Memorandum

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To: MR. TOM OSTROM
Supervising Bridge Engineer
Office of Earthquake Engineering

Attention: Mark Yashinsky

Date: June 18, 2013

File: 04-SM-1 PM R46.51
59-93034-N
EFIS# 0000001016-N
Gateway Drive Undercrossing

PROFESSIONAL GEOLOGIST ANNA SOJOURNER CERTIFIED ENGINEERING GEOLOGIST No. 2562 Exp. 12/31/13 STATE OF CALIFORNIA

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Subject: Preliminary Evaluation of Fault Rupture Potential for Gateway Drive Undercrossing, San Mateo County

SUMMARY

The Caltrans Gateway Drive Undercrossing (Bridge Number 35-0192) lies in Daly City, San Mateo County (SM-1-R46.51). The bridge lies within the Alquist-Priolo Earthquake Fault Zone (EFZ) of the 1906 trace of the San Andreas fault Peninsula segment, and is located approximately 740 feet (225 meters) from this trace (Figure 1).

The deterministic potential horizontal offset resulting from an earthquake on the San Andreas fault Peninsula segment is 25 feet (7.5 meters). The probabilistic potential offset on this trace incorporating nearby empirical measurements from the 1906 earthquake is 7.5 feet (2.3 meters). The deterministic potential offset on a possible unmapped fault strand within the bridge footprint is 2.45 feet (0.75 meters) and the probabilistic offset is 0.65 feet (0.2 meters).

Per Memo to Designers (MTD) 20-8, the larger of the deterministic and probabilistic values or a site-specific value should be used for design. If the existing bridge can tolerate 2.45 feet (0.75 meters) of horizontal offset roughly perpendicular to the bridge alignment, then no additional work is recommended at this time. If the deterministic offset value of 2.45 feet (0.75 meters) is not acceptable, I recommend the use of the probabilistic value (0.65 feet or 0.2 meters), also per MTD 20-8, which states that given sufficient reason, a lower probabilistic value may be used with permission from the Office of Earthquake Engineering. **Please respond with either a request for no further work, in which case the design value will be 2.45 feet (0.75 meters) unless field studies are undertaken, or permission to use the probabilistic value.** In either case, I will issue a final memo.

INTRODUCTION

This evaluation was prepared as part of a statewide evaluation of fault rupture potential at Caltrans bridges. Caltrans policies regarding fault rupture at bridges are described in Memo to Designers 20-10. Caltrans requires a fault rupture evaluation if a bridge is located within an Alquist-Priolo Earthquake Fault Zone (EFZ) or within 1,000 feet of an un-zoned fault 15,000 years or younger in age.

An initial estimate of potential offset was based on an analysis developed by Division of Research and Innovation in collaboration with Geotechnical Services, using methods presented in Abrahamson (2008) and Petersen, et al. (2011). Both a probabilistic (5% in 50 year) fault displacement analysis and a deterministic fault displacement analysis were performed, based on maximum magnitude earthquake, slip rate, assumed mapping and base map errors, and likelihood of secondary fault traces. If the San Andreas fault is located as shown on the 1982 EFZ Map (State of California, 1982), the expected displacement at the bridge was initially calculated to be 3.9 feet (1.2 meters; deterministic value; larger of the probabilistic and deterministic values were used in initial estimates). Mark Yashinsky and Fadel Alameddine reviewed the bridge plans and determined the bridge could not withstand 3.9 feet (1.2 meters) of displacement without modification. Therefore additional work, documented herein, was undertaken to better define the fault location.

The bridge is a reinforced concrete box girder bridge (22 cells), built in 1964 and widened in 1972. The bridge is on reinforced concrete walls, with reinforced concrete diaphragm-type abutments. The end spans are enclosed with curtain walls. The old pier walls are on spread footings, and the rest is on CIDH piles.

This evaluation of the Gateway Drive Undercrossing consisted of literature, air photo, and LiDAR review, a site visit, and deterministic and probabilistic calculations of expected offset.

LITERATURE, AIR PHOTO, AND LiDAR REVIEW

The bridge was built in 1964, and widened in 1972. The area around the bridge was graded and developed extensively in the 1960's, before the passage of the Alquist-Priolo Earthquake Fault Zoning (AP) Act in 1972. LiDAR hillslope images of the site show that nearly all natural topography, surface fault expression, and fault-related features have been lost (Figure 2).

Lawson (1908)

Lawson (1908) mapped fault features in the area shortly after the 1906 earthquake. He described a series of sag ponds and offsets, indicating multiple active strands. "From the top of these cliffs, at an elevation of about 500 feet above sea level, the course of the rift, as far as San Andreas Lake is marked by a line of shallow longitudinal depressions, ponds, and low scarps. There are eight ponds in a stretch of about 4.5 miles" (p. 35).

Caltrans Records

The Logs of Test Borings completed for the bridge in 1970 show the bridge lies on silt, clay, and sand, with abundant organic materials logged throughout the borings. The materials and original topography suggest the area could have been a pond, bog, or lake. There are numerous sag ponds in the area, including one directly southeast of the site potentially on trend with an unmapped northwest-trending fault trace crossing beneath the bridge.

1959 Air Photos

Air photos from 1959 clearly depict lineaments mapped by Pampeyan (1995), although many lineaments Pampeyan mapped from earlier air photos had been destroyed by 1959. Many lineaments adjoin sag ponds.

The 1959 air photos show that Gateway Drive Undercrossing was built at the northwestern edge of a sag pond. This fault feature was noted in the as-builts for the bridge. It was filled in and housing was built on top of it.

Alquist-Priolo Investigations

Two Alquist-Priolo (AP) Fault Investigation Reports (FIRs) have been conducted near the bridge. The locations of these studies are shown on Figure 2.

Fault Investigation Report (FIR) 279 (Figure 2), based on studies performed from 1971 to 1976, shows that the former Laguna Alta, a sag pond on the San Andreas fault, was filled in and graded for the construction of apartments at the corner of Gateway Drive and Hickey Boulevard. The report states: "Originally, the topography in the area of the site consisted of steep hills and valleys and a sag pond lake. Subsequent grading on the four-acre site consisted mainly of filling the old sag pond lake, known as Laguna Alta." Fills were placed in 1964, and could be up to 50 feet deep.

Three fault strands were mapped from air-photo lineaments in the property, but the authors declined to investigate the lineaments further, claiming that they were not offset in 1906 and were more likely the result of "movement which may be several thousands of years old." There was no evidence given of either activity or inactivity on the lineaments, nor was the age of the lineaments investigated.

Fault Investigation Report 519 (Figure 2) is for a site which only partially lies in the EFZ. The investigation was performed in 1977 on a site that already had been developed. The investigators traced air photo lineaments from 1958 air photos, before the site was graded and developed, and found lineaments along two sag ponds, which were subsequently filled. A third lineament was found northeast of the site and outside of the EFZ, consistent with Pampeyan (1995), whose map shows an active fault northeast of the EFZ (Figure 3). No further investigation of the faults and lineaments was made.

CDMG 1980 Fault Evaluation Report

The October, 1980 Fault Evaluation Report (FER; CDMG FER-120, 1980) interprets the fault splays mapped by Lawson (1908) and later by Pampeyan (1995) that lie outside of the EFZ as a "broad linear depression," which roughly paralleled the bedding orientation of the Merced Formation. The numerous sag ponds were considered a result of lateral spreading rather than fault rupture, because no other type of continuous, well-defined fault feature occurred between the sag ponds.

The strike of the Merced Formation does broadly parallel the fault strike in this area, and the beds dip steeply (40°-85°; Figure 4), which allows for the string of sag ponds to be a result of lateral spreading. However, this does not exclude the mapped lineaments from being fault and fault-related features. The EFZ map was revised and narrowed in 1982, and potentially active fault strands were not included in the active zone.

Pampeyan (1995)

Pameyan (1995) mapped numerous discontinuous splays along the main fault trace, based on the work of Lawson (1908) and air photo interpretation (Figure 3). The splays mostly occur northeast of the 1906 trace, in the Merced Formation (Figure 4). A small number of short splays were mapped in the Franciscan formation southeast of the fault. Most splays are 0.5 – 1 mile (0.8 – 1.6 kilometers) long, oriented at approximately 310°, or about 10° to 20° off the strike of the main trace. One or more of these lineaments were described in FIR 519. Although the majority of these splays were excluded from the EFZ in 1982, Pampeyan (1995) considered these lineaments active.

Catchings, et al. (2013)

Catchings, et al. (2013) created seismic imaging profiles of the Peninsula Segment of the San Andreas fault about 5 miles southeast of the site at San Andreas Lake. They found that "the main 1906 surface rupture zone consists of at least three near-surface fault traces" within an approximately 260 to 330 foot-wide (80 to 100 meter-wide) fault zone. These correspond to surface offset features mapped in 1906.

They conclude "Our study suggests that there are multiple near-surface fault traces within about 80–100 m of the 1906 main surface rupture, and based on observations after the 1906 earthquake (Schussler, 1906), these fault traces should be considered capable of moving during future earthquakes. Furthermore, differential movement on sub-parallel fault strands can result in complex shearing involving both compressive and extensional stresses."

Literature Review - Conclusions

The understanding of fault activity and expression has developed considerably since AP investigations were conducted in the 1970's. Pampeyan (1995) writes "Recently, the 1989 Loma Prieta....and 1992 Landers....earthquakes have shown that a through-going fault trace can be a complex zone of fractures rather than a single clear-cut break."

None of the work done for the AP investigations or the CDMG's FER eliminated the possibility that the lineaments northeast of the site and outside the EFZ zone are active fault traces. The CDMG 1980 FER removed from active zoning the lineaments very close to the Gateway Undercrossing, interpreting them as part of a broad linear depression. It is possible that these lineaments are a result of lateral spreading on bedding-parallel planes within the Merced Formation, but it is also possible that these lineaments are active fault features. In either case, there are pre-existing planes of weakness (either fault splays or bedding) within and outside of the EFZ that could be offset during an earthquake on the San Andreas fault. These potentially active fault features immediately outside the EFZ suggest that offset could also occur anywhere within the EFZ, including within the bridge footprint. Offset may occur on multiple traces of the fault in this location, on a single trace, or on fault trace and the lineaments simultaneously.

It is not known whether the subsurface geometry of the fault at the Gateway Drive Undercrossing is very similar to the multiple active strands described five miles away by Catchings, et al. (2013), but the current understanding of faults suggests the fault could be complex through much of its extent. The studies of the fault at this location in the 1970's and 1980's may have oversimplified the subsurface geometry, emphasizing activity on the main 1906 trace, and de-emphasizing the possibility of rupture on multiple anastomosing strands and co-occurring geomorphic features. Offset on an unmapped fault assumed to cross beneath the bridge is considered in the following probabilistic calculations of offset.

CALCULATIONS OF EXPECTED OFFSET

To quantify potential fault offset, I used a spreadsheet developed by the Division of Research and Innovation in collaboration with Geotechnical Services based upon methods presented in Petersen, et al. (2011), and Abrahamson (2008). Both a deterministic fault displacement analysis and a probabilistic fault displacement analysis were performed. The input parameters included maximum magnitude, slip rate, mapping and base map errors, and empirical slip measurements from literature.

Mmax

An $\mathbf{M}_{max}$ of 8.0 is cited in the Caltrans fault database[1], which references the USGS (2008). This $\mathbf{M}_{max}$ of 8.0 is in agreement with the $\mathbf{M}_{max}$ given by Hall, Wright, and Clahan (1999). This value also agrees with the magnitude of the 1906 earthquake, taken to be from 7.7 to 8.3. Since the 1906 earthquake ruptured the entire length of the fault used to estimate the $\mathbf{M}_{max}$ value, offset associated with that event may be used in probabilistic calculations of displacement.

Slip Rate

Paleoseismic studies were conducted on the San Andreas fault (Peninsula section) at Filoli Estate (Clahan, 1996) and Crystal Springs Reservoir (Hall, 1984; Hall, Wright, and Clahan, 1999; Feigelson, 2010). Filoli Estates lies about 17 miles southeast of the Gateway Drive Undercrossing. Crystal Springs Reservoir lies approximately 9 miles from Gateway Drive Undercrossing.

The early slip rate and fault activity studies on the Peninsula segment resulted in conflicting slip rates. Hall, Wright, and Clahan (1999) synthesized their previous individual studies at Crystal Springs Reservoir and Filoli Estate to derive a slip rate for the Peninsula Segment of 17 ± 4 mm/year, and defined the magnitude of offsets for the 1906 and penultimate earthquakes. Feigelson (2010) excavated another trench north of the Crystal Springs Reservoir trenches and found a similar slip rate of 14-18 mm/year. For this calculation, a slip rate of 17 mm/year was used.

Empirical Slip Measurements

Hall, Wright, and Clahan (1999) estimated the amount of slip for the 1906 earthquake on the Peninsula Segment as ≈2.5 m, based on two measurements obtained at Filoli Estate, located approximately 17 miles southeast of the bridge. This information was used in the probabilistic calculations per Hecker, et al. (2013).

Site-to-Source Distance

The Alquist-Priolo Map and the USGS Google Earth files (USGS, 2010) show the bridge lies 740 feet (225 meters) from the main 1906 trace of the fault. A rupture on this trace could produce offset at the bridge, but the probability of offset decreases rapidly with distance from the fault (Peterson, 2008), making this scenario unlikely. However, as discussed above, we consider

[1] CT fault database: http://dap3.dot.ca.gov/shake_stable/v2/technical.php

it likely that there could be offset on any of several strands within a broad fault zone. For calculated potential offset, the site-to-source distance was assumed to be 0 m, with a previously unmapped fault strand rupturing within the bridge footprint.

Calculated Potential Offset at the Gateway Undercrossing

Earthquake on the 1906 Trace

An earthquake on the 1906 trace of the San Andreas fault Peninsula segment could produce up to 25 feet (7.5 m) of offset deterministically (Wells and Coppersmith, 1994) , or 7 ½ feet (2.3 m) probabilistically (incorporating nearby empirical measurements).

Earthquake within the Bridge Footprint

The main 1906 trace lies 740 feet (225 meters) from the bridge. To assess fault rupture within the bridge footprint, I assigned a 10% probability of rupture on an unmapped trace of the fault passing directly beneath the bridge footprint. The calculated deterministic potential offset on a previously unmapped fault strand at the bridge is 3.45 feet (0.75 meters). The calculated probabilistic potential offset on a previously unmapped fault strand at the bridge is 0.8 feet (0.25 meters). Table 1summarizes these results.

Vertical Displacements

Vertical displacements of approximately 10% of the horizontal offset should be assumed to occur with the horizontal displacements. These displacements correspond to a few inches for either the deterministic or probabilistic case.

Table 1 - Results of Probabilistic Offset Calculations

Scenario	**M_{max}[2]**	**Slip Rate[3]**	**Site-to-source distance**	**Deterministic offset (horizontal)**	**Probabilistic offset, 975 yr return (horizontal)**
1906 trace (weighted 90%)	8.0	17 mm/yr	225 meters	7.6 meters	2.3 meters
Unmapped fault in bridge footprint (weighted 10%)	8.0	17 mm/yr	0	0.75 meters	0.25 meters

[2] CT fault database: http://dap3.dot.ca.gov/shake_stable/v2/technical.php
[3] Hall, Wright, and Clahan (1999)

RECOMMENDATIONS

If the bridge can withstand a lateral fault offset of up to 2.45 feet (0.75 meters) approximately normal to and anywhere beneath the bridge, then no further work is recommended at this time. If this potential offset is too large, I request we consider the probabilistic offset value of 0.65 feet (0.25 meters). If the deterministic value is preferred, we can discuss further investigations, such as geophysics, which could be used to identify any potential faults near the bridge. Trenching and other traditional methods of fault investigation are not feasible at this highly urbanized site.

If you have any questions, please contact Anna Sojourner at (510) 622-8839.

c: TPokrywka, CRisden, Daily File
ASojourner/mm
Fadel Alameddine
Attachments: Figures 1 - 6

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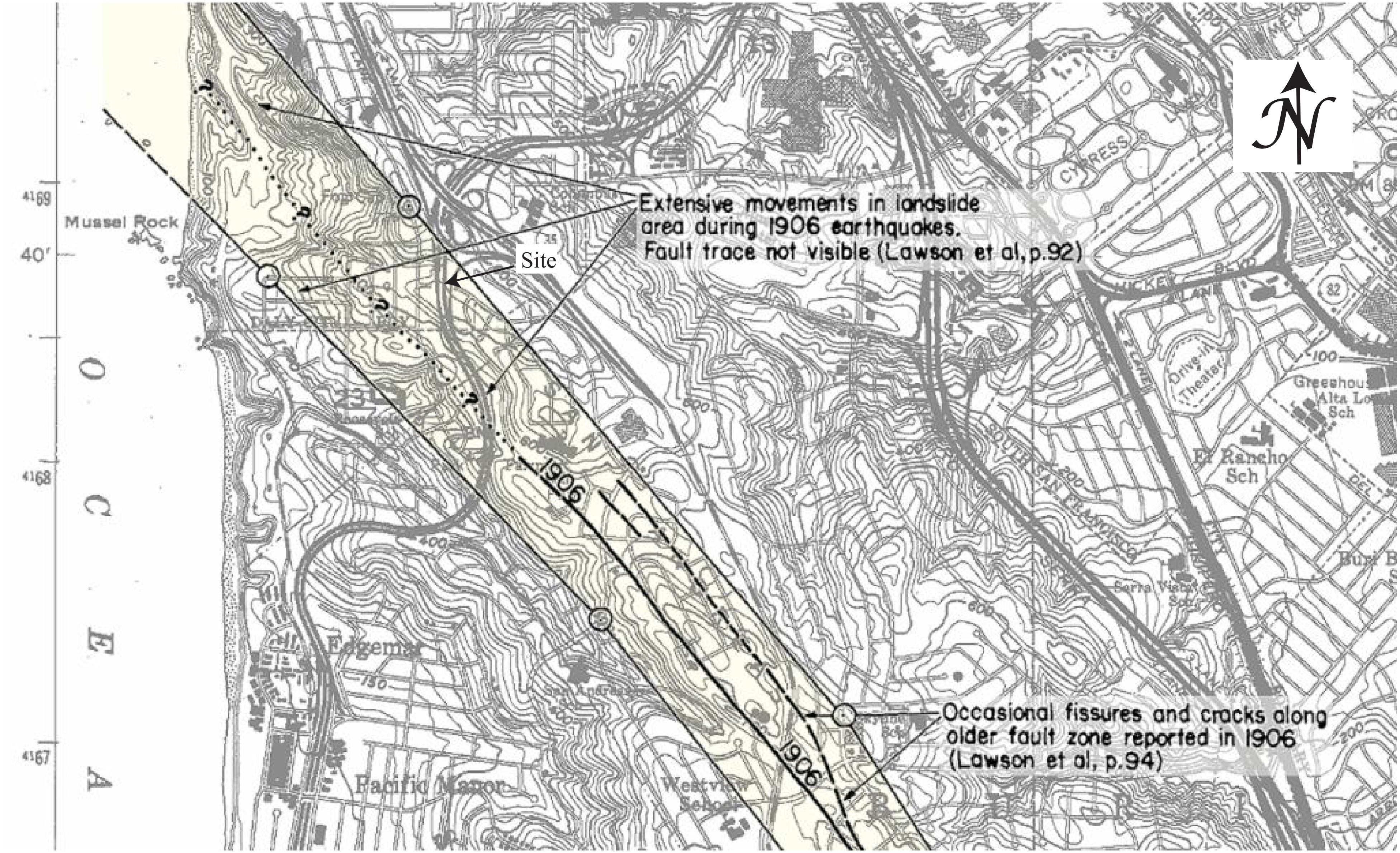

SCALE 1:24,000

Source: State of California, 1974, State of California Special Studies Zones, San Francisco South Quadrangle, Official Map, 1:24,000

Figure 1	**Alquist-Priolo Fault Map**
04-SM-1	PM R46.51
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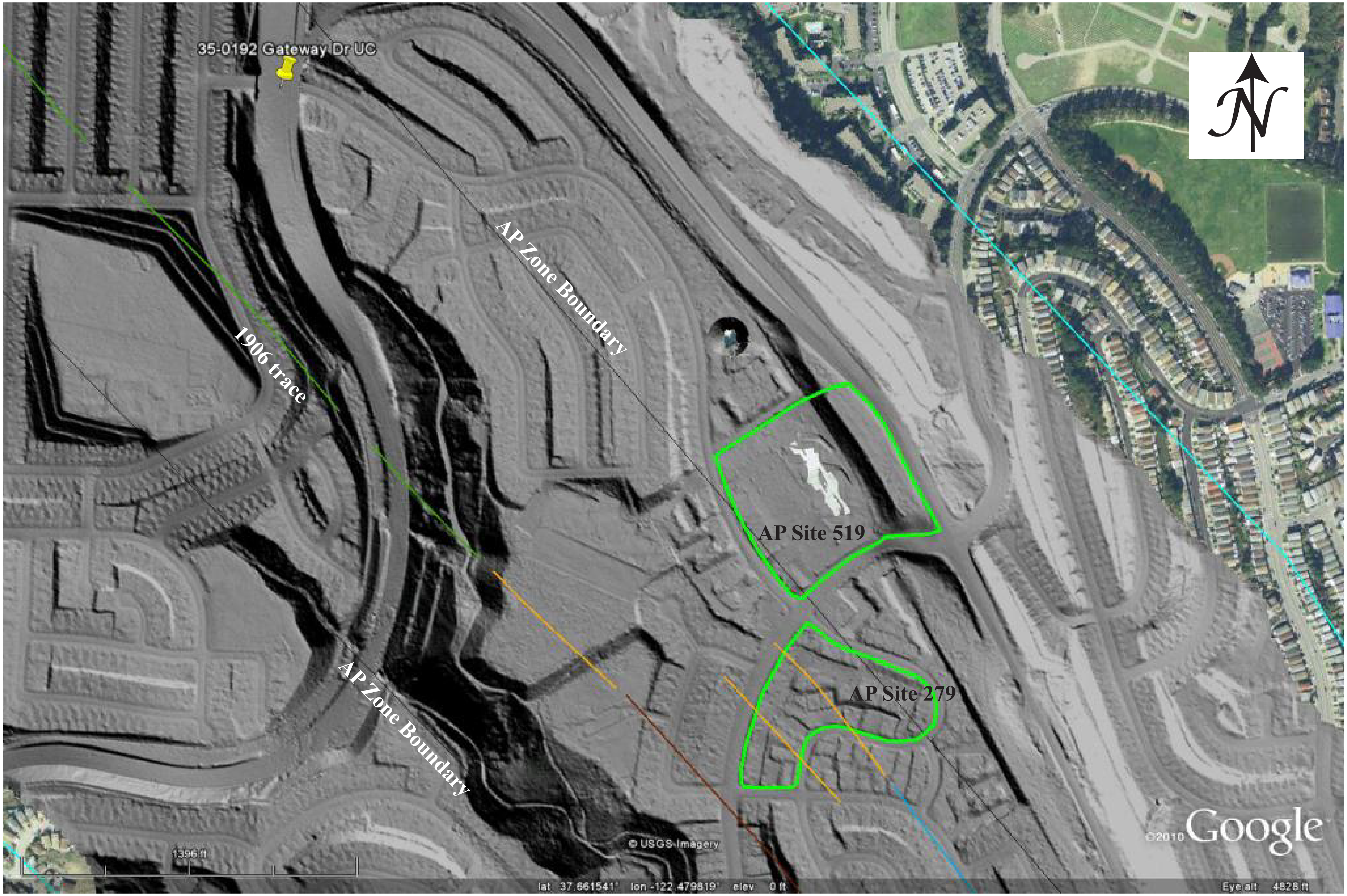

SCALE

0 ~1400 feet

Figure 2	LiDAR Image - Gateway Dr. UC
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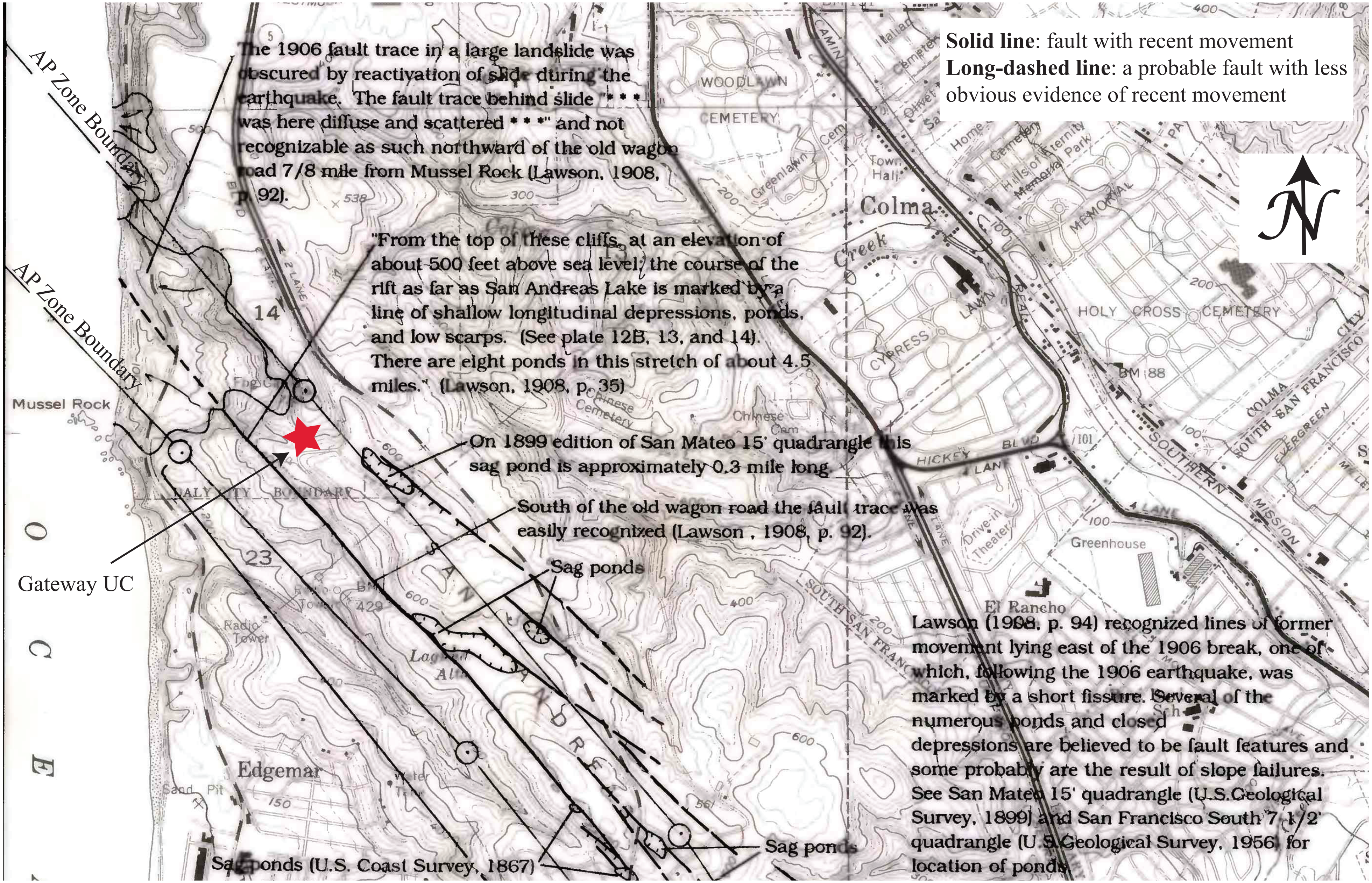

SCALE: 1:24,000

Pampeyan (1995) map, showing Lawson (1908) mapping and geomorphic features of the San Andreas fault. The base topographic map is from before Highway 1 was built and the area was developed. Current Alquist-Priolo zone boundaries are shown.

Figure 3	Fault Map by Pampeyan (1995)
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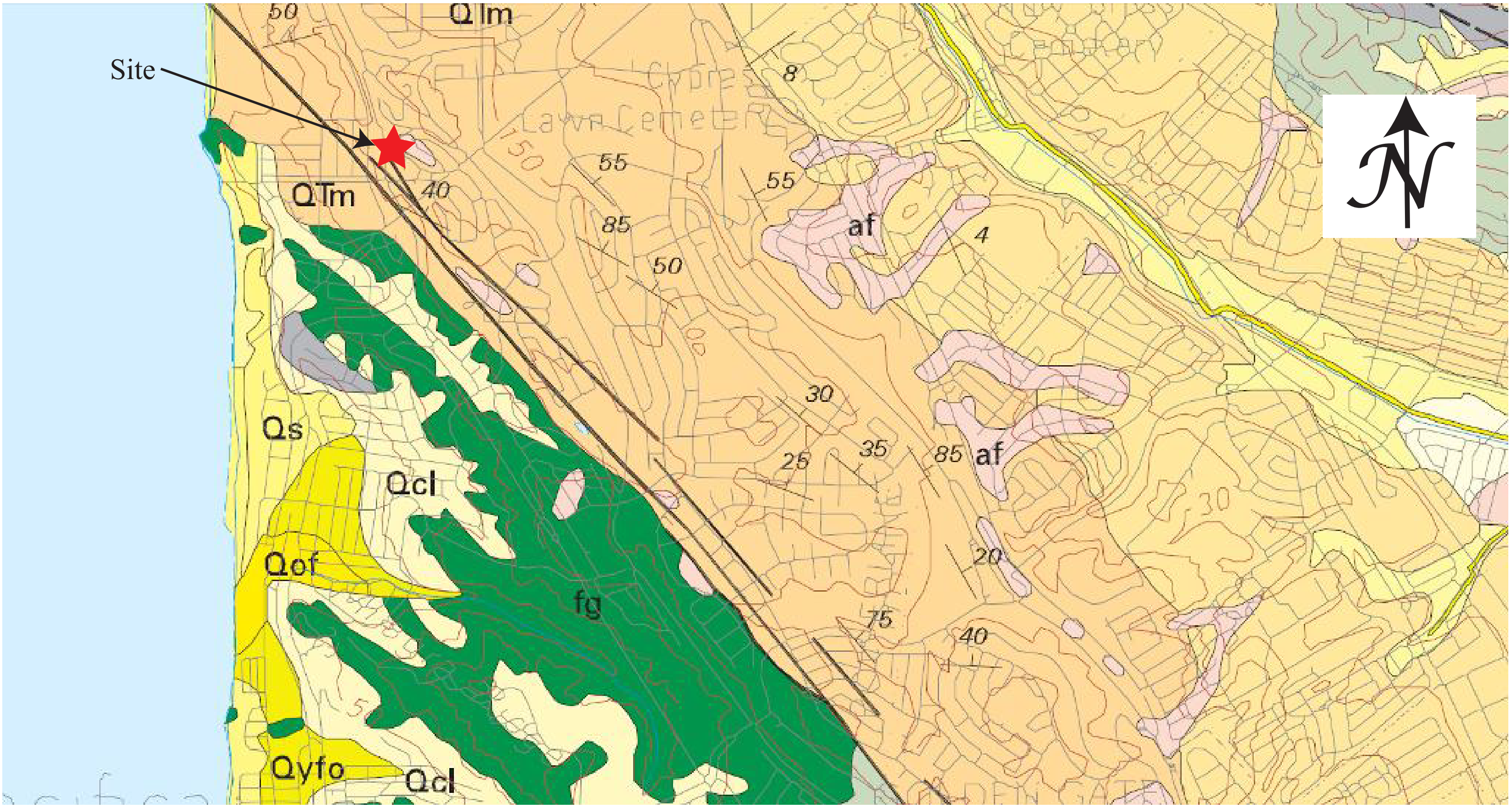

LEGEND
QTm - Merced Formation
fg - Franciscan formation
af - artificial fill

Source: USGS OFR 98-137

	Figure 4	**Geologic Map**
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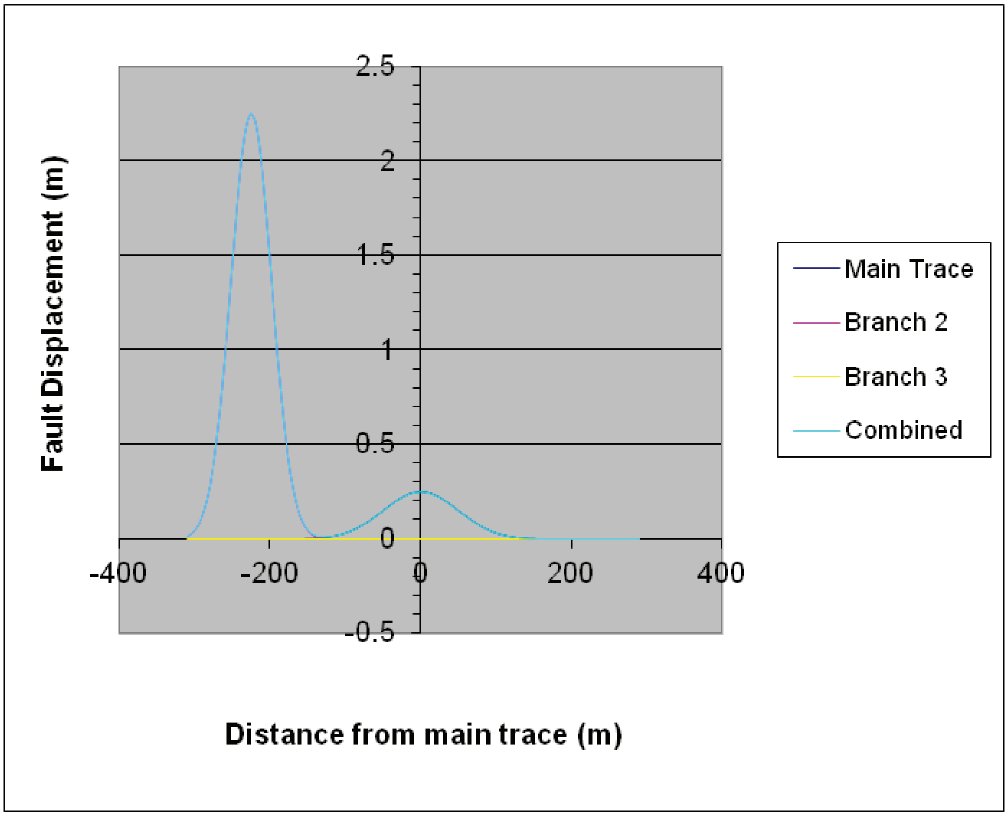

Graph showing probabilistic offset. Offset at the bridge (distance = 0) could be up to 0.2 meters with 10% probability of rupture on a previously unkonwn trace of the fault within the bridge footprint.

Figure 5	**Probabilistic Offset**
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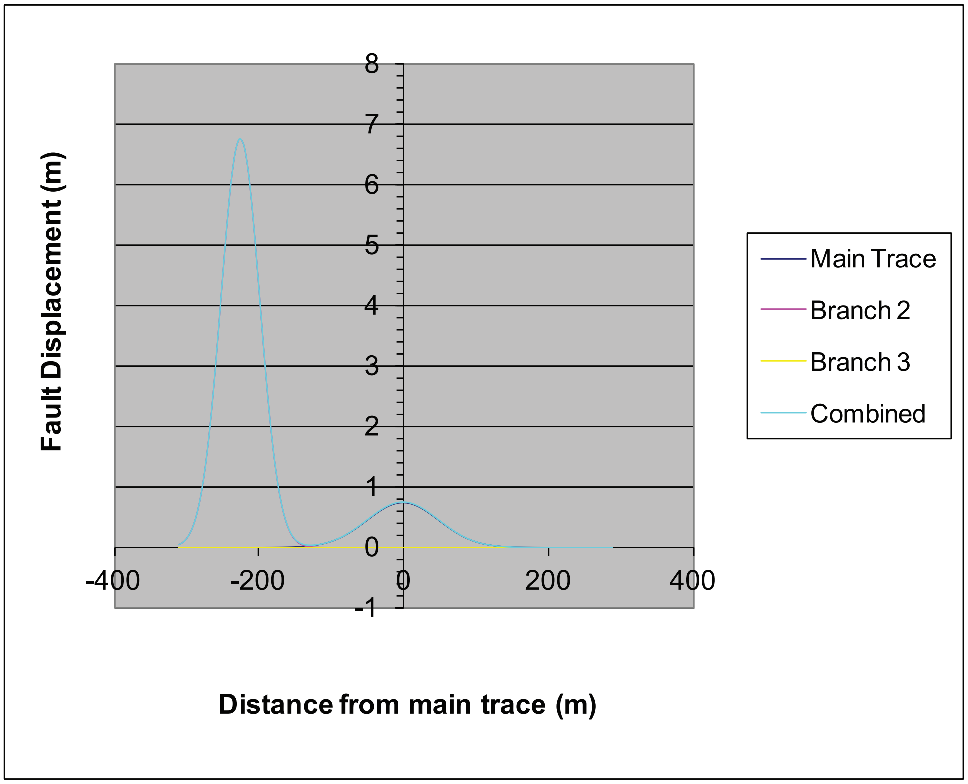

Graph showing deterministic offset. Offset at the bridge (distance = 0) could be up to 0.75 meters with 10% probability of rupture on a previously unkonwn trace of the fault within the bridge footprint.

Figure 6	**Deterministic Offset**
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