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

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

$$\left. + \sum_{k=1}^{m}\sum_{l=1}^{m}\sum_{i=1}^{N}\sum_{j=1}^{N} b_{ki} b_{lj} \rho_{s_{ki} s_{lj}} D_k(\omega_i,\zeta_i) D_l(\omega_j,\zeta_j)\right]^{1/2}$$

k, l indices for support motions (m = total number of support DOF)

i, j indices for modes (N = total number of modes)

MSRS method

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

k, l	indices for support motions (m = total number of support DOF)
i, j	indices for modes (N = 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

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

k, l	indices for support motions (m = total number of support DOF)
i, j	indices for modes (N = 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
$u_{k,\max}$	maximum ground displacement at support DOF k
$D_k(\omega_i,\zeta_i)$	ordinate of response spectrum at support DOF k for mode i

MSRS method

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

$$\left. + \sum_{k=1}^{m}\sum_{l=1}^{m}\sum_{i=1}^{N}\sum_{j=1}^{N} b_{ki} b_{lj} \rho_{s_{ki} s_{lj}} D_k(\omega_i,\zeta_i) D_l(\omega_j,\zeta_j)\right]^{1/2}$$

$\rho_{u_k u_l}$ correlation coefficient between displacements at support DOFs k and l

$\rho_{u_k s_{lj}}$ correlation coefficient between the displacement at support DOF k and the response of mode j to the ground motion at support DOF l

$\rho_{s_{ki} s_{lj}}$ correlation coefficient between the response of mode i to the ground motion at support DOF k and the response of mode j to the ground motion at support DOF l

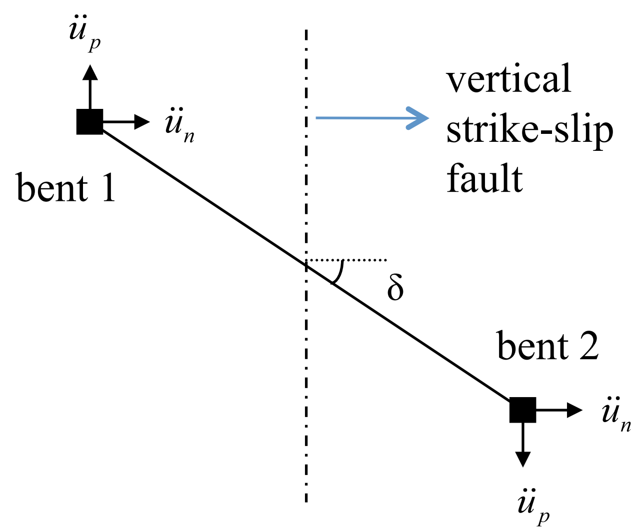
The three sets of correlation coefficients are functions of $u_{k,\max}$, $D_k(\omega_i,\zeta_i)$, ω_i, ζ_i and a **coherency function** defining the spatial variability of the ground motion field.

Coherency function
for the case of a strike-slip fault

Transverse support motions

$$\ddot{u}_1^Y(t) = \ddot{u}_p(t)\cos(\delta) + \ddot{u}_n(t)\sin(\delta)$$

$$\ddot{u}_2^Y(t) = -\ddot{u}_p(t)\cos(\delta) + \ddot{u}_n(t)\sin(\delta)$$



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

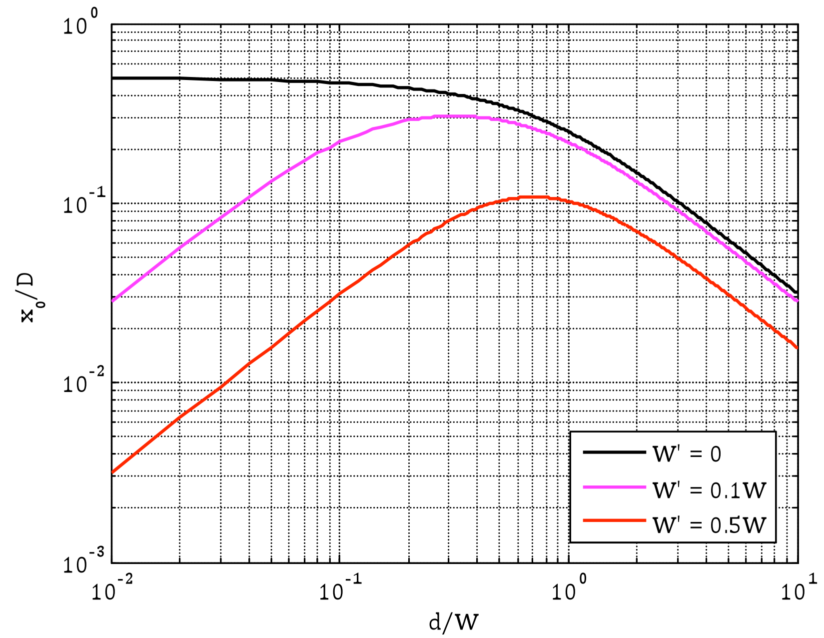
- If the fault ruptures to the surface

$$x_o = \frac{D}{2} - \frac{D}{2}\tan^{-1}\left(\frac{d}{W}\right)$$

- 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

$$\dot{x}(t) = ct^{\zeta} e^{-t/a}$$

- c : normalizing parameter so that $\int x(t)dt = x_o$
- $a = T_R / 4$, T_R: Rise time
- ζ : controls the high-frequency decay rate, $\zeta = 1 \rightarrow$ Brune source

- Displacement

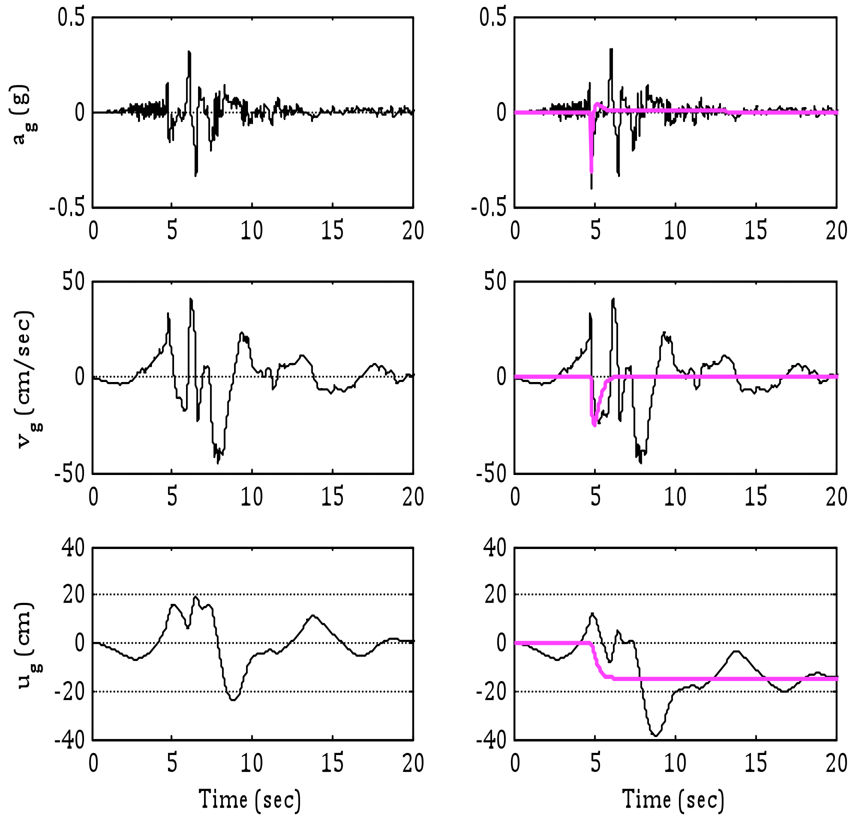
$$x(t) = -c(at + a^2)e^{-t/a} + ca^2$$

- Acceleration

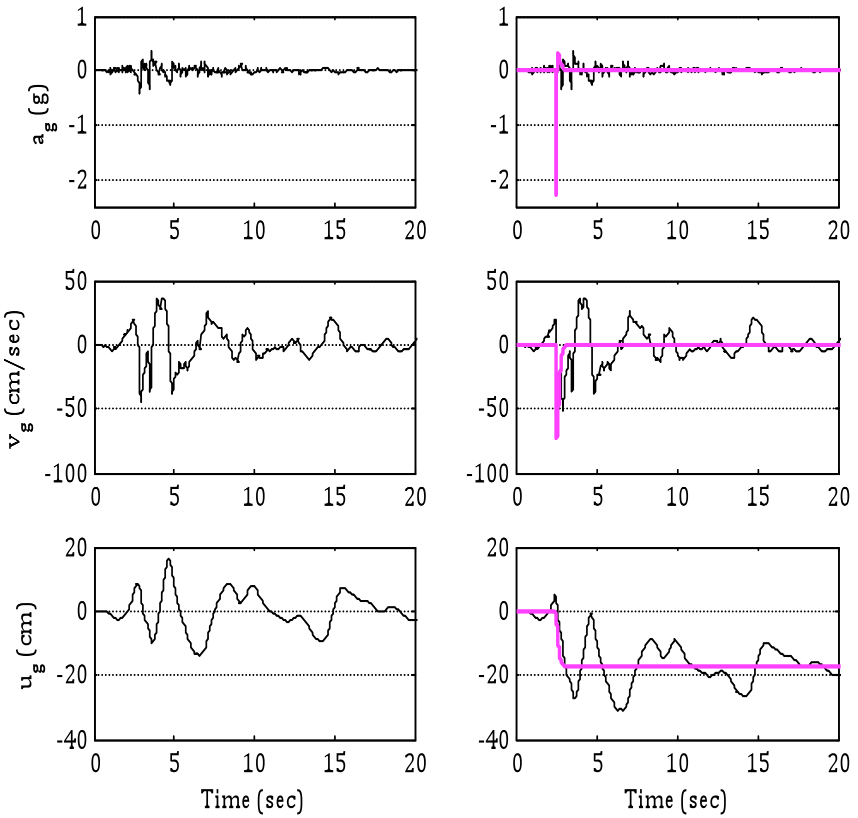
$$\ddot{x}(t) = c\left(1 - \frac{t}{a}\right)e^{-t/a}$$

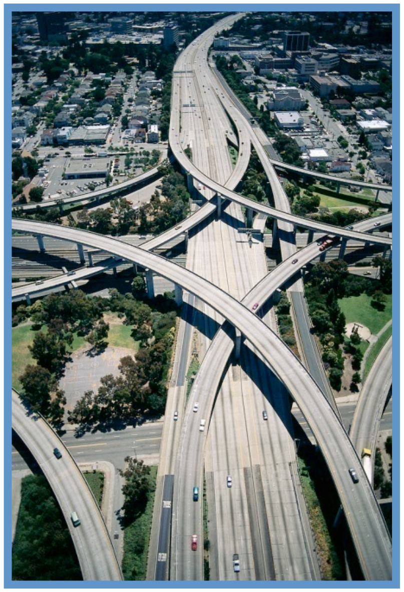
Example applications

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



1992 Erzikan Earthquake
Erzikan record, FP component





Thank you

Questions?