Fault Rupture

Caltrans bridges crossing active or potentially active faults may be subjected to surface fault rupture and ground displacement during or immediately after an earthquake. Surface fault rupture can cause large deformations in structures depending on the type of fault, total displacement, and angle of incidence of the fault rupture offset relative to the bridge. Memo to Designers (MTD) 20-10 requires a Surface Fault Rupture Displacement Hazard Analysis (SFRDHA) where any portion of the structure is located:

- Within an Alquist–Priolo Earthquake Fault Zone, as defined by the California Geological Survey.

- Within 1,000 feet of an unzoned fault (not located Alquist–Priolo Earthquake Fault Zone) that is Holocene (11,000 years) or younger in age.

Caltrans uses the Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3) model for its fault data base. This model does not separate Holocene aged faults (11,000 years) from Holocene-Latest Pleistocene (active within the last 15,000 years). Accordingly, structures located near faults that are Holocene-Latest Pleistocene age or younger must be evaluated for potential fault rupture hazard.

Evaluation of fault rupture occurs in two steps:

<u>Step 1: Preliminary Screening</u>

- Performed by the project Geoprofessional, preliminary screening consists of literature reviews and evaluation of existing data. If preliminary screening finds that the structure sits within the Alquist-Priolo Earthquake Fault Zone (APEFZ) or less than 1000 feet from an unzoned active fault, then the Geoprofessional must request a Surface Fault Rupture Displacement Hazard Analysis by an experienced engineering geologist. If the structure does not sit within the aforementioned boundaries, then the Geoprofessional must document the preliminary screening findings in an appropriate report.

<u>Step 2: Surface Fault Rupture Displacement Hazard Analysis (SFRDHA)</u>

- Performed by an experienced engineering geologist. May consist of a more in-depth literature review, site reconnaissance, geological mapping, and fault trench excavation to accurately locate and age-date the fault and/or splays with respect to the bridge. In cases where there is a confirmed fault rupture hazard, the SFRDHA will include calculation of the magnitude of anticipated surface displacement.

Preliminary Screening for Fault Rupture Potential

To screen for fault rupture, first determine whether the structure is in or near an earthquake fault zone.

DO NOT use the map presented in the ARS Online tool for preliminary screening for fault rupture. The Caltrans ARS Online tool for seismic response does not return accurate fault to site distances. The faults are simplified into the traces shown for the purpose of estimating ground motion.

If the structure currently being evaluated is located within 1000 feet of an active fault (15,000 years or younger) shown in any of the following references, then the site has the potential for surface fault rupture and a Surface Fault Rupture Displacement Hazard Analysis is required. Consult the following resources to determine if the structure is in or near an earthquake fault zone.

1. Caltrans Geotechnical Archive (GeoDOG)

   Surface Fault Rupture Displacement Hazard Analyses were conducted for over 250 bridges and culverts in California. A list of the bridges is on the Fault Rupture webpage and reports can be found in GeoDOG.

2. CA Geological Survey, Alquist-Priolo Earthquake Fault Zone Maps
   a. Review the Earthquake Fault Zone Map
   b. Review the Fault Evaluation Report(s) including the attached maps

3. USGS Quaternary Fault and Fold Database (Google Earth, KML file)
   a. Review (select) both the "Historic" and "Holocene to Latest Pleistocene"
   b. Evaluate whether the site is within 1000 ft. of the site using the "ruler" tool.
   c. Select the fault trace to obtain the fault name and web link to the fault report, which will provide the fault type, activity, and slip rate data to be used in the SFRDHA.

The site must have a Surface Fault Rupture Displacement Hazard Analysis performed if the preliminary screening determines that the structure:

- Is located within an Alquist–Priolo Earthquake Fault Zone, or
- Is located within 1,000 feet of an unzoned fault (not located Alquist–Priolo Earthquake Fault Zone) that is Holocene/Latest Pleistocene (15,000 years) or younger in age,

If the structure currently being evaluated meets any of the above criteria, contact your Office's designated Engineering Geologist and request that they prepare a *Fault Rupture Report*.

Surface Fault Rupture Displacement Hazard Analysis

A Surface Fault Rupture Displacement Hazard Analysis (SFRDHA), performed by an engineering geologist experienced in fault rupture evaluations, includes the following steps:

Step 1: Hazard Confirmation

- Confirm that the fault rupture hazard exists by repeating some or all of the preliminary screening performed by the Geoprofessional.

Step 2: Surface Fault Rupture Displacement Hazard Analysis

- If a hazard exists, perform the Surface Fault Rupture Displacement Hazard Analysis, which includes determining the magnitude and direction of anticipated ground surface displacement along the fault. The investigation should follow the applicable sections of California Geological Survey Note 49, *Guidelines for Evaluating the Hazard of Surface Fault Rupture*, and may include geologic mapping, fault trenching, borings, CPT soundings and/or geophysical studies.
- No single or predetermined combination of methods for the investigation and evaluation of surface fault rupture hazard potential should be considered as being complete due to the variability of site geological conditions and complexity of the faulting.

Examples of the calculations used and types of reports are presented on the Fault Rupture webpage.

Displacement Analysis

Use the appropriate "spreadsheet" analysis tool, located on the Fault Rupture webpage, to estimate the potential displacement. Both a deterministic fault displacement analysis (DFDHA) and a probabilistic fault displacement analysis (PFDHA) of 5% in 50 years probability of exceedance (975 year recurrence interval) must be performed using magnitude, slip rate (for PFDHA), mapping and base map errors, and likelihood of secondary fault traces.

Caltrans bases the design fault rupture displacement on the larger of the deterministic or probabilistic (5% in 50 year) displacement hazard values. For strike-slip and normal faults use the method developed by Wells and Coppersmith (1994), Abrahamson (2008), and Petersen, et al (2011). For reverse-slip faults use the probabilistic fault displacement analysis by Moss and Ross (2011).

If the estimated deterministic displacement is larger than the probabilistic displacement, consult with the Office Earthquake Engineering to determine the site-specific design parameters.

Reporting

Preliminary screening is typically reported in the SPGR, PFR, and FR. Stand-alone reports, if prepared, must be titled *Fault Rupture Hazard Evaluation Report*. If the preliminary screening determines that a fault rupture hazard does not exist then the reporting can be limited to a brief description of the investigation performed followed by the conclusion.

When a SFRHDA has been performed, prepare a *Fault Rupture Hazard Displacement Analysis Report* to document the investigations performed (both literature search and field work), the displacement hazard analysis (both DFDHA and PFDHA), findings, and recommendations. The report should contain the following elements:

- Literature Review: Identify the sources and types of literature, reports, images, maps, and plans used for the detailed evaluation.

- Bridge Review: Bridge name, location, Logs of Test Borings, depth to groundwater, "As-Built" foundation plans, modifications or retrofits, bridge inspection reports, structure type, foundation types, centerline trend, skew of crossing, skew relative to fault being evaluated.

- Fault evaluation: Fault name, verified distance to site, fault type, moment magnitude, recurrence interval, slip rate, amount and direction of potential offset, history of movement, age of fault, and zoning (if any).

- Field Investigations: Summarize site reconnaissance, local geologic mapping, fault trenching, geophysics explorations, subsurface borings, and/or CPT soundings used for the investigation. Append any logs, LOTBs, or reports as necessary to support the findings.

- Fault Rupture Analysis: Summarize the deterministic fault displacement analysis (DFDHA) and a probabilistic fault displacement analysis (PFDHA) of 5% in 50 years. Include tables and graphs presenting the findings of the analysis.

References

1. Abrahamson, N., 2008, Appendix C, Probabilistic Fault Rupture Hazard Analysis, San Francisco PUC, General Seismic Requirements for the Design on New Facilities and Upgrade of Existing Facilities.

2. Bryant, William A., Hart, Earl W., 2007, Fault-Rupture Hazard Zones in California, Alquist-Priolo Earthquake Fault Zoning Act With Index to Earthquake Fault Zones Maps, Special Publication 42.

3. California Geological Survey, 2002, *Guidelines for Evaluating the Hazard of Surface Fault Rupture*, CGS Note 49.

4. Caltrans, Memo to Designers 20-10, *Fault Rupture.*

5. Moss, R. and, Ross, Z., 2011, Probabilistic Fault Displacement Hazard Analysis for Reverse Faults, BSSA Vol. 101, pp 1542 – 1553.

6. Petersen, M., and others, 2011, Fault displacement hazard for strike-slip faults: Bulletin of the Seismological Society of America, Vol. 101, No. 2, pp. 805–825.

7. US Geological Survey, Faults in Google Earth, 2013.

8. US Geological Survey, 2008, National Seismic Hazard Maps and Data, Lower 48 Maps and Data.

9. Wells, D., and Coppersmith, K., 1994, New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement: Bulletin of the Seismological Society of America, Vol. 84, No. 4, pp. 974-1002.