006in/in. For liquefaction settlement occurring outside of the crossing area where the pipeline is located with near constant soil cover, the maximum longitudinal tension strain from 4 inches of ground settlement over 50 feet is 0.0004 in/in.

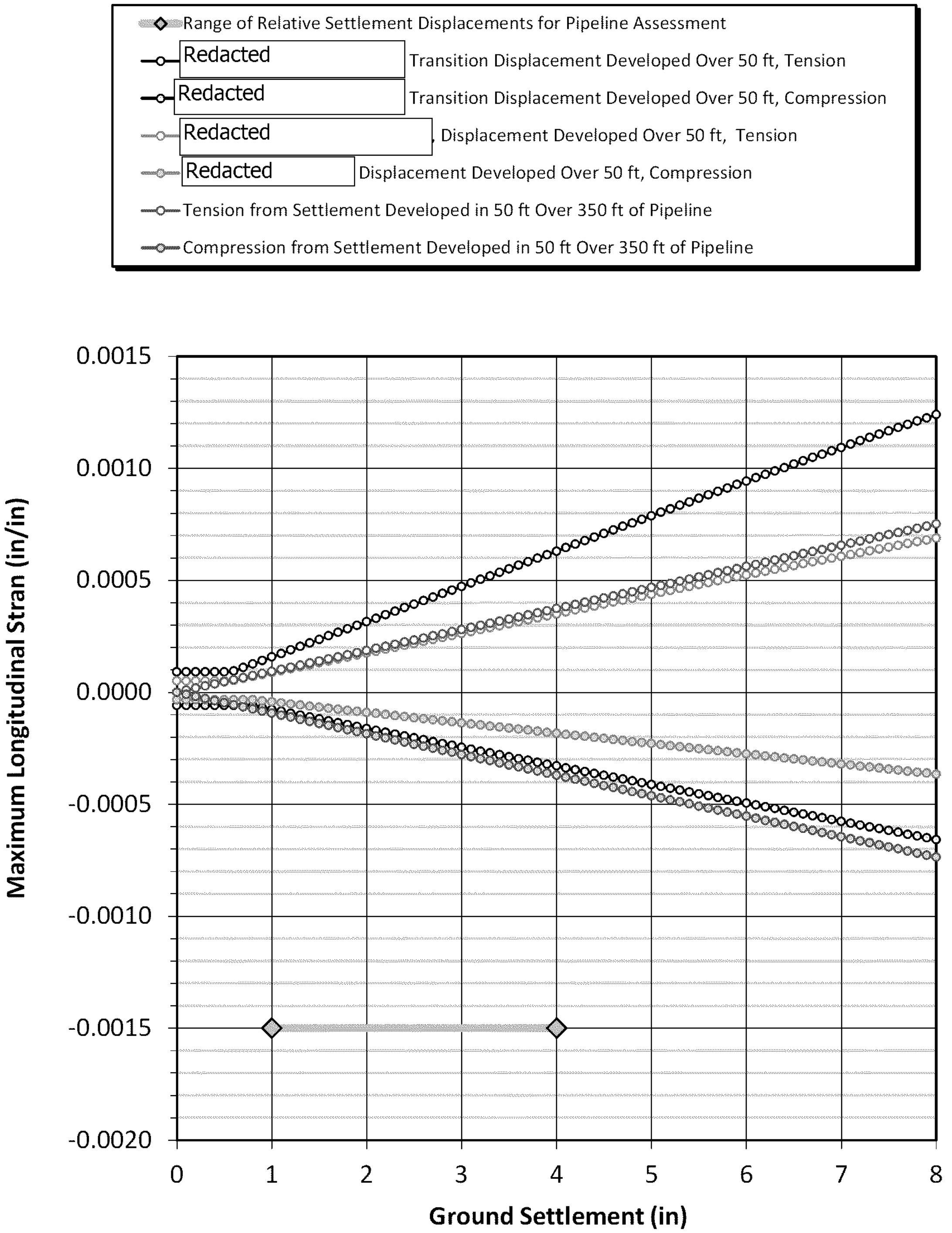

Figure 2: Longitudinal Strain Versus Vertical Settlement Developed Over a 50-ft Transition Distance