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E X T E R N A L   M E M O R A N D U M

TO: Brian M. Daubin

FROM: Redacted, Redacted

DATE: October 1, 2011

PROJECT: 1105054.000

SUBJECT: Methodology for Earthquake and Liquefaction Hazard Analysis for Pacific Gas and Electric Gas Transmission Pipeline 132

At your request, Exponent Failure Analysis Associates (Exponent) conducted an evaluation of the liquefaction hazard at the Redacted f Pacific Gas and Electric (PG&E) gas transmission pipeline 132 (Line 132). The following is a summary of Exponent's analysis methodology, assumptions, and results.

Background

The alignment of Redacted is shown in Figure 1. Kleinfelder, Inc., a consultant to PG&E, provided Exponent portions of ~~a~~ geotechnical engineering reports prepared by others for the BART SFO Extension Alignment.[1] These reports contain geotechnical data, such as soil borings, cone penetration soundings and groundwater levels utilized in the design of the BART extension. Soil borings in the vicinity of the Redacted Redacted were included in the transmitted data and evaluated by Exponent.

Due to time constraints, a probabilistic liquefaction hazard analysis of all available borings and cone penetration soundings was not performed. Based on review of data contained in the soil boring logs and analysis by others,[2] Exponent selected boring B-26 for the liquefaction hazard analysis performed for this evaluation.[3] The location of boring B-26 is shown in Figure 2. The

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1 Harding Lawson Associates, "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, dated March 25, 1999.

Geotechnical Consultants, Inc. (GTC), "San Francisco Bay Area Rapid Transit District Proposed SFO Extension – Geotechnical Data Report, Segment No. 1," prepared for Bay Area Transit Consultants, dated January, 1995.

2 Kleinfelder, "Geotechnical Evaluation (Update 1), Pacific Gas and Electric Company, Gas Transmission Redacted, South San Francisco, California," prepared for Pacific Gas and Electric Company, dated September 29, 2011.

3 Redacted drilled on May 18, 1994. The boring log for B-26 is Redacted of the GTC 1995 report.

stratigraphy described for borings near th Redacted showed a discontinuity of the liquefiable soil layers above apparently continuous dense layers. Boring B-26 was selected because the boring log described stratigraphy most likely to produce the greatest probability of liquefaction, thereby representing a worst case scenario for liquefaction and resulting magnitude volumetric compression (i.e., total liquefaction induced settlement predicted at the boring), in the vicinity of the crossing. The boring is located approximately Redacted at the Redacted

Earthquake Hazard

Exponent compiled hazard information related to earthquake ground shaking from the USGS.[4] Earthquake hazard can be expressed in the form of a relationship between ground shaking intensity and the average time period between earthquakes with ground shaking exceeding that intensity. One common measure of ground shaking intensity during an earthquake is peak ground acceleration (PGA), usually expressed as a fraction of the acceleration due to gravity (g). Figure 3 presents the earthquake hazard for the site in terms of PGA and incorporates possible earthquakes from all known sources in the vicinity of the site.

Liquefaction Triggering

Liquefaction triggering analyses were completed to evaluate whether or not the materials described in boring B-26 could potentially liquefy during the considered seismic events. For these analyses, the elevation of the groundwater table was assumed to be the elevation represented in the BART SFO Extension design profile, i.e. five to ten feet above the elevation measured in the reviewed borings. This groundwater table is below loose deposits that have the potential to liquefy if the groundwater table were at a higher elevation.

The following steps were followed in the analyses:

1. Assess liquefaction susceptibility: Coarse-grained soils were considered liquefaction susceptible, and the methodology presented by Seed et al. (2003)[5] was used to assess liquefaction susceptibility depending on fines content amount and properties. Materials with very high SPT blow counts were considered non-susceptible to liquefaction. Materials non-susceptible to liquefaction were classified as non-liquefiable, irrespective of the earthquake loading.

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4 http://earthquake.usgs.gov/hazards/designmaps/javacalc.php

5 Seed, R.B., Cetin, K.O., Moss, R.E.S., Kammerer, A., Wu, J., Pestana, J. and Riemer, M., Sancio, R.B., Bray, J.D., Kayen, R.E., and Faris, A. 2003. “Recent Advances in Soil Liquefaction Engineering: A Unified and Consistent Framework," Keynote Address, Proceedings, 26th Annual Geotechnical Spring Seminar, Los Angeles Section of the GeoInstitute, American Society of Civil Engineers.

2. Evaluate the Cyclic Resistance Ratio (CRR) using SPT data: The CRR is calculated for the appropriate earthquake magnitude (Mw). The CRR values were calculated in accordance with the procedure recommended by Cetin et al. (2004). [6]
3. Evaluate the cyclic stress ratio (CSR): For the evaluated PGA values, the CSR is evaluated using the Cetin et al. (2004) procedure.
4. Assess Factor of Safety (FS) against liquefaction (CRR/CSR) and the probability of liquefaction (P_L).
5. Estimate the liquefaction-induced settlement based on the curves of liquefaction-induced volumetric strain by Wu (2002).[7]

Following the above methodology, the liquefaction fragility curve, which presents the probability of liquefaction at specific levels of peak ground acceleration, for boring B-26 is shown in Figure 4. The liquefaction-induced settlement given the occurrence of liquefaction is shown in Figure 5.

Annual Liquefaction Frequency

The fragility curve presented above is an expression of the probability of liquefaction given a seismic demand; however, the functions include no information related to the frequency of occurrence associated with a seismic demand (e.g., PGA). Thus, while the probability of liquefaction in boring B-26 is relatively high for a PGA of, say, 0.90g, the frequency of occurrence associated with that ground motion is very low. This information can be combined with the fragility functions to determine the annual frequency of liquefaction, considering a large suit of seismic events, as shown in Figure 6.

For boring B-26, the annual probability of liquefaction was calculated to be $7x10^{-3}$ or 0.7%. This is equivalent to an average rate of return of approximately 150 years. The probability that the liquefaction-induced settlement will be greater than or equal to 2 inches is $4x10^{-3}$ or 0.4%. This is equivalent to an average rate of return of approximately 260 years.

Summary

This memorandum describes the methodology and assumptions used to estimate the liquefaction hazard at boring B-26. As previously discussed, this boring was chosen as a representation of the worst case scenario of the available borings that are close to Line 132 at the Colma Creek Crossing, in terms of liquefiable material encountered in the borings.

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6 Cetin, K. O., Seed, R. B., Der Kiureghian, A., Tokimatsu, K., Harder, L. F., Jr., Kayen, R. E., and Moss, R. E. S. 2004 "Standard penetration test-based probabilistic and deterministic assessment of seismic soil liquefaction potential." J. Geotech. Geoenviron. Eng., 130(12),1314–1340.

7 Wu, J. 2002. "Liquefaction Triggering and Post Liquefaction Deformations of Monterey 0/30 Sand Under Uni-Directional Cyclic Simple Shear Loading." Dissertation in partial fulfillment for the degree of doctor of philosophy, University of California, Berkeley.

Based on the above analysis, the probability of liquefaction at boring B-26 for a one year time interval is $7x10^{-3}$ or 0.7%, and the probability that liquefaction-induced settlement will be greater than or equal to 2 inches is $4x10^{-3}$ or 0.4%. For a four month time interval, the probability of liquefaction at boring B-26 is $2x10^{-3}$ or 0.2%, and the probability that liquefaction-induced settlement will be greater than or equal to 2 inches is $1x10^{-3}$ or 0.1%.

Limitations

The study presented in this report is intended for use by PG&E to assist with their decision making related to a fit for service analysis of Line 132. Proper application of this memorandum requires recognition and understanding of the limitations of both the scope and methodology of the study.

Exponent has no direct knowledge of, and offers no warranty regarding, subsurface conditions beyond what was interpreted from the reviewed documents. Comments regarding subsurface conditions are professional opinions, derived in accordance with current standards of professional practice based on our engineering experience and judgment.

The scope of the study was the development of probabilistic liquefaction hazard. The risk assessment methodology forming the basis of the results presented in this report is based on mathematical and statistical modeling of physical phenomena as well as data from third parties that is located several hundred feet from Line 132. Given the nature of these evaluations, significant uncertainties are associated with the various hazard computations, some of which are accounted for in the methodology, while other uncertainties such as for example, material characteristics directly under the entire length of the Line 132 alignment, cannot be readily incorporated into the analyses. These uncertainties are inherent in the methodology and subsequently in the generated hazard results.

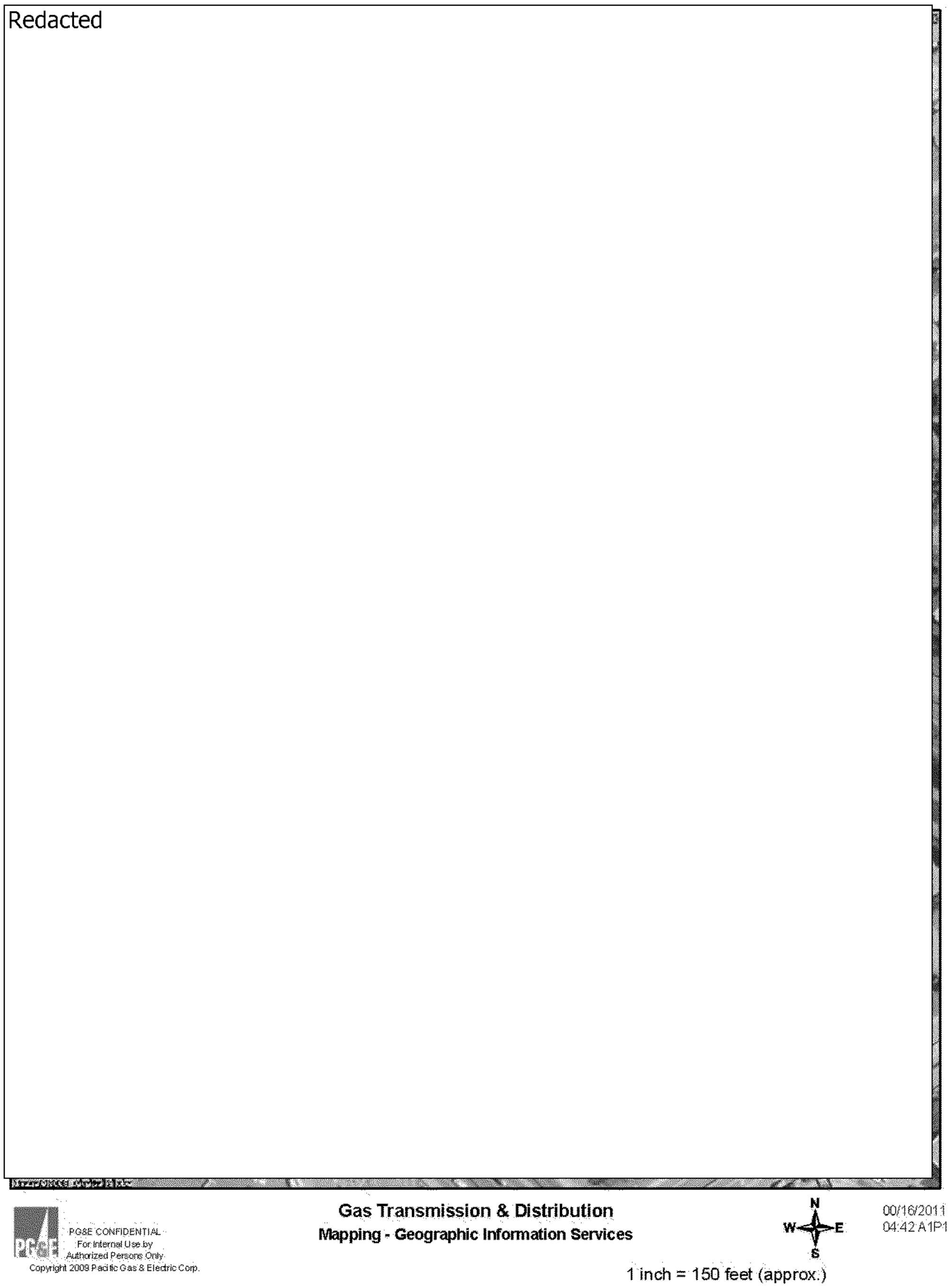

Figure 1. Redacted

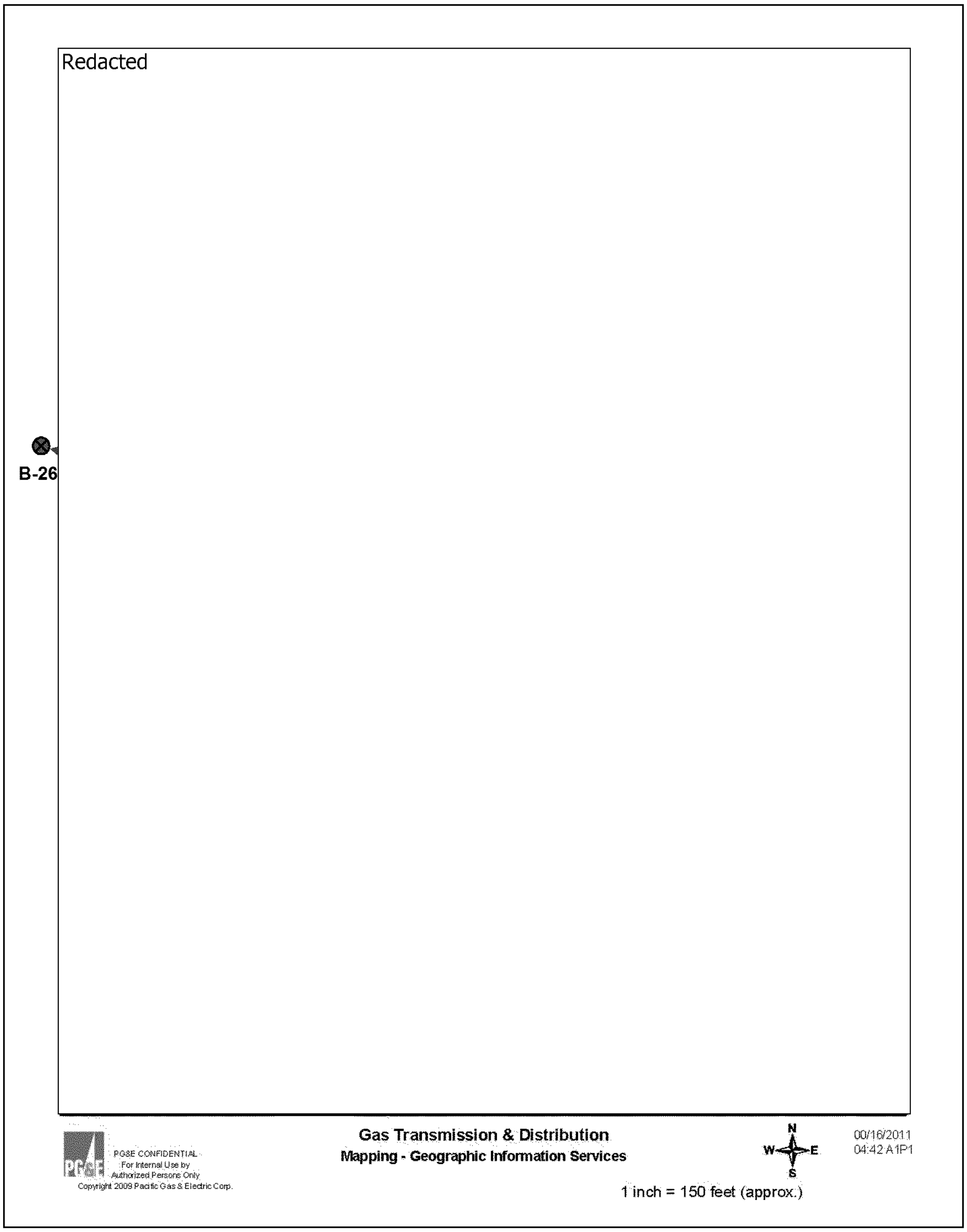

Figure 2. Map showing pipeline alignment and approximate location of boring B-26

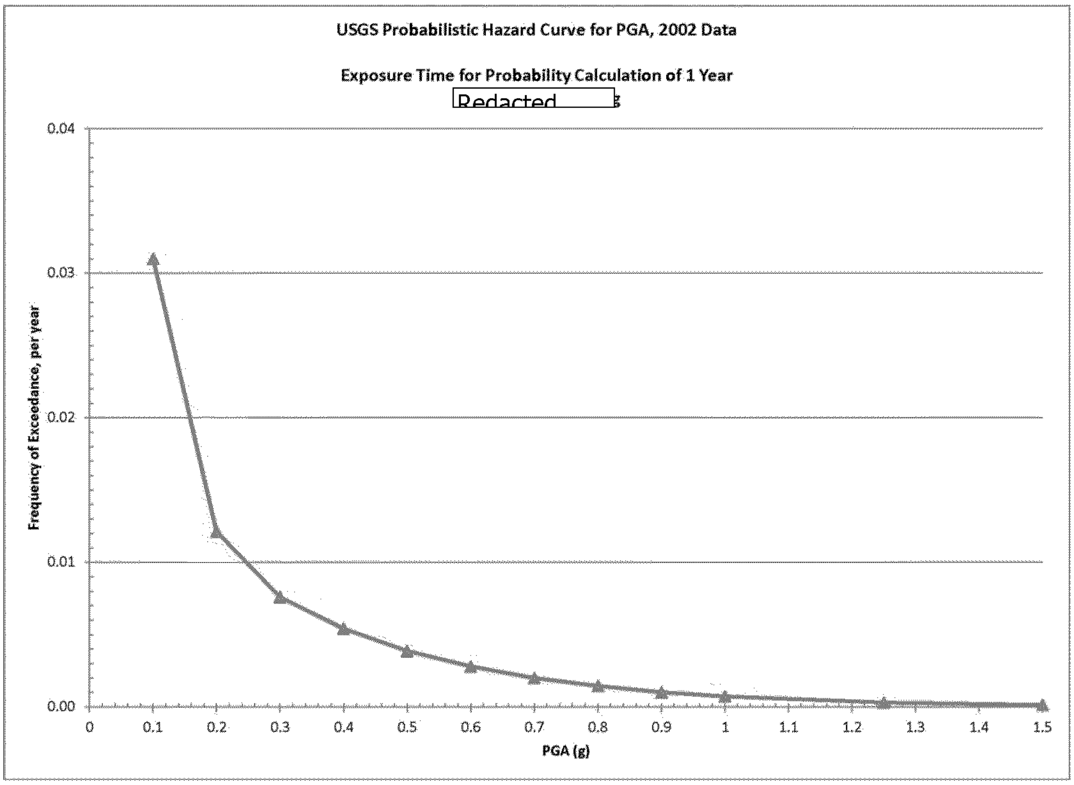

Figure 3. Probabilistic hazard curve for Peak Ground Acceleration (PGA) at Redacted Redacted

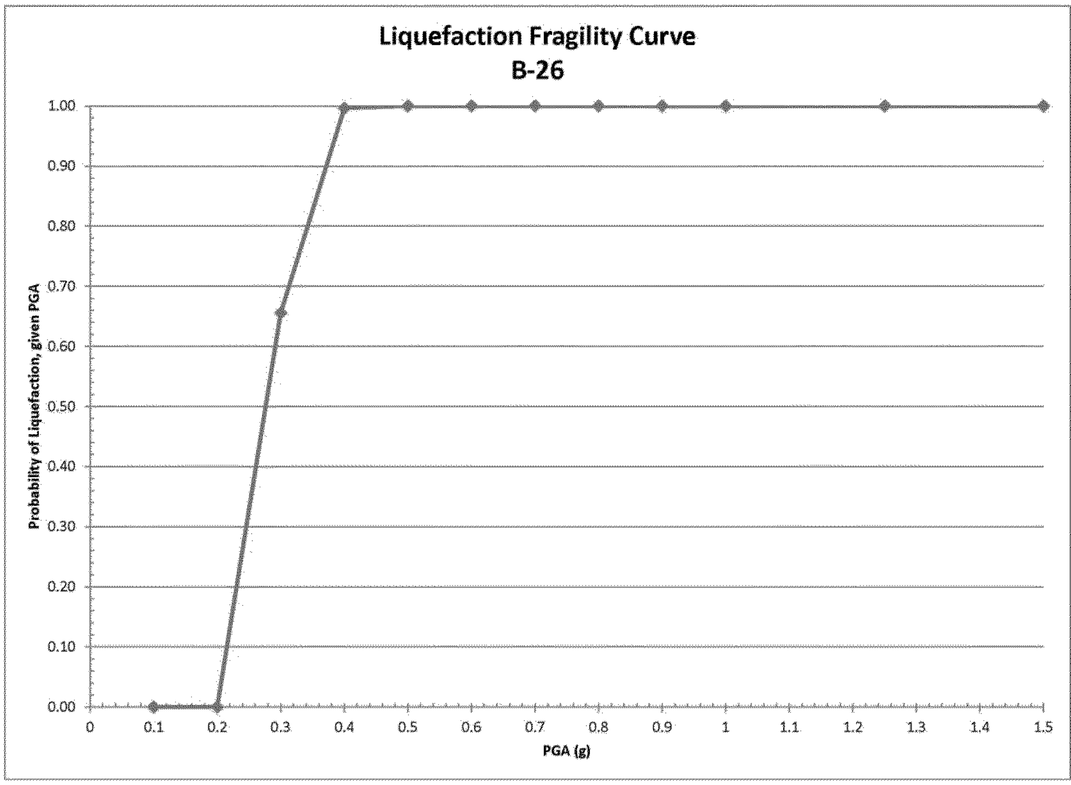

Figure 4. Liquefaction fragility curve for boring B-26

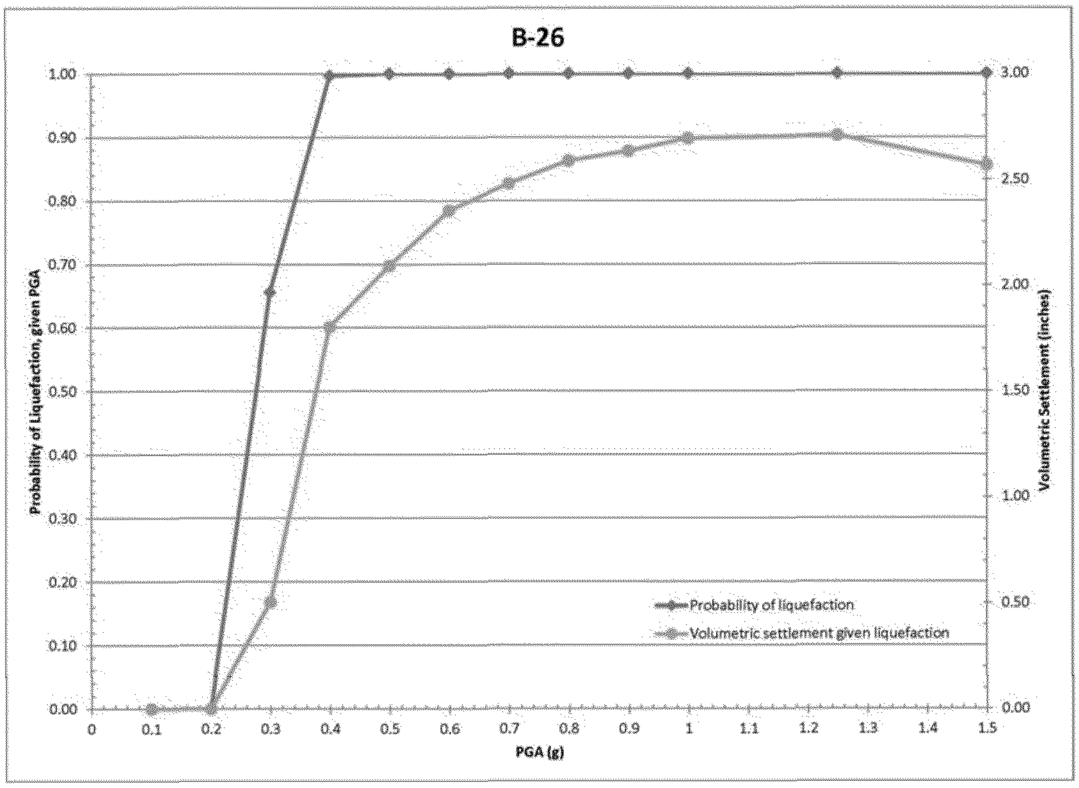

Figure 5. Estimates of liquefaction-induced settlement and the liquefaction fragility curve for boring B-26

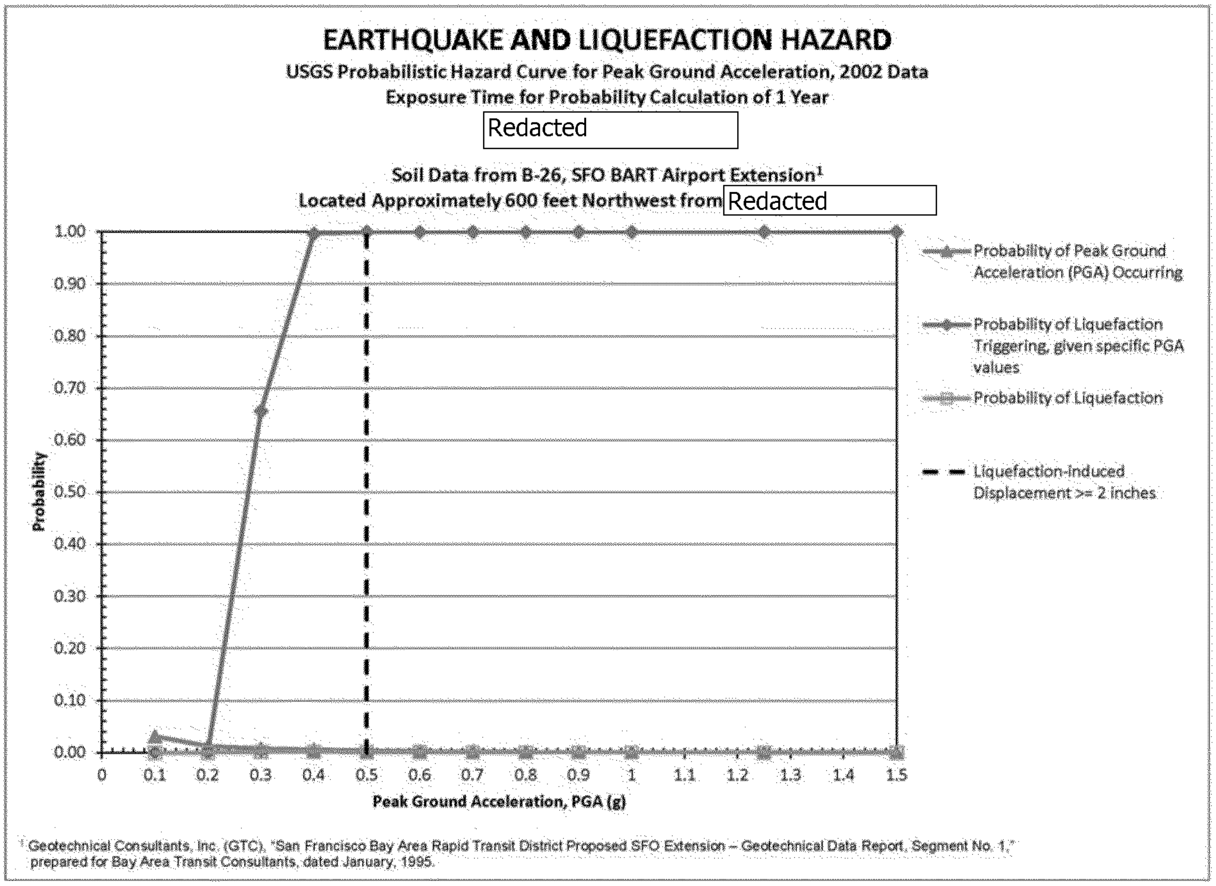

Figure 6. Earthquake and liquefaction hazard at boring B-26