20.22 Analysis of New Bridges in Fault Rupture Zones

20.22.1 GENERAL

This policy addresses the analysis requirements for the design of ordinary and recovery bridges that cross strike-slip fault zones. The criteria cover how the effects of fault rupture offsets are considered in design, and address the use of nonlinear time history analysis, and simplified analysis based on linear elastic analysis and nonlinear pushover analysis.

20.22.2 DEFINITIONS

Strike-Slip Fault—A fault in which rock strata are displaced mainly in a horizontal direction parallel to the fault trace.

Fault Offset—The relative movement across a surface fault rupture.

20.22.3 NOTATION

A_i	=	Response spectrum acceleration coefficient corresponding to the vibration period of mode *i*
A_{max}	=	Peak spectral acceleration coefficient
g	=	Acceleration of gravity
LDA	=	Linear dynamic analysis
LSA	=	Linear static analysis
$\boldsymbol{m}$	=	Matrix of superstructure mass lumped at superstructure support locations with zero off-diagonal elements (superstructure tributary mass at the bents and abutments)
$m_{i,eff}$	=	Effective transverse modal mass for vibration mode *i*
m_{tot}	=	Total superstructure mass computed as the sum of the elements of the mass matrix $\boldsymbol{m}$.
MR_i	=	Mass participation factor for vibration mode *i*
NTHA	=	Nonlinear time history analysis
SRSS	=	Square root of the sum of the squares
Δ_N	=	Fault rupture influence vector (normalized superstructure transverse displacements due to a unit fault offset)

ϕ_i = Vector of transverse components for vibration mode *i*

20.22.4 ANALYSIS REQUIREMENTS

Fault rupture offset shall be considered to act concurrently with dynamic shaking and other seismic design hazards. The probabilistic fault offset, with 5% probability of exceedance in 50 years, shall be used. The analysis shall be based on the location, direction, and magnitude of ground displacement at the structure due to the fault offset, as well as the ground motion response spectrum associated with the design fault offset.

Analysis models for fault rupture shall include column plastic hinges, and nonlinear springs for the abutment shear keys along with abutment and foundation soil springs. Deep foundations shall be modeled explicitly.

Bridge displacement demands shall be determined using NTHA or the simplified analysis procedure in this STP. Other responses, such as shear and flexural demands, shall be based on plastic hinging of the columns as specified in SDC (Caltrans, 2019).

20.22.4.1 Nonlinear Time History Analysis

Displacement time histories shall capture the velocity pulse effects of near field ground motions. The displacement time histories shall also include the static fault offset (Kamani, 2014).

20.22.4.2 Simplified Analysis

The horizontal fault offset is resolved into two components, a parallel component, and a normal component, relative to the longitudinal axis of the bridge. The normal component of the fault offset shall be used for the combined static and dynamic response in the simplified analysis procedure. The parallel component of the fault offset, in combination with any vertical offset, shall be considered as static deformations to be applied to the bridge model in the longitudinal pushover analysis.

The simplified analysis procedure consists of four steps as follows:

Step 1: Obtain the bridge static response due to the fault offset. Use nonlinear static pushover analysis to apply the gravity loads and the normal component of the fault offset to the bridge model. Fault offsets are applied to the fixed end of the foundation springs. The static displacement demands are computed as the relative displacements between the center of gravity of the superstructure and the ground.

Step 2: Obtain the bridge dynamic response due to ground shaking. The dynamic response of the structure must be determined using either the LSA or the LDA procedure (Chopra, 2008).

Step 3: Add the static and dynamic responses to obtain the total displacement demand.

Step 4: Perform transverse pushover analysis to determine the displacement capacity at each bent. This may be done one bent at a time or on the whole bridge. Gravity loads and fault offsets must be included in the pushover analysis.

20.22.4.2.1 Linear Static Analysis Procedure (LSA)

The dynamic displacement demand of the bridge is estimated with a linear analysis of the structure due to the transverse forces F_{LSA} applied to the superstructure at the support locations. F_{LSA} is computed as:

$$F_{LSA} = \boldsymbol{m} g \Delta_N A_{\max} \qquad (20.22.4.2.1.1)$$

20.22.4.2.2 Linear Dynamic Analysis Procedure (LDA)

LDA is carried out using vibration modes such that the cumulative transverse mass participation factor is at least 90%.

The effective transverse modal mass for fault rupture is computed as:

$$m_{eff,i} = \frac{(\phi_i^T \boldsymbol{m} \Delta_N)^2}{\phi_i^T \boldsymbol{m} \phi_i} \qquad (20.22.4.2.2.1)$$

The mass participation factor for each mode, MR_i, is computed as:

$$MR_i = \frac{m_{eff,i}}{m_{tot}} \qquad (20.22.4.2.2.2)$$

The modal load vector, F_i, for each selected mode is computed as:

$$F_i = \frac{\phi_i^T \boldsymbol{m} \Delta_N}{\phi_i^T \boldsymbol{m} \phi_i} \boldsymbol{m} g \phi_i A_i \qquad (20.22.4.2.2.3)$$

The next step is to determine modal displacement demands, $\Delta_{u,i}$, using static analysis of the bridge under the action of the modal load vectors, F_i, applied to the superstructure at the intersection with the superstructure supports. The load vector for each mode is assigned to a separate static load case in the analysis model. The result of load case *i* is the modal displacement demand $\Delta_{u,i}$ of mode *i*.

The superstructure dynamic displacement demand at each support location is obtained by SRSS combination of the modal displacement demands as:

$$\Delta_{u,LDA} = \sqrt{\sum_{i=1}^{n} (\Delta_{u,i})^2} \quad (20.22.4.2.2.5)$$

Where *n* is the total number of selected modes.

20.22.5 REFERENCES

1. Chopra, A. K., AND Geol, R. K. (2008). "Analysis of Ordinary Bridges Crossing Fault-Rupture Zones," *Report No. UCB/EERC-2008/01*, University of California at Berkeley, CA.
2. Kamani, R., Abrahamson, N., AND Graves, R. (2014). "Adding Fling Effects to Processed Ground-Motions Time histories," *Bulletin of the Seismological Society of America*, 104(4), 1914-1929.
3. Caltrans. (2019). *Seismic Design Criteria*, Version 2.0. California Department of Transportation, Sacramento, CA.