Response Spectrum Analysis of Bridges Crossing Faults

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Analysis of bridges crossing faults

Investigation of the problem with consideration of

- Ground motion spatial variability near the fault
- Characteristics of near-fault ground motions
  - Pulse-type nature
  - ‘Fling’ step
MSRS method

\[
E[\max |z(t)|] = \left[ \sum_{k=1}^{m} \sum_{l=1}^{m} a_k a_l \rho_{u_k u_l} u_{k,\text{max}} u_{l,\text{max}} + 2 \sum_{k=1}^{m} \sum_{l=1}^{m} \sum_{j=1}^{N} a_k b_{lj} \rho_{u_k s_j} u_{k,\text{max}} D_i(\omega_j, \zeta_j) \right]^{1/2}
\]

\[
+ \sum_{k=1}^{m} \sum_{l=1}^{m} \sum_{i=1}^{N} \sum_{j=1}^{N} b_{ki} b_{lj} \rho_{s_i s_j} D_k(\omega_i, \zeta_i) D_l(\omega_j, \zeta_j)
\]

\(k, l\) indices for support motions \((m = \text{total number of support DOF})\)

\(i, j\) indices for modes \((N = \text{total number of modes})\)
\textbf{MSRS method}

\[
E\left[ \max \left| z(t) \right| \right] = \left[ \sum_{k=1}^{m} \sum_{l=1}^{m} a_k a_l \rho_{u_k u_l} u_{k,\max} u_{l,\max} + 2 \sum_{k=1}^{m} \sum_{l=1}^{m} \sum_{j=1}^{N} a_k b_{lj} \rho_{u_k s_j} u_{k,\max} D_j(\omega_j, \zeta_j) \right. \\
+ \left. \sum_{k=1}^{m} \sum_{l=1}^{m} \sum_{i=1}^{N} \sum_{j=1}^{N} b_{ki} b_{lj} \rho_{s_k s_j} D_k(\omega_i, \zeta_i) D_j(\omega_j, \zeta_j) \right]^{1/2}
\]

\(k, l\) indices for support motions \((m = \text{total number of support DOF})\)

\(i, j\) indices for modes \((N = \text{total number of modes})\)

\(a_k, b_{ki}\) effective response factors associated with support DOF \(k\) and mode \(i\)

– functions of structural mass and stiffness properties
MSRS method

\[
E\left[\max |z(t)| \right] = \left[ \sum_{k=1}^{m} \sum_{l=1}^{m} a_k a_l \rho_{u_k u_l} u_{k, \text{max}}^{2} u_{l, \text{max}}^{2} + 2 \sum_{k=1}^{m} \sum_{l=1}^{m} \sum_{j=1}^{N} a_k b_j \rho_{u_k s_j} u_{k, \text{max}} D_l(\omega_j, \zeta_j) \right]^{1/2}
\]

- \(k, l\) indices for support motions \((m = \text{total number of support DOF})\)
- \(i, j\) indices for modes \((N = \text{total number of modes})\)
- \(a_k, b_{ki}\) effective response factors associated with support DOF \(k\) and mode \(i\) – functions of structural mass and stiffness properties
- \(u_{k, \text{max}}\) maximum ground displacement at support DOF \(k\)
- \(D_k(\omega_i, \zeta_i)\) ordinate of response spectrum at support DOF \(k\) for mode \(i\)
The three sets of correlation coefficients are functions of $u_{k,\text{max}}$, $D_k(\omega_i, \zeta_i)$, $\omega_i$, $\zeta_i$ and a coherency function defining the spatial variability of the ground motion field.
Coherency function for the case of a strike-slip fault

Transverse support motions

\[ \ddot{u}_1^y(t) = \ddot{u}_p \delta(t) \cos \phi \sin \delta \ t \]

\[ \ddot{u}_2^y(t) = -\ddot{u}_n (t) \cos \phi \sin \delta \ t \]

Assuming FN and FP components are statistically independent:

\[ \gamma_{12}^y(\omega) = \frac{-G_{\ddot{u}_p \ddot{u}_p}(\omega)(\cos \delta)^2 + G_{\ddot{u}_n \ddot{u}_n}(\omega)(\sin \delta)^2}{G_{\ddot{u}_p \ddot{u}_p}(\omega)(\cos \delta)^2 + G_{\ddot{u}_n \ddot{u}_n}(\omega)(\sin \delta)^2} \]

\( G_{\ddot{u}_p \ddot{u}_p}(\omega), G_{\ddot{u}_n \ddot{u}_n}(\omega) \) obtained in terms of corresponding response spectra
Input ground motions

Concerns

- Modification of response spectra to account for near-fault effects
- The narrow-band and distinctly non-stationary nature of near-fault ground motions violates fundamental assumptions of the MSRS method
- Lack of strong motion records at distances less than a hundred meters from the fault
  - use of simulated ground motions
  - use of ground motions recorded at larger distances
- Ground motions from the NGA database do not include the ‘fling step’ due to baseline correction
Evaluation of static offset

- If the fault ruptures to the surface
  \[ x_o = \frac{D}{2} - \frac{D}{2} \tan^{-1}\left(\frac{d}{W}\right) \]

- otherwise
  \[ x_o = \frac{D}{\pi} \left[ \tan^{-1}\left(\frac{d}{W'}\right) - \tan^{-1}\left(\frac{d}{W}\right) \right] \]

- \( W \): Fault width
- \( W' \): Depth to the top of fault rupture
- \( d \): Distance from the fault
- \( D \): Average fault slip
‘Fling’ step time histories

- **Velocity**
  \[ \dot{x}(t) = ct^\xi e^{-t/\alpha} \]
  - \( c \): normalizing parameter so that \( \int x(t) dt = x_0 \)
  - \( \alpha = T_R / 4, \ T_R \): Rise time
  - \( \xi \): controls the high-frequency decay rate, \( \xi = 1 \rightarrow \text{Brune source} \)

- **Displacement**
  \[ x(t) = -c(at + a^2)e^{-t/\alpha} + ca^2 \]

- **Acceleration**
  \[ \ddot{x}(t) = c \left( 1 - \frac{t}{a} \right) e^{-t/\alpha} \]
Example applications

1979 Imperial Valley Earthquake
El Centro #7 Array record, FP component

1992 Erzikan Earthquake
Erzikan record, FP component
Thank you

Questions?