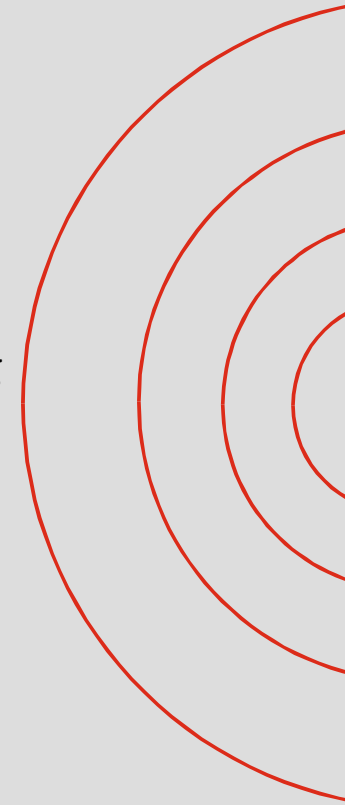


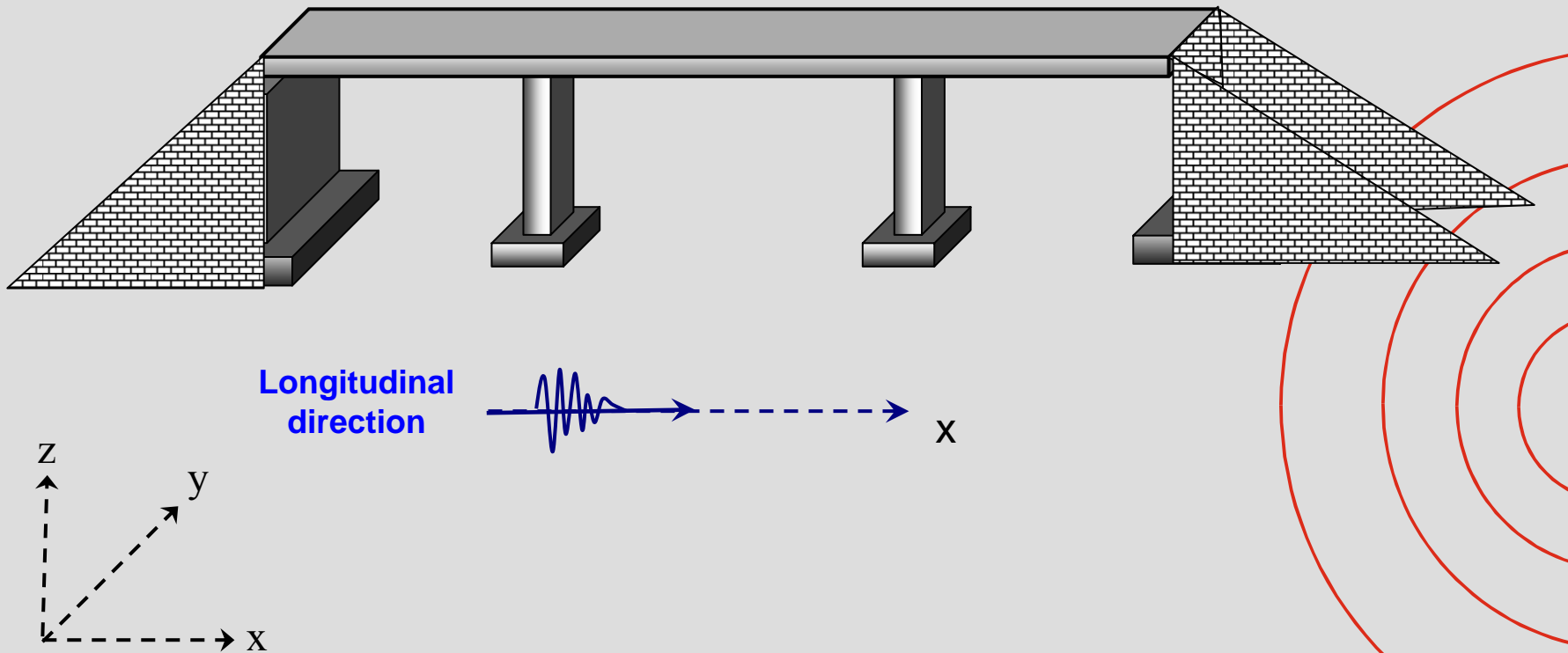
Directionality Effect of Earthquake Ground Motion on Bridge Performance Analysis

Masanobu Shinozuka and Swagata Banerjee
Department of Civil and Environmental Engineering
University of California, Irvine

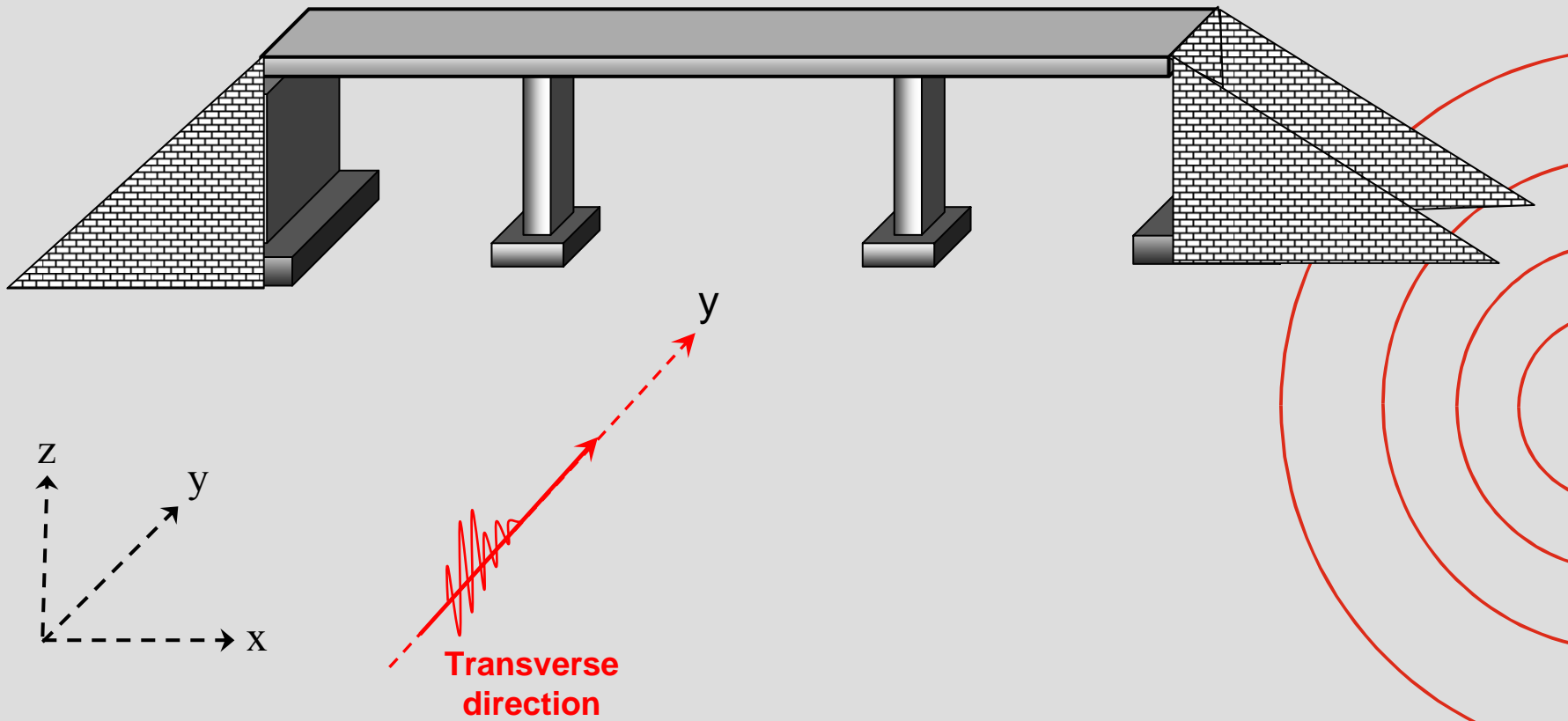
Tri-Center Meeting on Transportation Networks
October, 13-14, 2005; Las Vegas, NV
Imperial and Forum Boardrooms



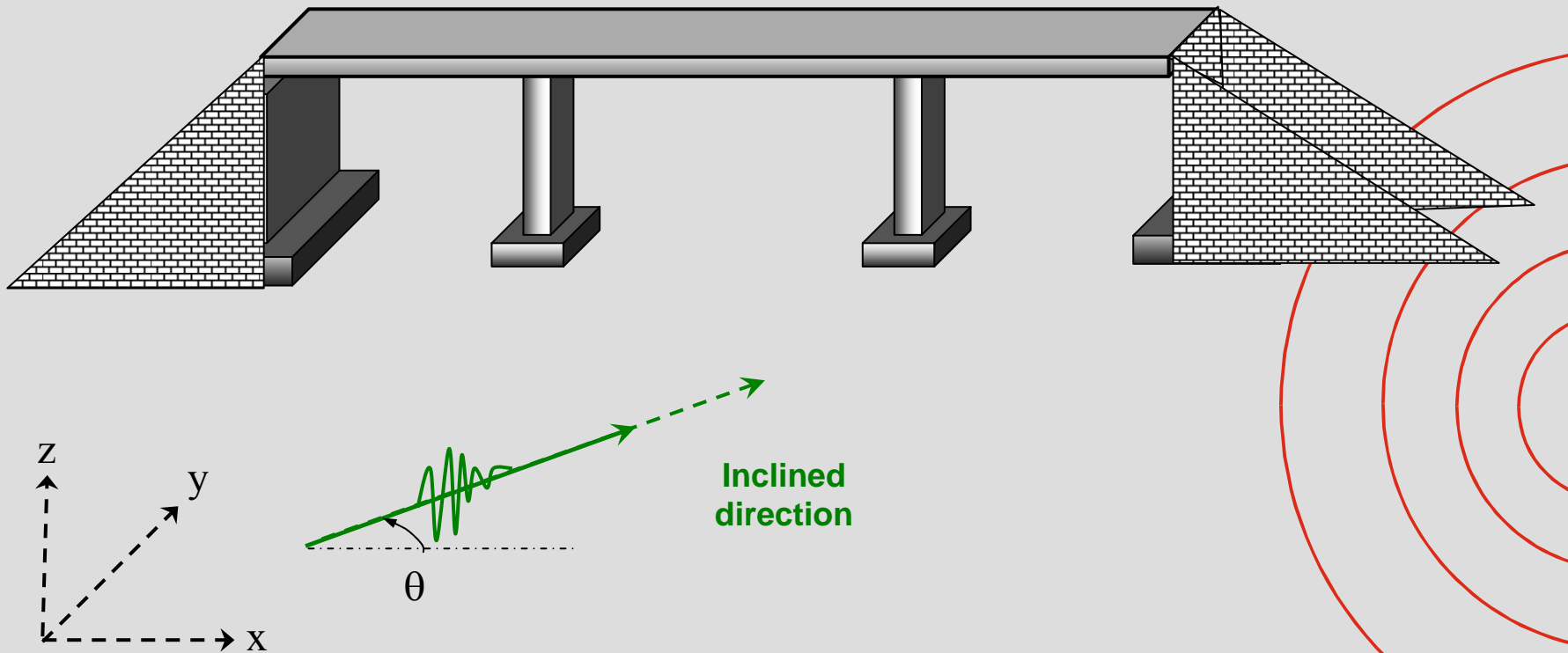
What is Directionality of EQ Motion...



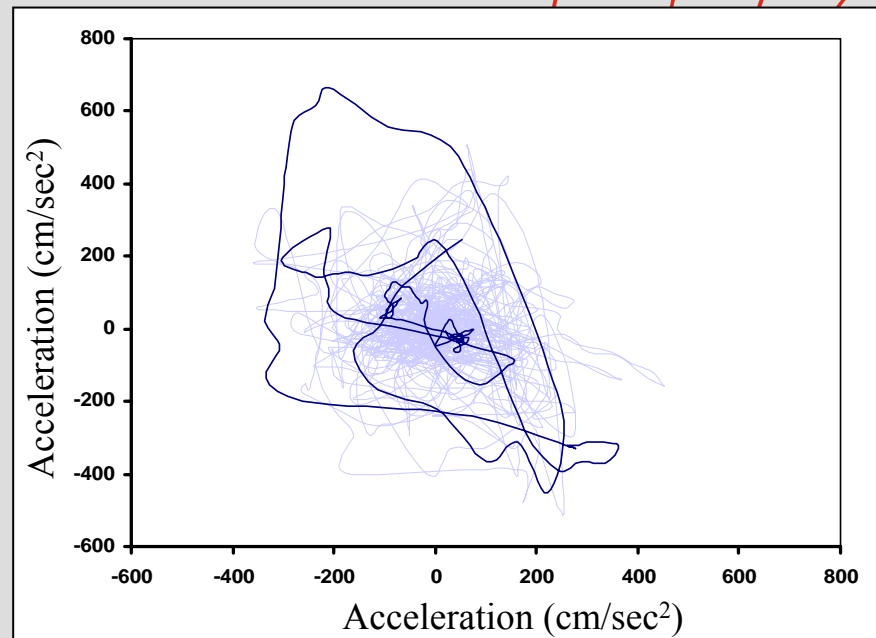
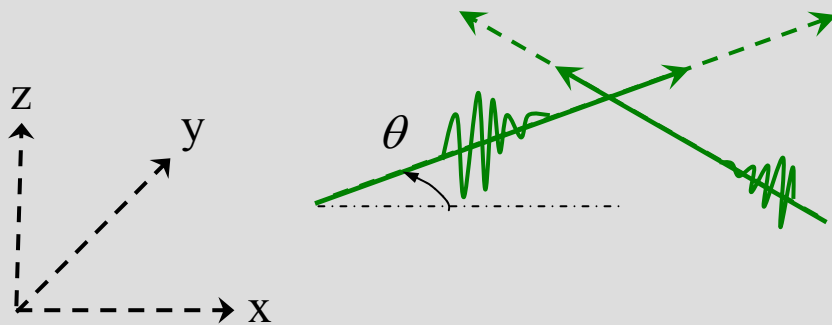
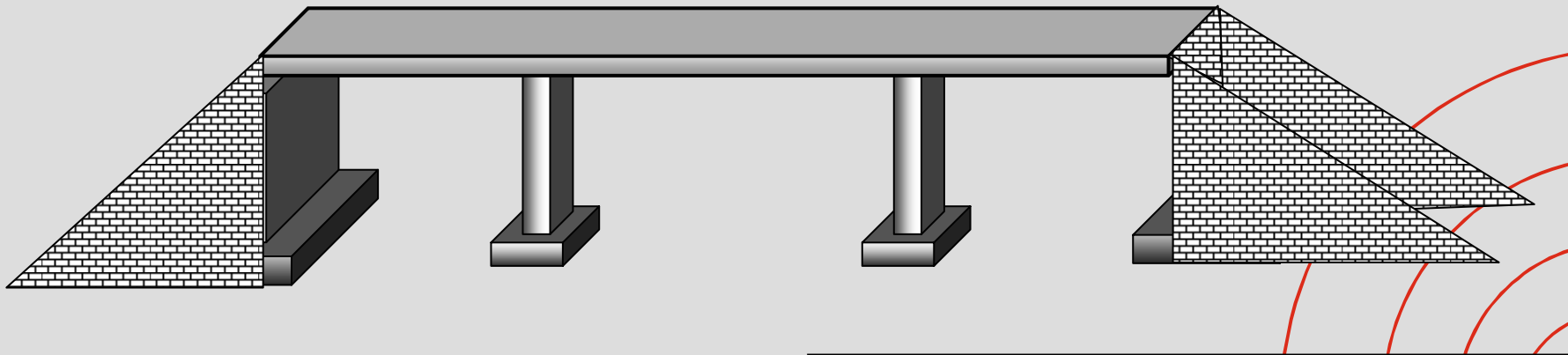
What is Directionality of EQ Motion...



What is Directionality of EQ Motion...

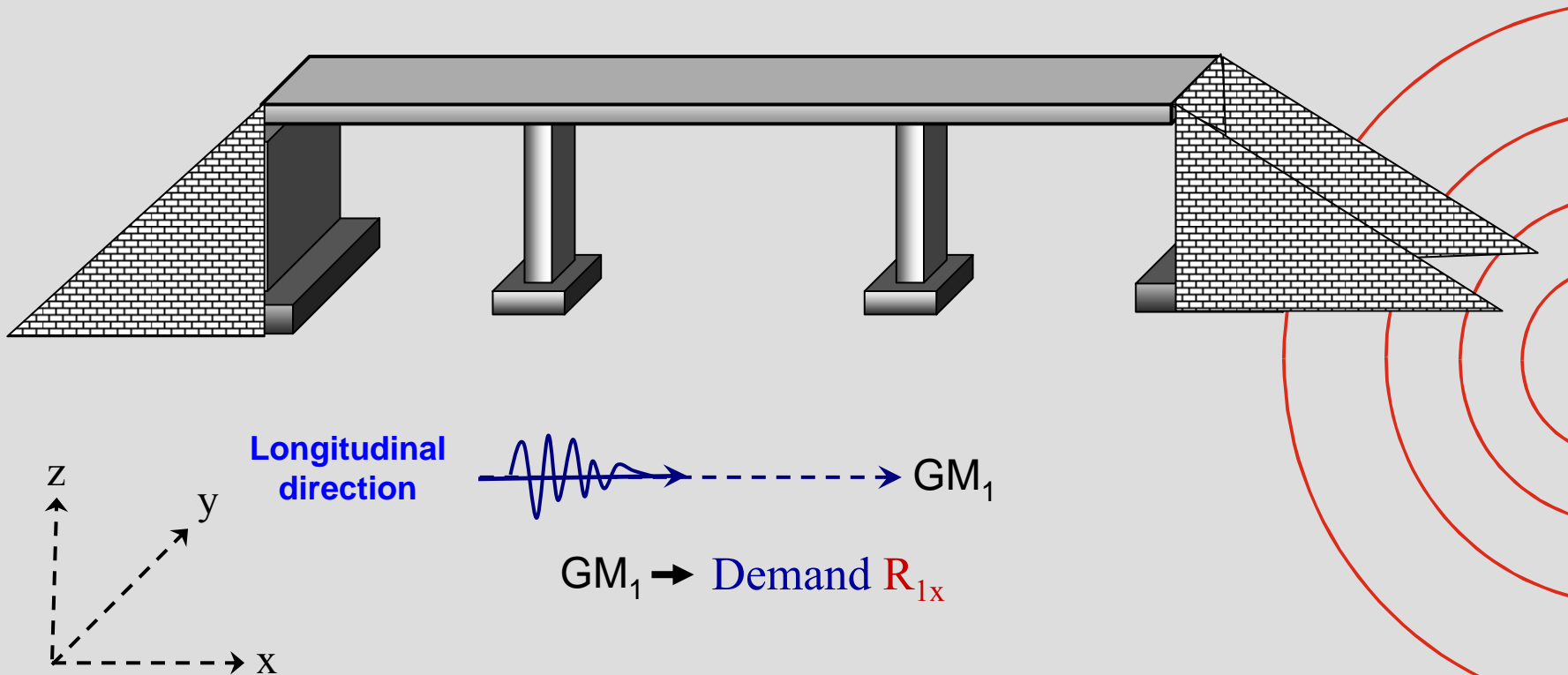


What is Directionality of EQ Motion...



Analytical Procedure

1. Bridge is analyzed in *Longitudinal* direction

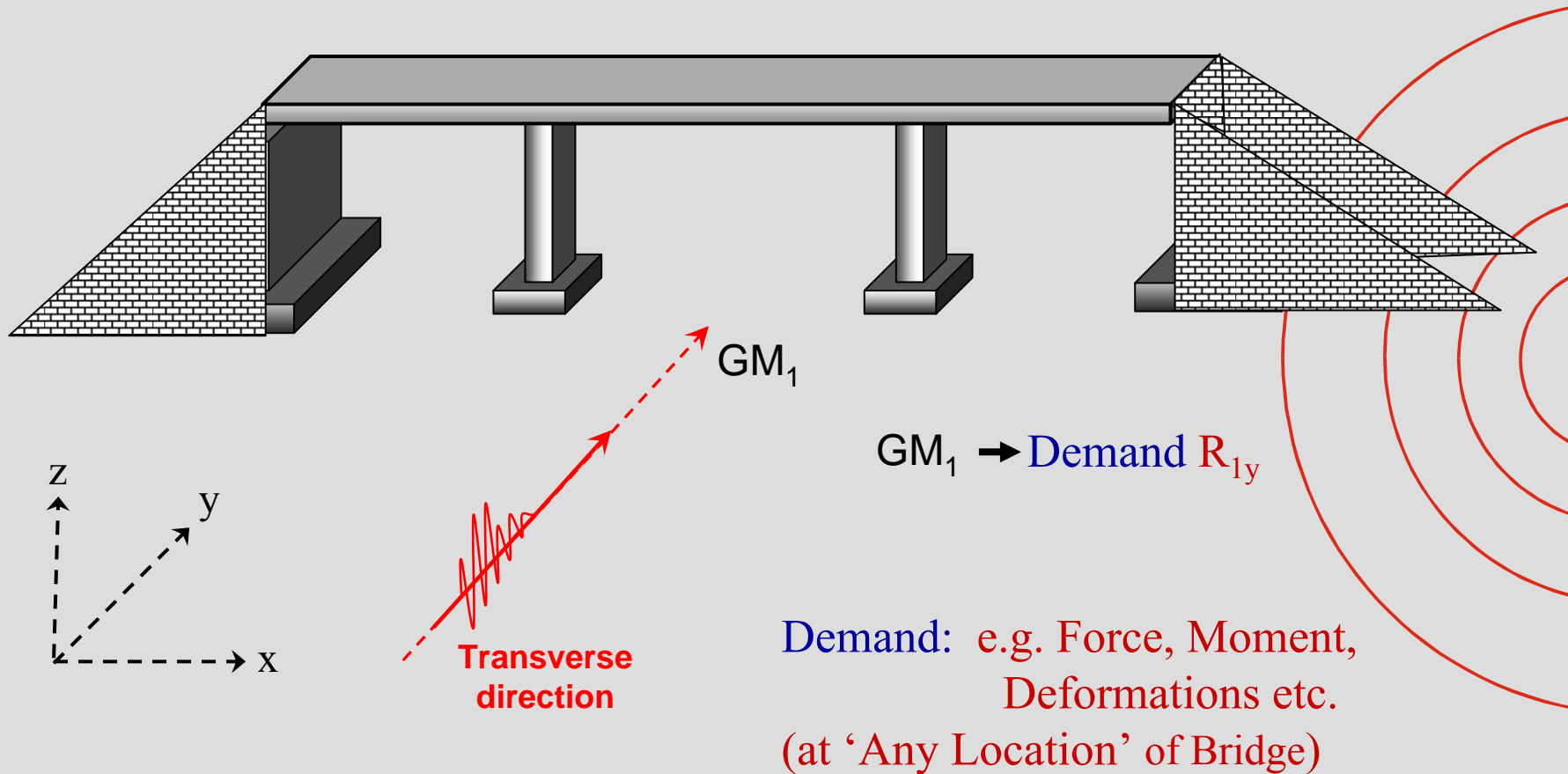


Demand: e.g. Force, Moment, Deformations etc.
(at 'Any Location' of Bridge)



Analytical Procedure

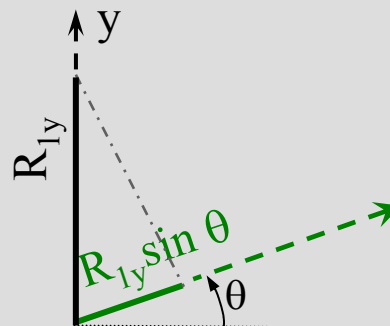
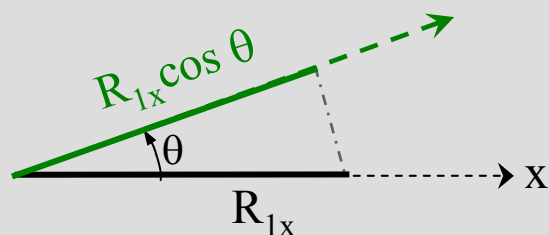
2. Bridge is analyzed in *Transverse* direction



Analytical Procedure

3. Bridge response in *Inclined* direction (at any location)

For Ground Motion 1 (GM_1),



Total Demand:

$$R_{1\theta} = R_{1x} \cos \theta + R_{1y} \sin \theta$$

Critical Angle:

$$\tan \theta_{cr} = \frac{2(R_{1x} R_{1y})}{(R_{1x}^2 - R_{1y}^2)}$$

Maximum Demand:

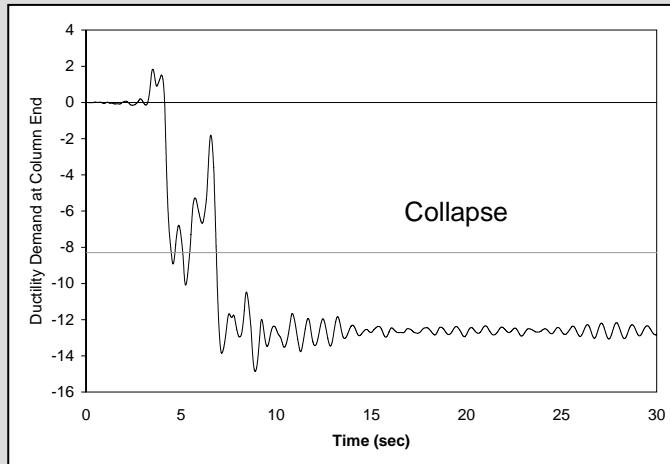
$$R = (R_{1x} \cos \theta_{cr} + R_{1y} \sin \theta_{cr})$$

Ref: (Wilson et al., (1982) and (1995) suggested to use Response Spectrum Analysis)

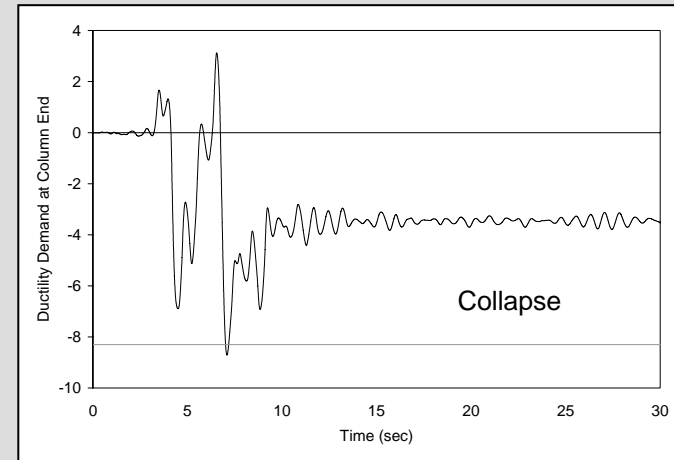


Variation of Transverse Response of Bridge with Abutment Stiffness

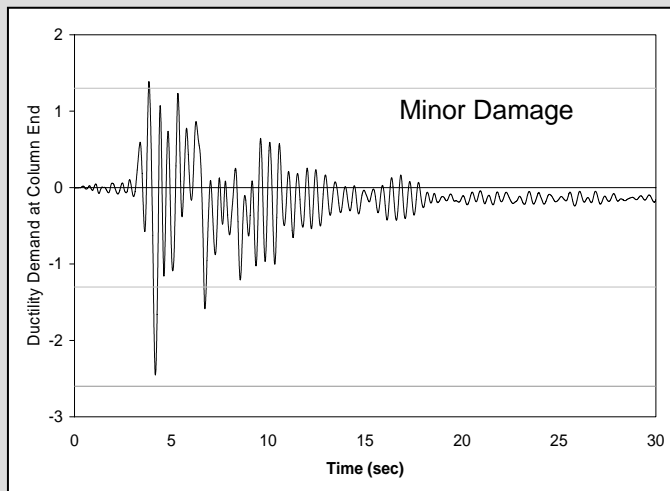
Ground Motion: LA27; Bridge 1



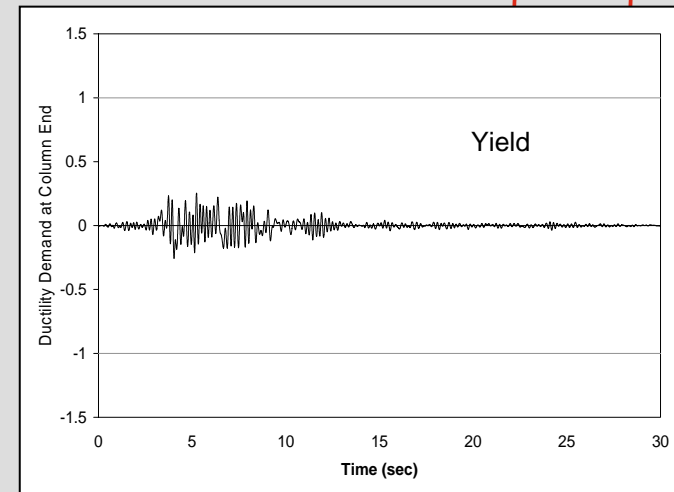
Abt. Stiffness:
14.6 kN/m (1 kips/ft)



Abt. Stiffness:
2920 kN/m (200 kips/ft)

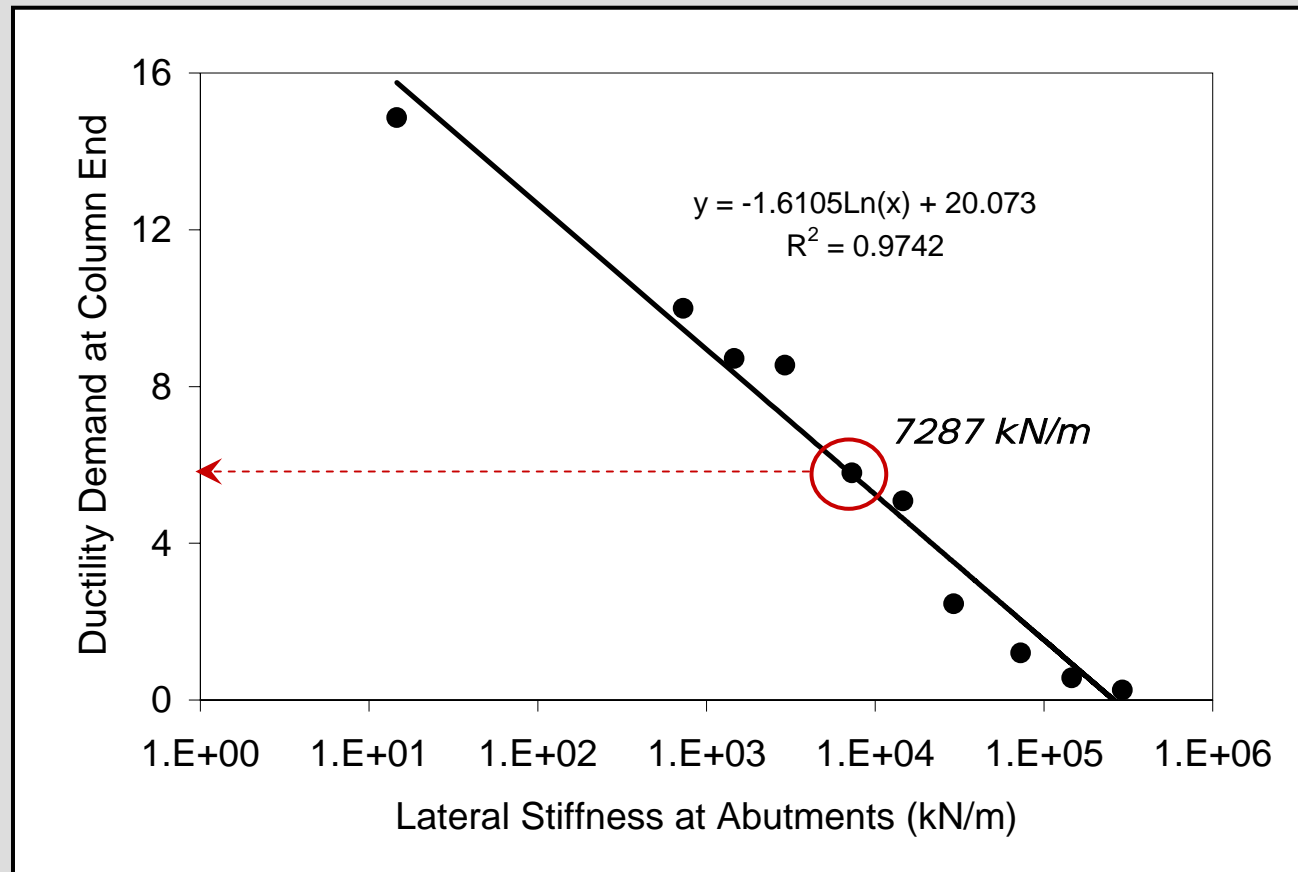


Abt. Stiffness:
29200 kN/m (2000 kips/ft)



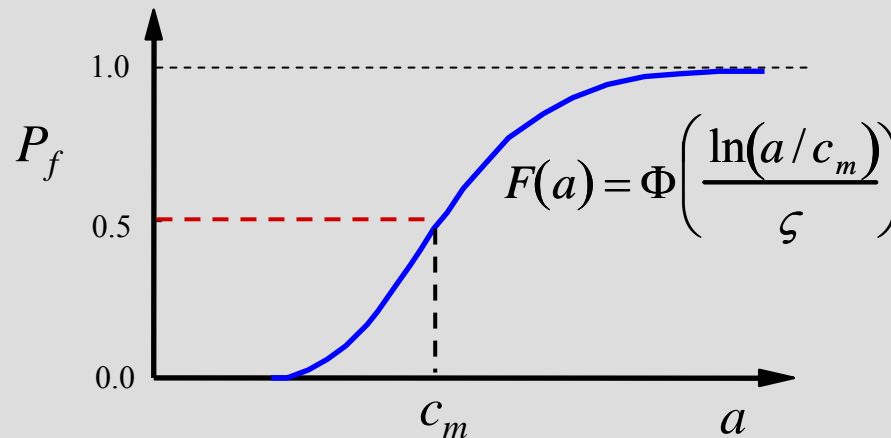
Abt. Stiffness:
292000 kN/m (20000 kips/ft)

Variation of Transverse Response of Bridge with Abutment Stiffness



Fragility Curves

- Two-parameter lognormal distribution functions of seismic ground motion intensity are used for fragility curves
- Median c_m and log-standard deviation ζ are fragility parameters to be estimated by **maximum likelihood method**.



Parameter Estimation

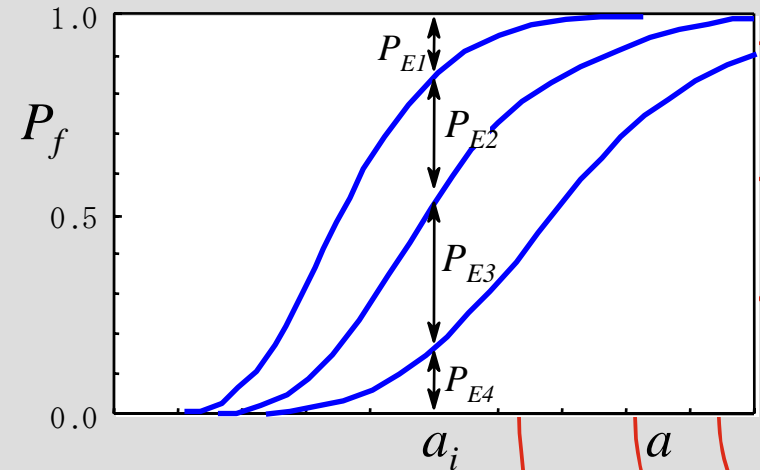
Probability of occurrence of each damage state

$$P_{E1} = P(a_i, E_1) = 1 - F_1(a_i; c_1, \zeta)$$

$$P_{E2} = P(a_i, E_2) = F_1(a_i; c_1, \zeta) - F_2(a_i; c_2, \zeta)$$

$$P_{E3} = P(a_i, E_3) = F_2(a_i; c_2, \zeta) - F_3(a_i; c_3, \zeta)$$

$$P_{E4} = P(a_i, E_4) = F_3(a_i; c_3, \zeta)$$



Likelihood Function

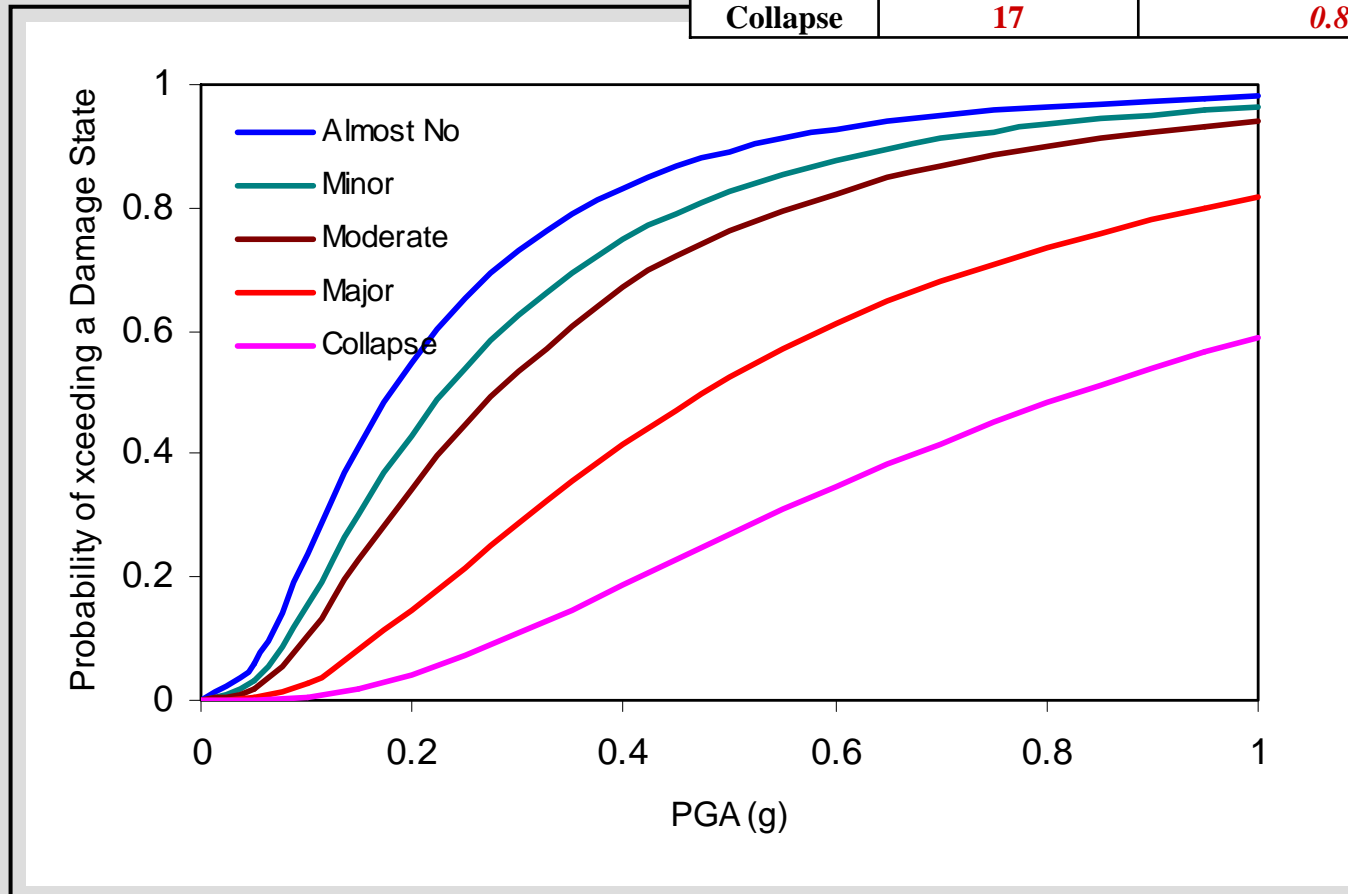
$$L(c_1, c_2, c_3, \zeta) = \prod_{i=1}^n \prod_{k=1}^4 P(a_i; E_k)^{x_{ik}}$$

where $x_{ik} = 1$ (if damage state E_k occurs for the i -th bridge subjected to $a = a_i$),
 $x_{ik} = 0$ (otherwise)

(Shinozuka et al., 2003a)

Fragility Curves in Longitudinal Direction

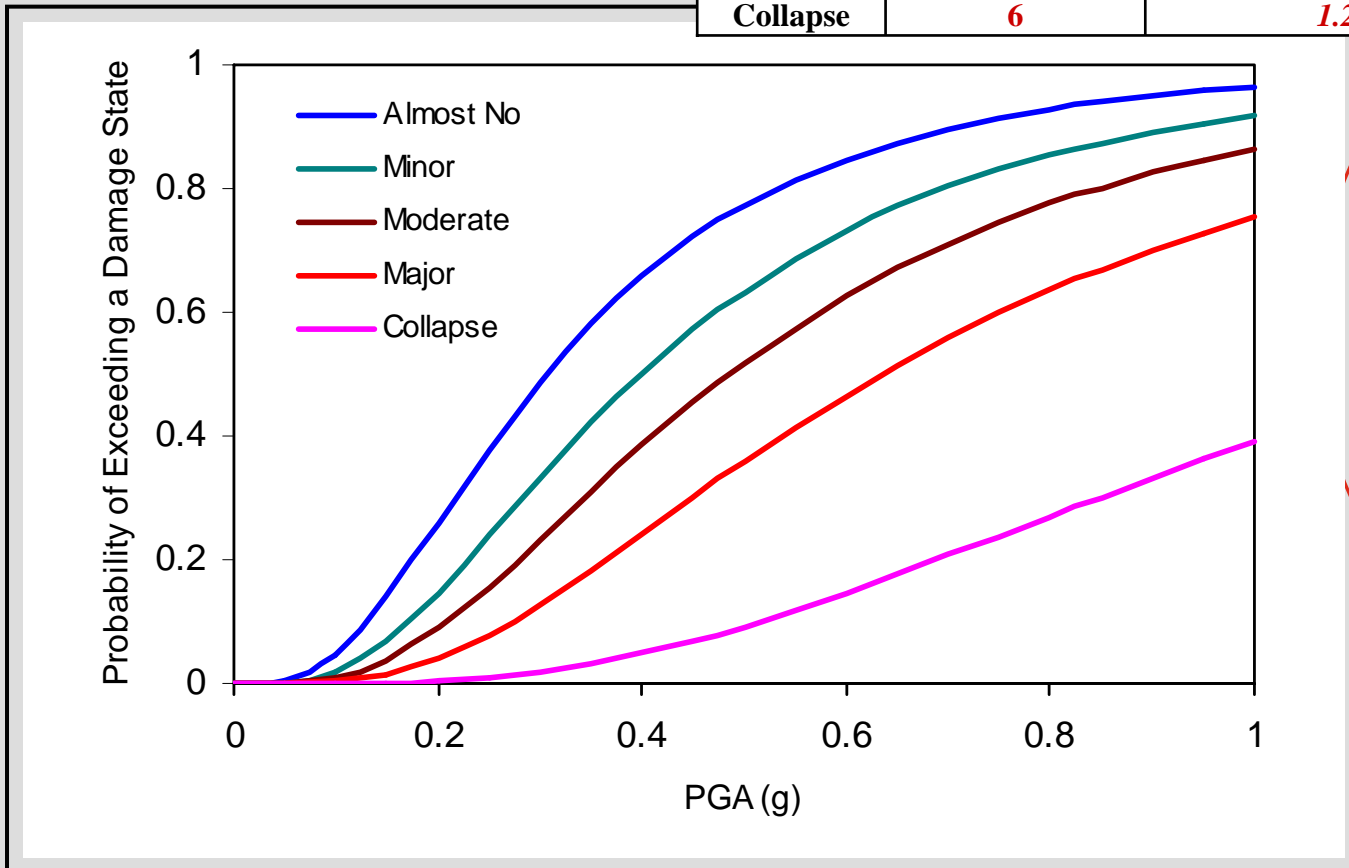
Damage States	Damaged Bridges (Sample Size 60)	Required PGA for 50% Failure Probability (PGA)
Almost No	56	0.18
Minor	50	0.23
Moderate	48	0.27
Major	36	0.47
Collapse	17	0.83



Fragility Curves in Transverse Direction

Damage States	Damaged Bridges (Sample Size 60)	Required PGA for 50% Failure Probability (PGA)
Almost No	50	0.31
Minor	41	0.40
Moderate	37	0.49
Major	27	0.64
Collapse	6	1.20

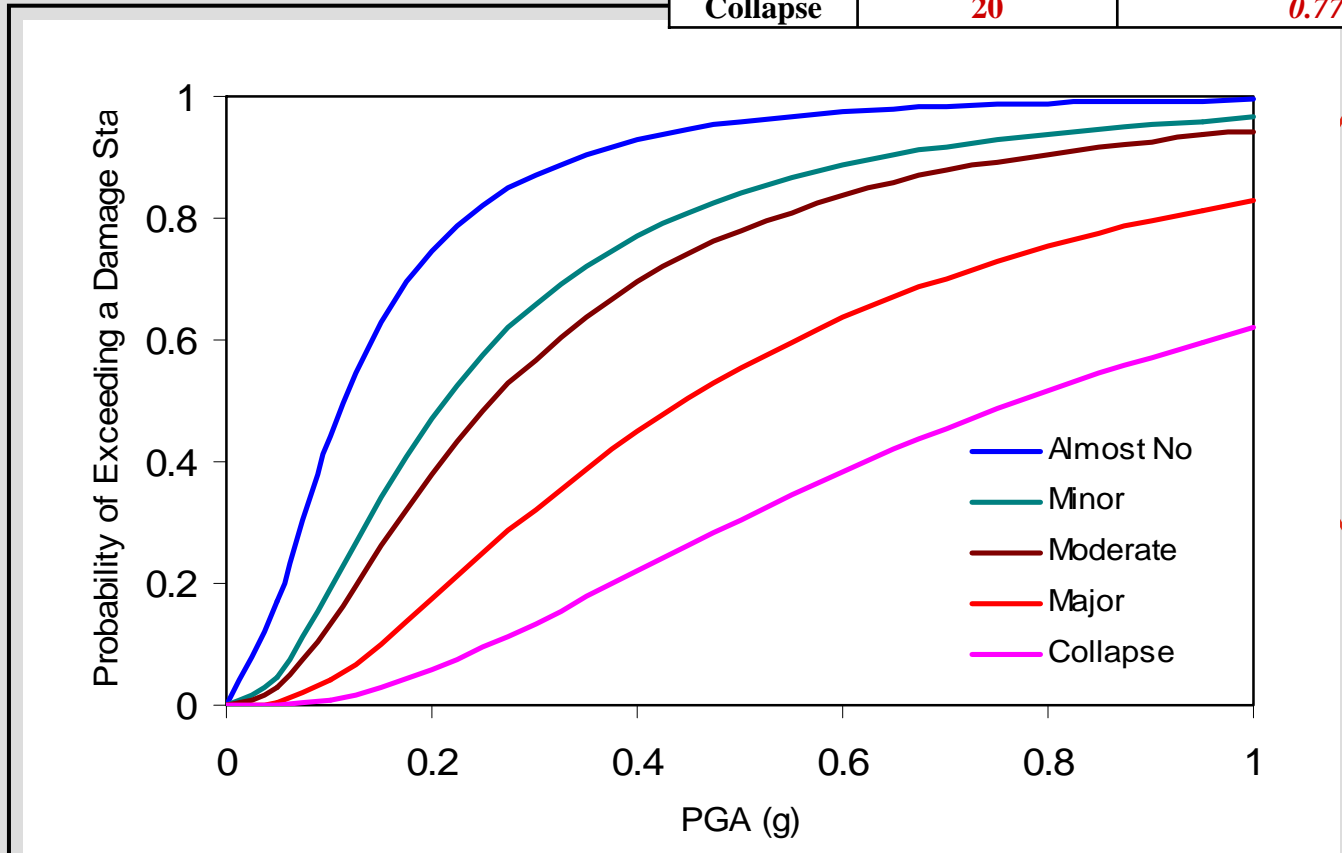
Lateral Stiffness at Abutments: 7287 kN/m



Fragility Curves for One Component of Ground Motion acting at angle 30^0

Damage States	Damaged Bridges (Sample Size 60)	Required PGA for 50% Failure Probability (PGA)
Almost No	59	0.11
Minor	54	0.21
Moderate	49	0.26
Major	39	0.45
Collapse	20	0.77

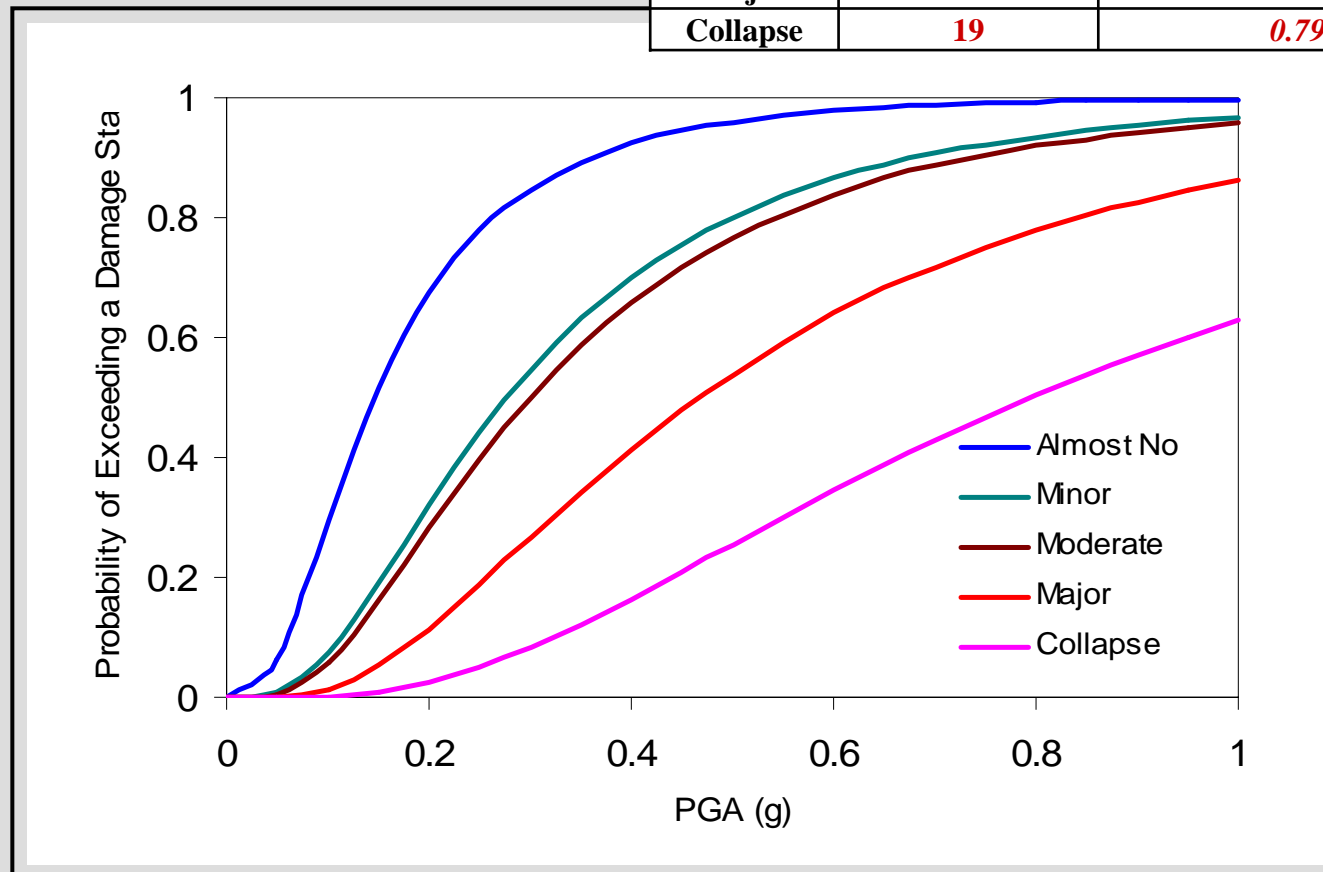
Lateral Stiffness at Abutments: 7287 kN/m



Fragility Curves for One Component of Ground Motion acting at angle 60°

Damage States	Damaged Bridges (Sample Size 60)	Required PGA for 50% Failure Probability (PGA)
Almost No	57	0.15
Minor	51	0.28
Moderate	48	0.30
Major	38	0.47
Collapse	19	0.79

Lateral Stiffness at Abutments: 7287 kN/m



Comparative Study (Moderate Damage)

Lateral Stiffness at Abutments: 7287 kN/m

