Performance-based Evaluation of the Seismic Response of Bridges with Foundations Designed to Uplift

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Acknowledgments

Pacific Earthquake Engineering Research (PEER) Center for funding this work through the Transportation Research Program

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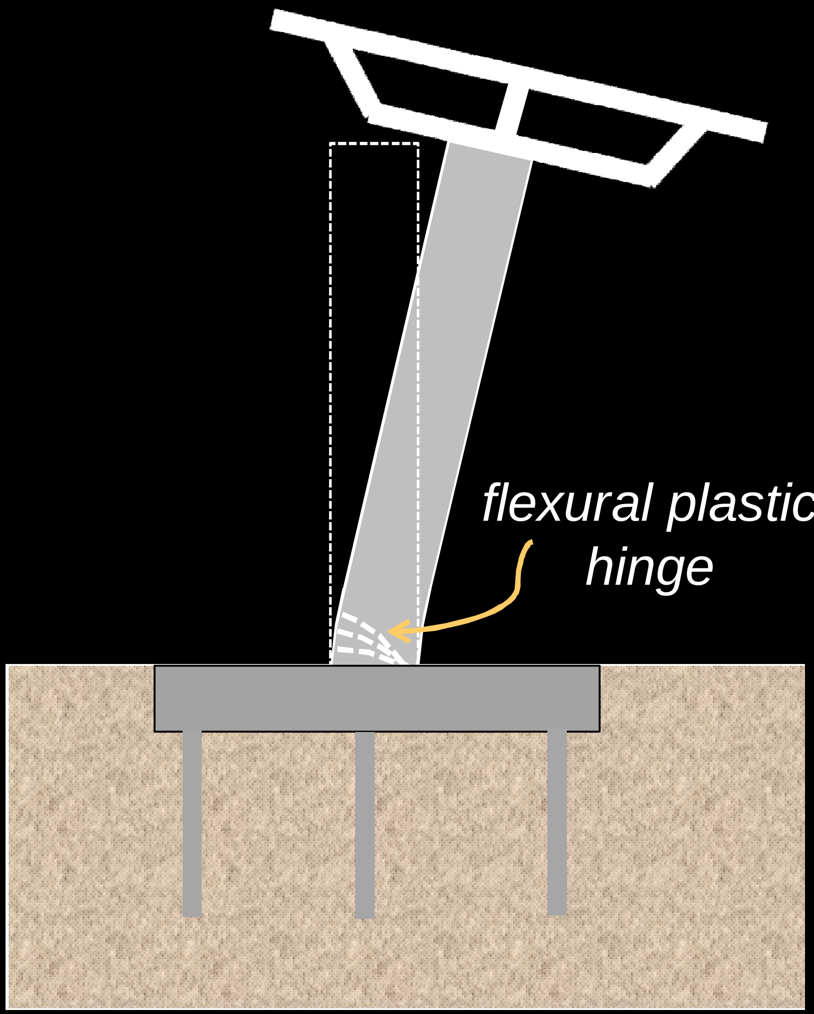
3 Questions

1. ***Can foundation rocking be considered as an alternative seismic design method of bridges resulting in reduced: i) post-earthquake damage, ii) required repairs, and iii) loss of function ?***

2. ***What are the ground motion characteristics that can lead to overturn of a pier supported on a rocking foundation?***

3. ***Probabilistic performance-based earthquake evaluation ?***

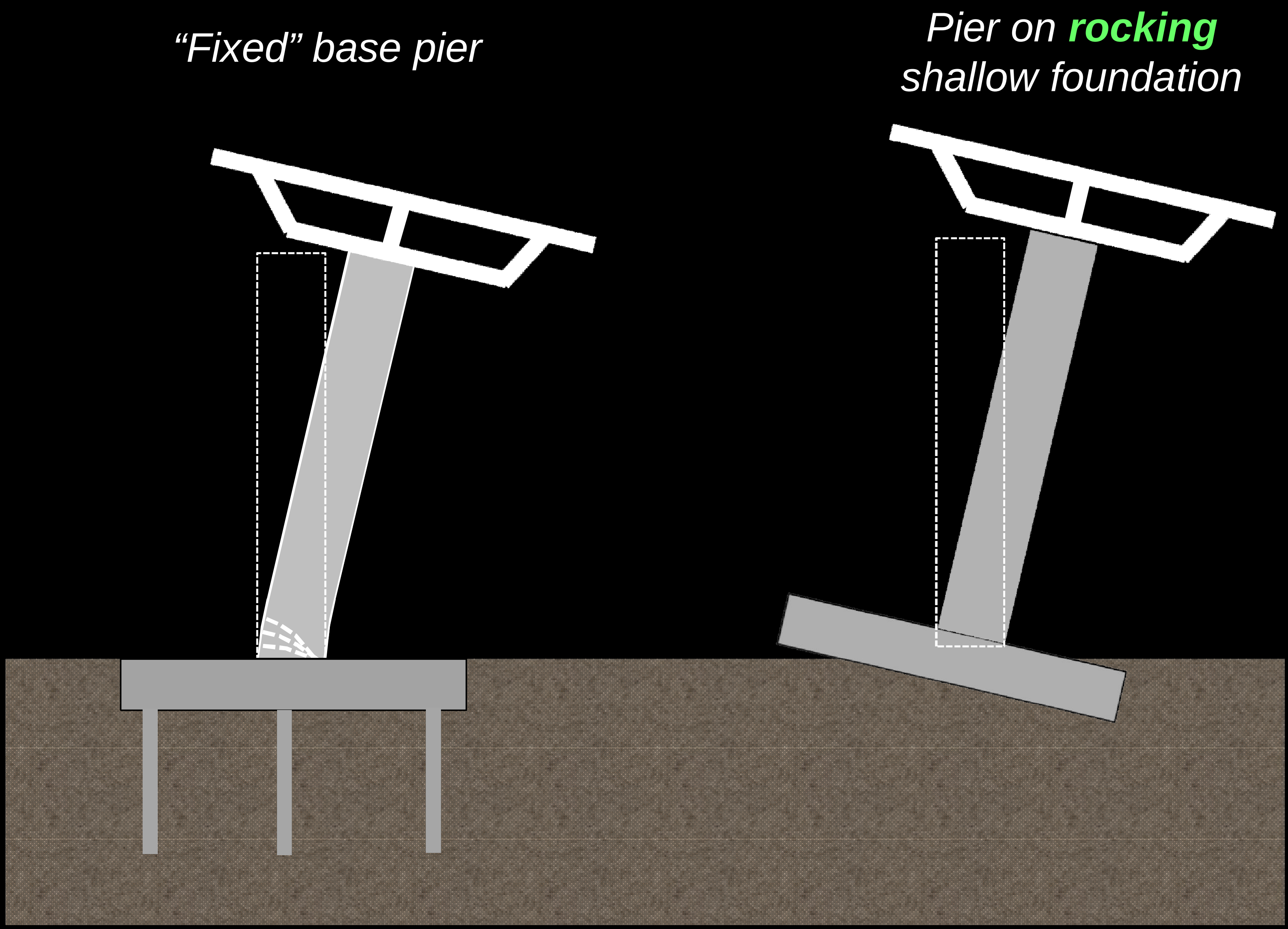
“Fixed” Base Design



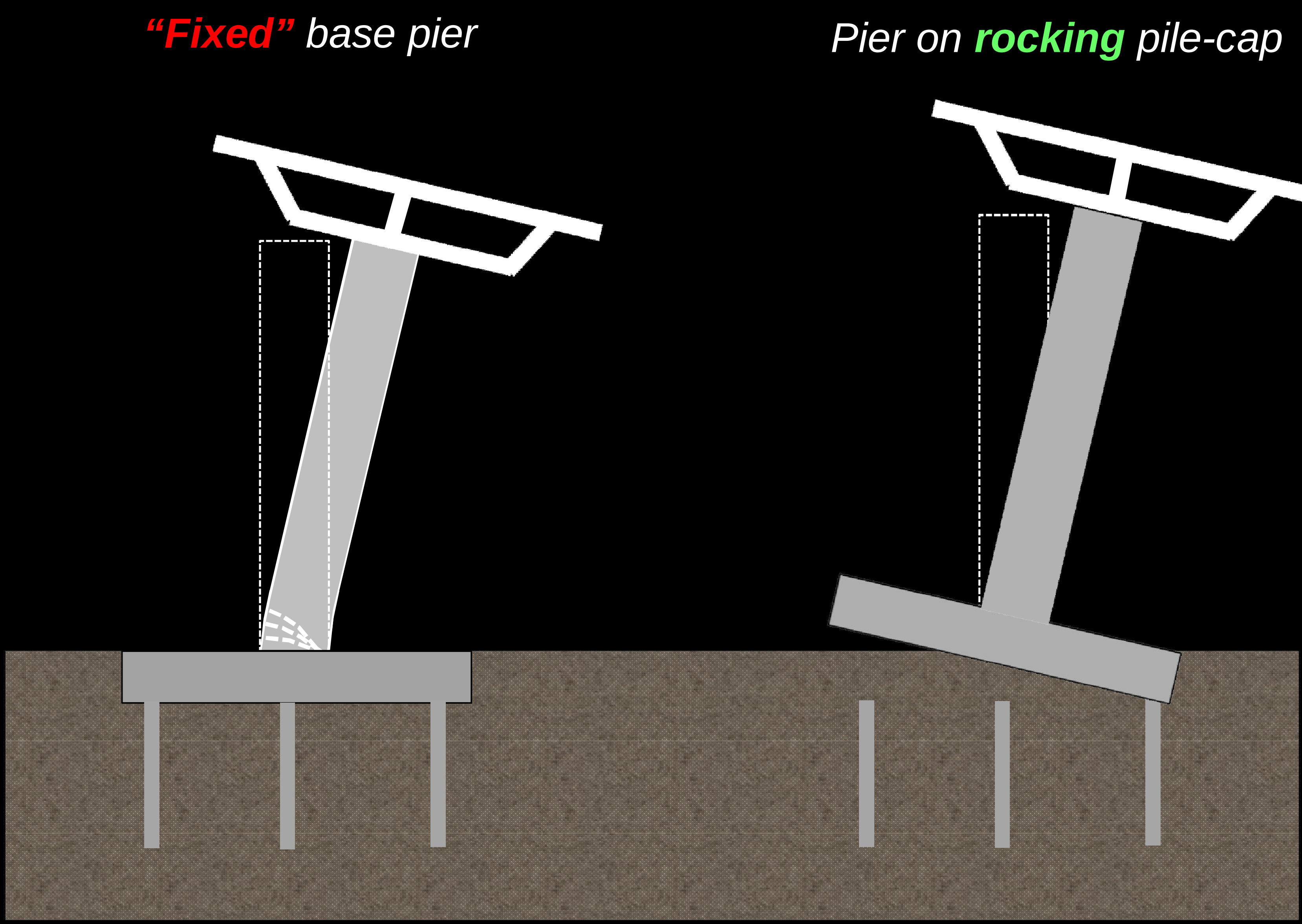
Susceptible to significant post-earthquake ***damage*** *and permanent lateral deformations that:*

- *Impair traffic flow*
- *Necessitate costly and time consuming repairs*

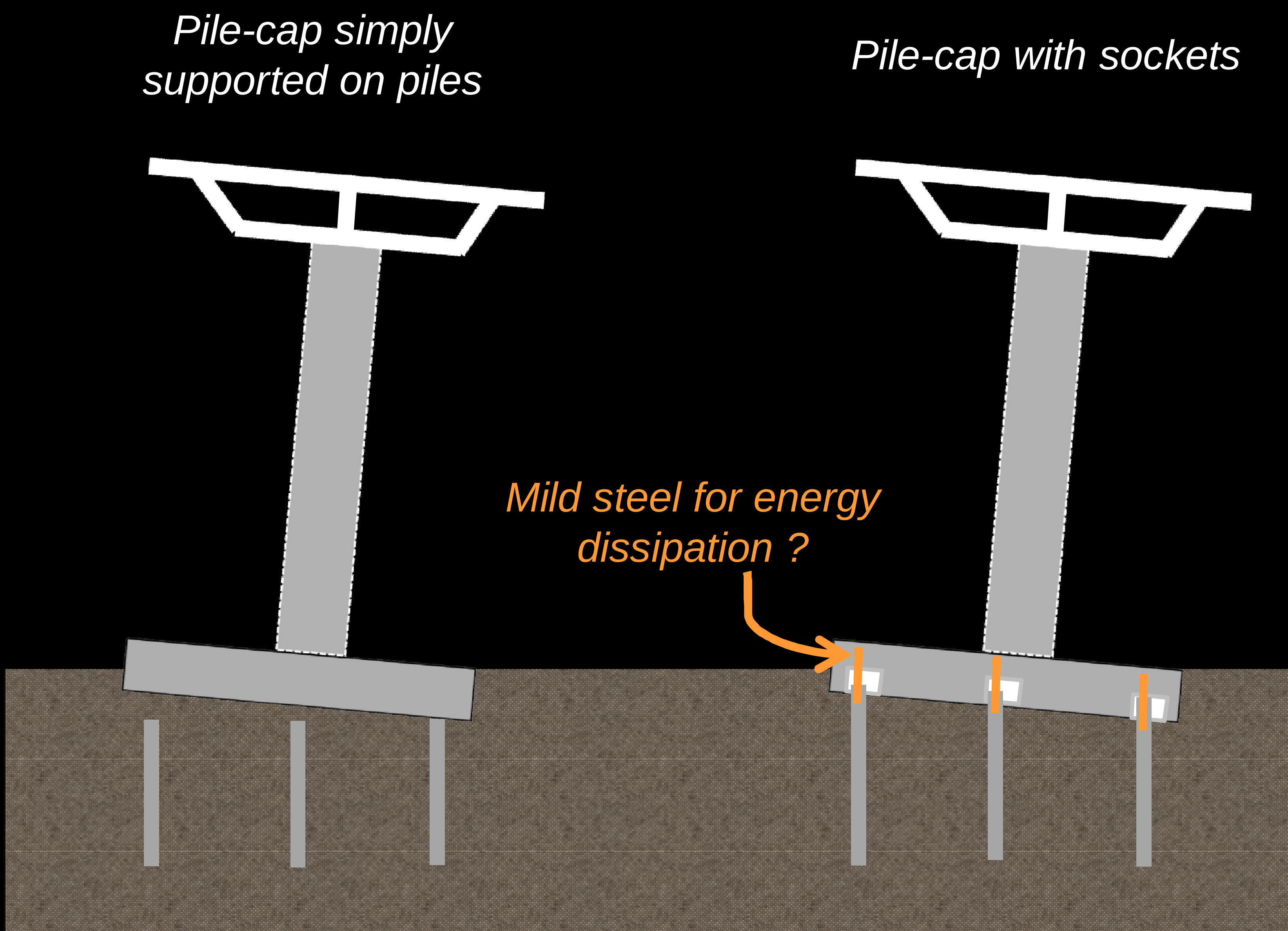
*Design Using **Rocking** Shallow Foundations*



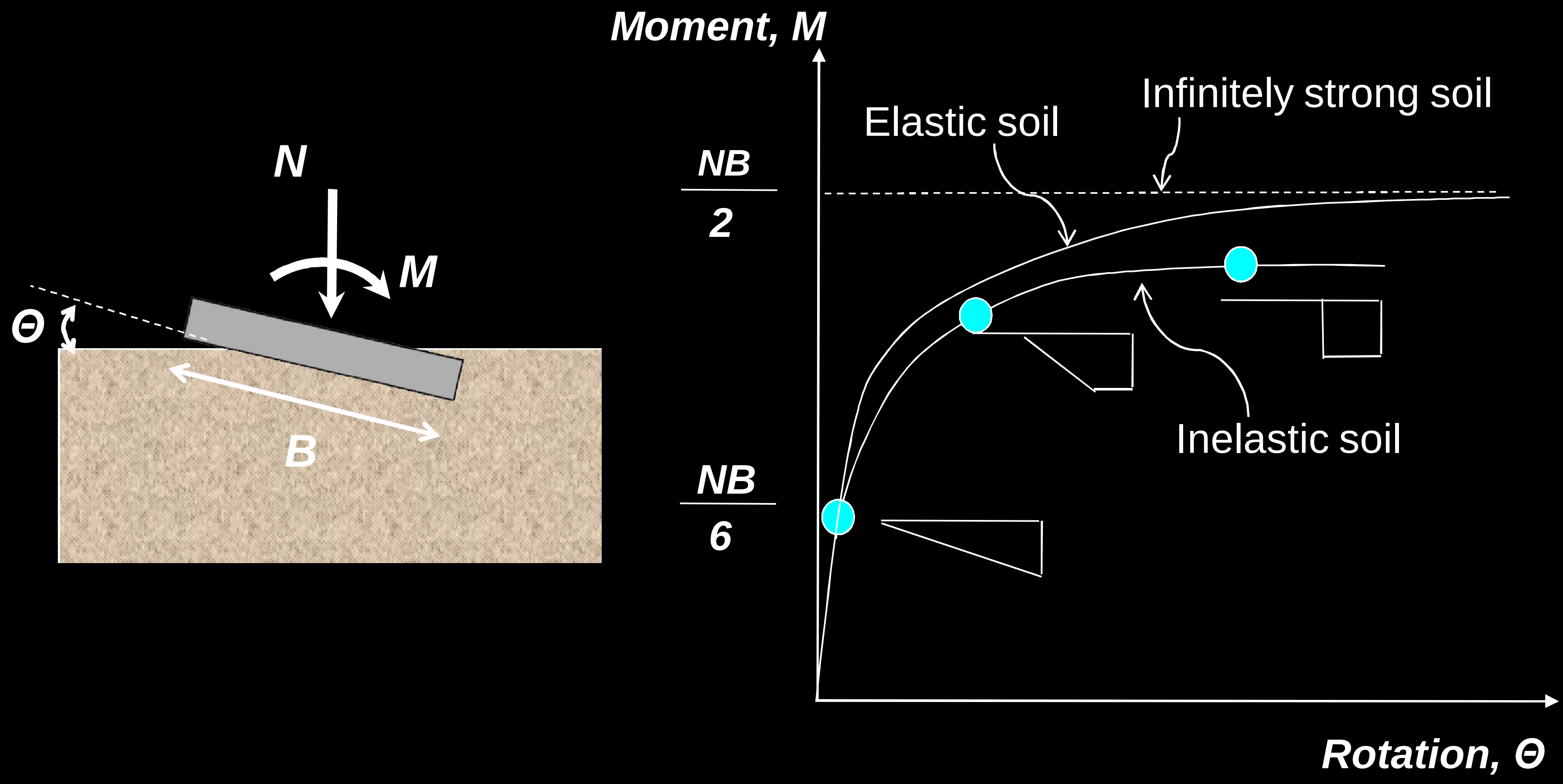
Design Using Rocking Pile Caps



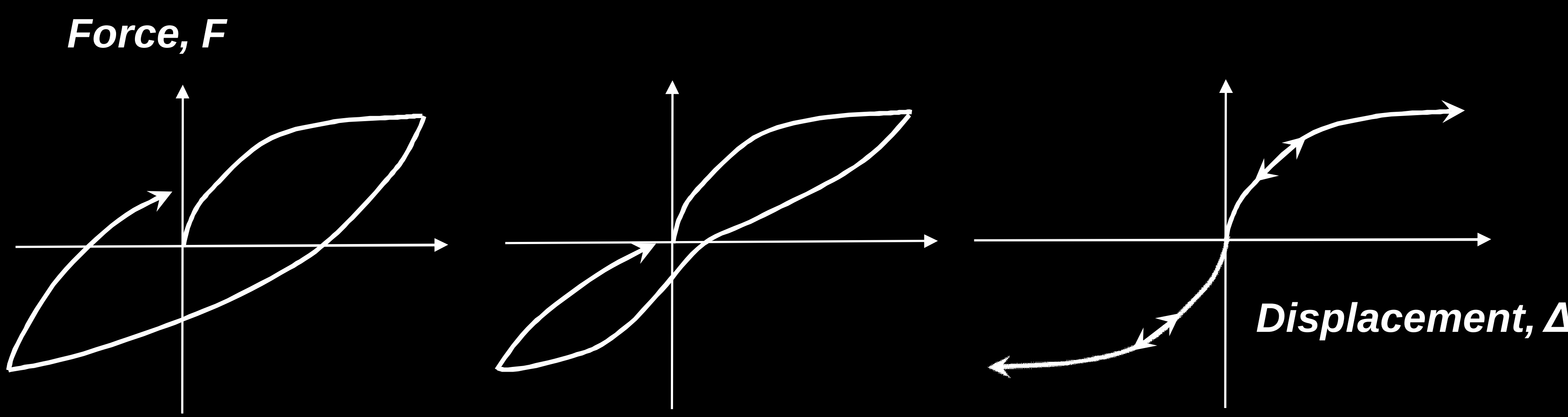
Design Using Rocking Pile-Caps



Rocking Foundations - Nonlinear Behavior



Nonlinear Behavior Characteristics



Fixed-base or

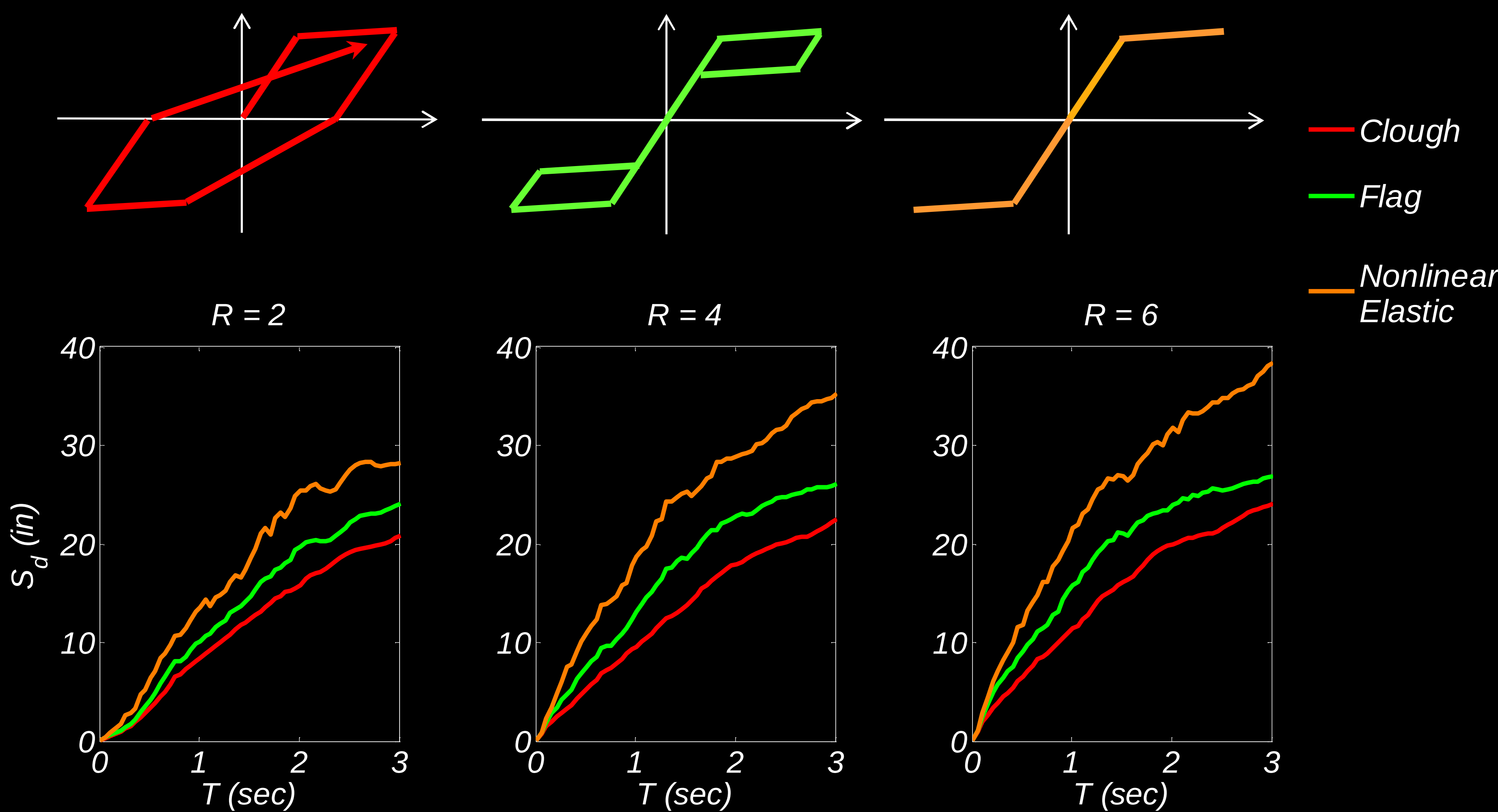
shallow foundation with extensive soil inelasticity

Shallow foundation with limited soil inelasticity

Rocking pile-cap or shallow foundation on elastic soil

SDOF Nonlinear Displacement Response

Mean results of 40 near-fault ground motions



Numerical Case Study of a Bridge

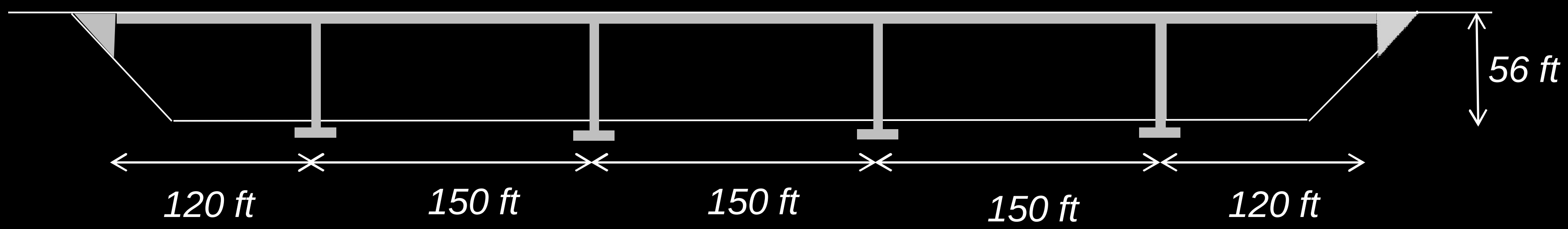
An archetype bridge is considered and is designed with:

i) fixed base piers

ii) with piers supported on rocking foundations

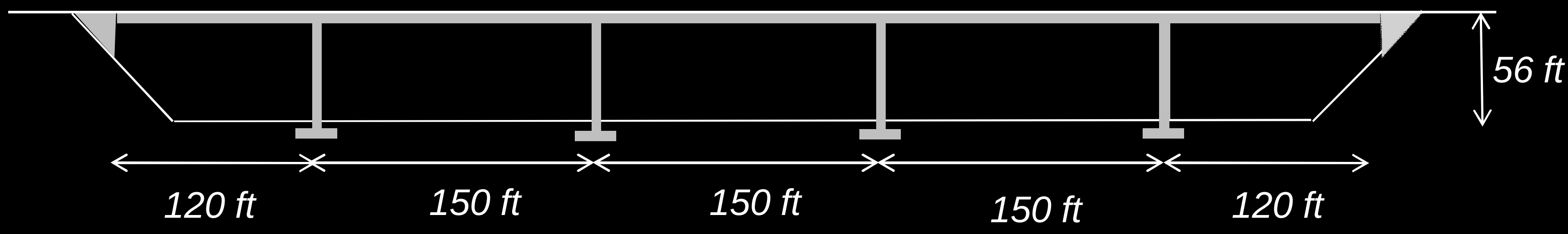
Analysis using 40 near-fault ground motions

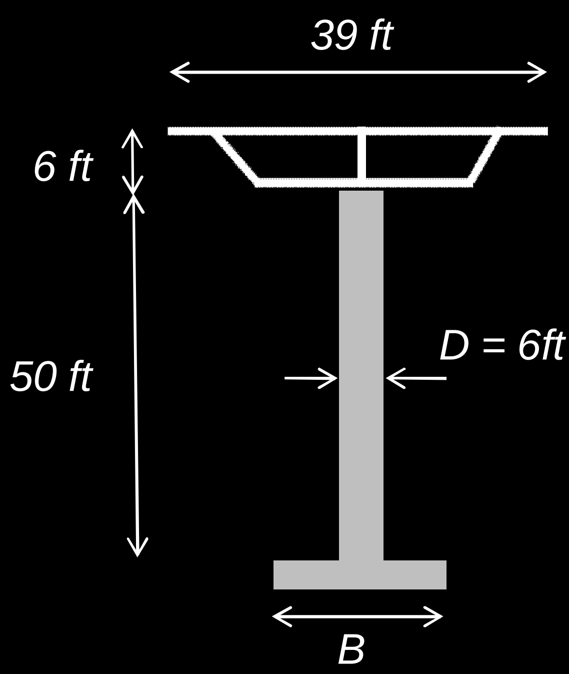
Archetype bridge considered – Tall Overpass



Computed Response of a Bridge System

Archetype bridge considered – Tall Overpass



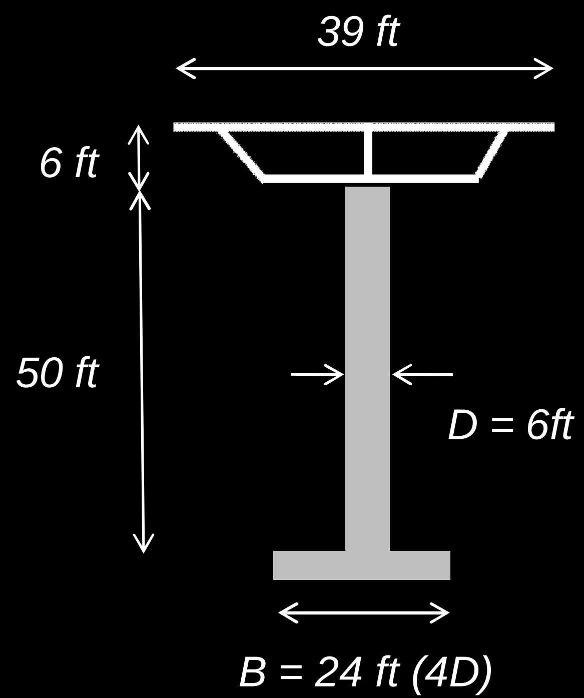


- 5 Spans
- Single column bents
- Cast in place box girder

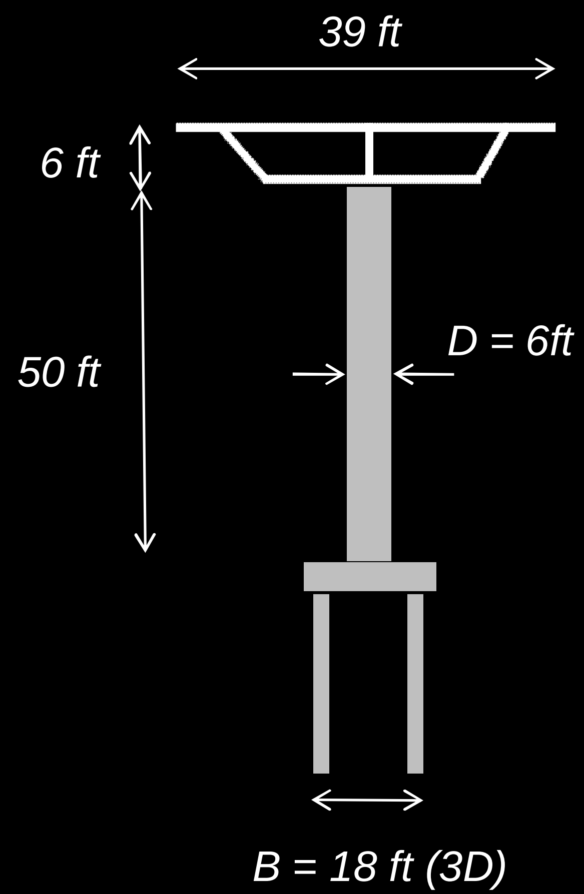
- Column axial load ratio $N / f_c' A_g = 0.1$
- Longitudinal steel ratio $\rho_l = 2\%$

Designs Using Rocking Foundations

Shallow foundation



Rocking Pile-Cap

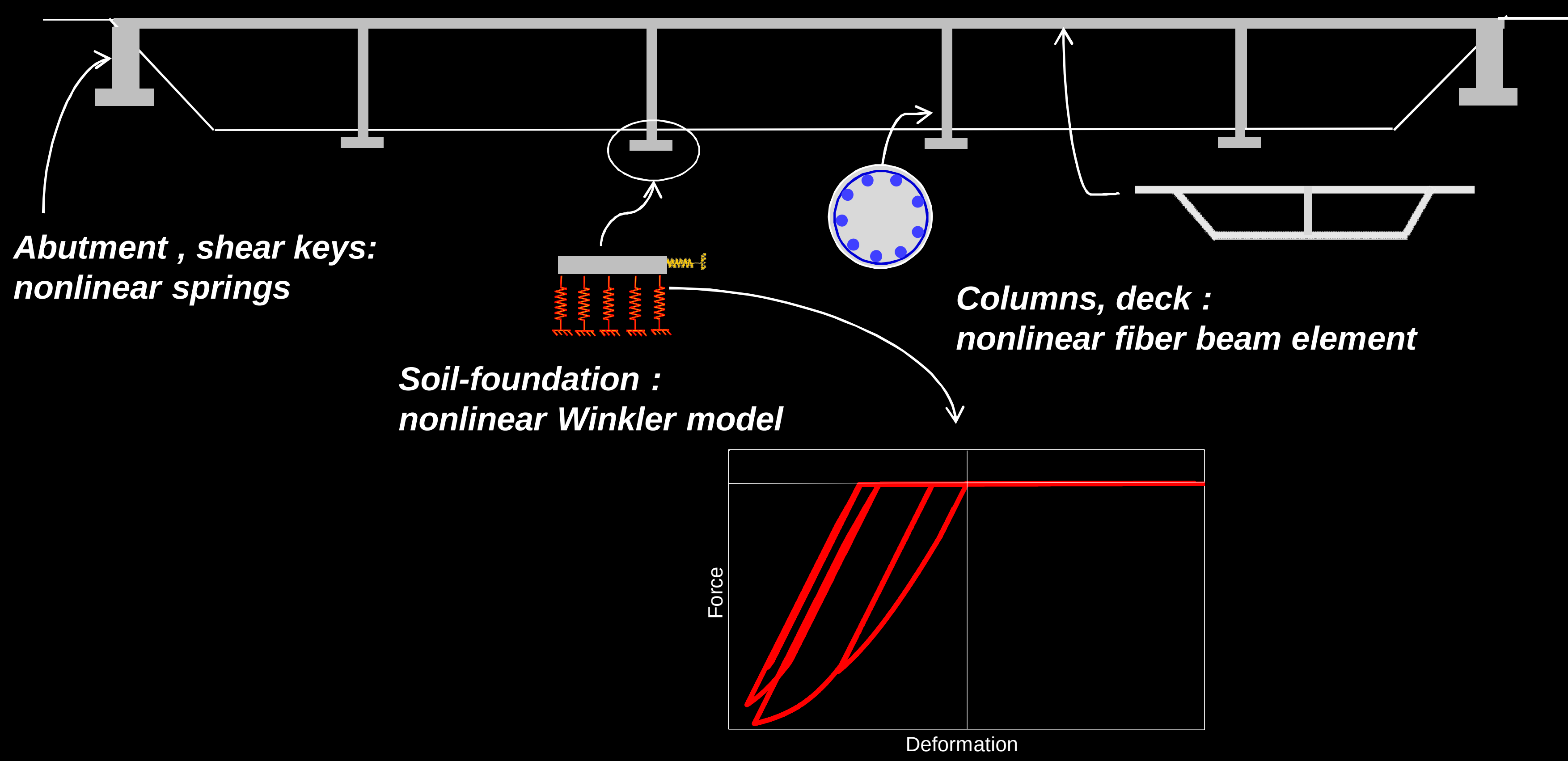


Soil ultimate stress $\sigma_u = 0.08$ *ksi*

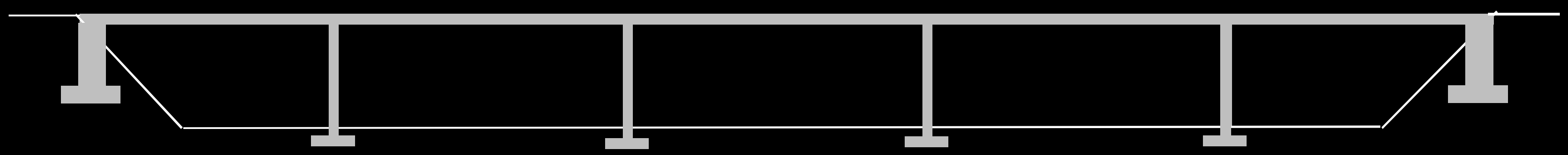
$FS_v = A\sigma_u / N = 5.4$

Modeling of Bridge

OPENSEES 3-dimensional model

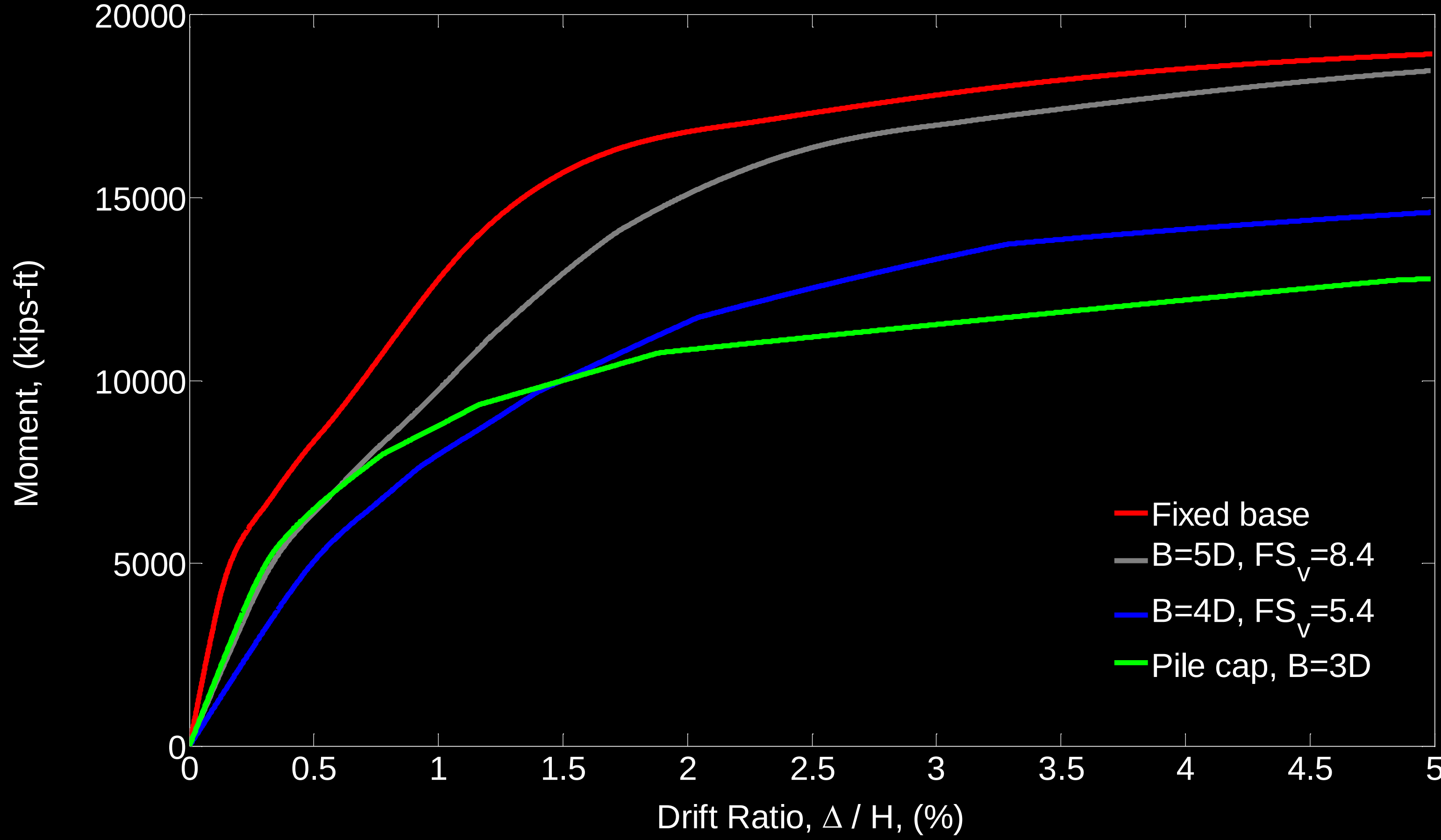


Bridge Model - Dynamic Characteristics

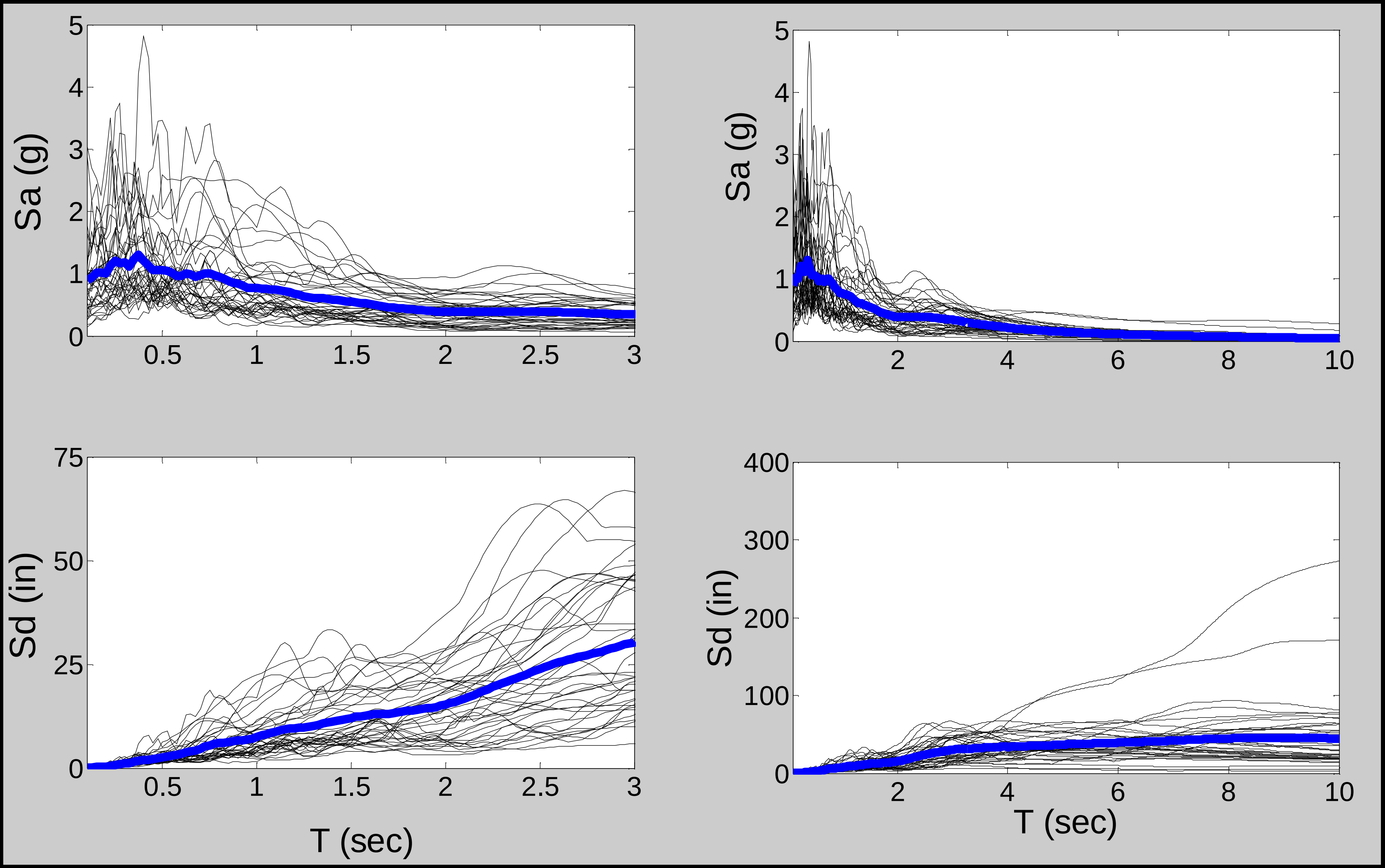


	Fixed - base	B = 4D	Rocking Pile Cap B=3D
1st mode, T1 (sec)	1.1	2.1	1.9
2nd mode, T2 (sec)	0.8	1.9	1.8

Monotonic Behavior – Individual Pier



Ground Motions Considered – Response Spectra , 2% Damping

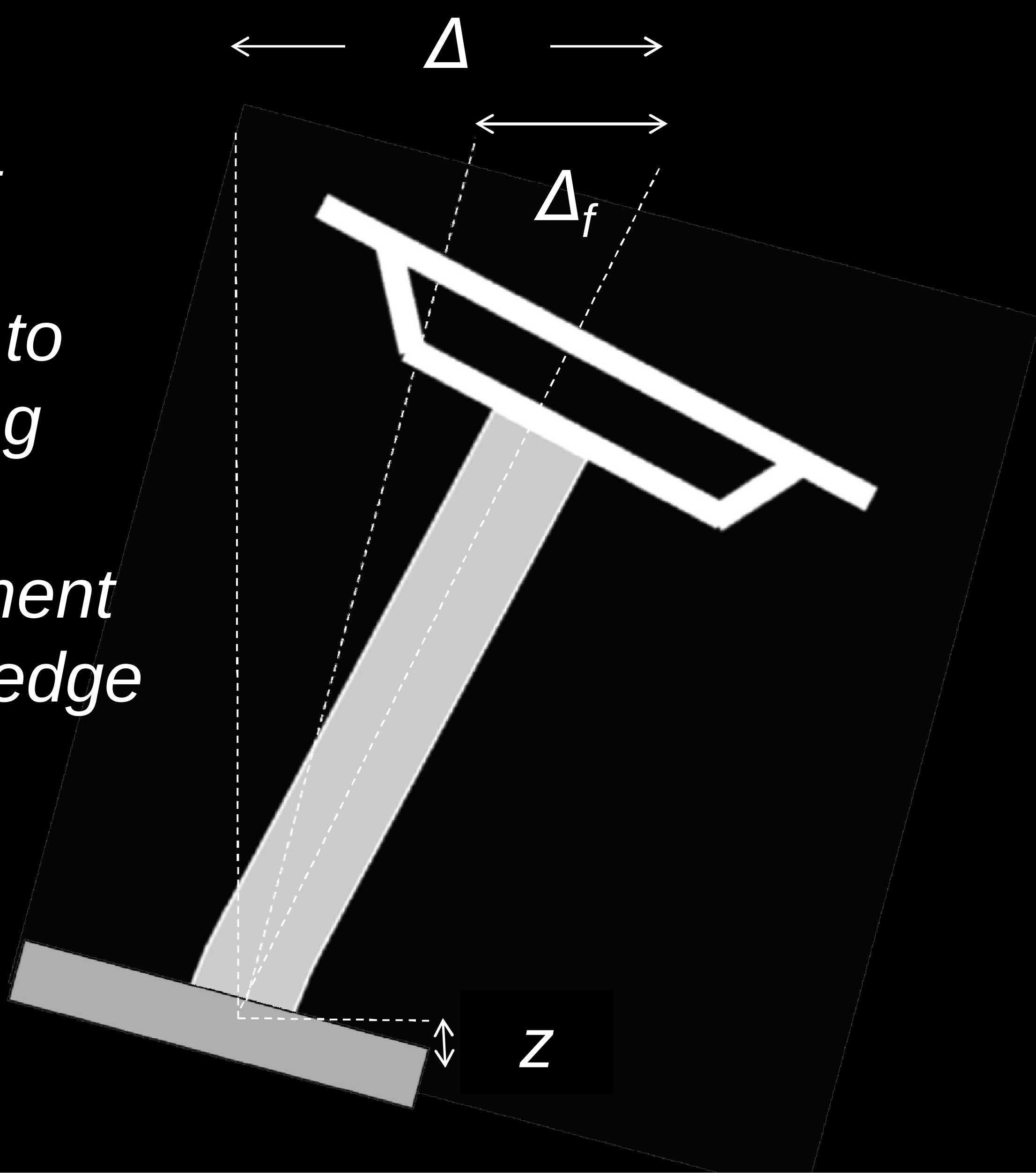


Computed Response of Bridge

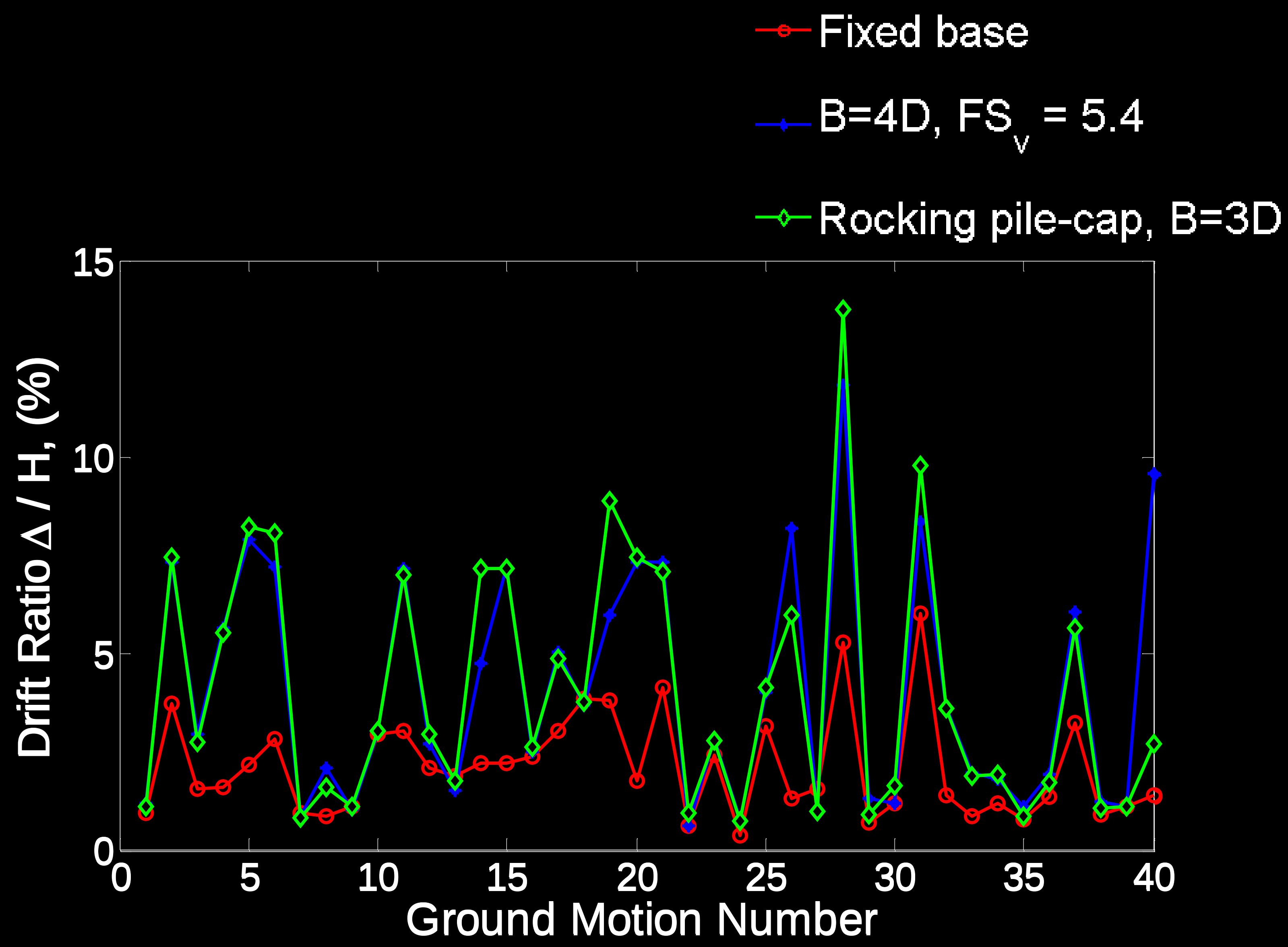
Δ: total drift

Δ_f: drift due to pier bending

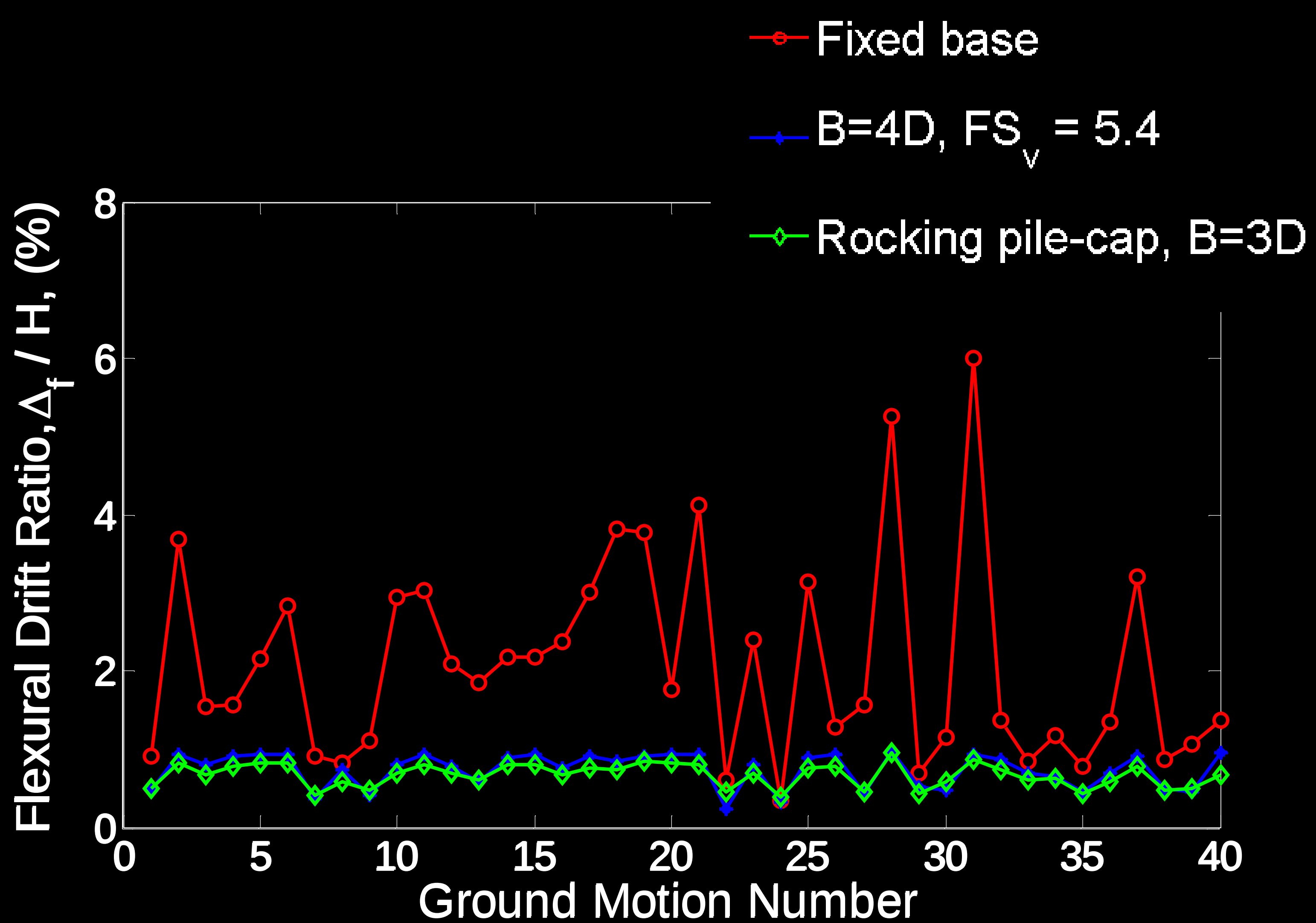
z: soil settlement at foundation edge



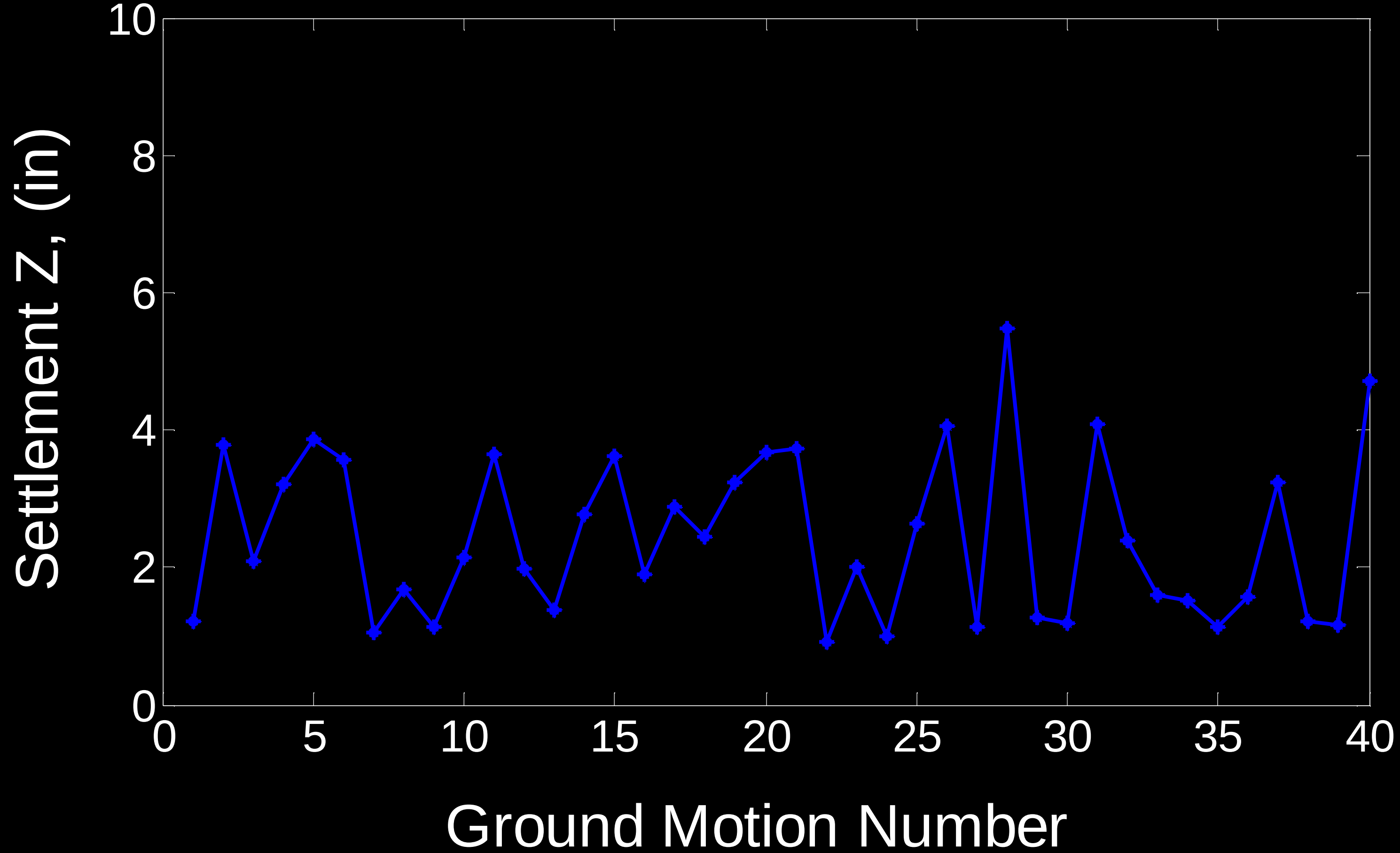
Computed Bridge Response - Total drift, Δ



Computed Bridge Response
Drift due to pier bending Δ_f

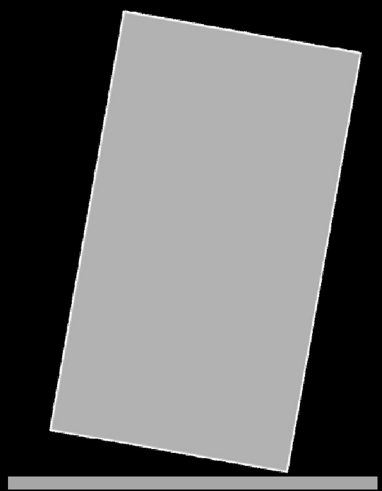


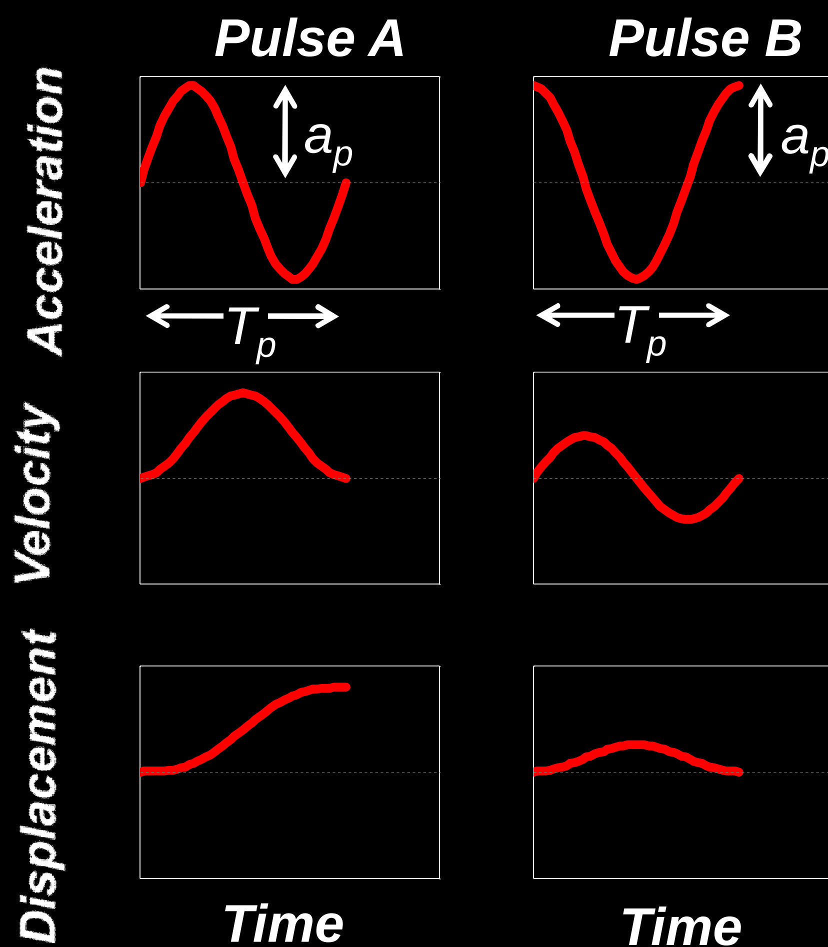
Computed Bridge Response



Ground motion characteristics that may lead to overturn ?

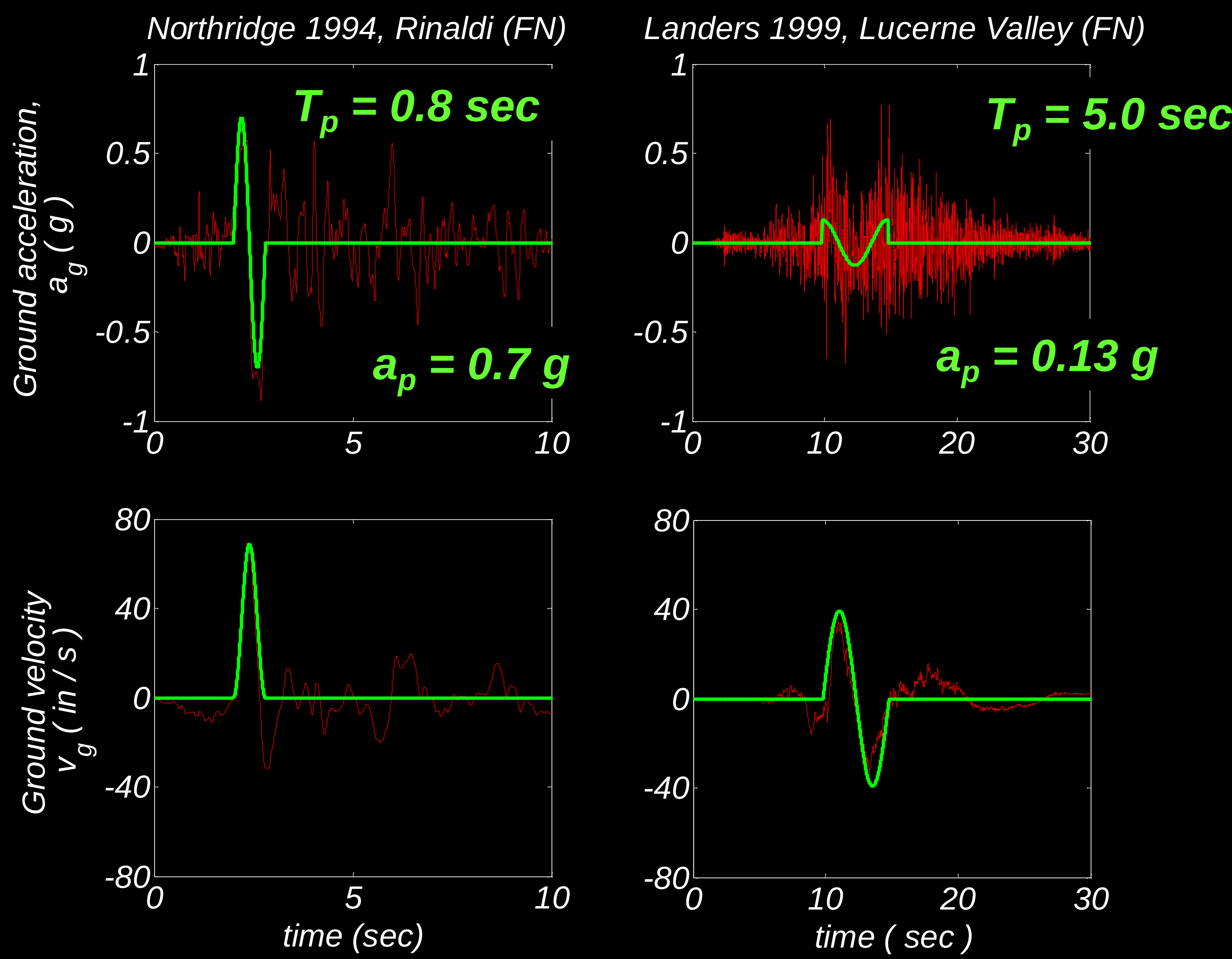
Ground motions with strong pulses (especially low frequency) that result in significant nonlinear displacement demand



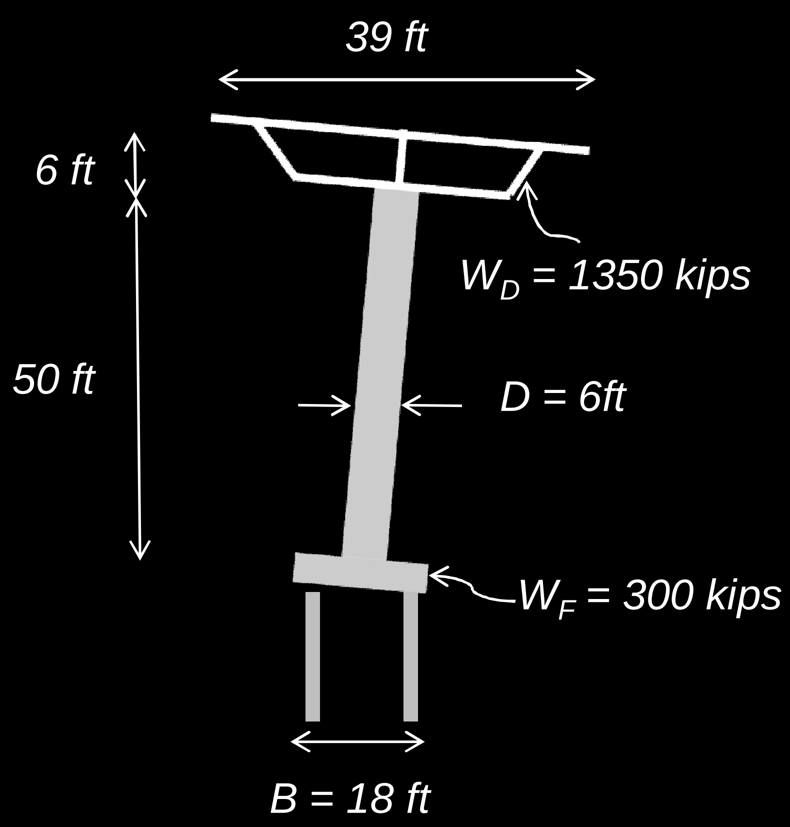


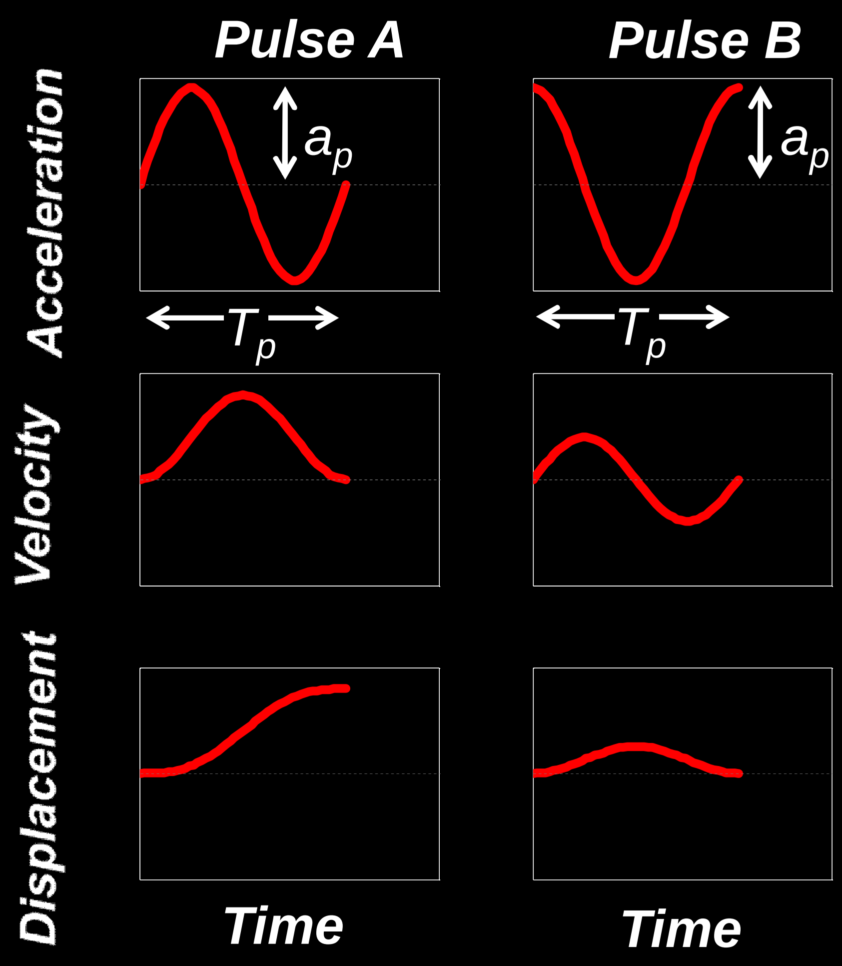
Rocking response of rigid block on rigid base to pulse-type excitation
Zhang and Makris (2001)

Near Fault Ground Motions and their representation using Trigonometric Pulses



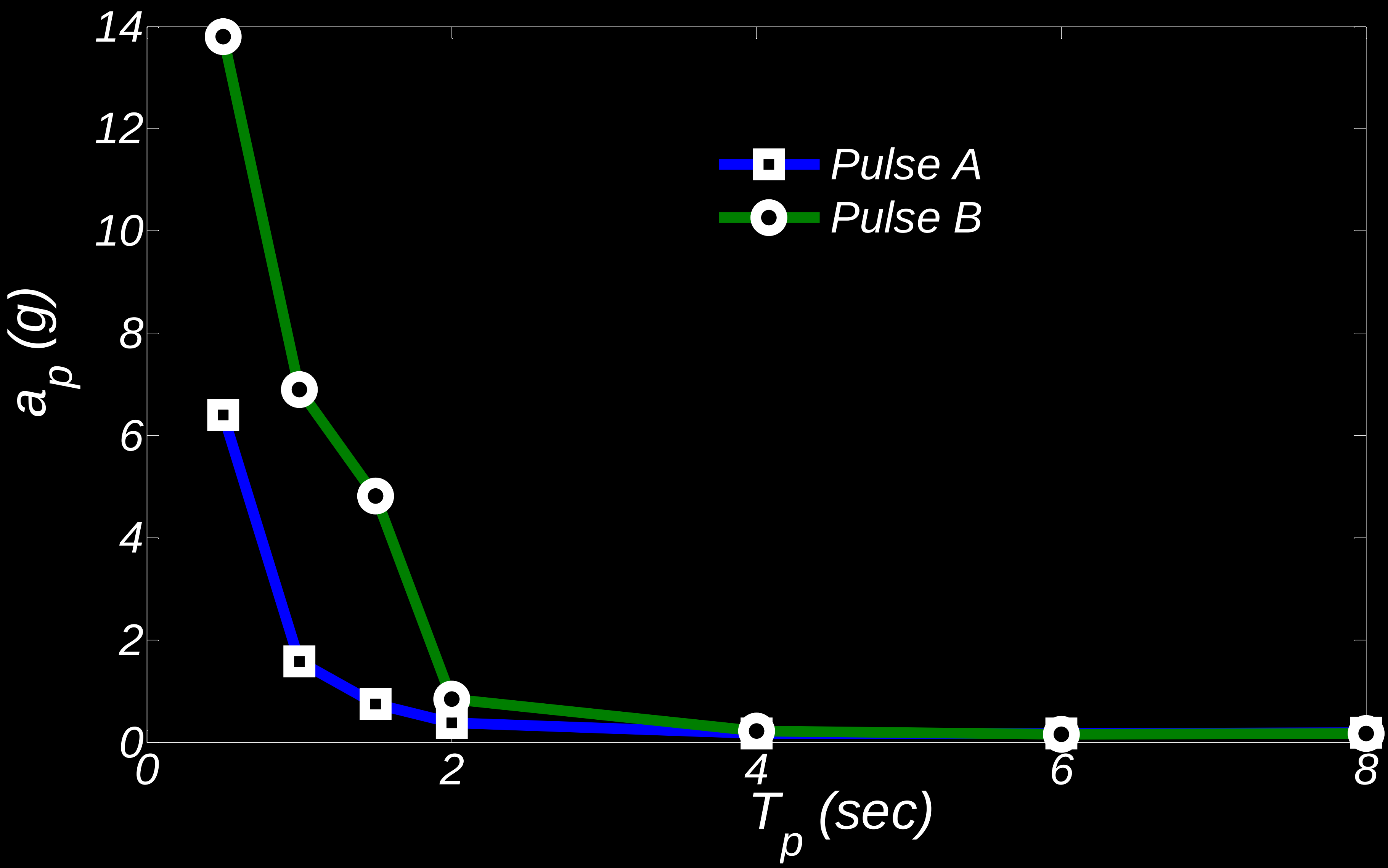
Conditions that may lead to overturn



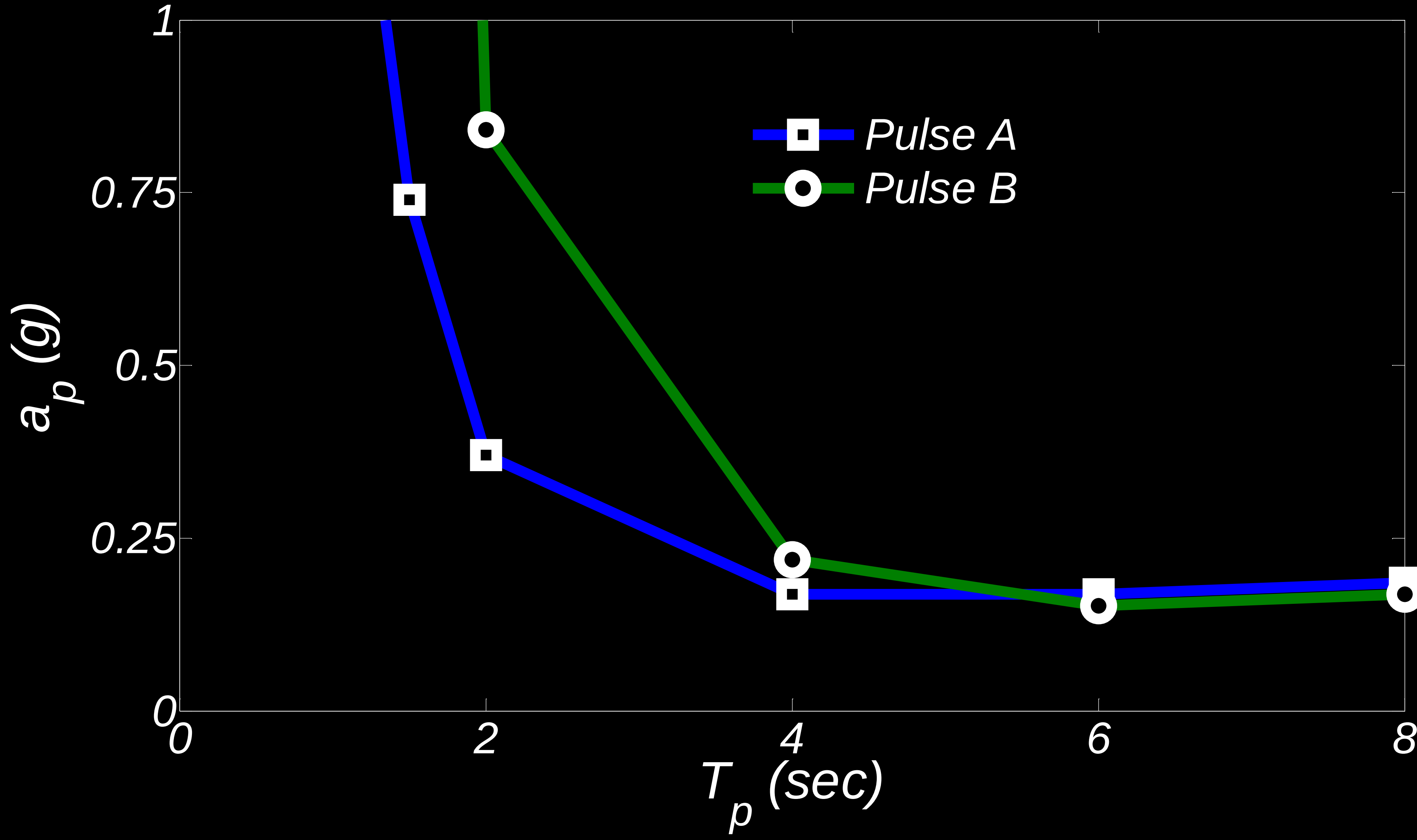


Minimum a_p at different T_p that results in overturn ?

Conditions that may lead to overturn



Conditions that may lead to overturn

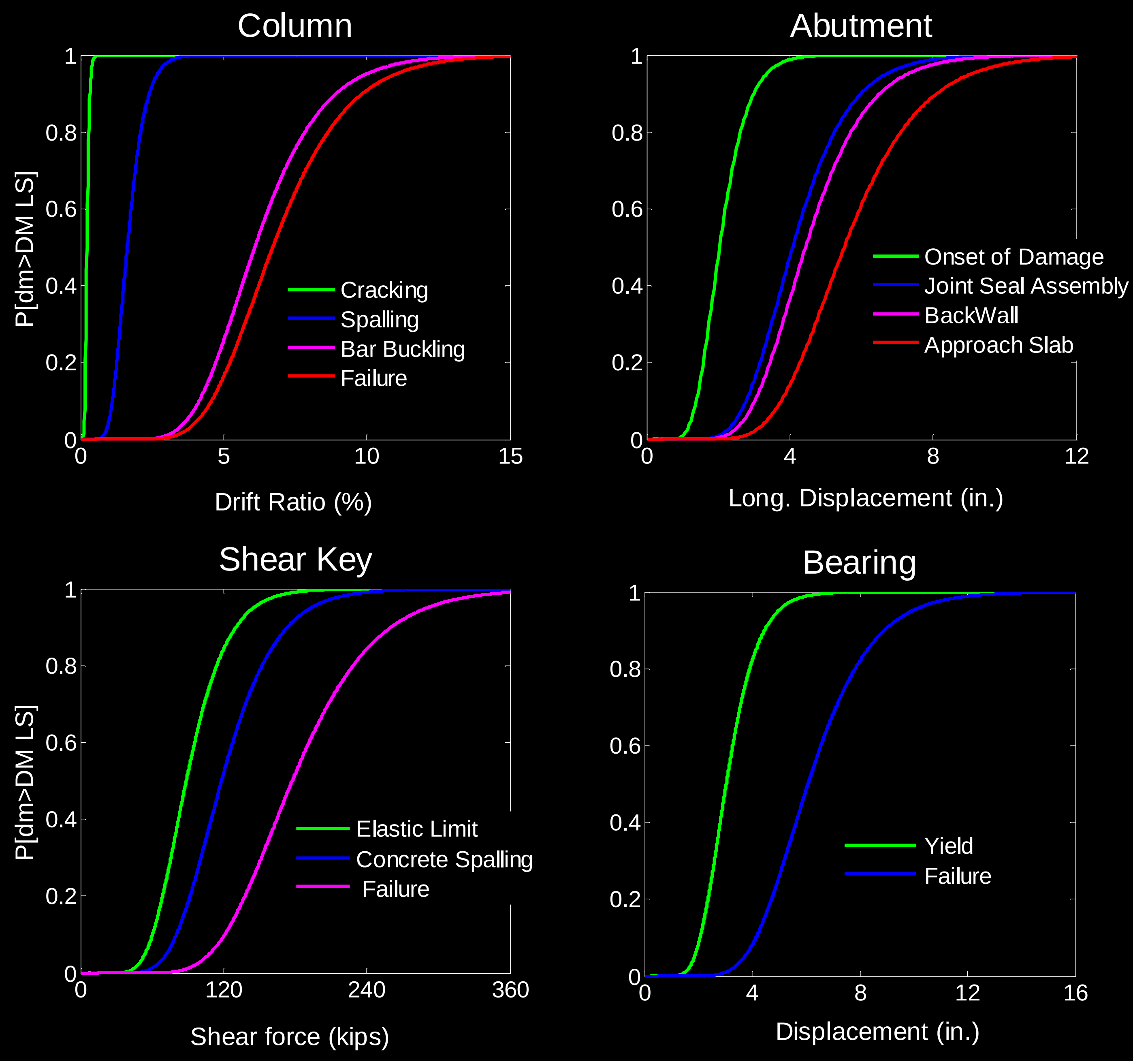


Probabilistic Performance Based Earthquake Evaluation (PBEE)

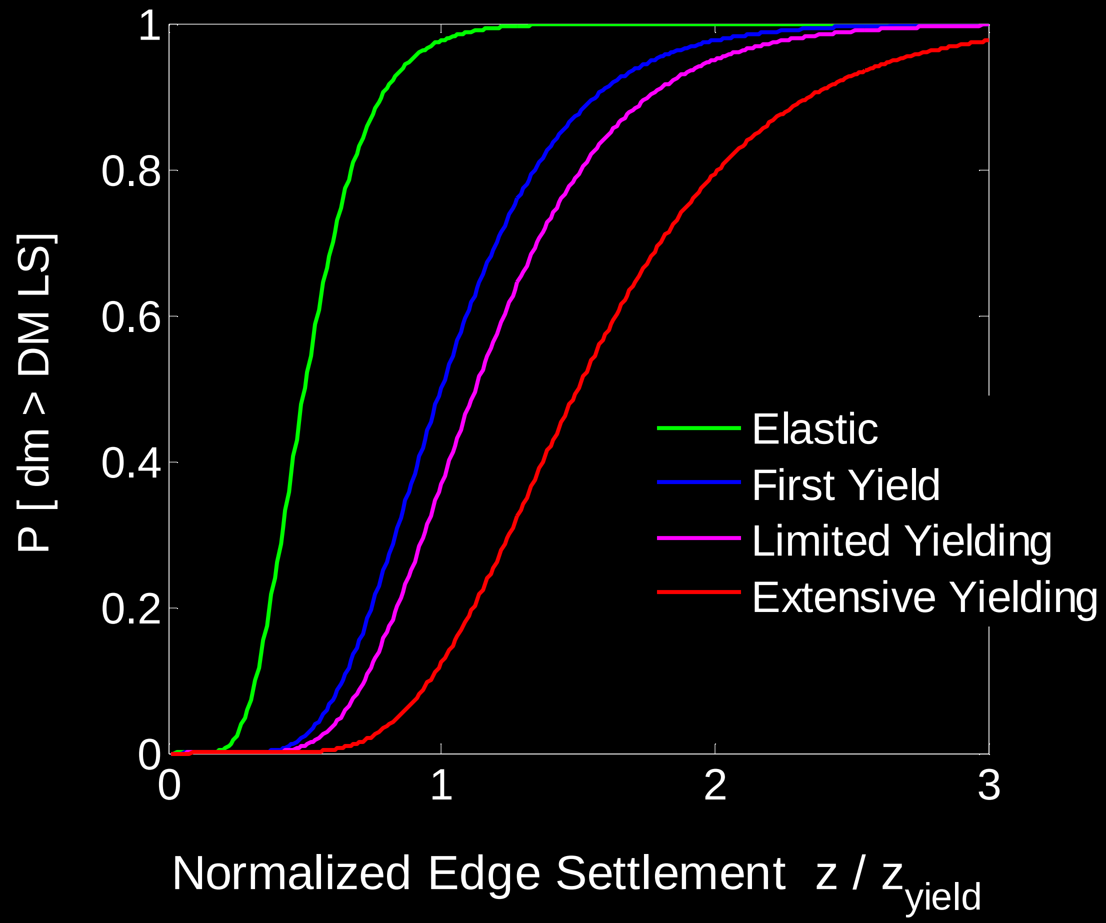
The PEER methodology and the framework of Mackie et al. (2008) was used for the PBEE comparison of the fixed base and the rocking designs.

- ***Ground Motion Intensity Measures [Sa (T_1)]***
- ***Engineering Demand Parameters (e.g. Pier Drift)***
- ***Damage in Bridge Components***
- ***Repair Cost of Bridge System***

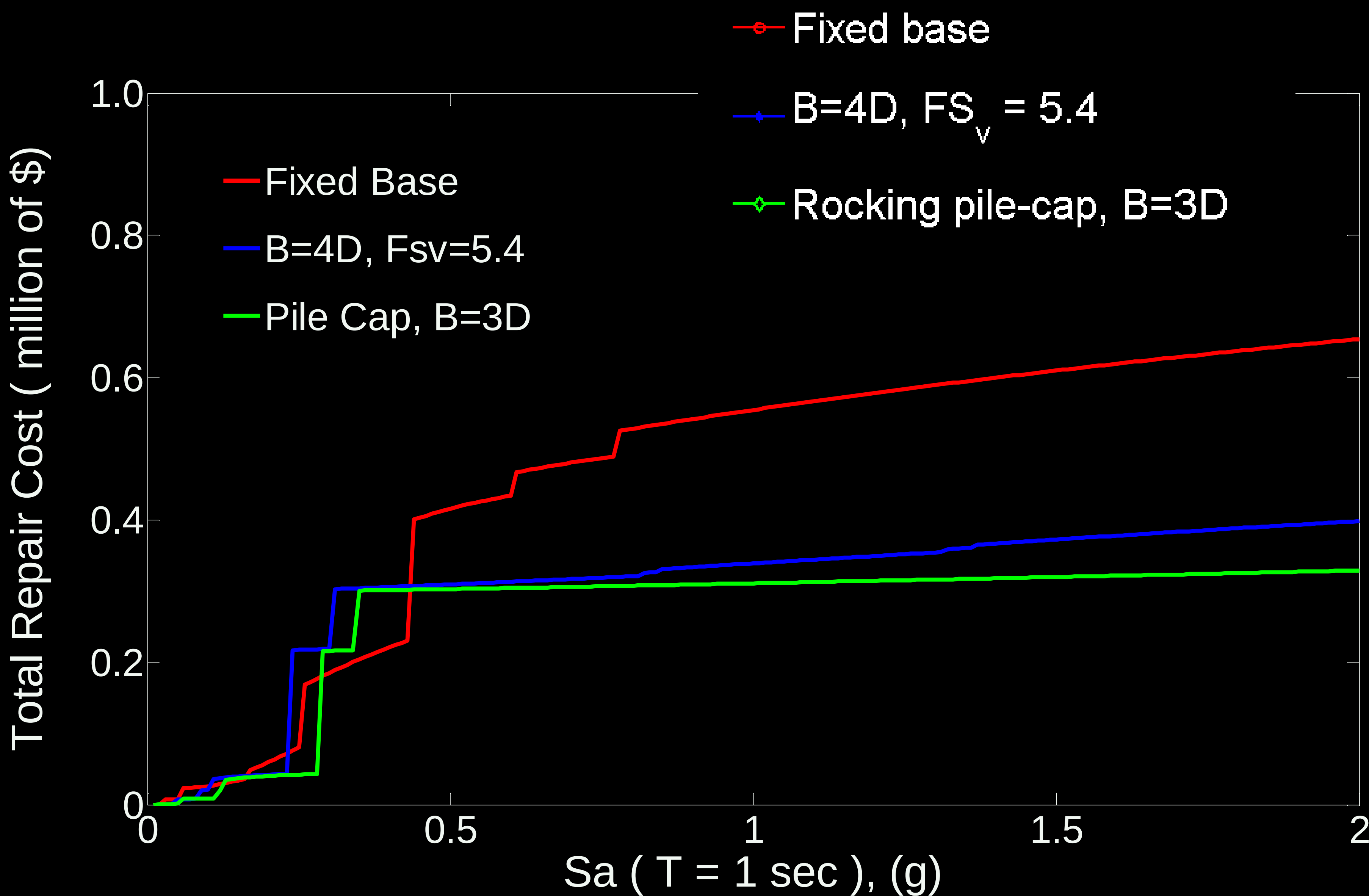
PBEE Evaluation – Damage Models (Mackie et al. 2008)



PBEE Evaluation
Foundation Damage Model

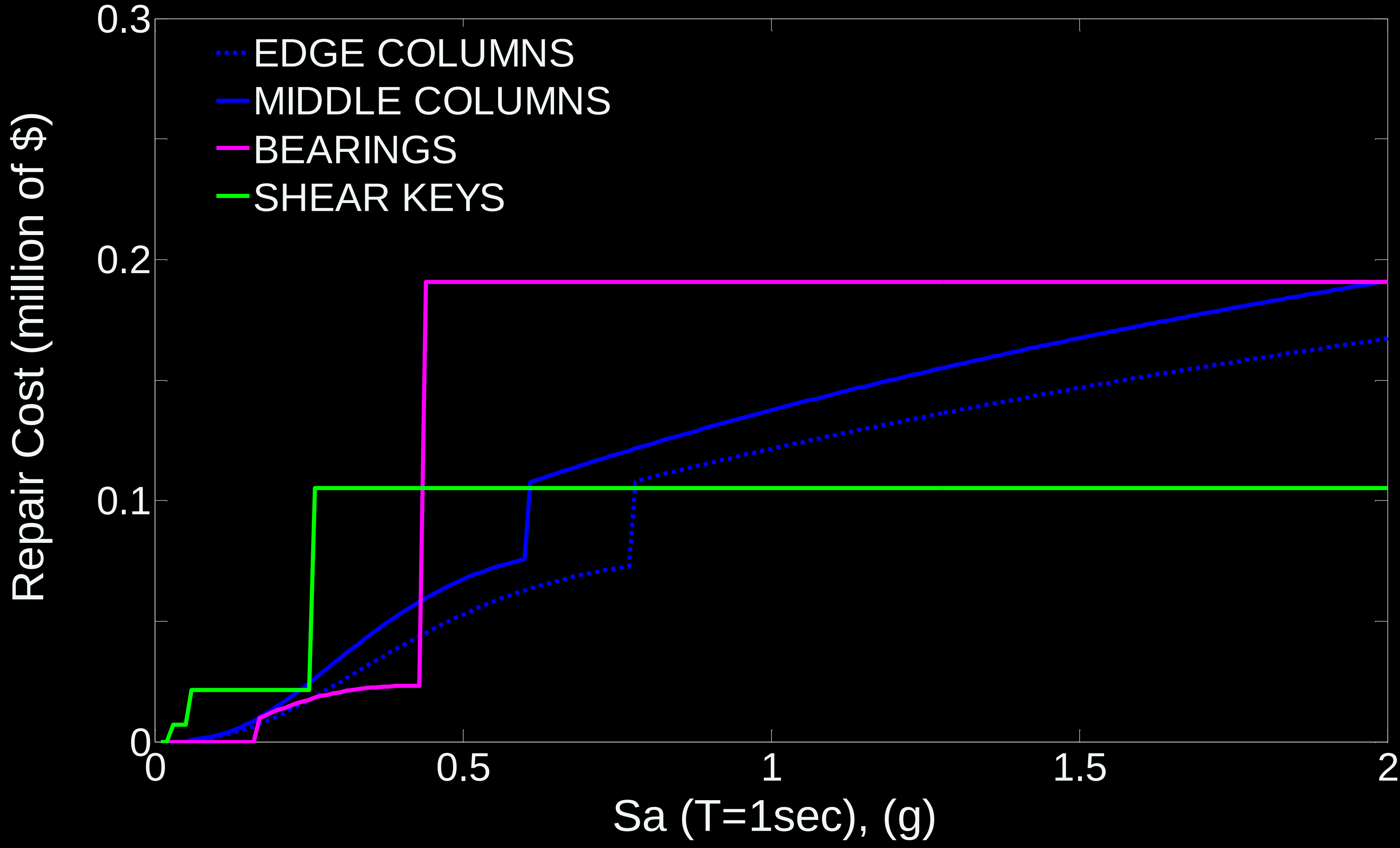


PBEE – Median Total Repair Cost



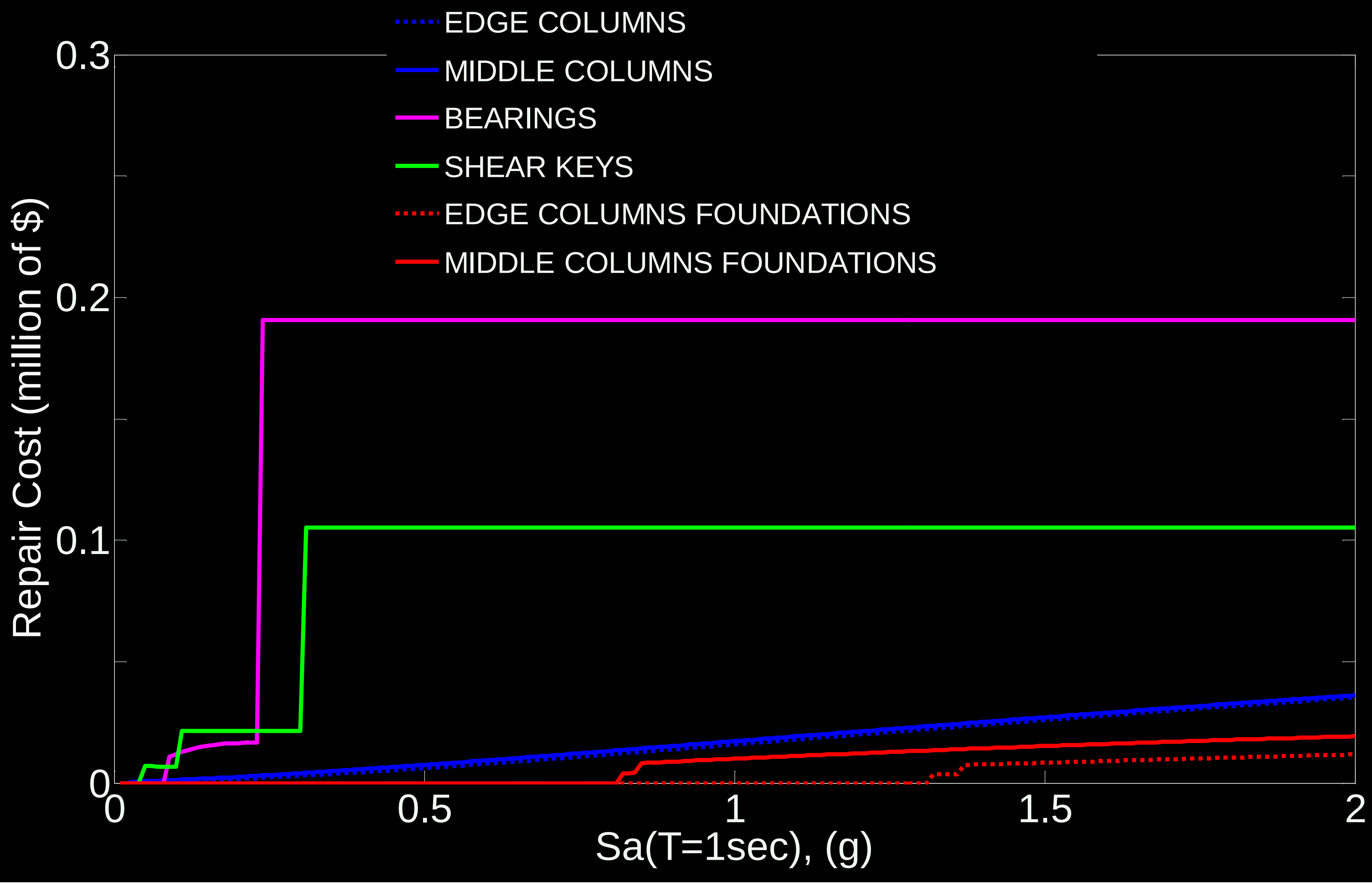
PBEE – Disaggregation of Cost

Fixed Base Bridge



PBEE – Disaggregation of Cost

Bridge with Shallow Foundations B=4D



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