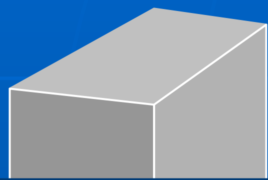
Caltrans-PEER Seismic Research Seminar
Sacramento, CA, USA

Rocking Seismic Isolation of Bridges Supported by Direct Foundations

June 8, 2009

Kazuhiko Kawashima
Tokyo Institute of Technology

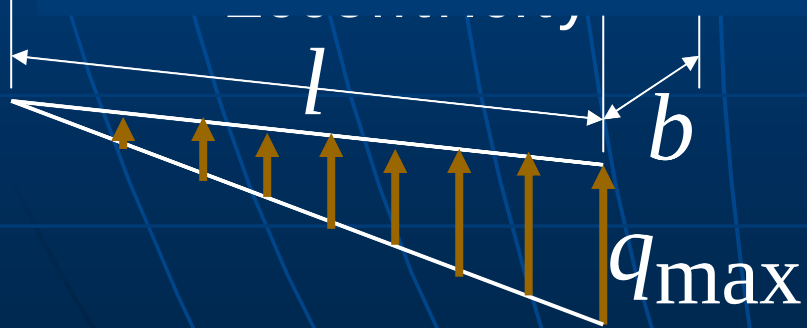
Requirements in the Overturning Based on Static Analysis



Eccentricity

- Size effect is not included in the conventional static analysis

- As long as the shape and mass density are the same, a foundation can overturn in the conventional static analysis no matter how the foundation is extremely large



+Seismic

Bearing Capacity

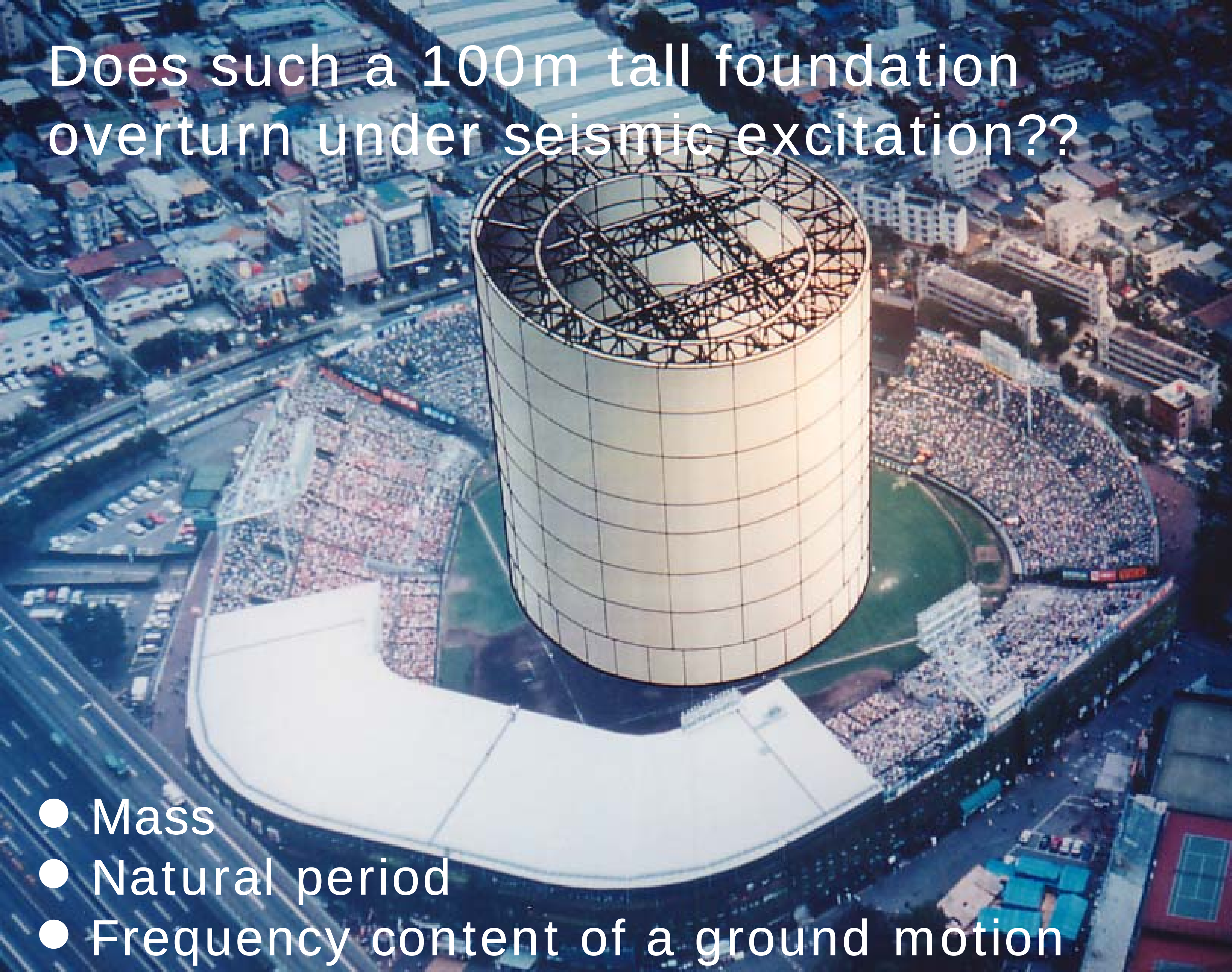
$$q_{max} = \frac{V}{lb} + \frac{6M_B}{lb^2} < q_a$$

Akashi Strait Bridge

The World Longest Bridge

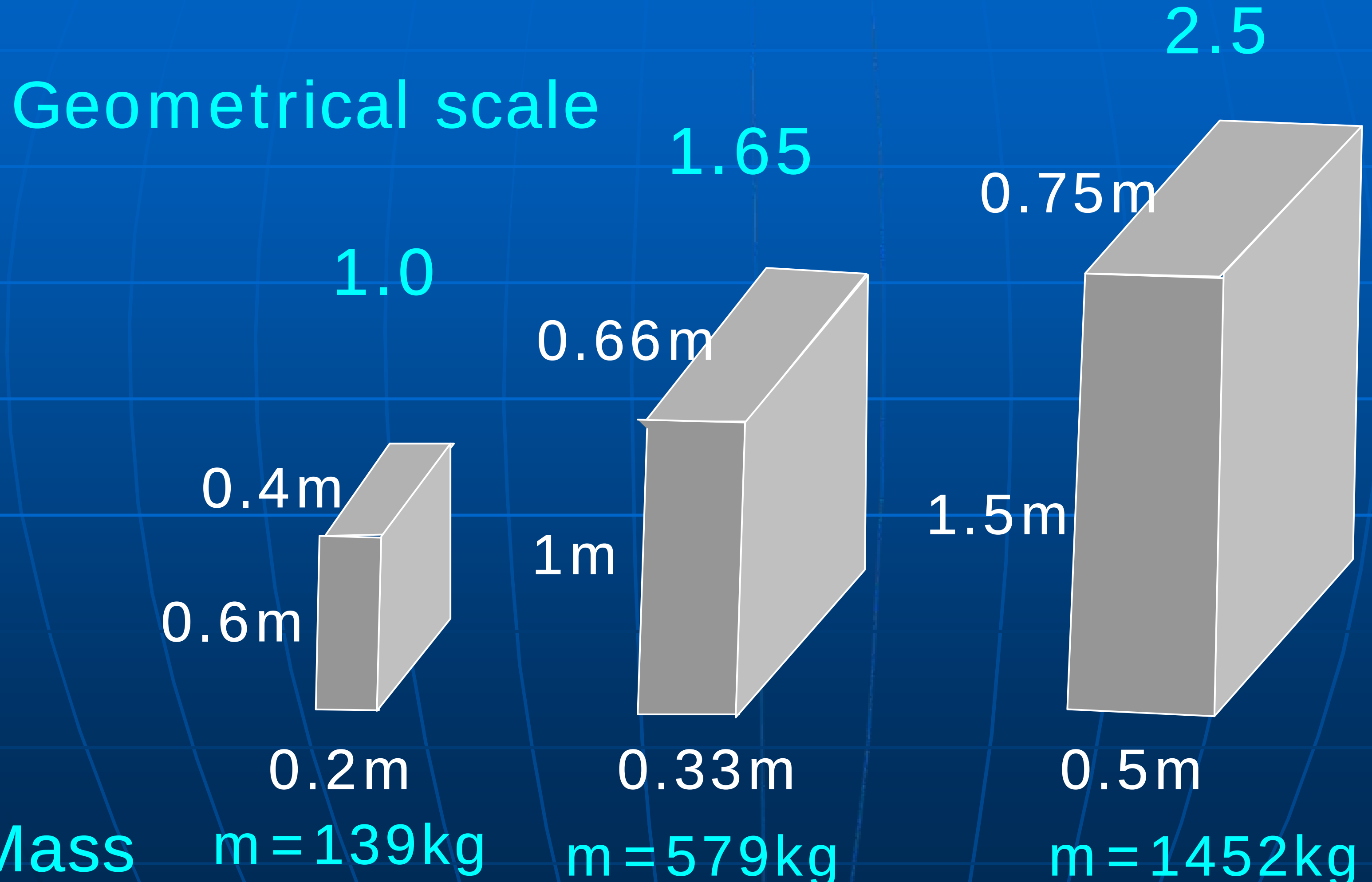
In the static design, overturning was the major factor for sizing of those foundations based on the conventional analysis

Does such a 100m tall foundation overturn under seismic excitation??



- Mass
- Natural period
- Frequency content of a ground motion

Shake Table Experiment on the Effect of Size & Mass for Overturning of Rigid Foundations



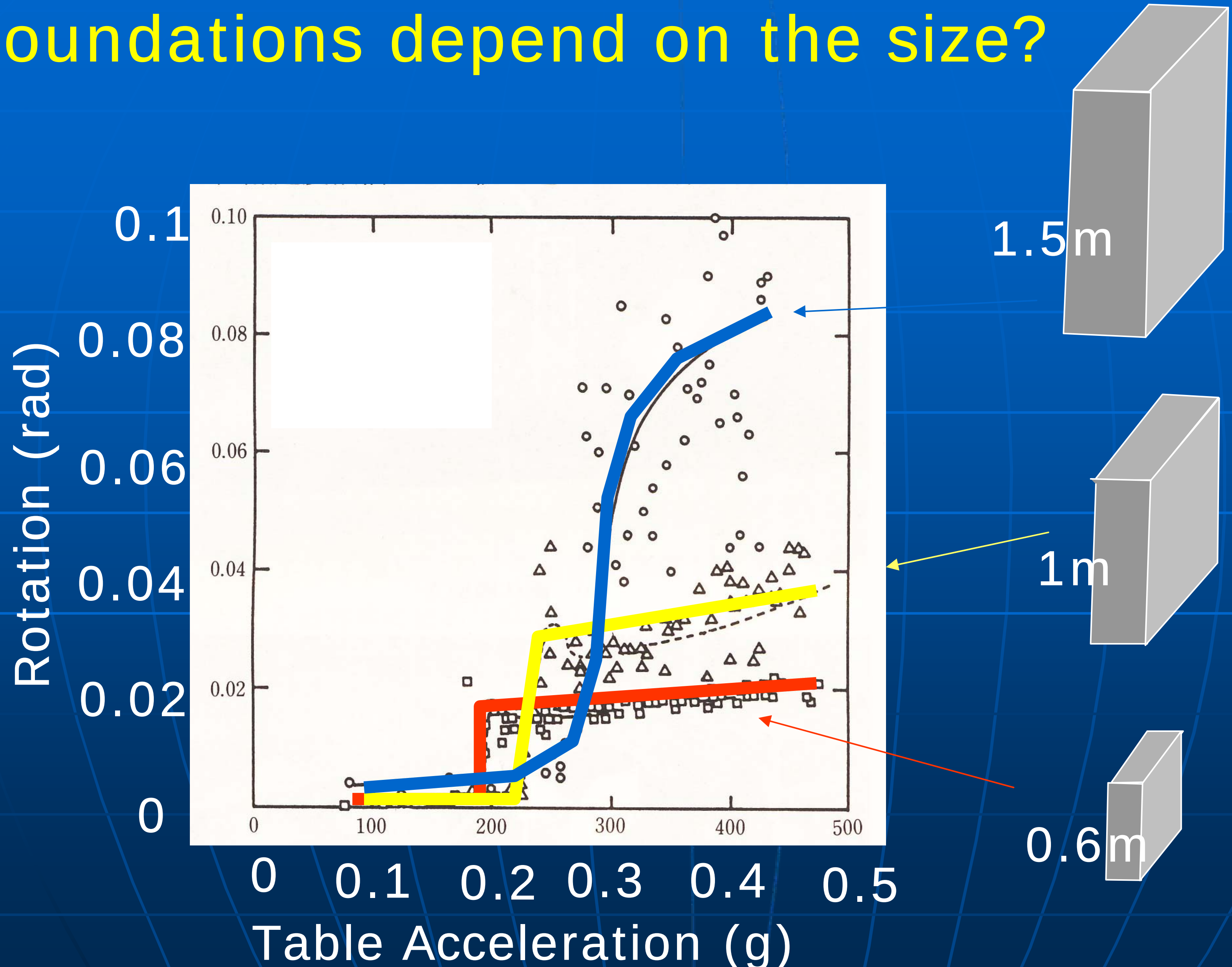
Kawashima & Unjoh (1992)

Shake Table Experiment on the Effect of Size & Mass for Overturning of Rigid Foundations

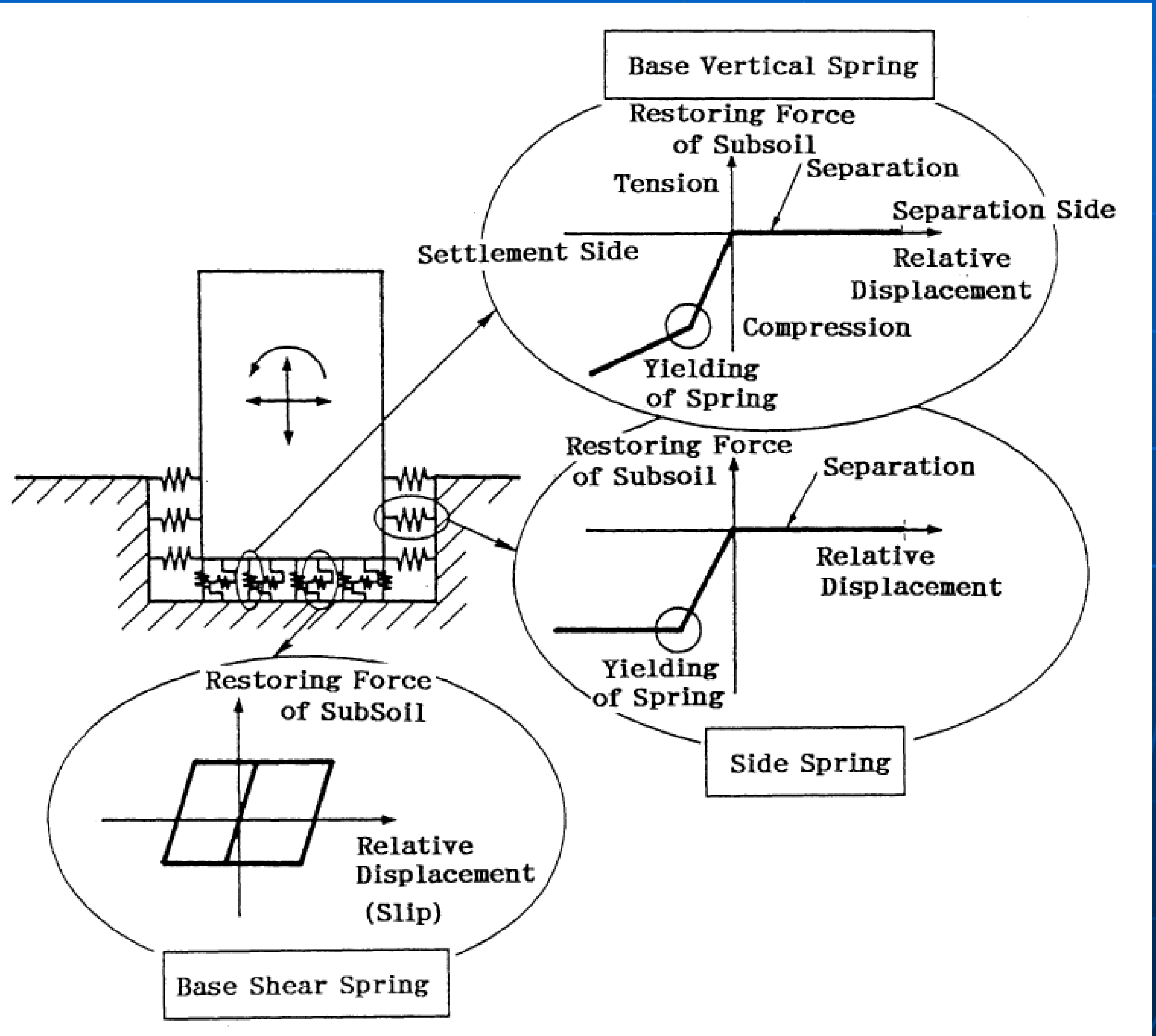
Public Works Research Institute

Kawashima & Unjoh (1992)

How does the rocking of rigid foundations depend on the size?

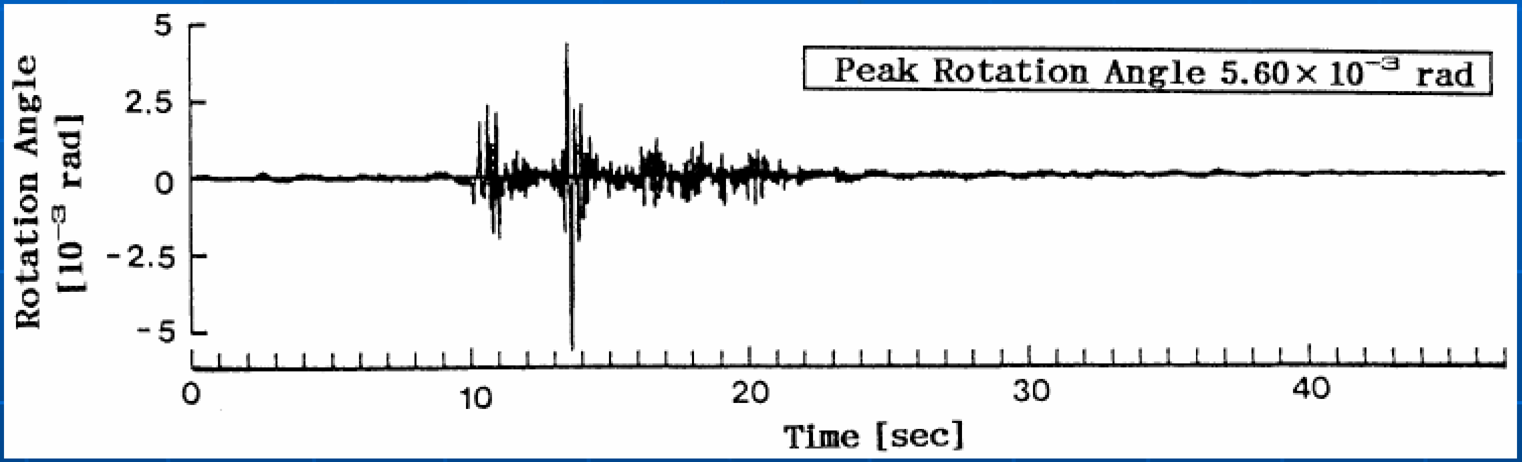


Analytical Idealization for Rocking and Sliding Response of a Rigid Foundation

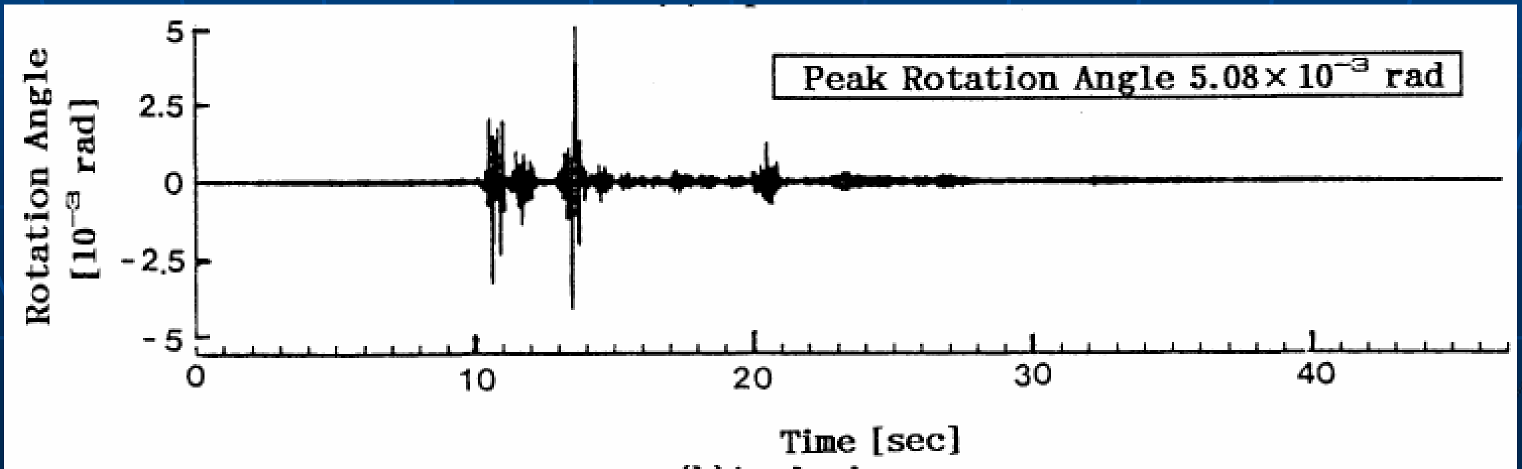


Analytical Correlation on the Rocking Response of a 1.5m Tall Rigid Foundation

Experimental



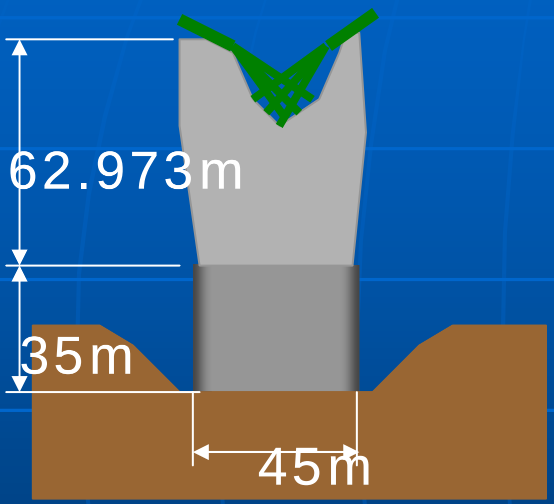
Analytical

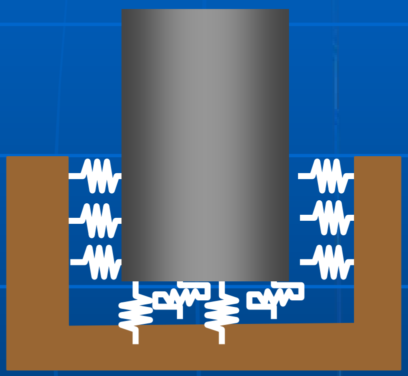


Seismic Response Analysis of Kurushima Straight Bridge

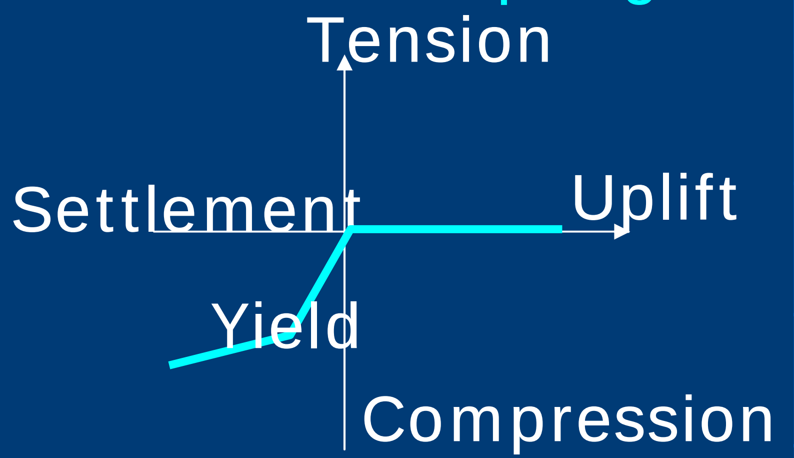
Kawashima et al (1994)

Seismic Response Analysis of Anchorages, Towers and Superstructure System of Kurushima Straight Bridge

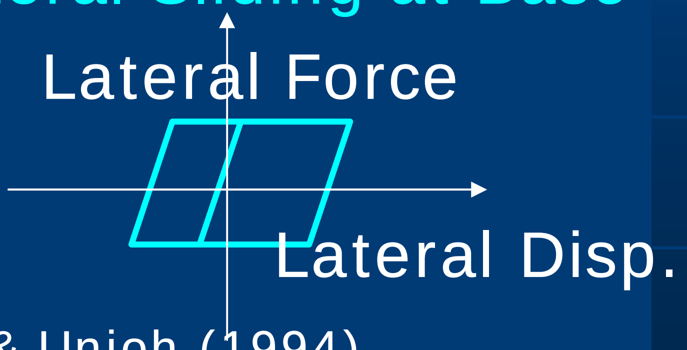




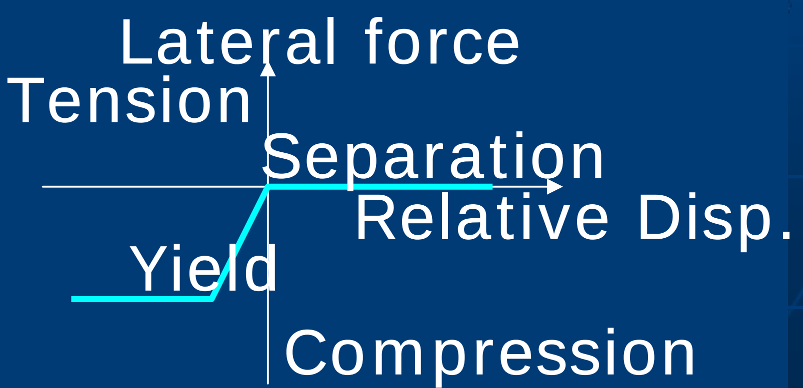
Base Vertical Springs



Lateral Sliding at Base



Side Soils

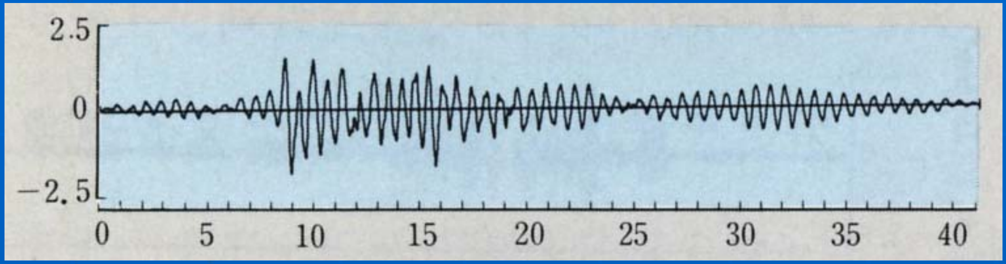


Kawashima & Unjoh (1994)

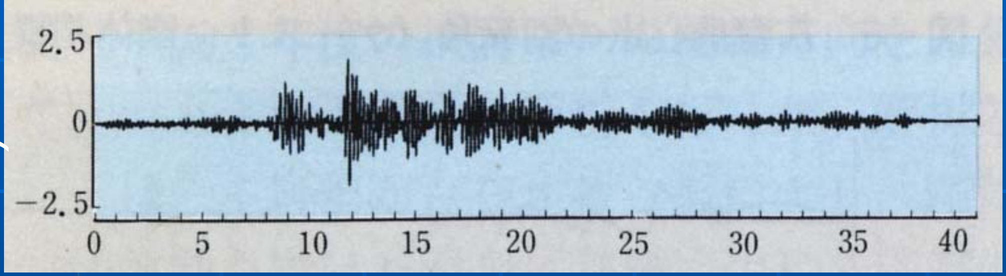
Peak Responses

Soft rock does not yield

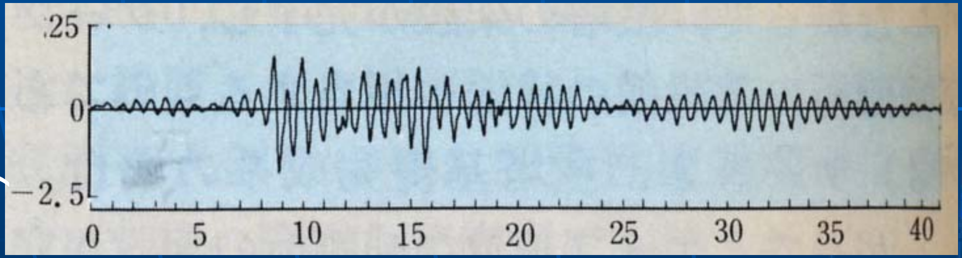
Response displacement at the top of a tower



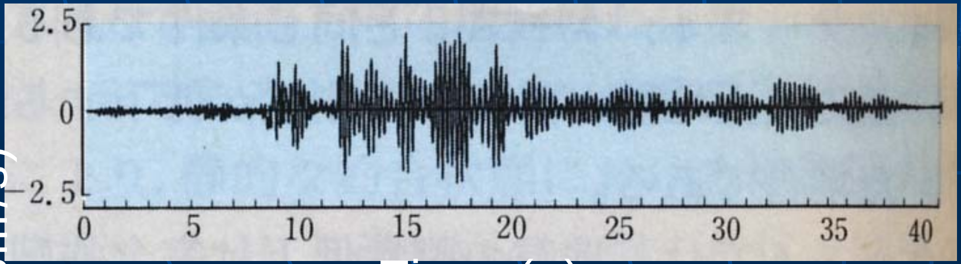
Response rotation of an anchorage



Soft rock yields

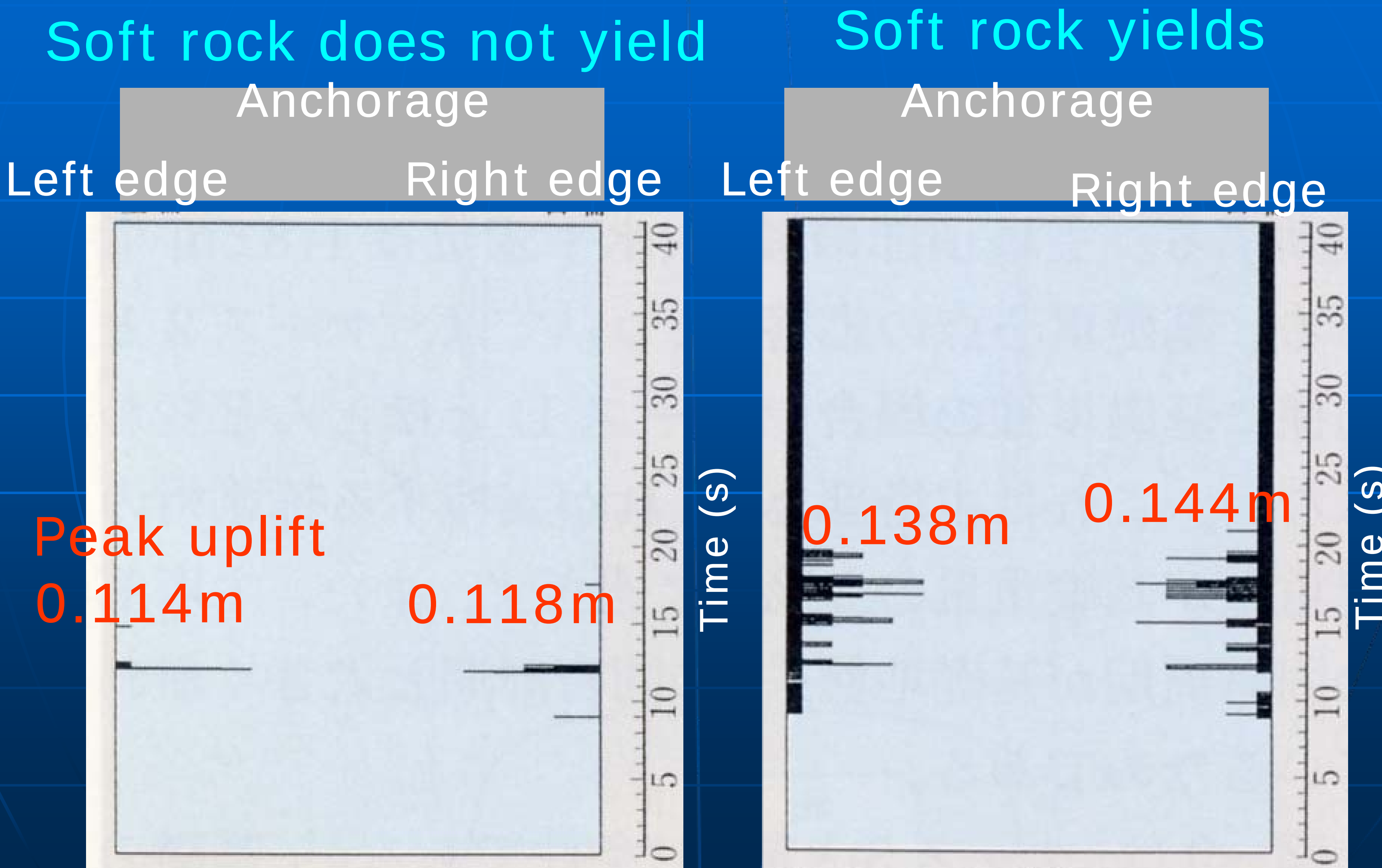


Response displacement at the top of a tower

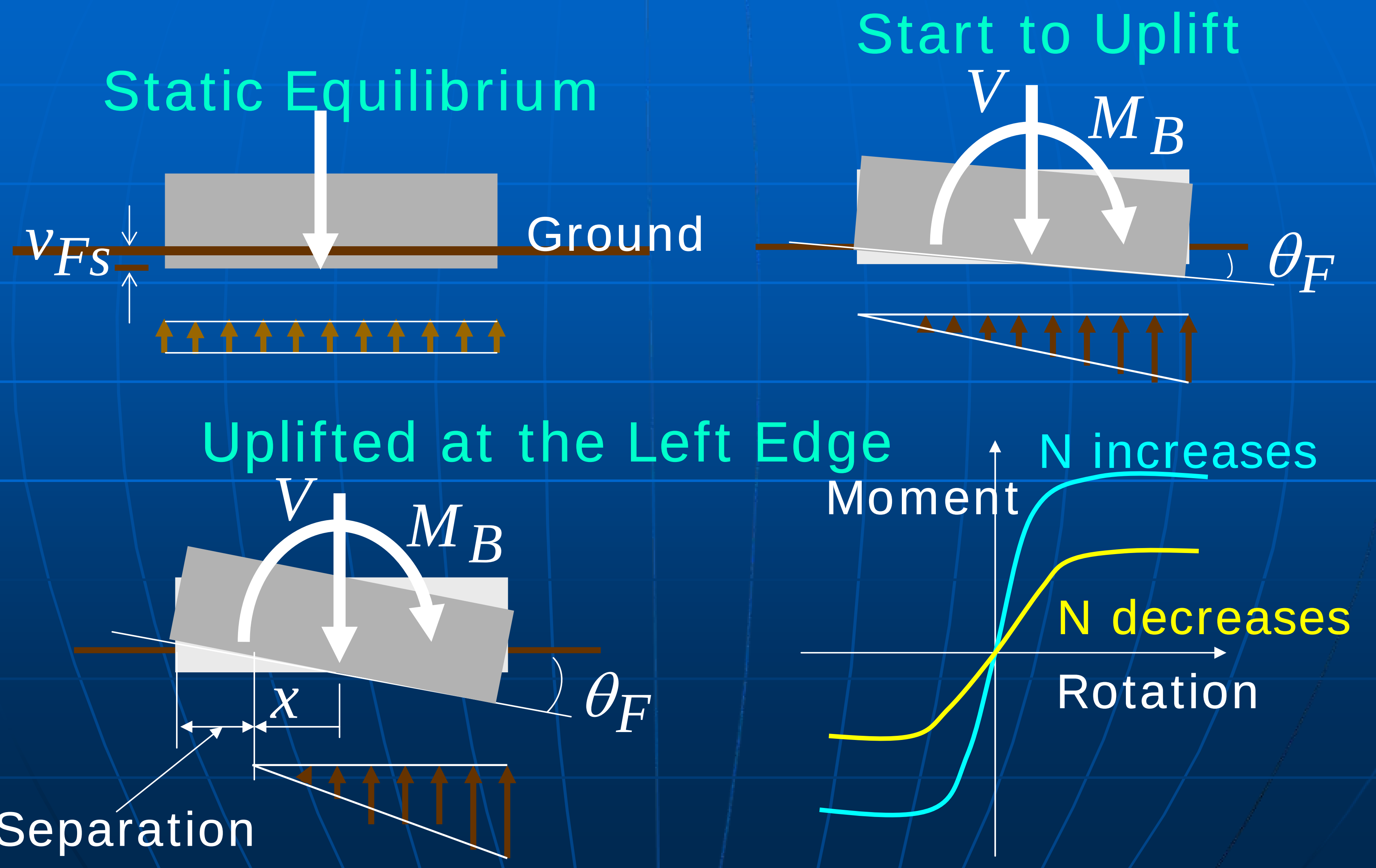


Response rotation of an anchorage

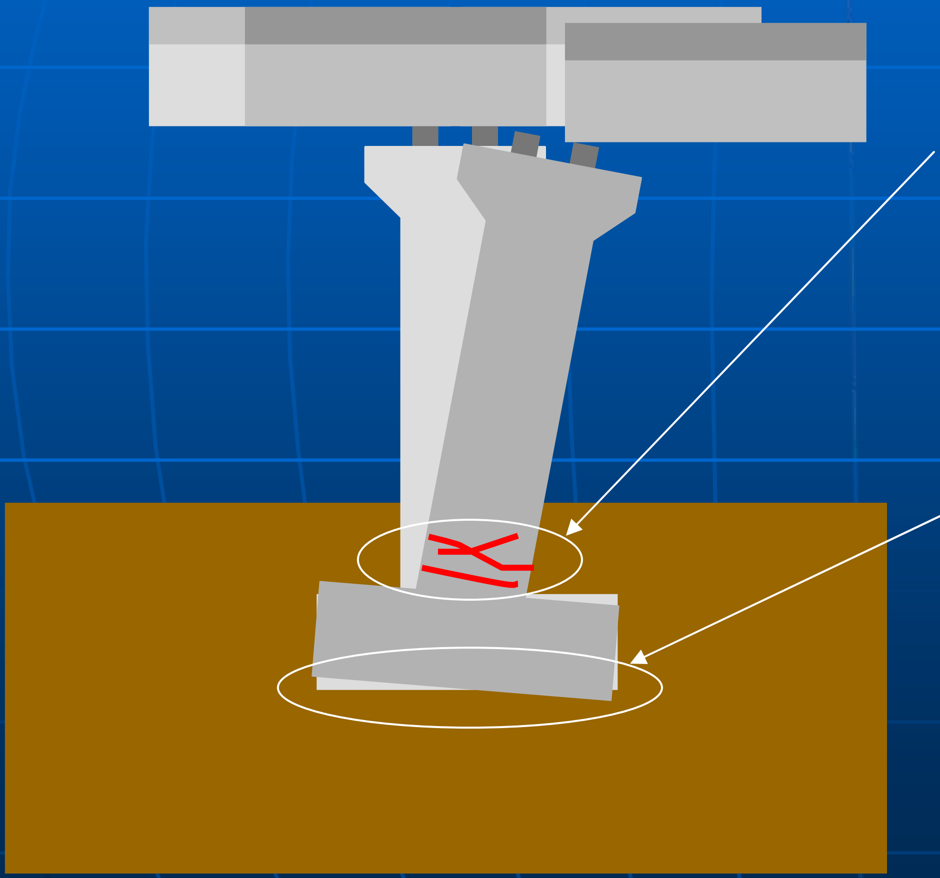
How frequently does the anchorage uplift?



Uplift & separation and contact of a foundation with the underlying ground



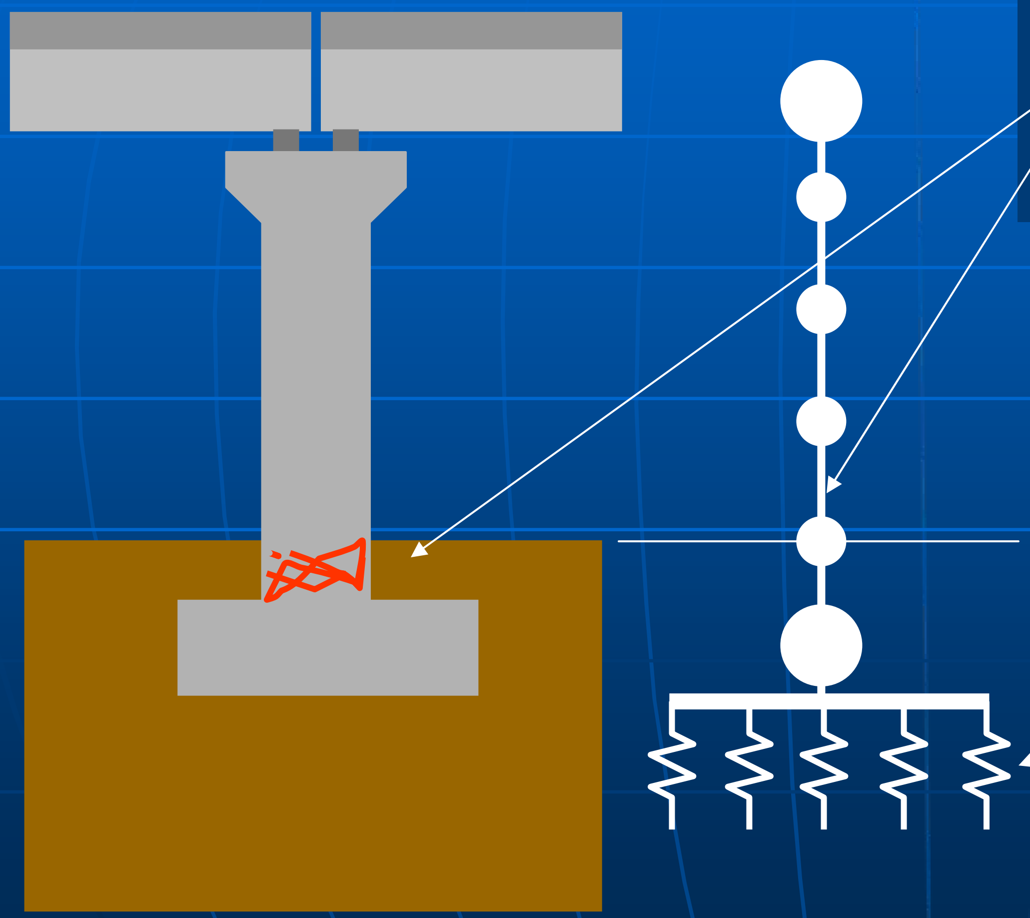
Nonlinear Interaction between 2 plastic hinges; (1) Column Plastic Hinge and (2) Foundation Nonlinear Behavior



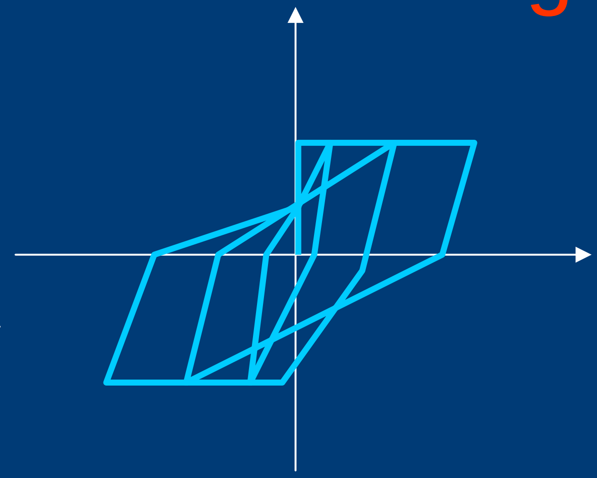
Plastic deformation of a column

Rocking response of a foundation

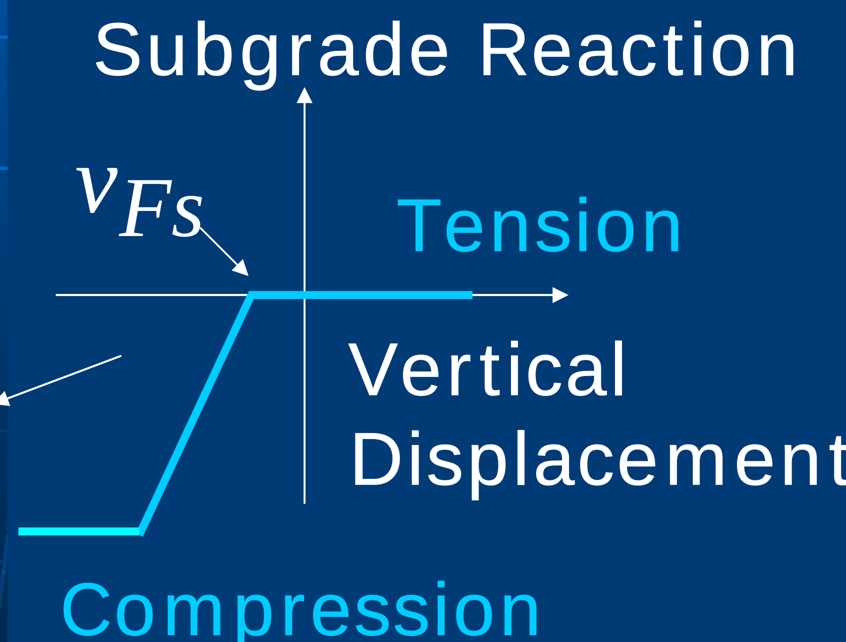
Analytical Idealization



Plastic Hinge

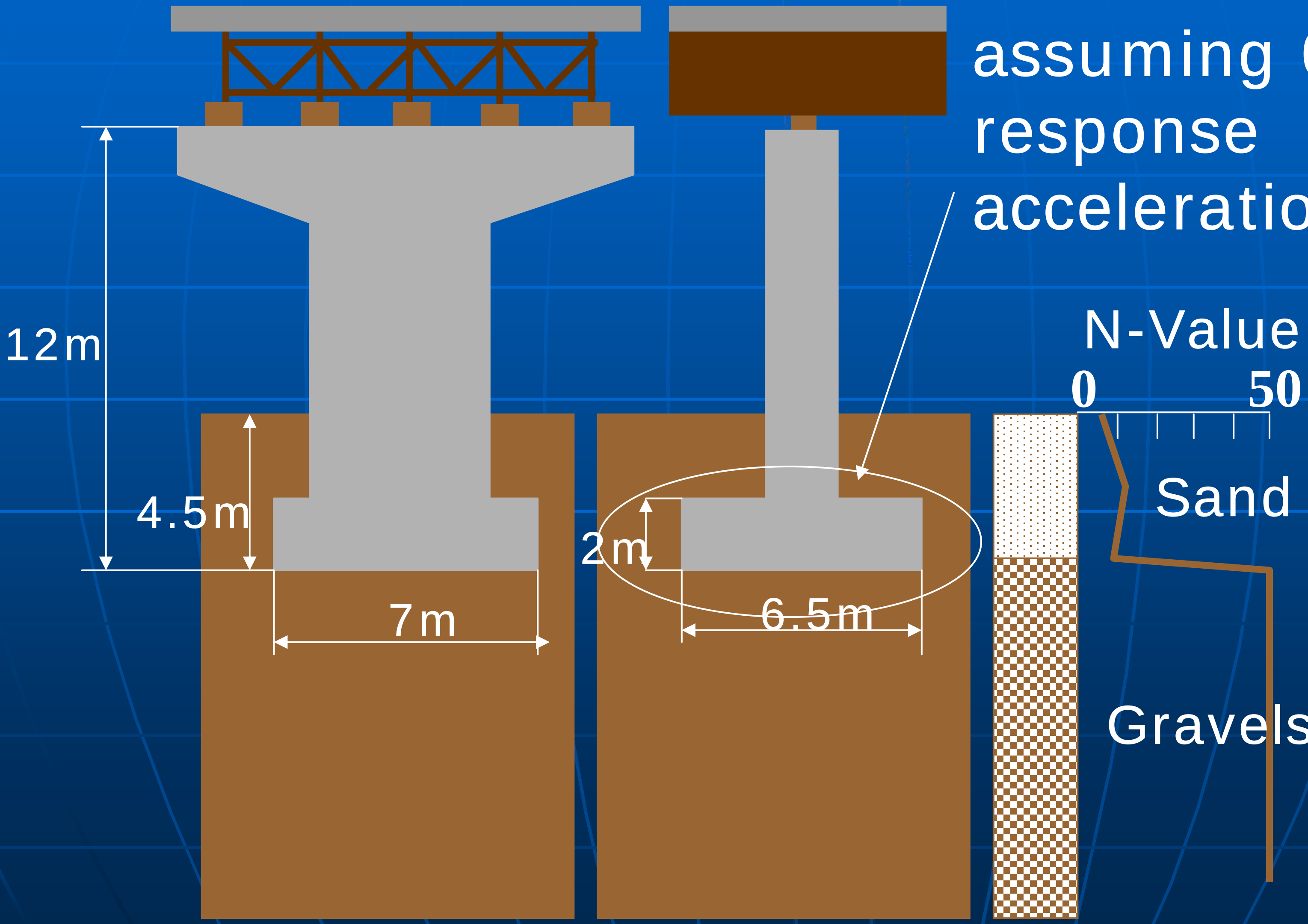


Uplift of Foundation



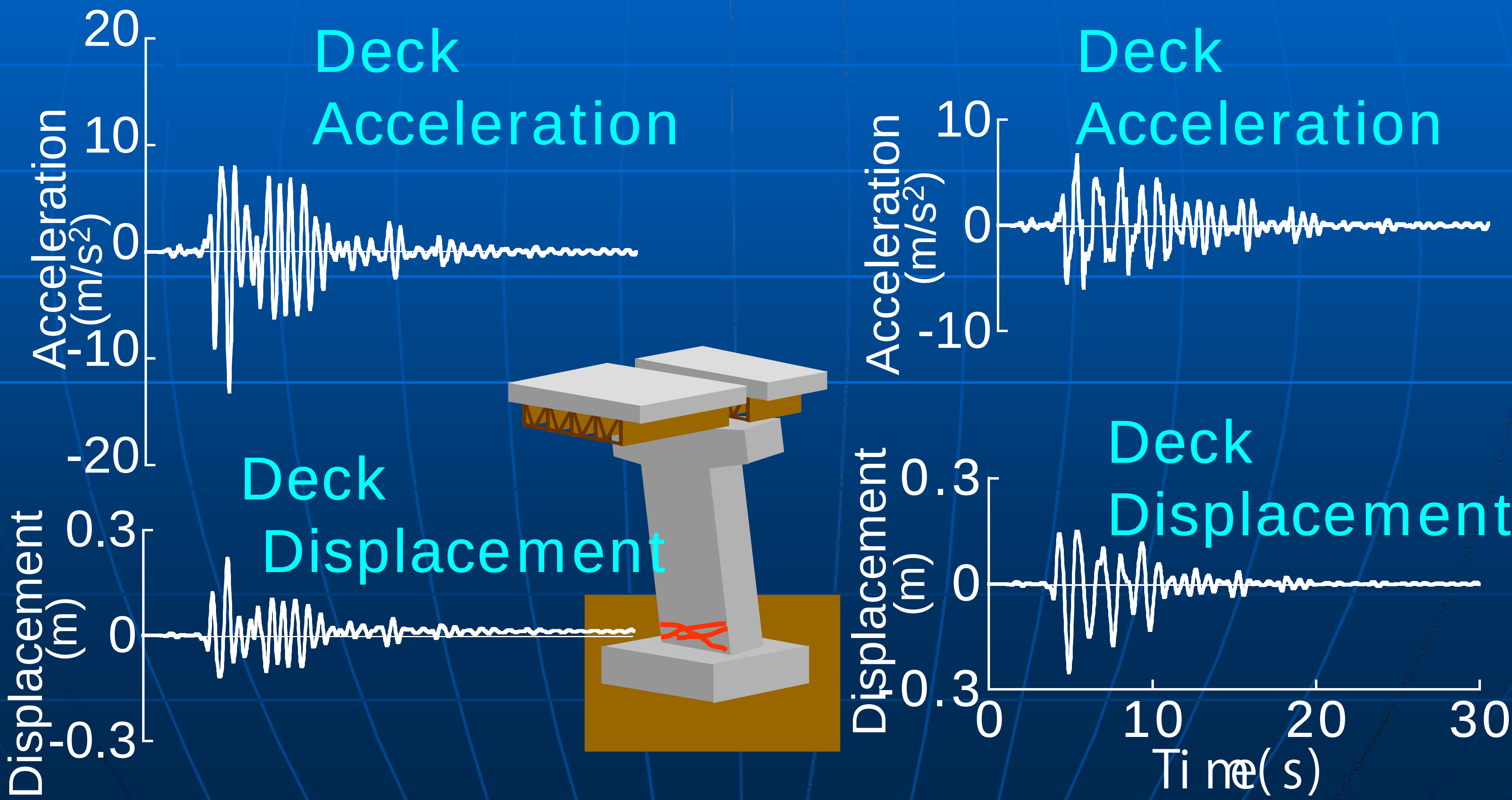
Bridge Analyzed

Designed based on the static analysis assuming 0.2g response acceleration



Deck Response under Longitudinal and Vertical Excitation

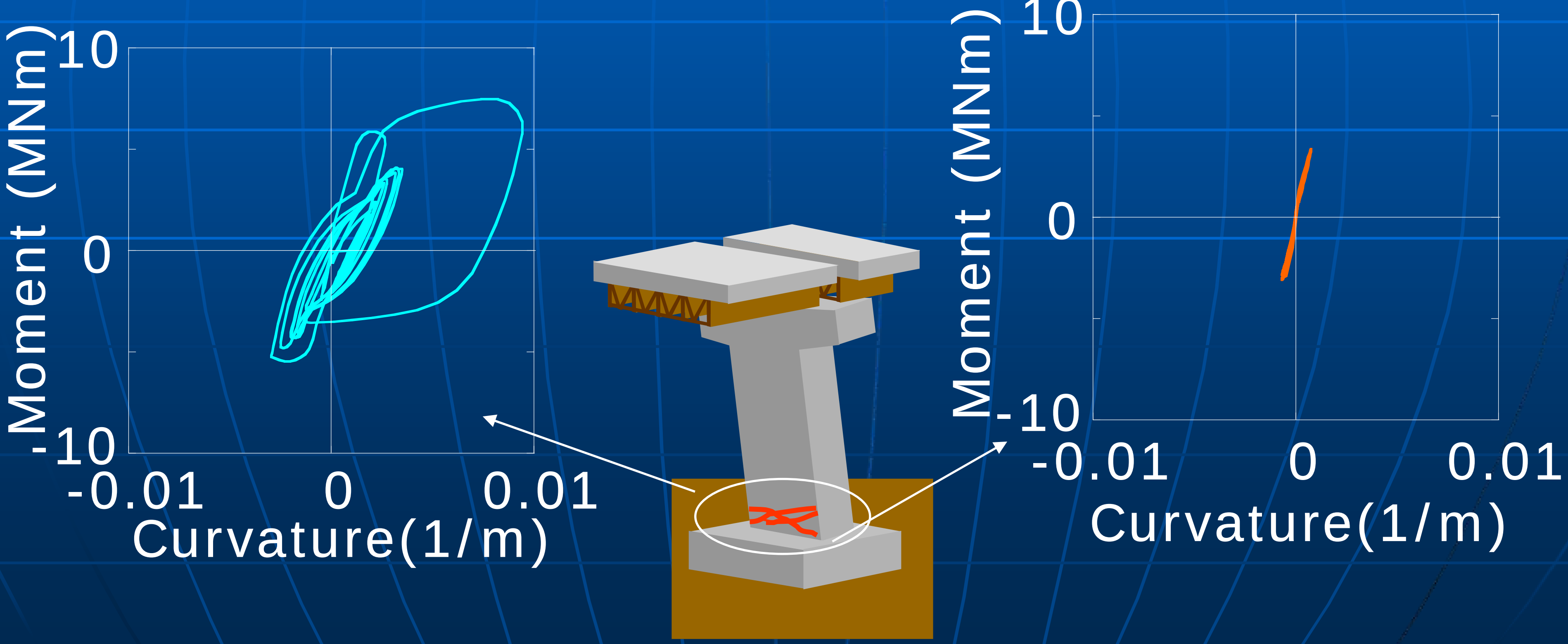
Conventional Analysis | Rocking Isolation



Column Curvature at the Plastic Hinge under Longitudinal and Vertical Excitation

Conventional Analysis

Rocking Isolation

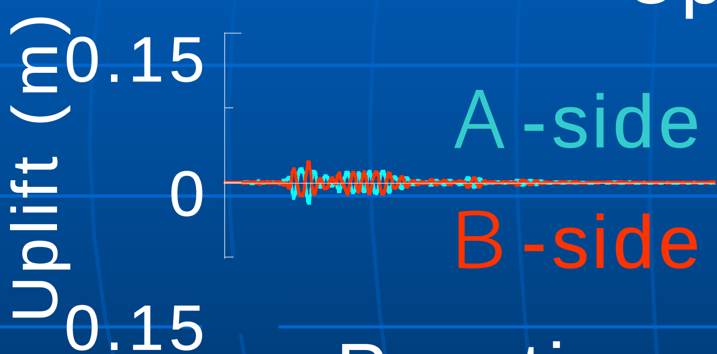


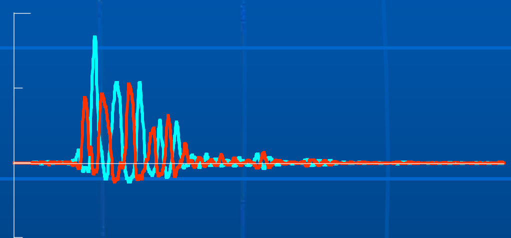
How Large Uplift occur at the Footing?

Conventional Analysis

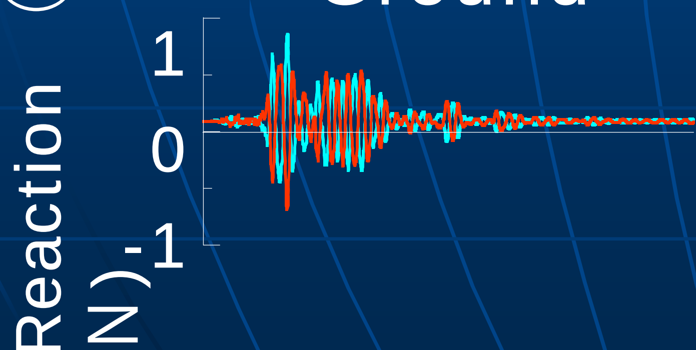
Rocking Isolation

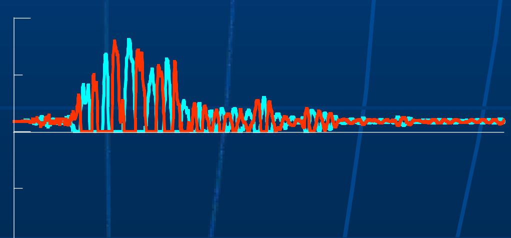
Uplift



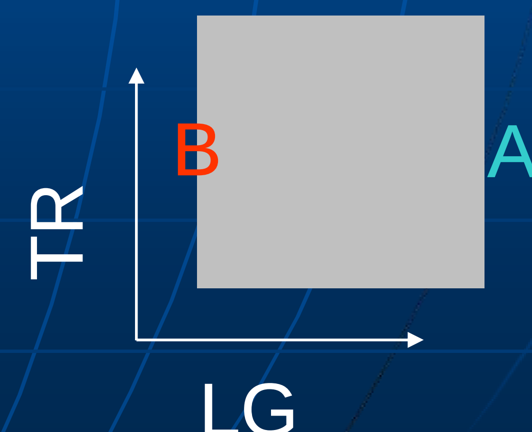


Reaction of Underlying Ground

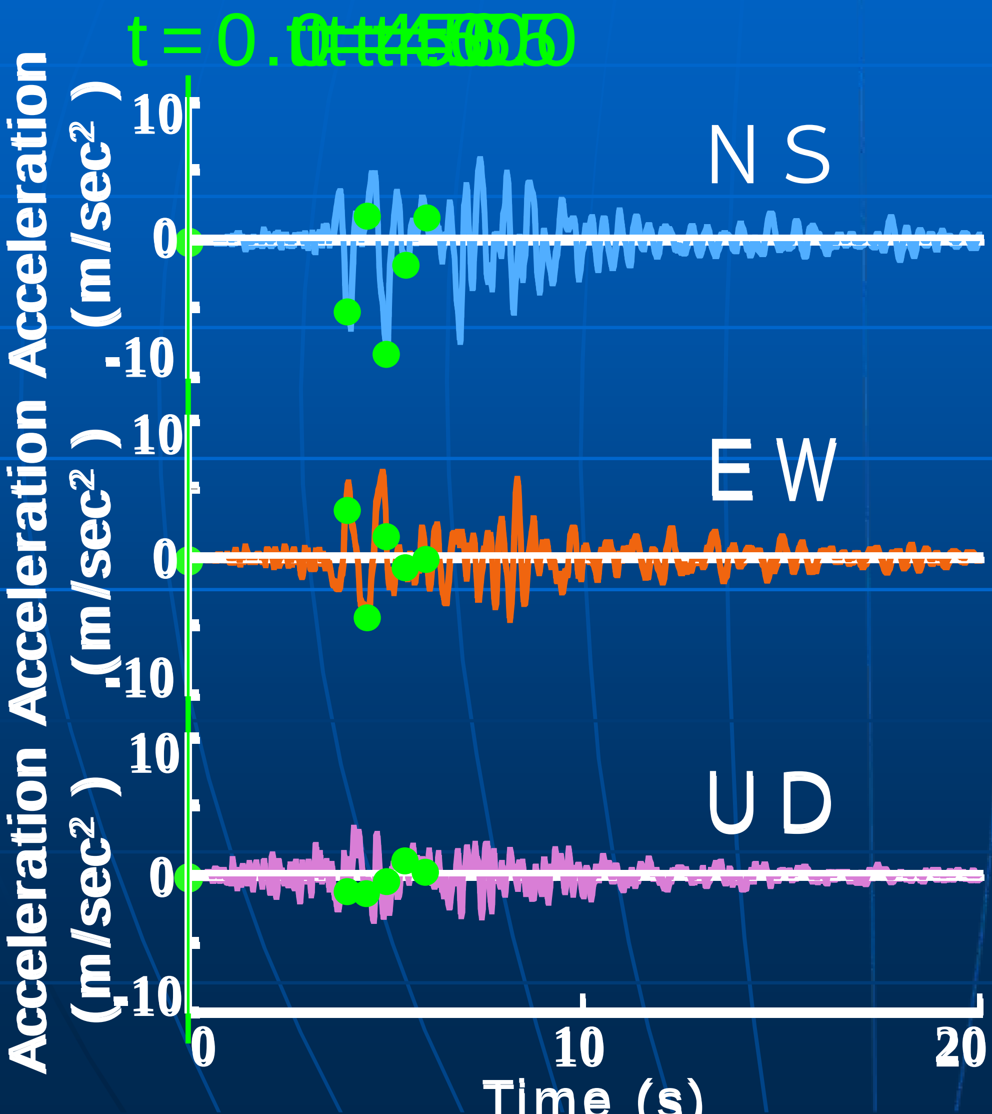


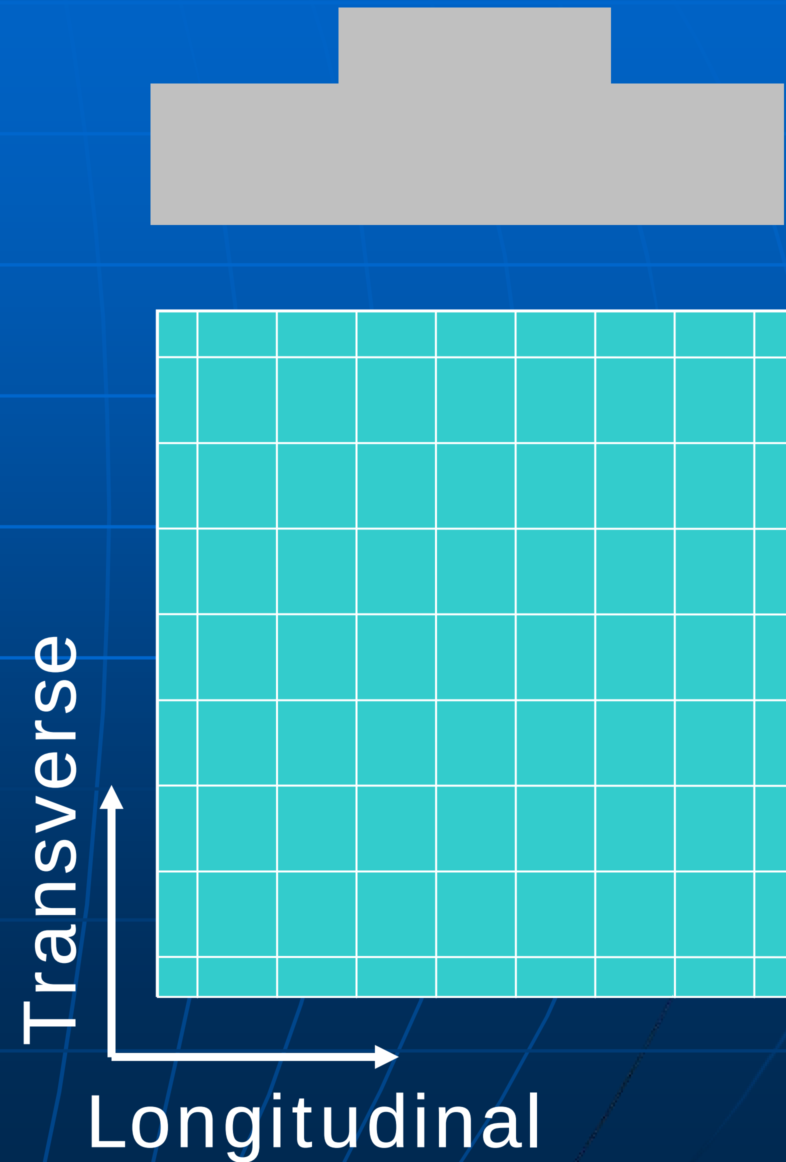


Footing

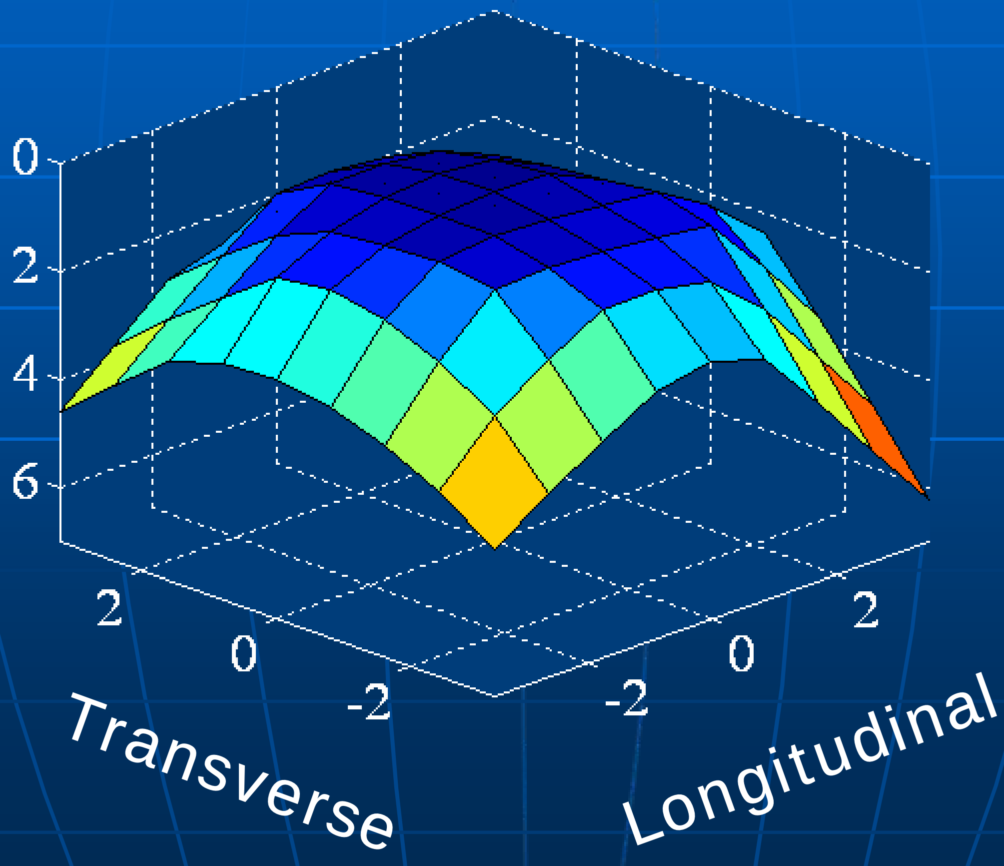


Uplift of the Footing from the Underlying Ground

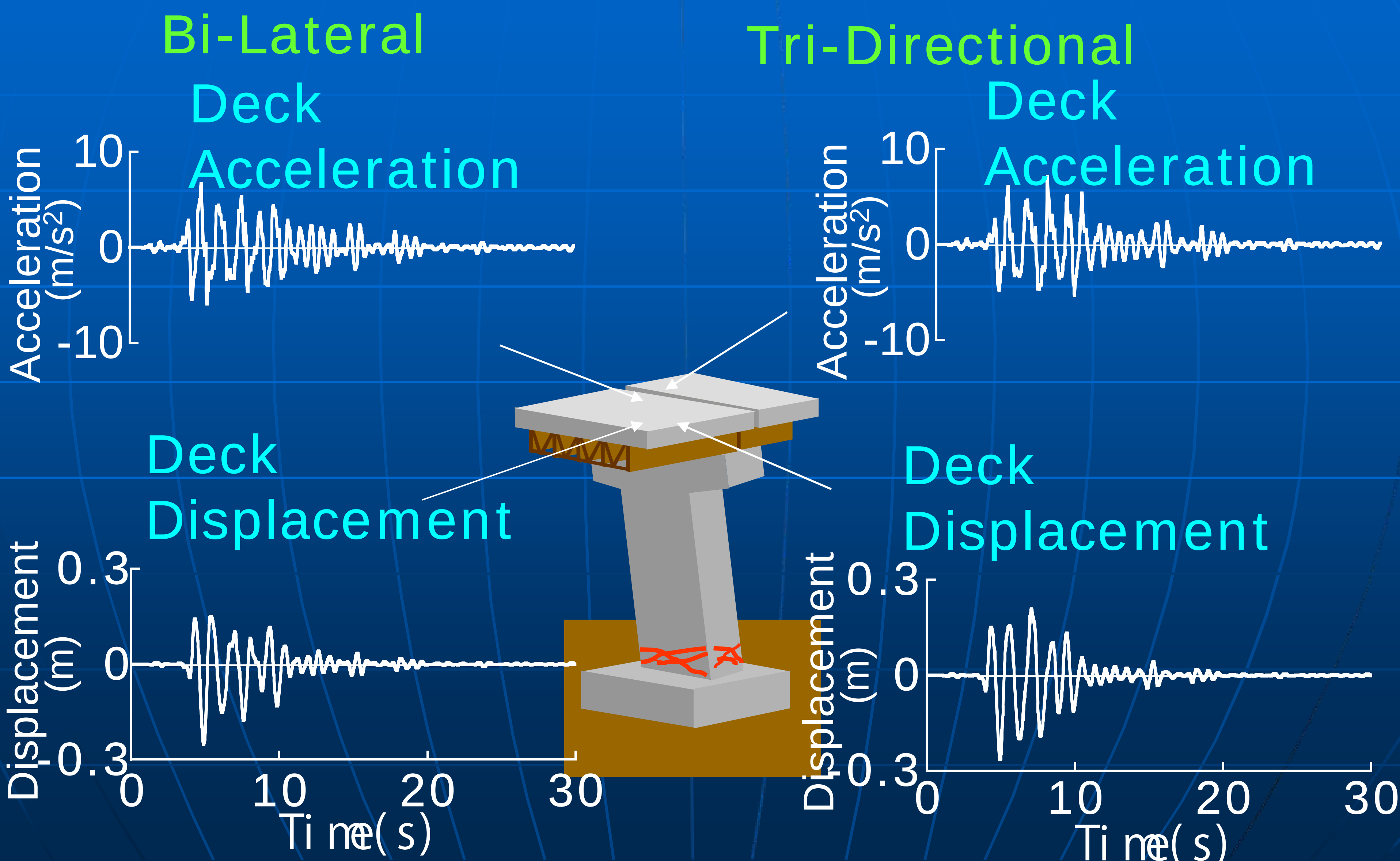




Reaction Force of the Underlying Ground at Corners increases under Bilateral Excitation

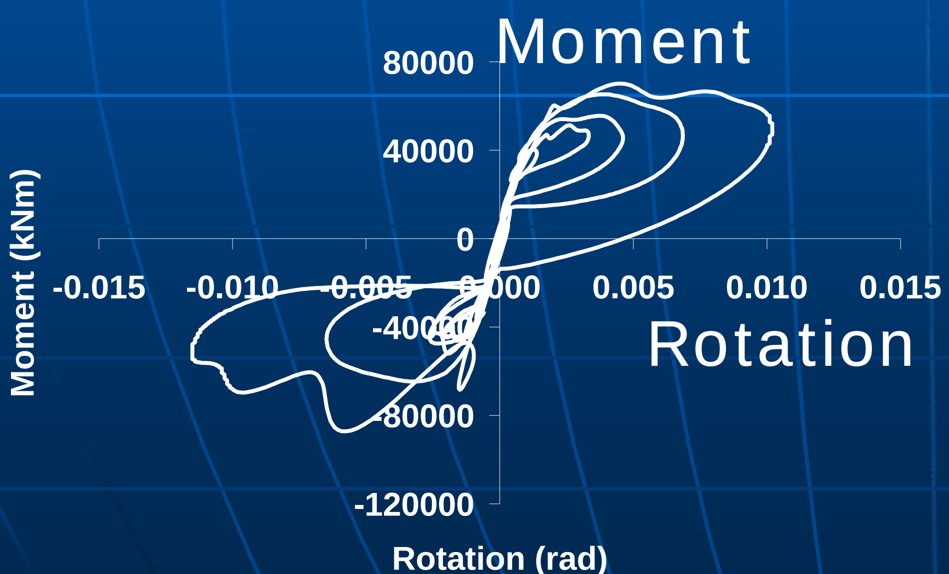


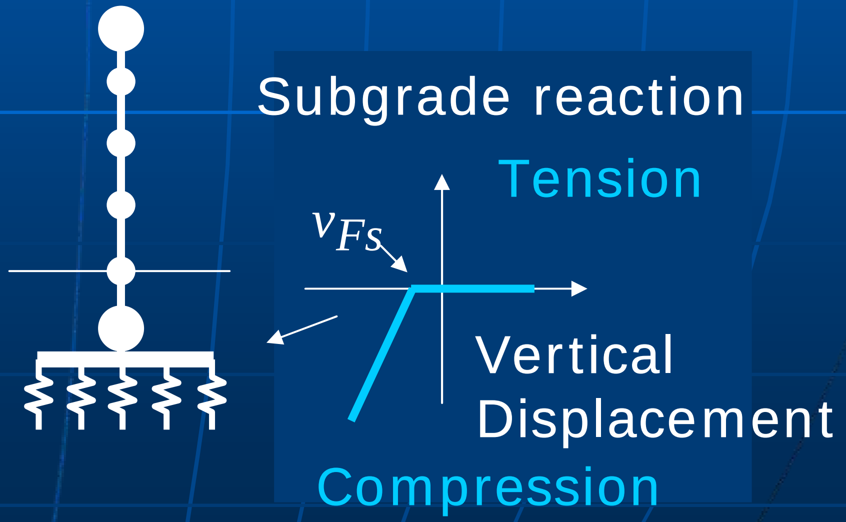
Seismic Response under 3 Directional Excitation



Why do we have an isolation effect by the foundation rocking no matter how we assume the elastic soil spring?

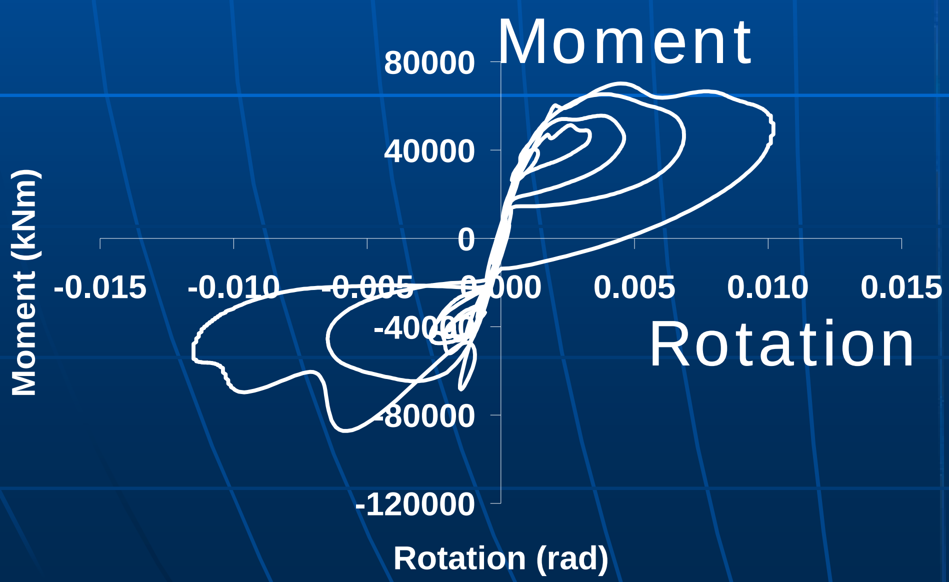
- There is no energy dissipation in the soil spring if we assume the elastic behavior
- Amplitude dependent period shift

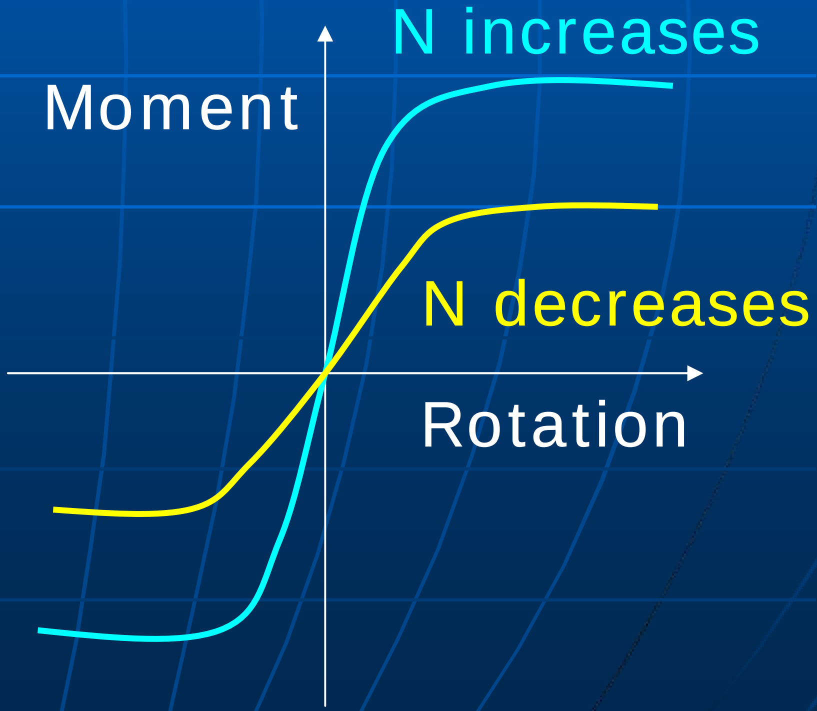




Why do we have “hysteretic-like” moment vs. curvature relation no matter how we assume the elastic soil spring?

- Moment vs. rotation relation depends on the vertical force, and this results in “hysteretic-like” relation under variation of the vertical force.

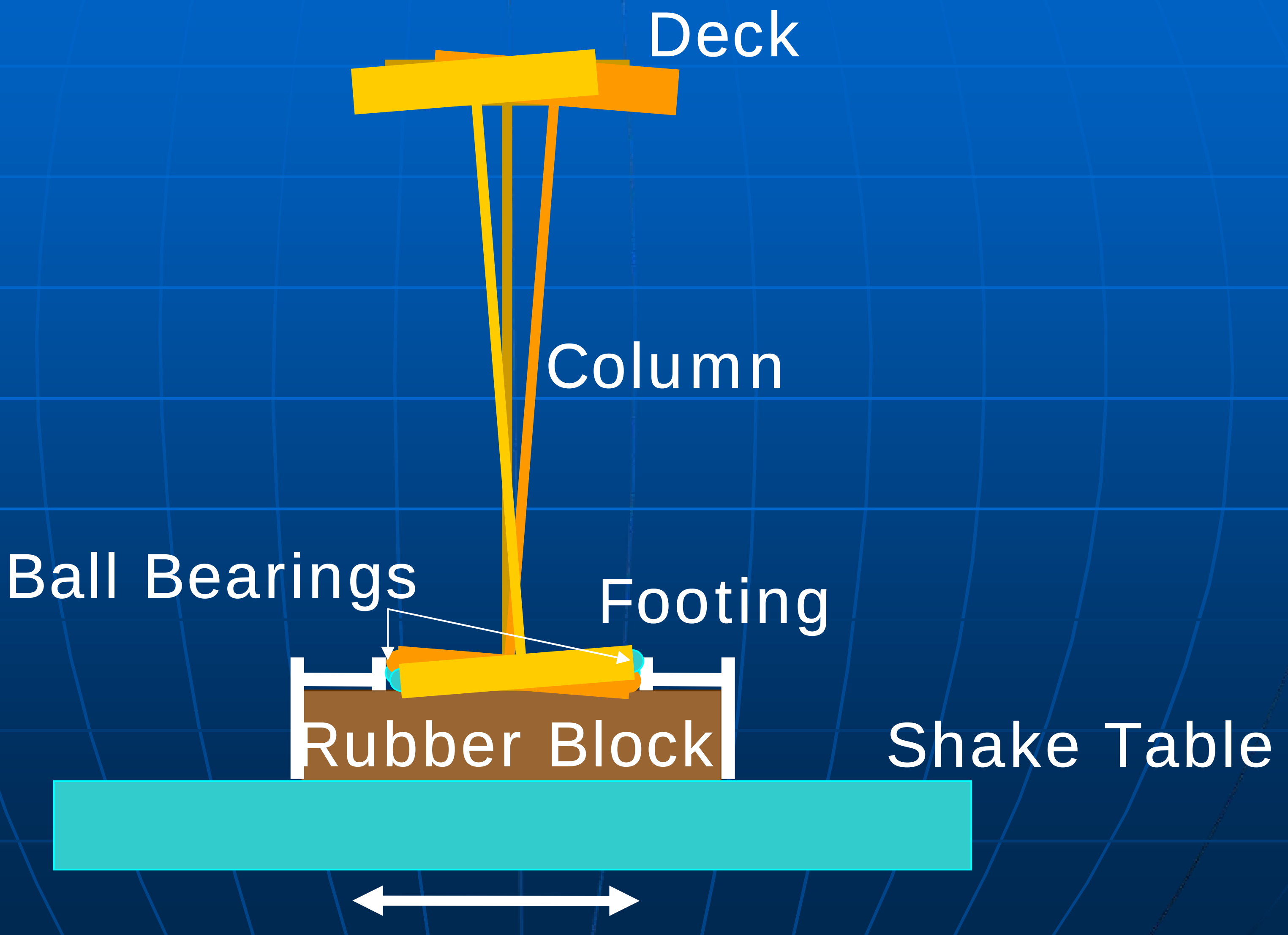




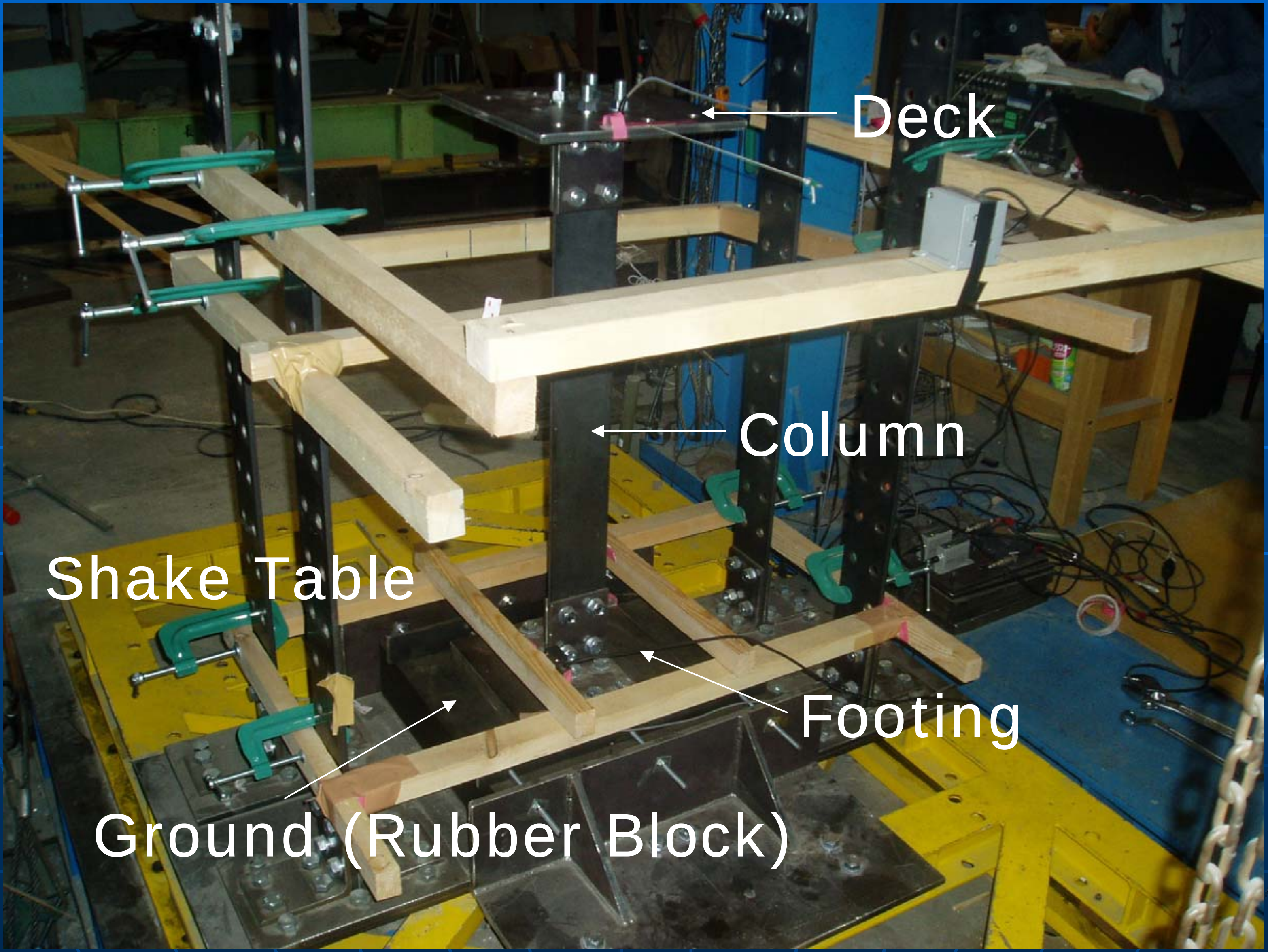
Factors which contribute to the energy dissipation of a foundation during rocking response

- Nonlinear soil behavior around a foundation (nonlinearity of soils, yield of bearing capacity, sliding & slip, etc)
- Energy dissipation due to pounding of the footing to the underlying ground
- Radiational damping
- ...

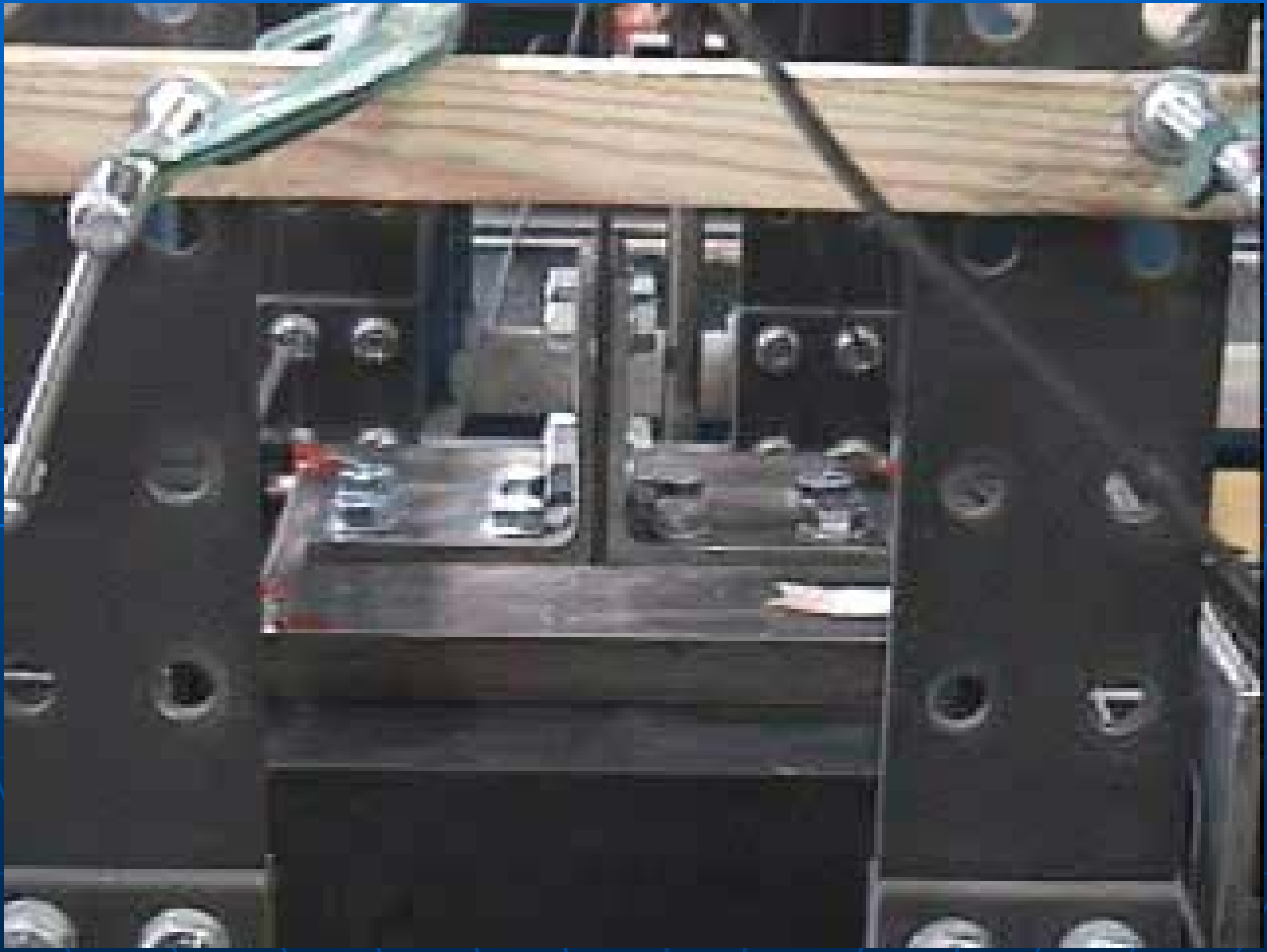
Verification of Seismic Rocking Isolation by a Shake Table Experiment



Experimental Model

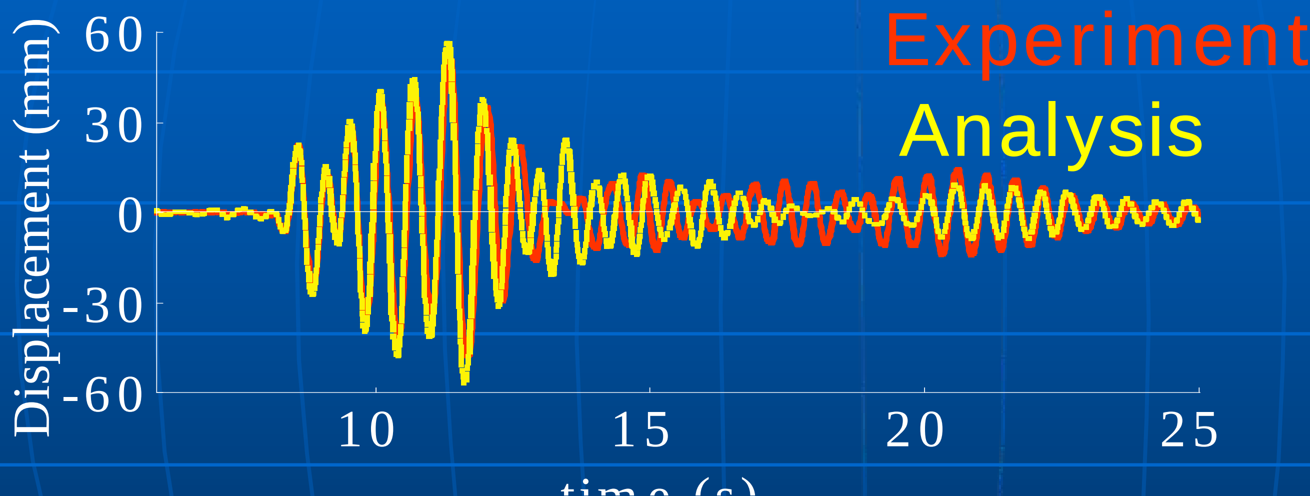


Excitation of Model Foundation under Niigata-Chuetsu Ground Motion

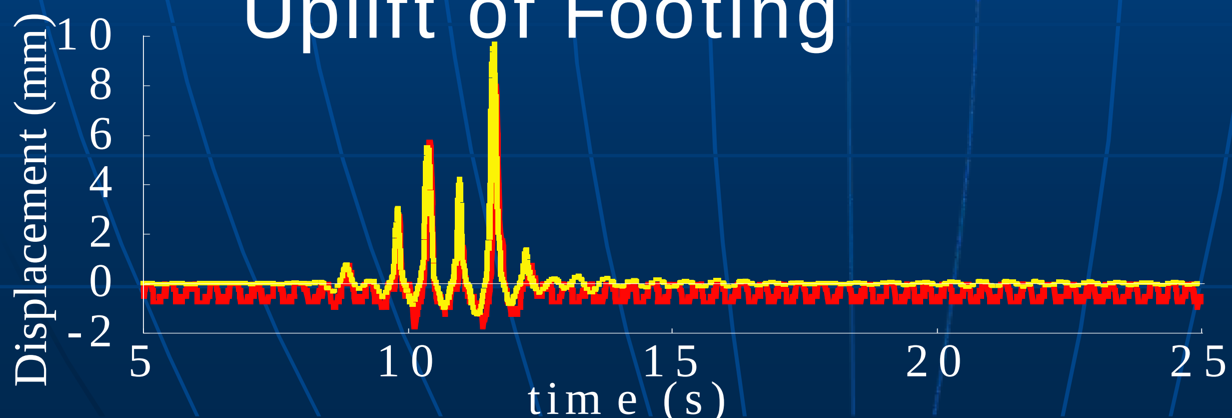


Correlation of the Experimental Response by Analysis

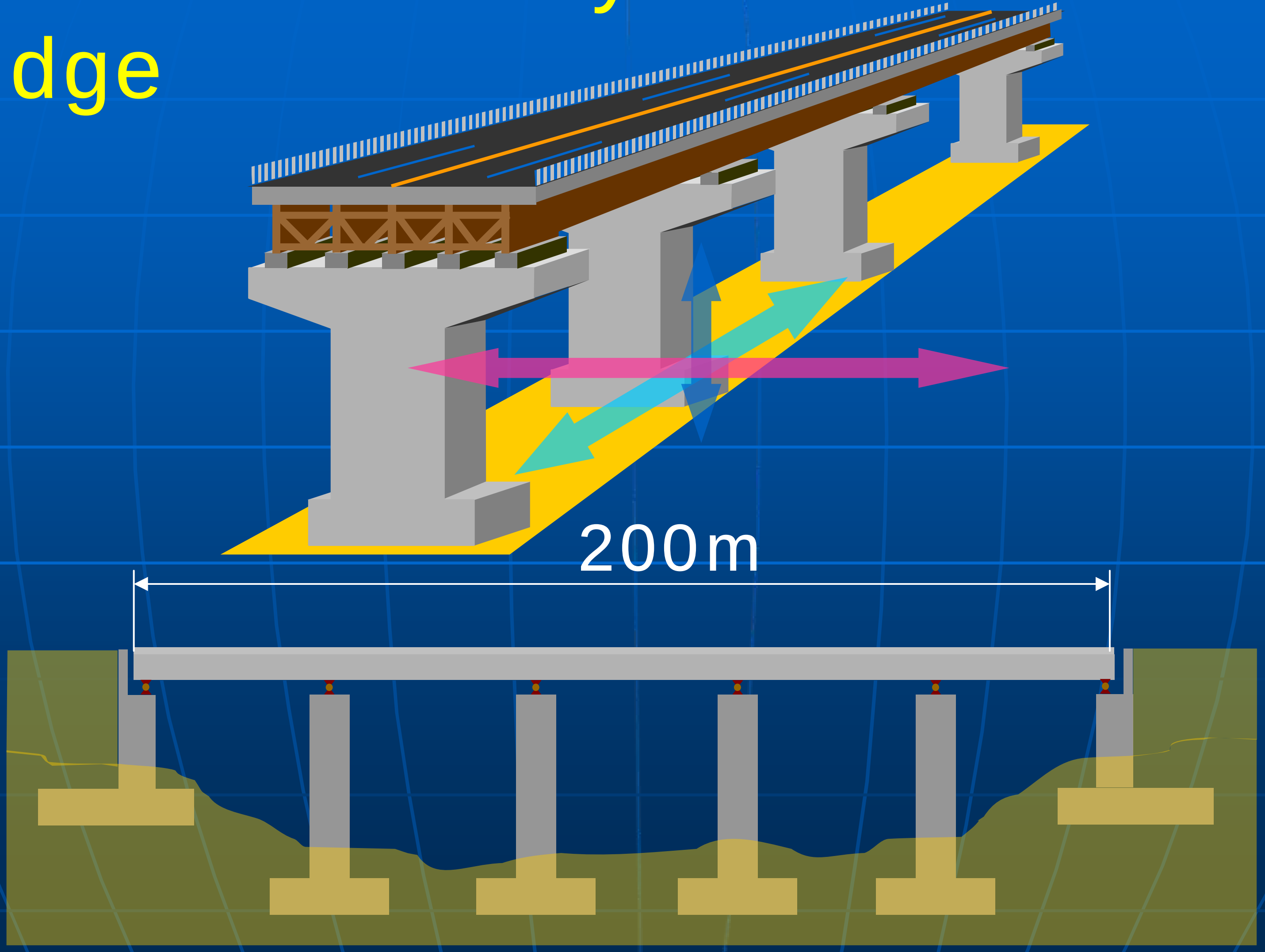
Deck Displacement



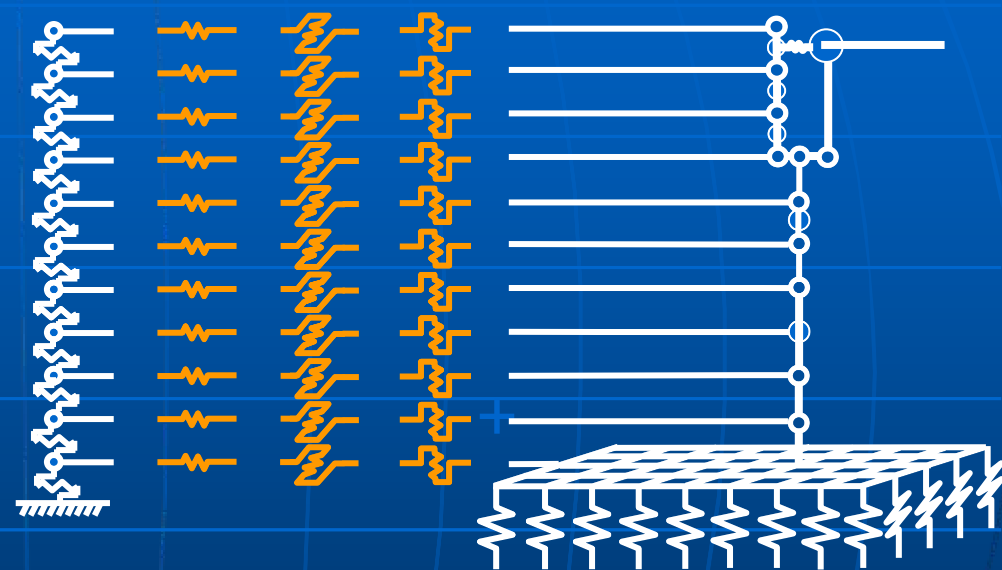
Uplift of Footing



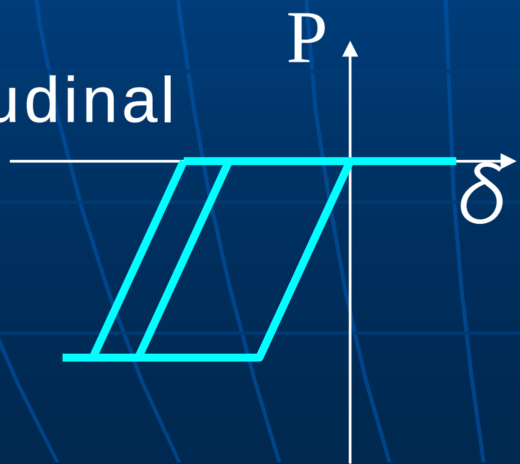
Implementation of Rocking Isolation to Analysis of a Whole Bridge



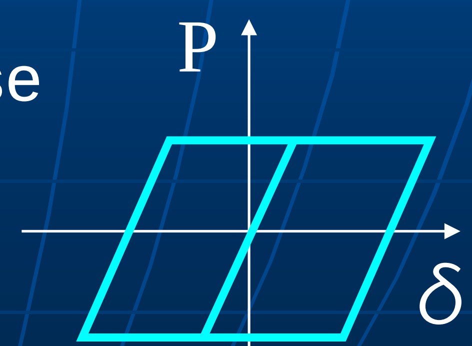
Idealization of Interaction between Abutment and Backsoils



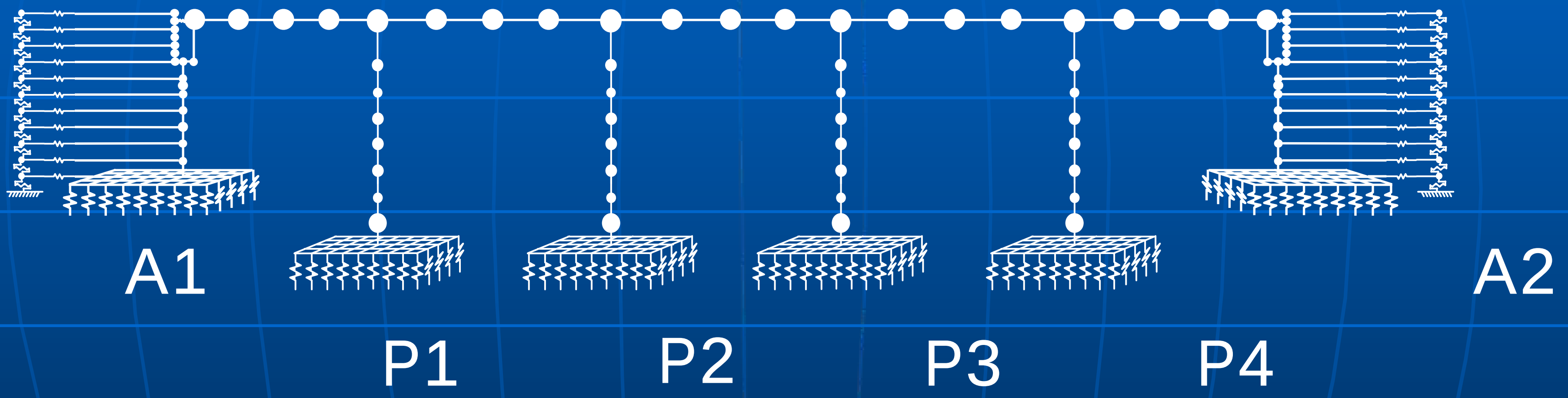
Longitudinal



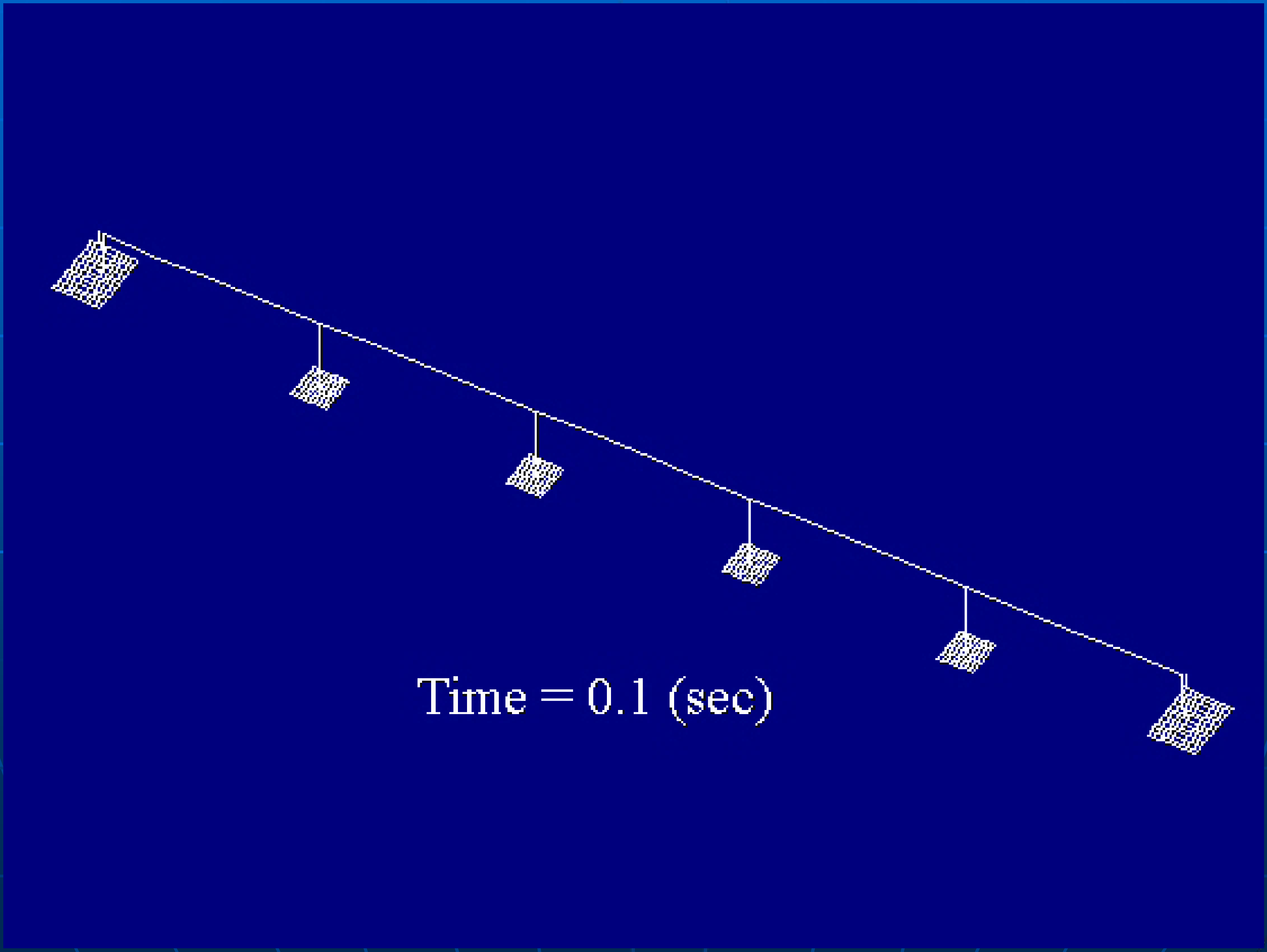
Transverse and Vertical



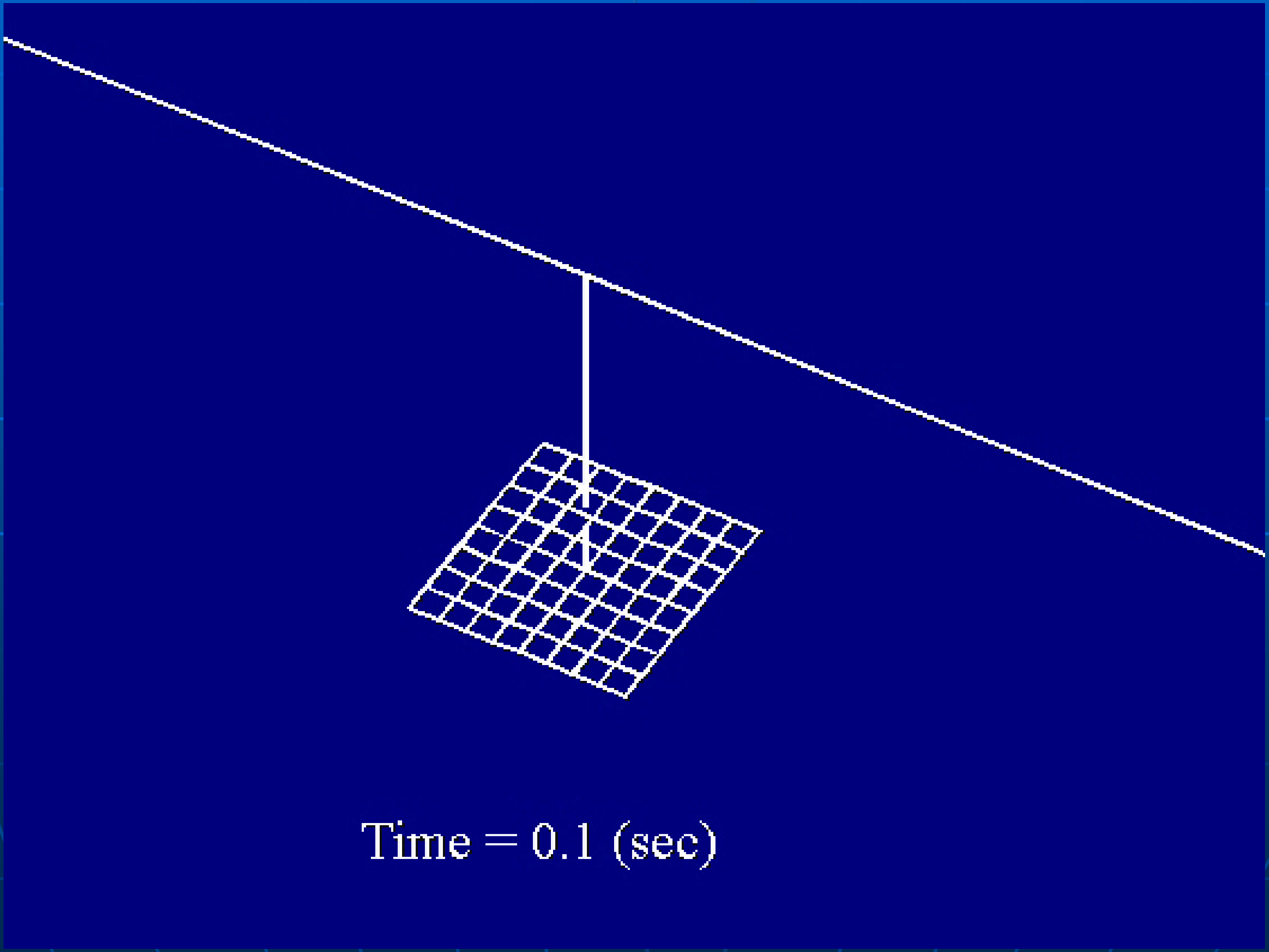
Idealization of Target Bridge



Response of Target Bridge under JMA Kobe Ground Motion



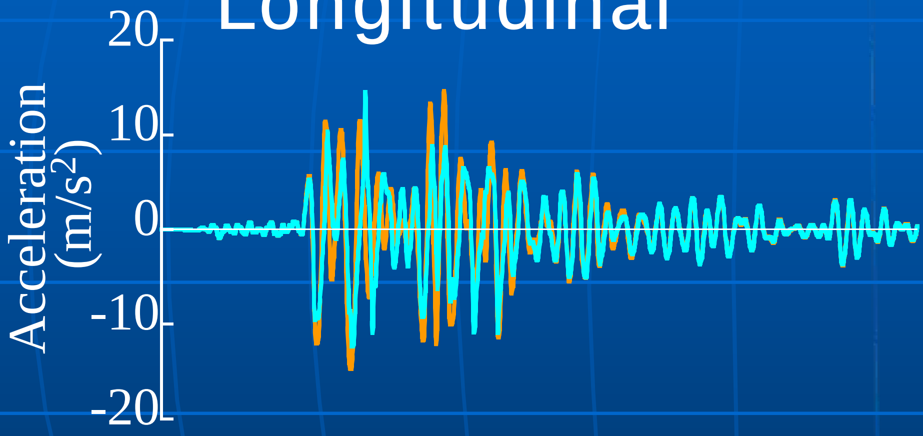
Response of P2 under JMA Kobe Ground Motion



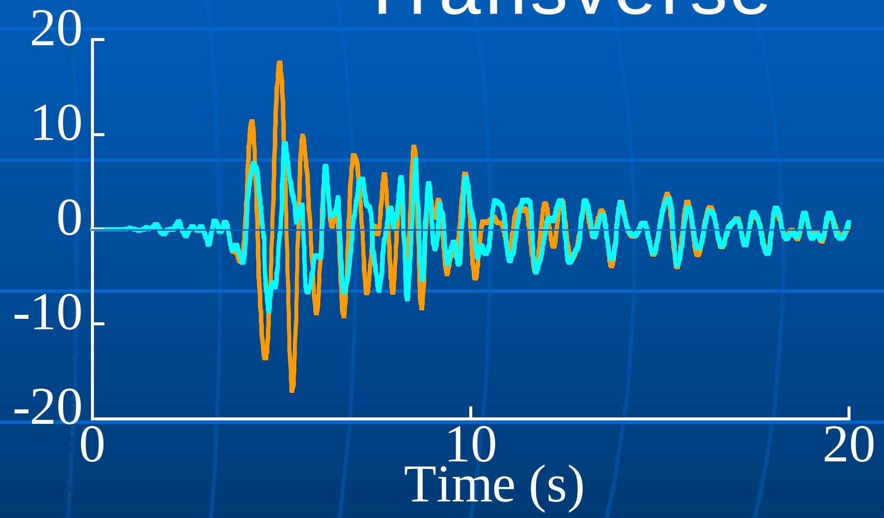
Deck Acceleration at P2

Conventional / Rocking Isolation

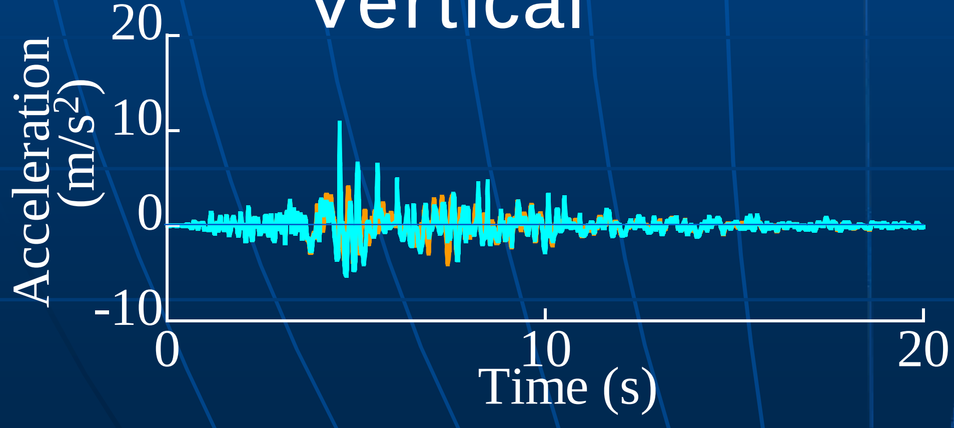
Longitudinal

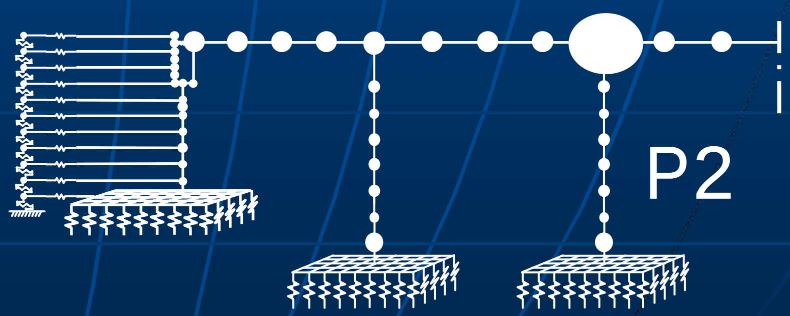


Transverse



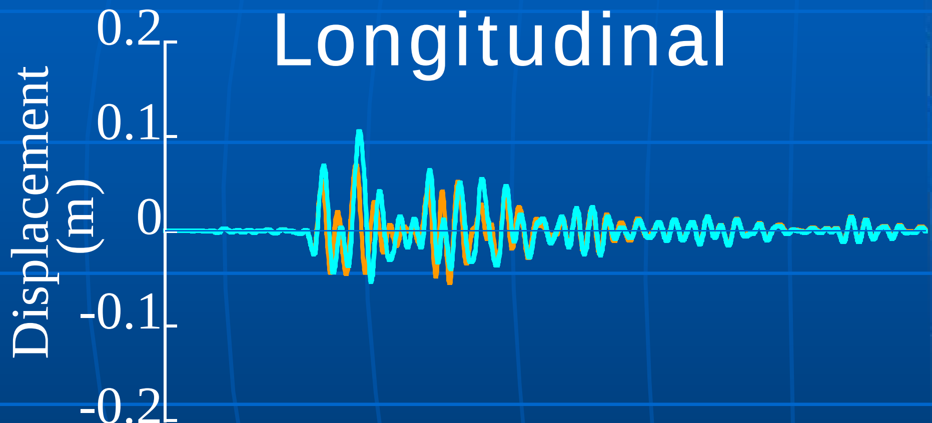
Vertical

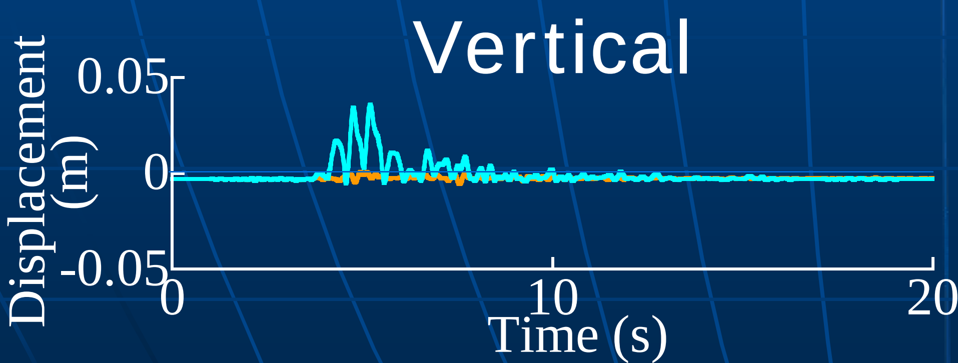




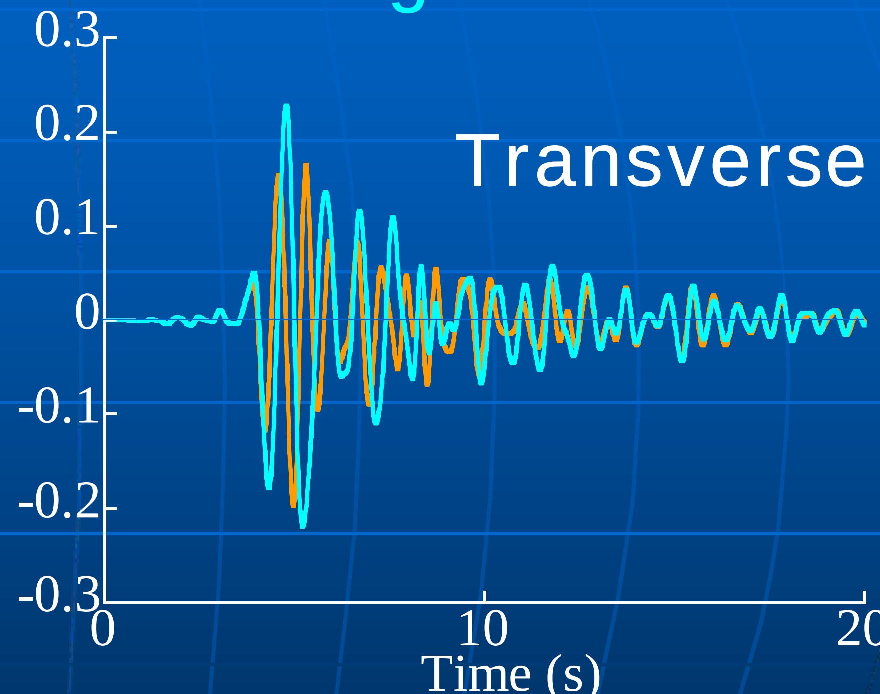
Deck Displacement at P2

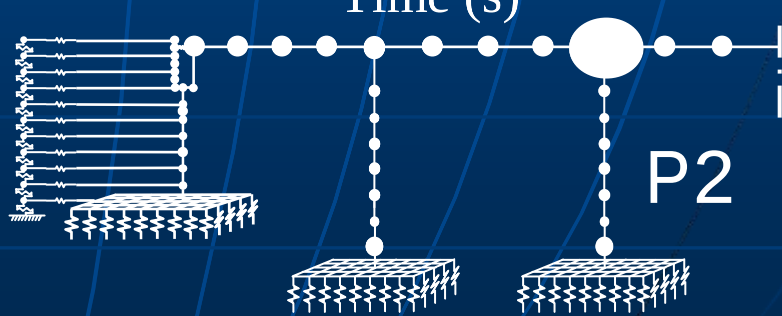
Conventional





Rocking Isolation

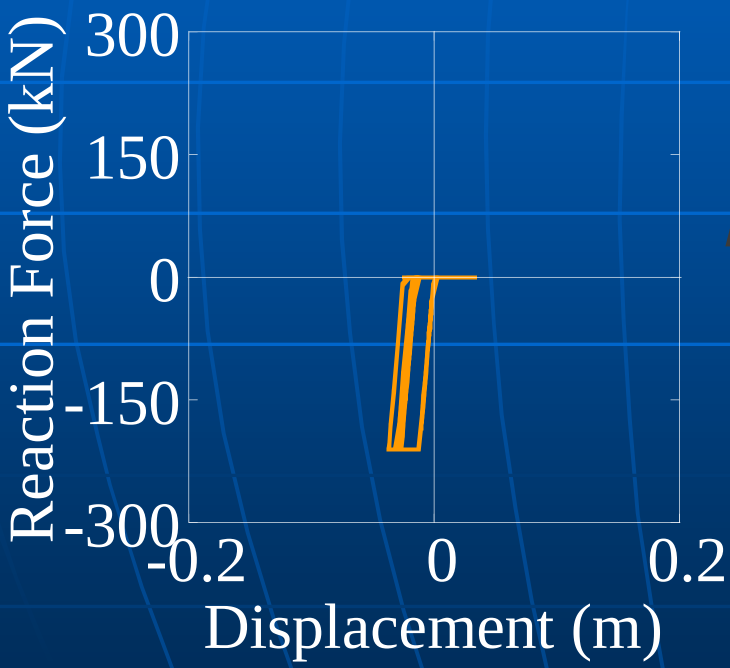


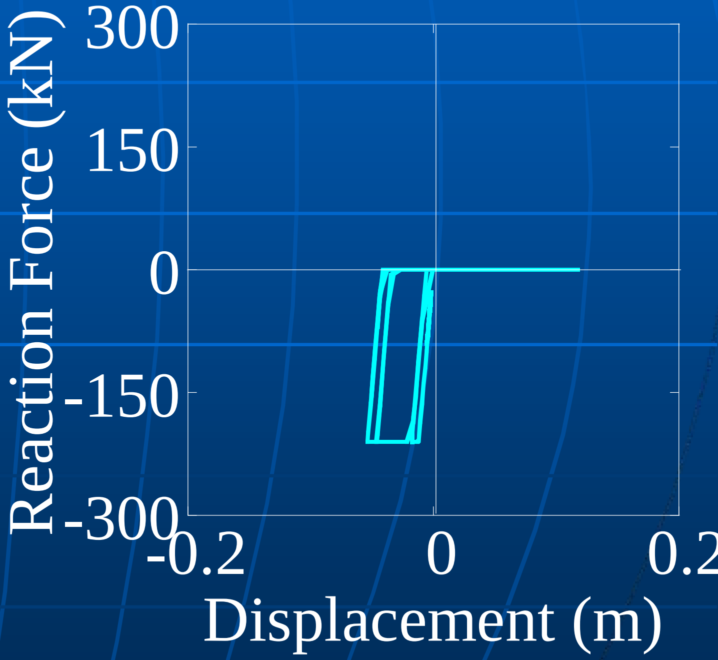


Abutment and Backsoils Interaction in the Longitudinal Direction

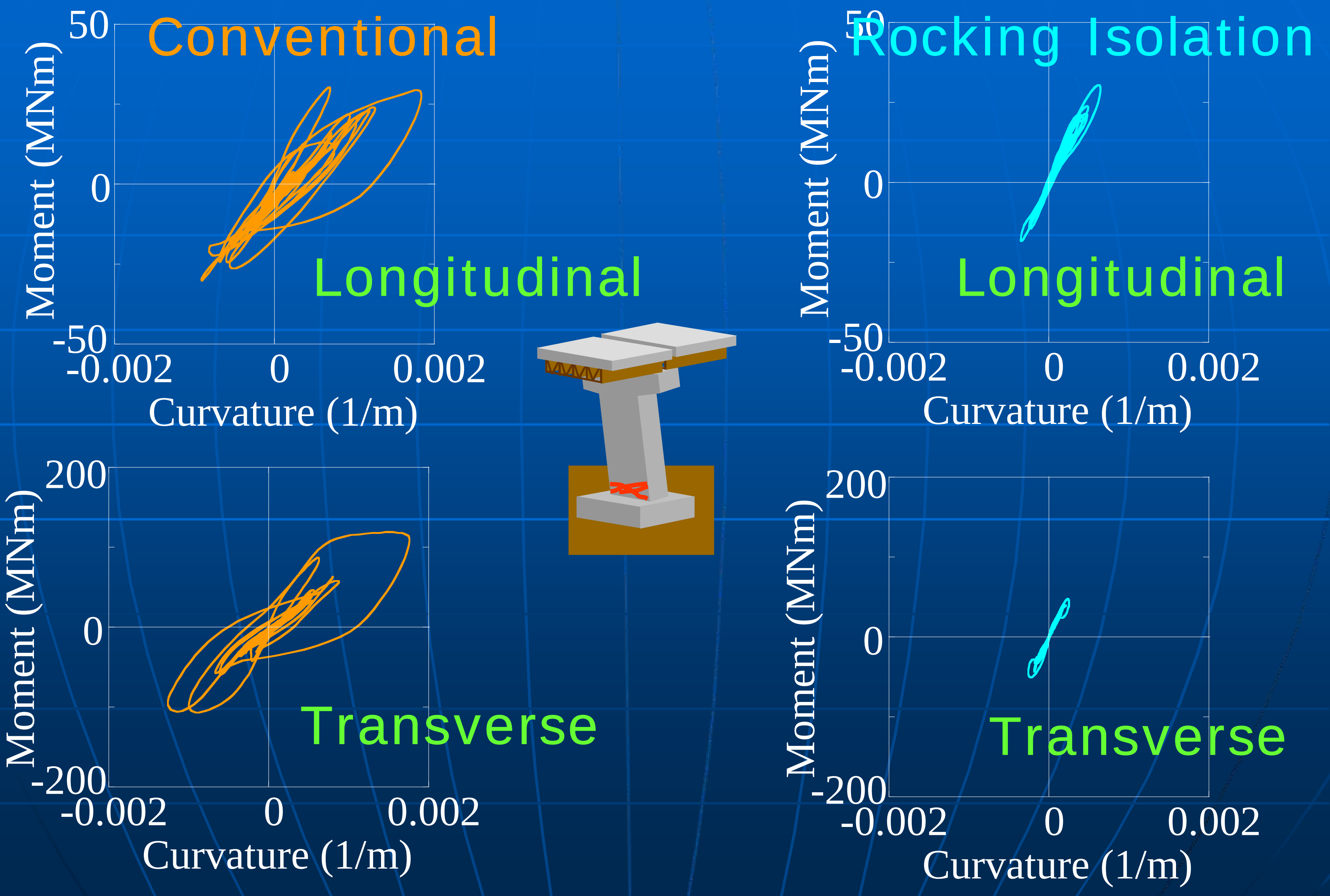
Conventional

Rocking Isolation



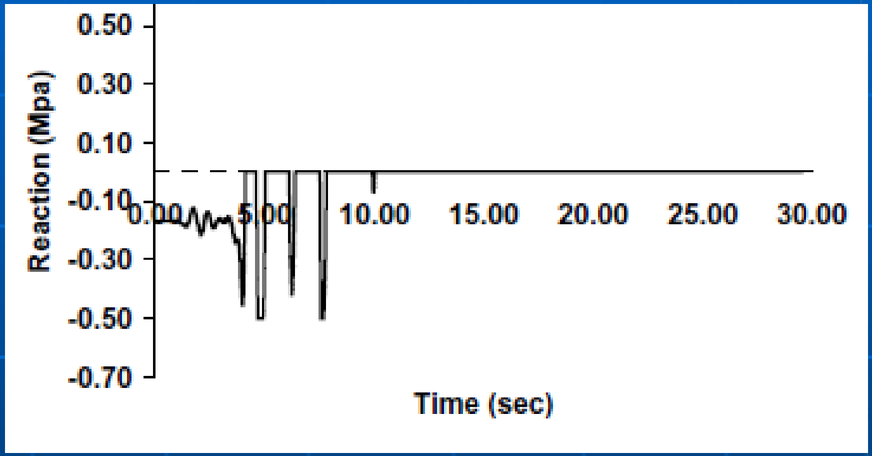


Curvature at the Plastic Hinge of P2

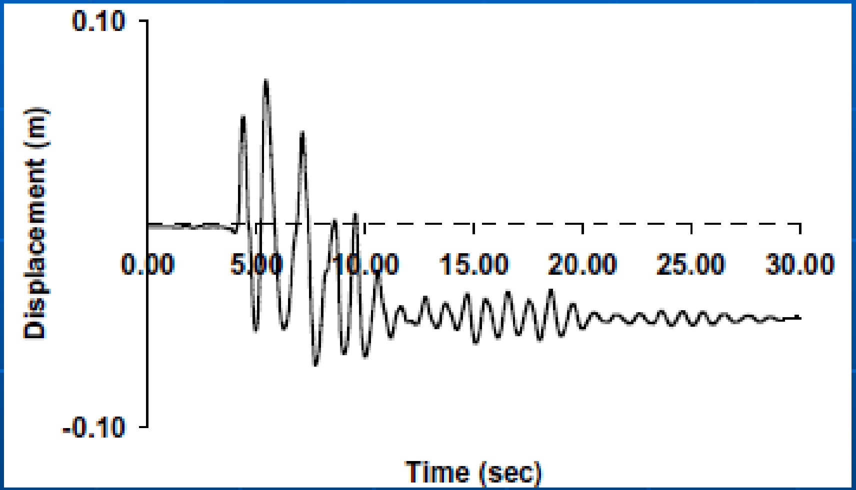


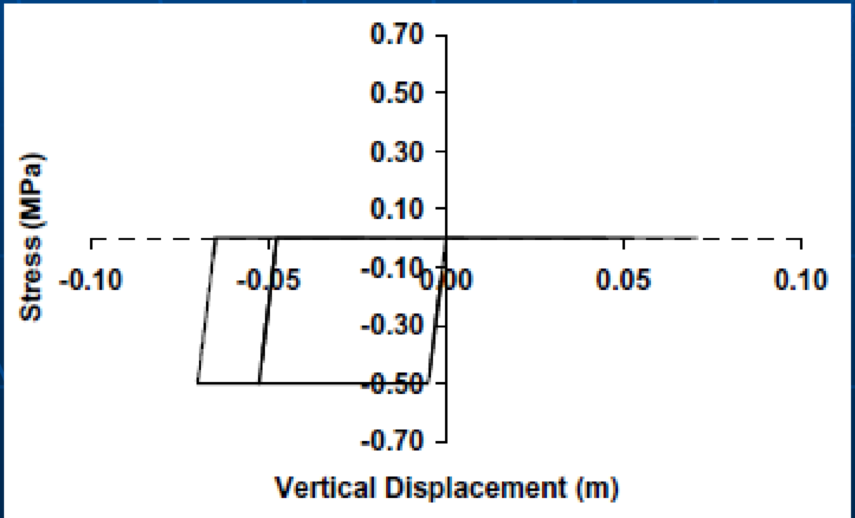
Effect of Yield of the Underlying Ground (0.5MPa)

Vertical stress



Vertical displacement





Stress vs. vertical displacement

Conclusions

- When separation of a footing from the underlying ground due to rocking response is included in analysis, the plastic deformation of a column significantly decreases as a result of softening of the moment vs. rotation hysteresis of the footing.
- If the underlying ground yields, it enhances the effect of rocking isolation, however it increases the deck response displacement and it can result in residual drift.
- Bridge response acceleration decreases under the seismic rocking isolation, however bridge response displacement increases.

Related publications

●Kawashima, K., Unjoh, S. and Shimizu, H.: Analysis of rocking vibration of rigid foundations, Proc. 8th US-Japan Bridge Workshopn, Panel on Wind & Seismic Effects, UJNR, Chicago, USA, pp. 3-17, 1992

●Kawashima, K., Unjoh, S., Shimizu, H. and Mukai, H.: Analytical method of seismic rocking response of a rigid foundation considering the response of superstructure, Journal of Civil Engineering, Vol. 36, No. 2, pp. 42-36, 1994

Kawashima, K. and Hosoiri, K.: Rocking response of bridge columns on direct foundation, Proc. Fib-Symposium, Concrete structures in seismic region, Paper No. 118 (CD-ROM), Athens, 2003

●Mergos, P. E., and Kawashima, K.: Rocking isolation of a typical bridge pier on spread foundation, Journal of Earthquake Engineering, Vol. 9, Special Issue 2, pp. 395-414, 2005

●Sakellaraki, D. and Kawashima, K.: Effectiveness of seismic rocking isolation of bridges based on shake table test, First European Conference on Earthquake engineering and Seismology, Paper No. 364, pp. 1-10, Geneva, Switzerland, 2006

Thank you for your kind attention.