Bridges Crossing Faults

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Rakesh K. Goel, PhD, PE, F.ASCE
California Polytechnic State University
San Luis Obispo, CA
rgoel@calpoly.edu
Objectives

- Develop simplified procedure to estimate seismic demands in “ordinary” bridges crossing fault-rupture zone
  - Rooted in structural dynamics theory
  - Simpler than nonlinear response history analysis
  - Utilize special feature of support motions in fault-rupture zones
Current Analytical Procedures

- Bridge subjected to uniform support excitation
  - Linear ELF analysis, NSP, Linear RSA, linear/nonlinear RHA
- Bridges crossing fault-rupture zones
  - Linear/nonlinear RHA for multiple support excitation
Ground Motions

- Motions at bridge supports on two sides of the fault are needed
  - Bridge supports are very close to the fault
    - Supports are within few tens of meters from the fault
  - Motions have not been recorded so close to the fault on both sides
    - Recorded motions are at few hundred meters from the fault
- Support motions were simulated on faults with various orientations
  - Simulations by Prof. Doug Dreger at UC Berkeley
Motions Across Strike-Slip Fault

- FP motions are anti-symmetric with respect to the fault
- FN motions are symmetric with respect to the fault
- Vertical motions are anti-symmetric with respect to the fault
- Vertical motions for strike-slip fault at selected location are very small
Motions in Fault-Rupture Zones

\[ u_{g_l}(t) = \alpha_l \ u_g(t) \]

Motion at \( l^{th} \) Support

Motion at a Reference Location

Proportionality Constant

Proportional Multiple-Support Excitation
Proportional Excitation – Strike-Slip Fault

\[ u_{gl}(t) = \alpha_{1}u_{g,\text{Abut1}}(t) \]

Fault-Parallel Motions
\[ \alpha_{\text{Abut1}} \quad \text{and} \quad \alpha_{\text{Bent2}} = 1 \]
\[ \alpha_{\text{Bent3}} \quad \text{and} \quad \alpha_{\text{Abut4}} = -1 \]

Fault-Normal Motions
\[ \alpha_{\text{Abut1}} \quad \text{and} \quad \alpha_{\text{Bent2}} = 1 \]
\[ \alpha_{\text{Bent3}} \quad \text{and} \quad \alpha_{\text{Abut4}} = 1 \]
Equations of Motion: Linear Systems

General Multiple -Support Excitation

\[ m \ddot{u} + c \dot{u} + ku = -m \sum_{l=1}^{N_g} l_l \ddot{u}_l(t) \]

Proportional Multiple -Support Excitation

\[ m \ddot{u} + c \dot{u} + ku = -m \ell_{\text{eff}} \ddot{u}_g(t) \]

\[ u^t(t) = \sum_{l=1}^{N_g} l_l u_{gl}(t) \]

Quasi-Static

\[ u^t(t) = \ell_{\text{eff}} u_g(t) \]

Dynamic

\[ + \sum_{n=1}^{N} \Gamma_n \phi_n D_n(t) \]
Peak Response

Peak response from quasi-static analysis:
Apply peak support displacements statically

\[ u^t_o \approx u^s_o + u_o \]

Peak response from dynamic analysis:
Combine peak values from significant modes using appropriate combination rule: SRSS or CQC

\[ u^s_o = \lambda_{\text{eff}} \ u_{go} \]
Dynamic Response

\[ u_o \approx \left[ \sum_{n=1}^{J \leq N} (u_{no})^2 \right]^{1/2} \]

\[ u_{no} = \Gamma_n \phi_n D_{no} \]

\[ \Gamma_n = \frac{\phi_n^T m \iota_{\text{eff}}}{\phi_n^T m \phi_n} \]

Utilizes “Effective” Influence Vector

Not same as standard RSA

Peak Displacement of SDF System with \( T_n \) and \( \zeta_n \)

From Response or Design Spectrum
Effective Influence Vector

- Essentially translation in bridges subjected to spatially uniform support excitation
- Significant torsional motions about a vertical axis in bridges crossing fault-rupture zones

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Spatially-Uniform

Fault-Rupture Zone
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Analysis: Linear Systems

- **RHA:** Response history analysis to multiple-support excitation
- **RSA:** Response spectrum analysis
  - Use ground motions spectrum that is appropriate for motions in fault-rupture zones
  - Carefully select modes that are excited by motions in fault rupture zones
- **RSA:1-Mode:** Response spectrum analysis considering only the most dominant mode
- **LSA:** Linear static analysis due to forces equal to $2.5m_{\text{eff}}\ddot{u}_{go}$
Modes Excited

"Effective" Influence Vector

Mode 1: T=1.08 sec
Mode 2: T=0.8249 sec
Mode 3: T=0.4191 sec
Mode 4: T=0.3395 sec
Mode 5: T=0.3318 sec
Mode 6: T=0.3051 sec
Bridges Selected

Shear Key Cases: Elastic shear keys and no shear keys
Response of Linear Bridges

![Graphs showing response of linear bridges]

- Column Drift in Bent 2, m
- Deck Disp. at Abut. 1, m

Legend:
- RHA
- RSA
- RSA:1-Mode
- LSA
Extension to Nonlinear Bridges

- Superposition assumed to be applicable
- Quasi-static response from **nonlinear static analysis** due to peak ground displacements applied simultaneously at all supports
- Dynamic response from
  - MPA: Modal pushover analysis (**nonlinear static pushover**)
  - LDA: Linear dynamic analysis (RSA or RSA: 1-Mode)
  - LSA: Linear static analysis due to forces equal to $2.5m_{eff} \ddot{u}_{go}$
Response of Nonlinear Bridges

![Graphs showing response of nonlinear bridges](image-url)
Recommended Procedure

- Linear Static Analysis Procedure
  - Compute the peak value of the quasi-static response including effects of gravity loads by nonlinear static analysis of the bridge due to peak ground displacement applied at all supports simultaneously.
  - Compute peak value of the dynamic response by linear static analysis of the bridge due to lateral forces equal to $2.5m_{\text{eff}}u_{go}$
    - Carefully compute the effective influence vector, which differs for bridges in fault-rupture zones.
  - Compute the total response as superposition of the quasi-static and dynamic responses.
Recommended Procedure

- Linear static analysis procedure is recommended because
  - It is simple to implement
  - It does not require mode shapes and frequencies
  - Provides results that are “accurate” for most practical applications
  - MPA and LDA are more complicated and offer only slight improvement
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