BRIDGE RESPONSE TO NEAR-FIELD GROUND MOTIONS

Genda Chen*, Ph.D., P.E., and Mostafa El-Engebawy, Ph.D.
*Associate Professor of Civil Engineering
Department of Civil, Architecture and Environmental Engineering
University of Missouri-Rolla
gchen@umr.edu

Geotechnical and Bridge Seismic Design Workshop
New Madrid Seismic Zone Experience
October 28-29, 2004

NATURAL HAZARDS MITIGATION INSTITUTE

Bri. Resp. - 1

UMR

Participants

Genda Chen, Ph.D., P.E. (Team Leader)
Mostafa El-Engebawy, Ph.D.
Ronaldo Luna, Ph.D., P.E.
Richard Stephenson, Ph.D., P.E.
Wei Zheng, Ph.D. Graduate Student
Wenxig Liu, Ph.D. Graduate Student

NATURAL HAZARDS MITIGATION INSTITUTE

Bri. Resp. - 2

UMR

Outline of Presentation

- Objectives
- Description of Bridge Systems
- Foundation Model and Bridge Model
- Dynamic Characteristics of Selected Bridges
- Discussion of Results
  - Influence of Rupture Directivity
  - Influence of Vertical Acceleration
  - Influence of Liquefaction
  - Comparison with Far-Field Ground Motions
- Concluding Remarks
- Recommendations for including Near-Field Effects in Highway Bridge Design

NATURAL HAZARDS MITIGATION INSTITUTE

UMR UNIVERSITY OF MISSOURI-ROLLA

Objectives

- To evaluate the response of a multi-span simply supported bridge (L472) and a multi-span continuous bridge (A1466) to near-field ground motions from future earthquake scenarios in the NMSZ
- To compare the bridge response subjected to near-field ground motions simulated using the composite-source model with that of far-field motions of the point-source model
- To recommend a simple method for including near-field effects in highway bridge design

NATURAL HAZARDS MITIGATION INSTITUTE

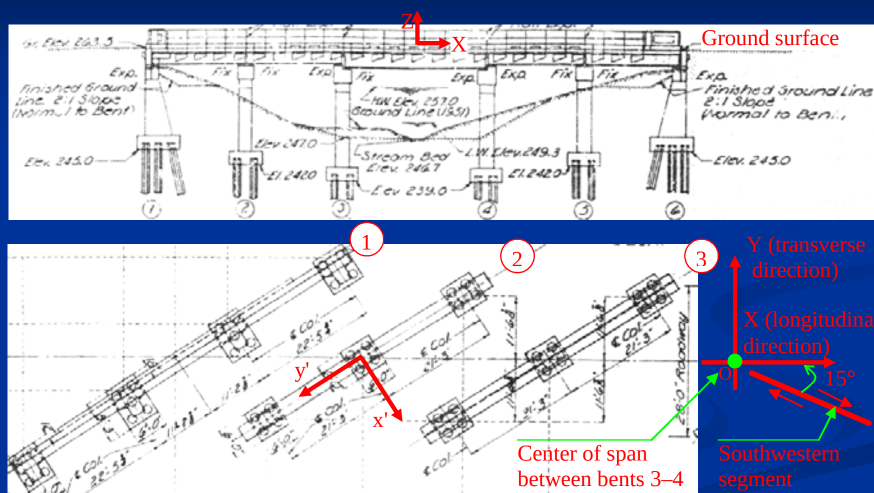
UMR UNIVERSITY OF MISSOURI-ROLLA

Description of L472 Bridge

- Located on interstate highway I55, Pemiscot County
  - Multi-span simply supported (MSSS) bridge – 5 spans
  - Designed according to the 1949 AASHO specifications without seismic considerations
  - 57° skew
  - Laterally-restrained steel plate girders
  - TYPE "C" fixed and expansion steel bearings
  - Supported by deep pile foundations

Description of L472 Bridge

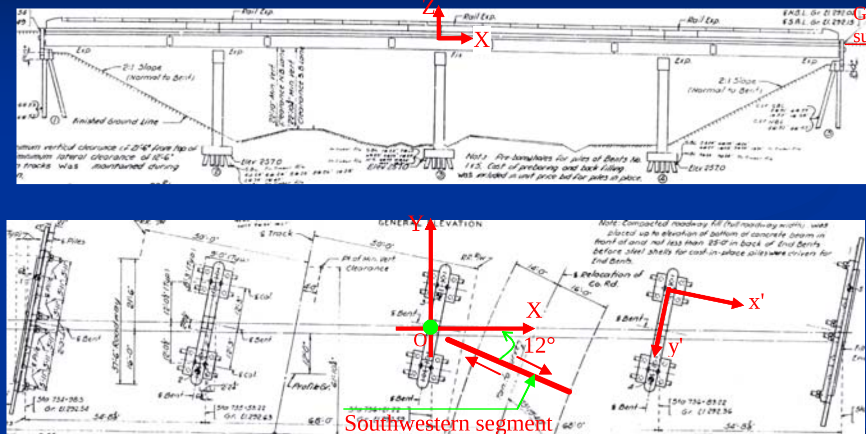
Description of L472 Bridge



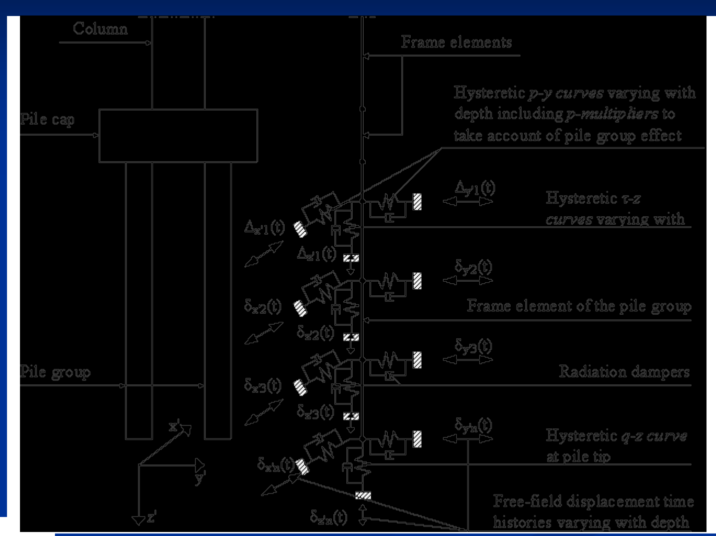
Description of A1466 Bridge

- Located on interstate highway I55, Pemiscot County
  - Multi-span continuous bridge – 4 spans
  - Designed according to the 1949 AASHO specifications without seismic considerations
  - 10º skew
  - Laterally-restrained steel plate girders
  - TYPE "D" fixed and expansion steel bearings
  - Supported by deep pile foundations

Description of A1466 Bridge



Foundation Model

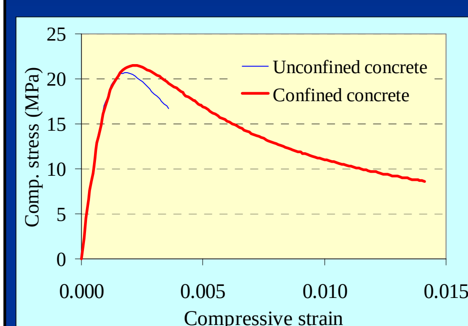


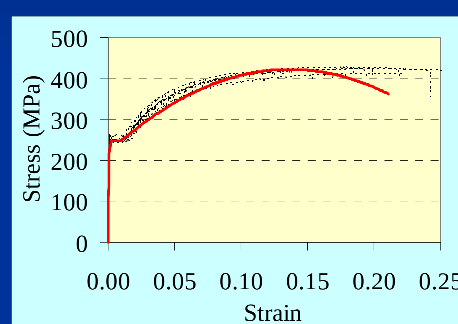
Bridge Model

- Initial stiffness of all RC elements to account for concrete cracking, confinement, reinforcement yielding, and expected level of axial forces
- Nonlinear elements to account for:
  - *Plastic zones at the top and bottom of columns*
  - *TYPE “C” and “D” expansion bearings*
  - *Pounding*

Bridge Model

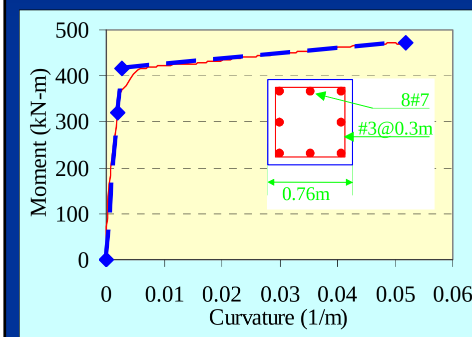
Stress-Strain Relations

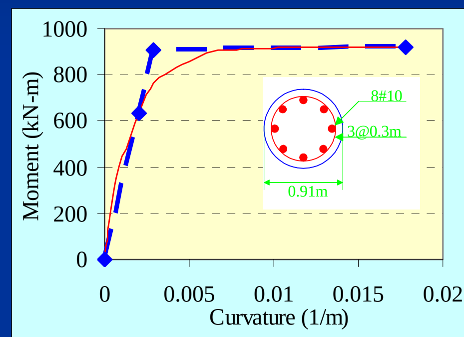




Bridge Model

Moment-Curvature Analysis





L472 Bridge Columns   A1466 Bridge Columns

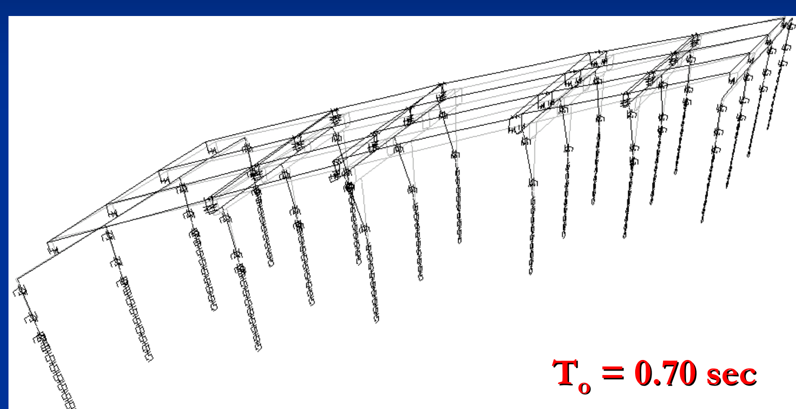
NATURAL HAZARDS MITIGATION INSTITUTE

Bri. Resp. - 13

UMR UNIVERSITY OF MISSOURI-ROLLA

Dynamic Characteristics

L472 Bridge – Fundamental mode of vibration



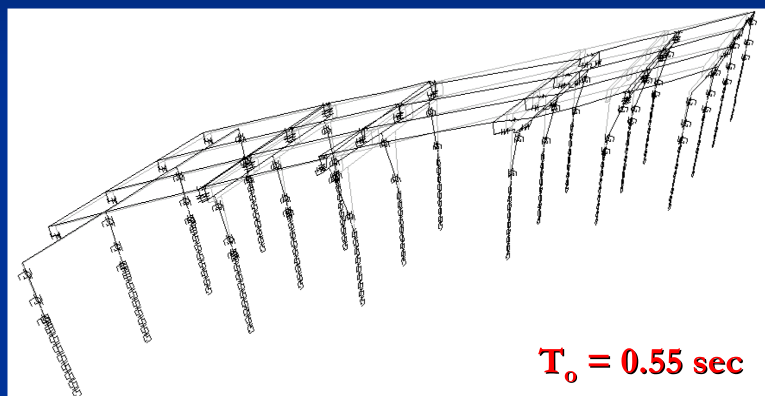
NATURAL HAZARDS MITIGATION INSTITUTE

Bri. Resp. - 14

UMR UNIVERSITY OF MISSOURI-ROLLA

Dynamic Characteristics

L472 Bridge – Second mode of vibration



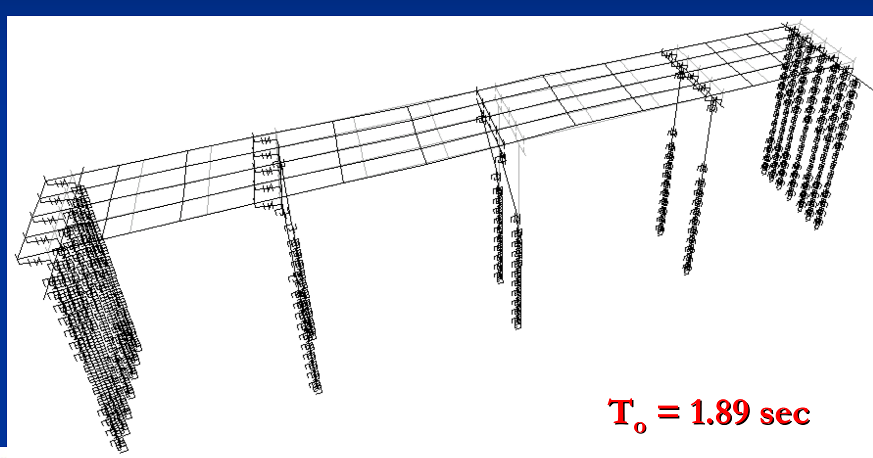
NATURAL HAZARDS MITIGATION INSTITUTE

Bri. Resp. - 15

UMR UNIVERSITY OF MISSOURI-ROLLA

Dynamic Characteristics

A1466 Bridge – Fundamental mode of vibration



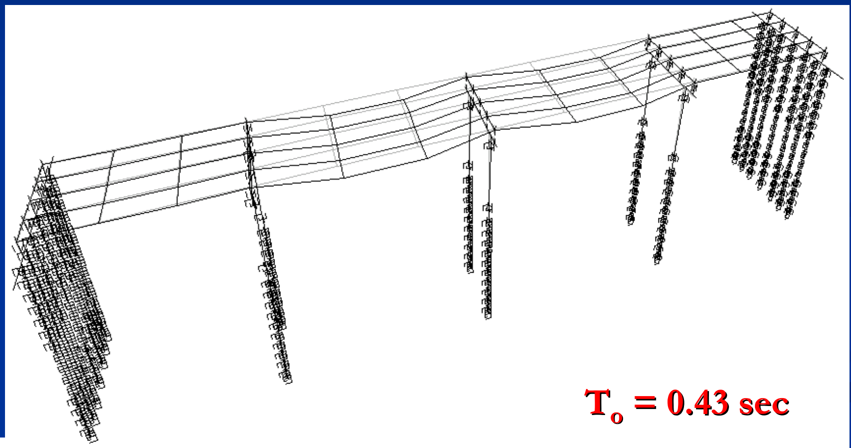
NATURAL HAZARDS MITIGATION INSTITUTE

Bri. Resp. - 16

UMR UNIVERSITY OF MISSOURI-ROLLA

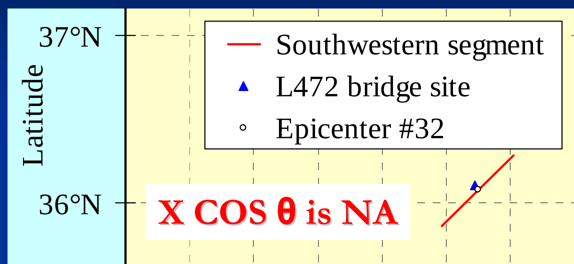
Dynamic Characteristics

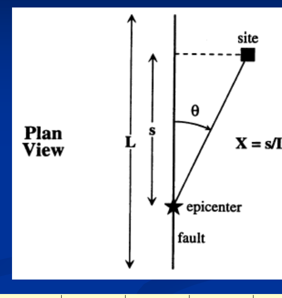
A1466 Bridge – Second mode of vibration



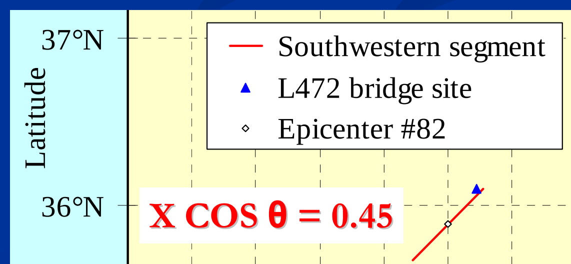
Discussion of Results

Influence of Rupture Directivity (L472)





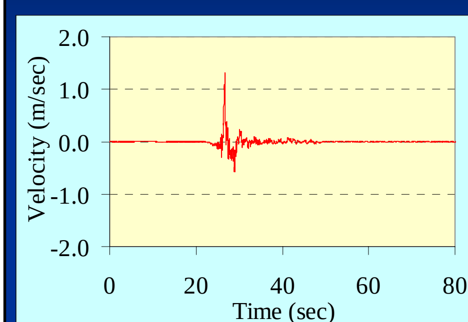
M_W 7.0



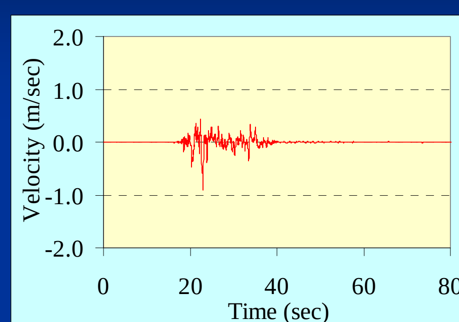
NATURAL HAZARDS MITIGATION INSTITUTE

UMR UNIVERSITY OF MISSOURI-ROLLA

Influence of Rupture Directivity (L472)



Sim #82 – FN rock motion with velocity pulses



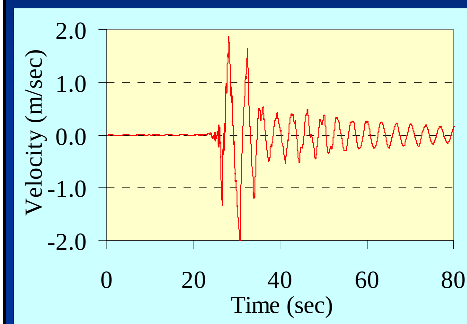
Sim #32 – FN rock motion without velocity pulses

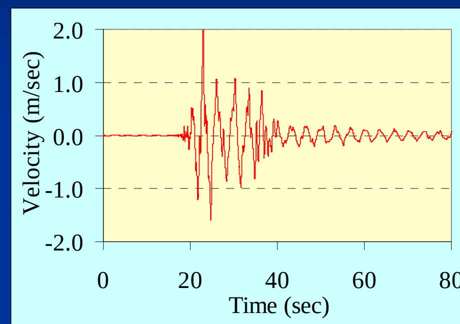
NATURAL HAZARDS MITIGATION INSTITUTE

Bri. Resp. - 20

UMR UNIVERSITY OF MISSOURI-ROLLA

Influence of Rupture Directivity (L472)

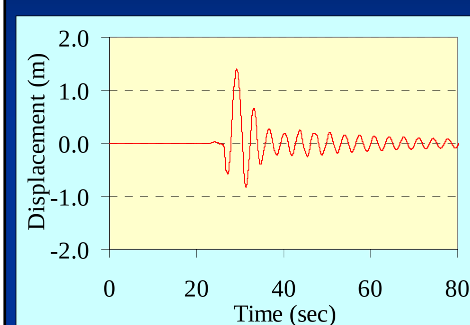


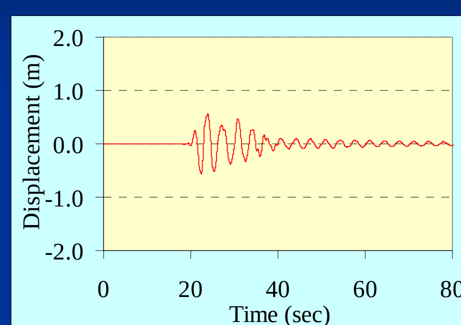


Sim #82 – FN ground motion with velocity pulses

Sim #32 – FN ground motion without velocity pulses

Influence of Rupture Directivity (L472)

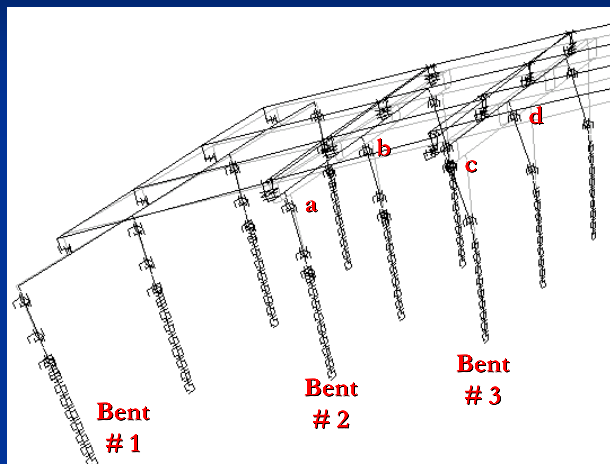




Sim #82 – FN ground motion with displacement pulses

Sim #32 – FN ground motion without displacement pulses

Influence of Rupture Directivity (L472)



Location	Sim #32	Sim #82
a	1.7	2.3
b	2.3	2.8
c	2.5	2.7
d	3.1	3.2

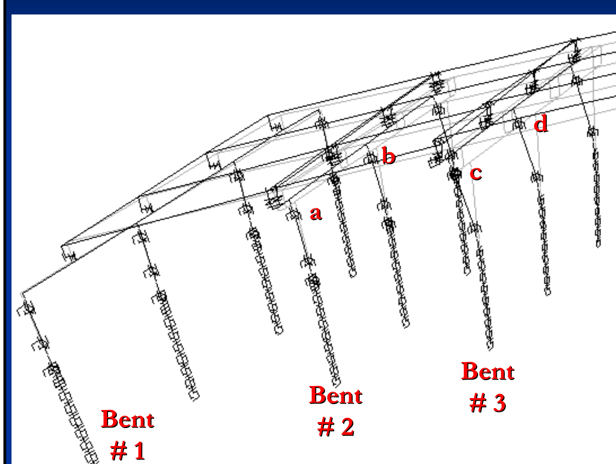
In-plane curvature ductility

M_W 7.0

NATURAL HAZARDS MITIGATION INSTITUTE

UMR UNIVERSITY OF MISSOURI-ROLLA

Influence of Vertical Acceleration (L472)



Location	with V	without V
a	-1386	-1006
b	-1679	-796
c	-1741	-1279
d	-1662	-897

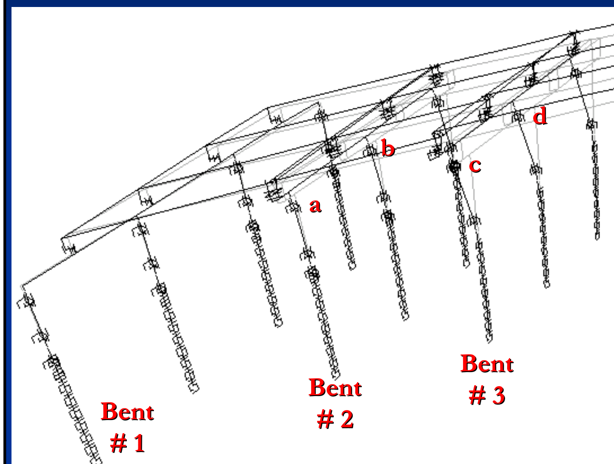
Compressive force

M_W 7.5

NATURAL HAZARDS MITIGATION INSTITUTE

UMR UNIVERSITY OF MISSOURI-ROLLA

Influence of Vertical Acceleration (L472)



Location	with V	without V
a	4.2	5.3
b	5.6	6.5
c	6.7	8.1
d	8.1	9.4

In-plane curvature ductility

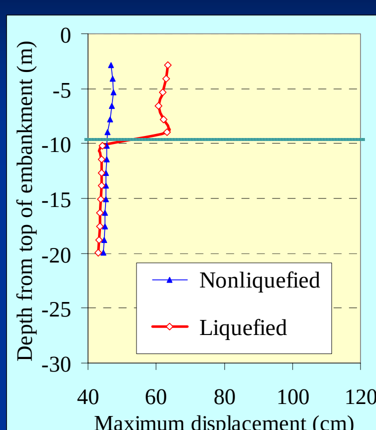
M_W 7.5

NATURAL HAZARDS MITIGATION INSTITUTE

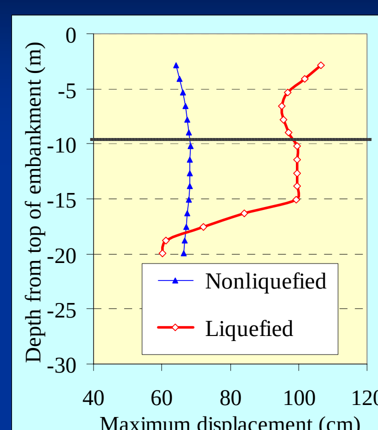
Bri. Resp. - 25

UMR UNIVERSITY OF MISSOURI-ROLLA

Influence of Liquefaction (A1466)



Maximum FP displacements



Maximum FN displacements

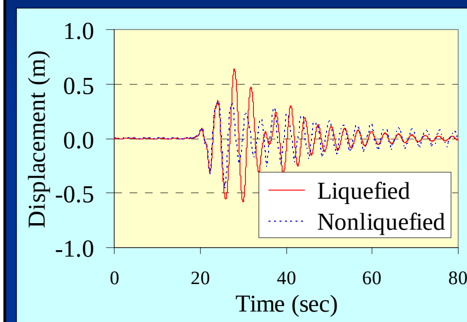
M_W 7.0 – Sim #12

NATURAL HAZARDS MITIGATION INSTITUTE

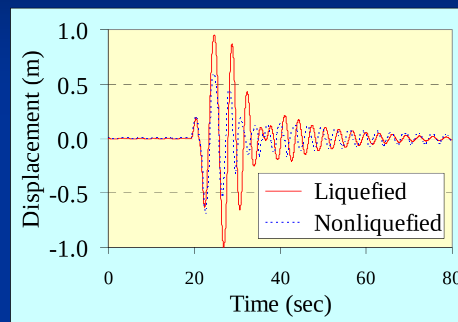
Bri. Resp. - 26

UMR UNIVERSITY OF MISSOURI-ROLLA

Influence of Liquefaction (A1466)



FP at bottom of embankment



FN at bottom of embankment

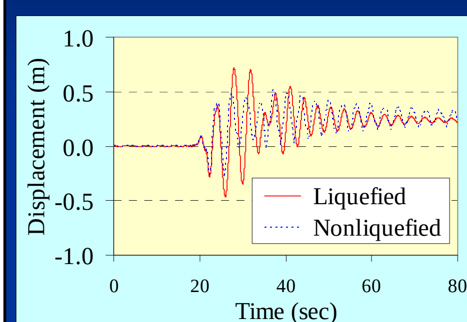
M_W 7.0 – Sim #12

NATURAL HAZARDS MITIGATION INSTITUTE

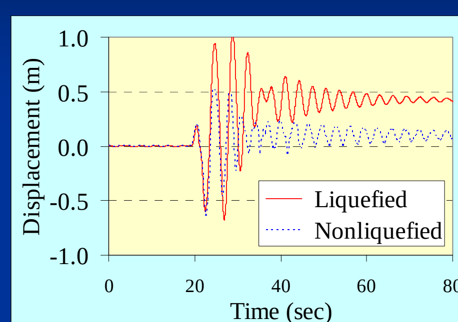
Bri. Resp. - 27

UMR UNIVERSITY OF MISSOURI-ROLLA

Influence of Liquefaction (A1466)



FP at top of embankment



FN at top of embankment

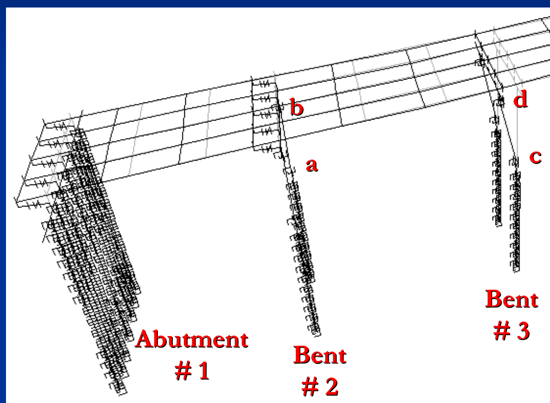
M_W 7.0 – Sim #12

NATURAL HAZARDS MITIGATION INSTITUTE

Bri. Resp. - 28

UMR UNIVERSITY OF MISSOURI-ROLLA

Influence of Liquefaction (A1466)



Location	with LIQ	without LIQ
a	31.6	6.3
b	20.2	6.1
c	31.0	6.4
d	18.9	6.3

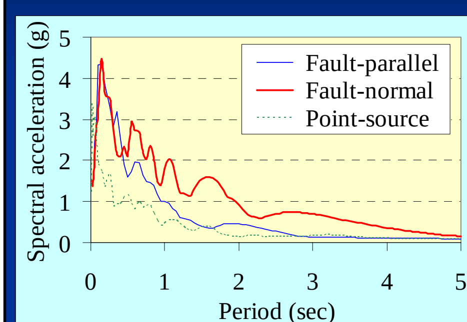
In-plane curvature ductility

M_W 7.0 – Sim #12

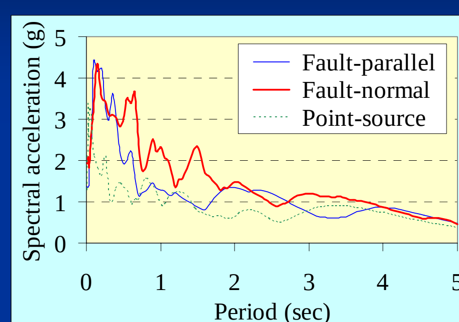
NATURAL HAZARDS MITIGATION INSTITUTE

UMR UNIVERSITY OF MISSOURI-ROLLA

Comparison with Far-Field Motions



Rock motions



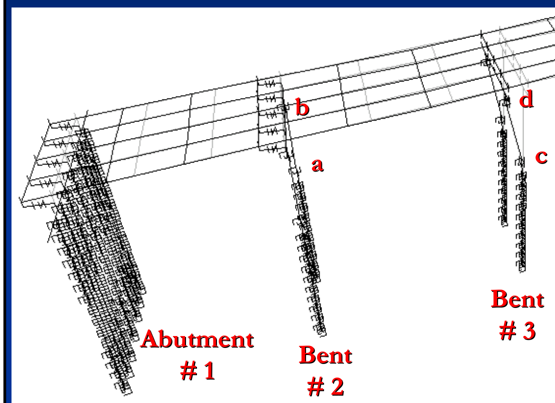
Ground motions

M_W 7.5 – L472

NATURAL HAZARDS MITIGATION INSTITUTE

UMR UNIVERSITY OF MISSOURI-ROLLA

Comparison with Far-Field Motions



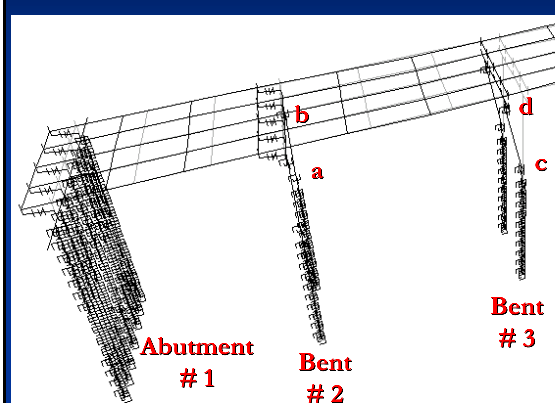
Location	Composite-source	Point-source
a	4.4	1.6
b	5.2	1.9
c	5.9	1.8
d	6.7	2.3

In-plane curvature ductility

Motions applied along the longitudinal axis of the bridge

M_W 7.5 – L472

Comparison with Far-Field Motions



Location	Composite-source	Point-source
a	2.7	1.0
b	3.2	1.1
c	4.0	1.1
d	4.5	1.3

In-plane curvature ductility

Motions applied along the transverse axis of the bridge

M_W 7.5 – L472

Recommendations for including Near-Field Effects in Highway Bridge Design

Based on Abrahamson's model (2000) and Somerville et al. (1997)

NATURAL HAZARDS MITIGATION INSTITUTE

UMR UNIVERSITY OF MISSOURI-ROLLA

Directivity model

STEP I

Scale factor for the average horizontal component AvH
(after Abrahamson, 2000)

$\ln[Dir(X, \theta, T)] = C1(T) + 1.88\ C2(T)\ X\cos\theta \qquad X\cos\theta \leq 0.4$
$\ln[Dir(X, \theta, T)] = C1(T) + 0.75\ C2(T) \qquad X\cos\theta > 0.4$

STEP II

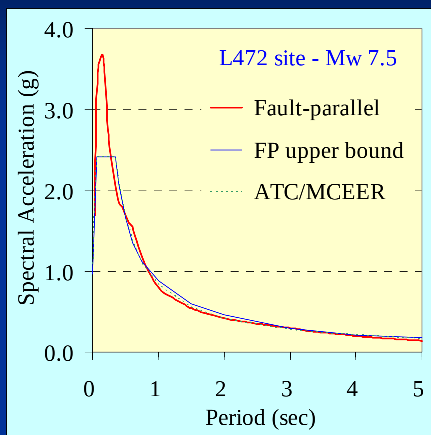
Difference between FN and FP components of motion
(after Somerville et al., 1997)

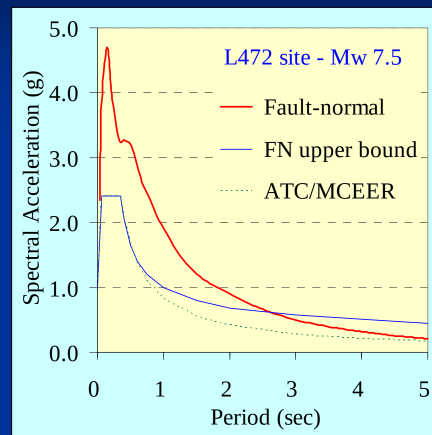
$\ln(FN/AvH) = \cos(2\theta)\ [C3(T) + C4(T)\ \ln(r_{rup}+1) + C5(M_W-6)] \qquad \theta < 45°$
$\ln(FN/AvH) = 0 \qquad \theta \geq 45°$
$\ln(FP/AvH) = -\ln(FN/AvH)$

NATURAL HAZARDS MITIGATION INSTITUTE

UMR UNIVERSITY OF MISSOURI-ROLLA

Upper bound of Directivity Conditions





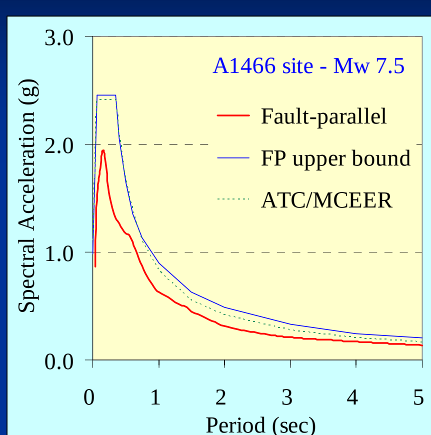
Assuming XCosθ=0.40 then θ=4.4° for L472 bridge (3.7 km from fault)

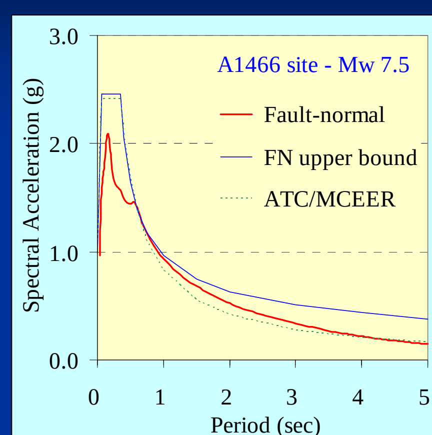
Natural Hazards Mitigation Institute

Bri. Resp. - 35

UMR University of Missouri-Rolla

Upper bound of Directivity Conditions





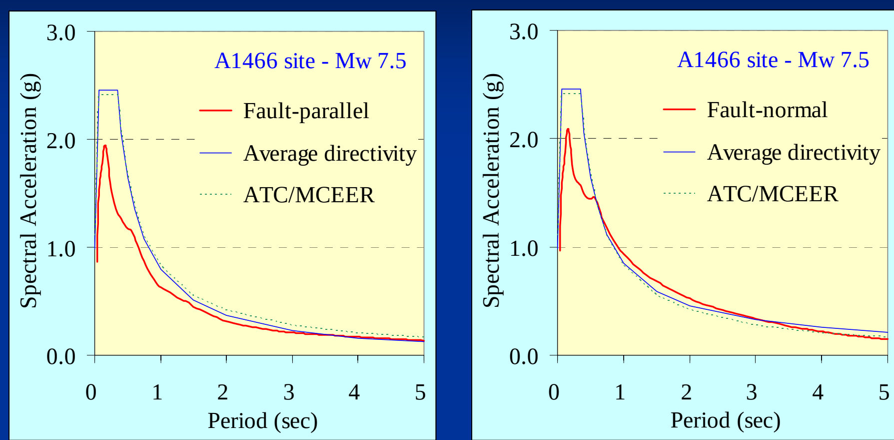
Assuming XCosθ=0.40 then θ=12.5° for A1466 bridge (10.9 km from fault)

Natural Hazards Mitigation Institute

Bri. Resp. - 36

UMR University of Missouri-Rolla

Average Directivity Conditions



Assuming the epicenter at the middle of the fault then XCosθ=0.24 and θ=19.5° for A1466 bridge (10.9 km from fault)

NATURAL HAZARDS MITIGATION INSTITUTE

UMR UNIVERSITY OF MISSOURI-ROLLA

Concluding Remarks

- The curvature ductility ratio of columns increase significantly with the moment magnitude. Forward rupture directivity and liquefaction effects are the dominant reasons for the high ratios
- The vertical acceleration increases the compressive forces in the columns under the maximum considered earthquake. They are remarkably reduced with lower moment magnitudes
- Liquefaction yields large displacements in the fault-normal direction and permanent offset of the soil near the top of the embankment that develop extreme large deformations in the plane of the bridge bents leading to large in-plane curvature ductility ratios of the columns

NATURAL HAZARDS MITIGATION INSTITUTE

UMR UNIVERSITY OF MISSOURI-ROLLA

Recommendations

- A site-specific rock and ground motion simulations are recommended for highway bridges within 10 km from active faults in the NMSZ. The resulting rock motions should include forward rupture directivity while fling step is not likely to occur in future earthquake events
- For highway bridges located beyond 10 km, a simple methodology is recommended for considering near-field effects in their design response spectra based on the average directivity conditions at the site and the directivity models of Abrahamson (2000) and Somerville et al. (1997)