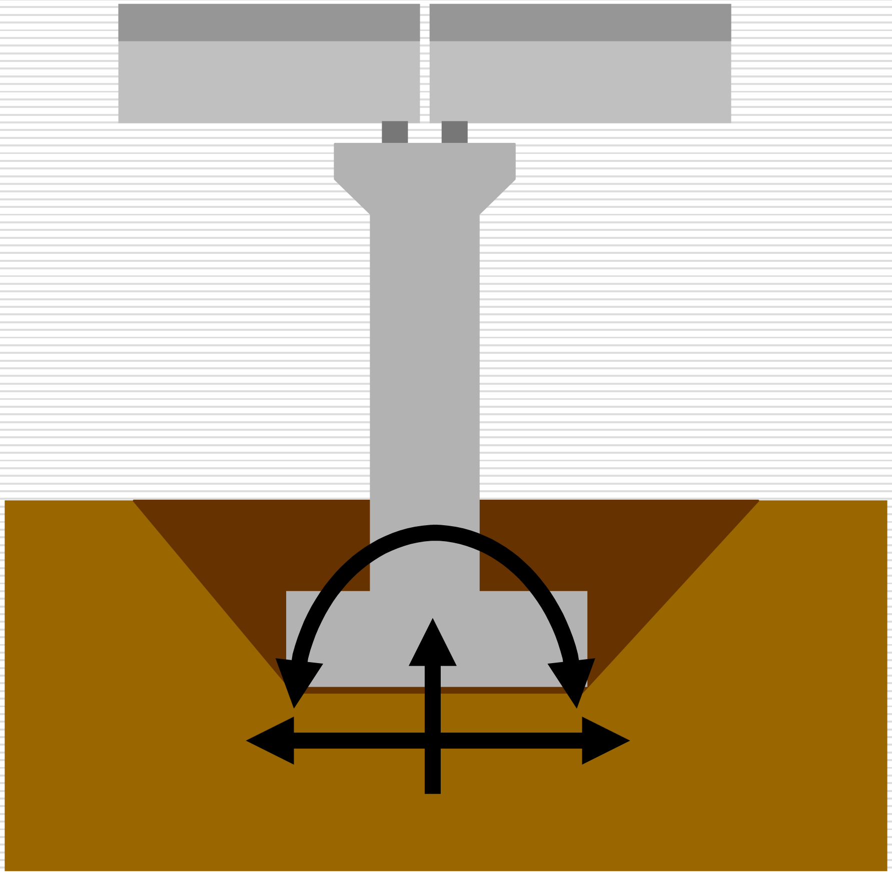
Response Modification of Urban Infrastructure
都市施設の免震設計

第7章　基礎ロッキング免震
Chapter 7 Rocking Isolation of Foundations

東京工業大学
川島一彦
Kazuhiko Kawashima
Tokyo Institute of Technology

Requirements of Foundations in Seismic Design
基礎の耐震設計の要件



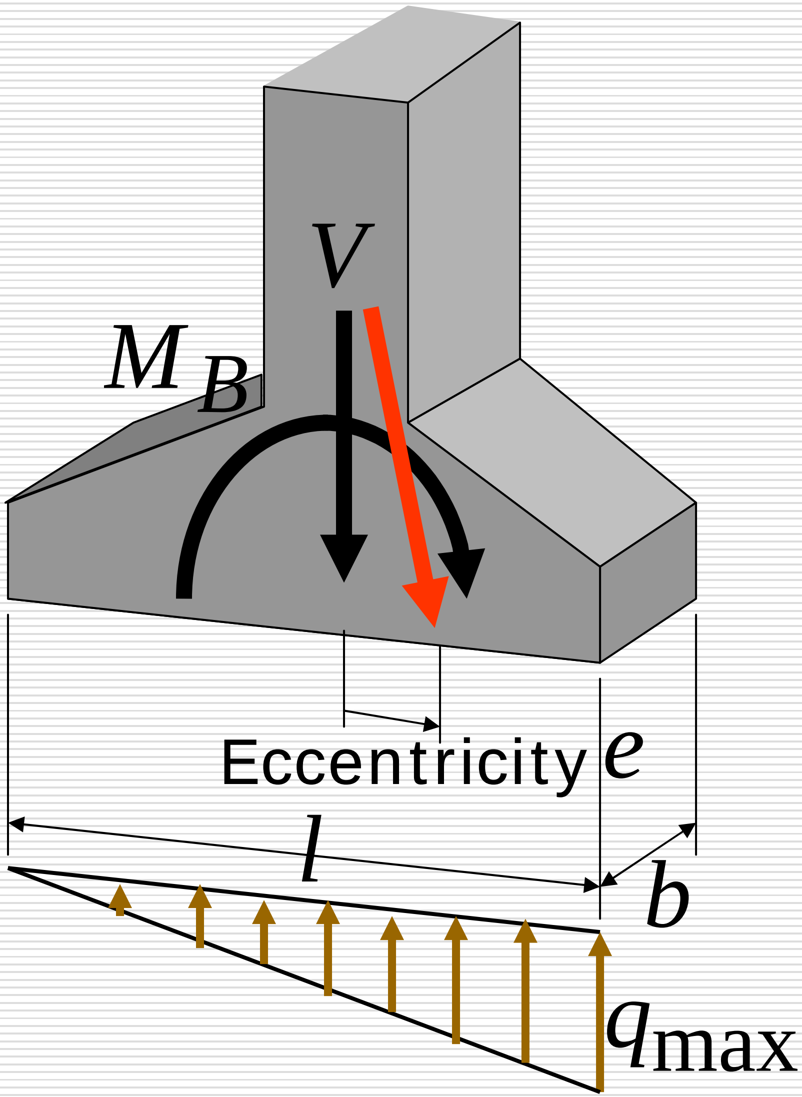
Static Seismic Design

- Bearing capacity耐力
- Sliding滑動
- Rocking転倒

Dynamic Response

- Sliding + Rocking
- Rocking + Jump

Requirements for Rocking Response in the Static Design静的な転倒照査



Eccentricity偏心率

$$e = \frac{M_B}{V} < e_a$$

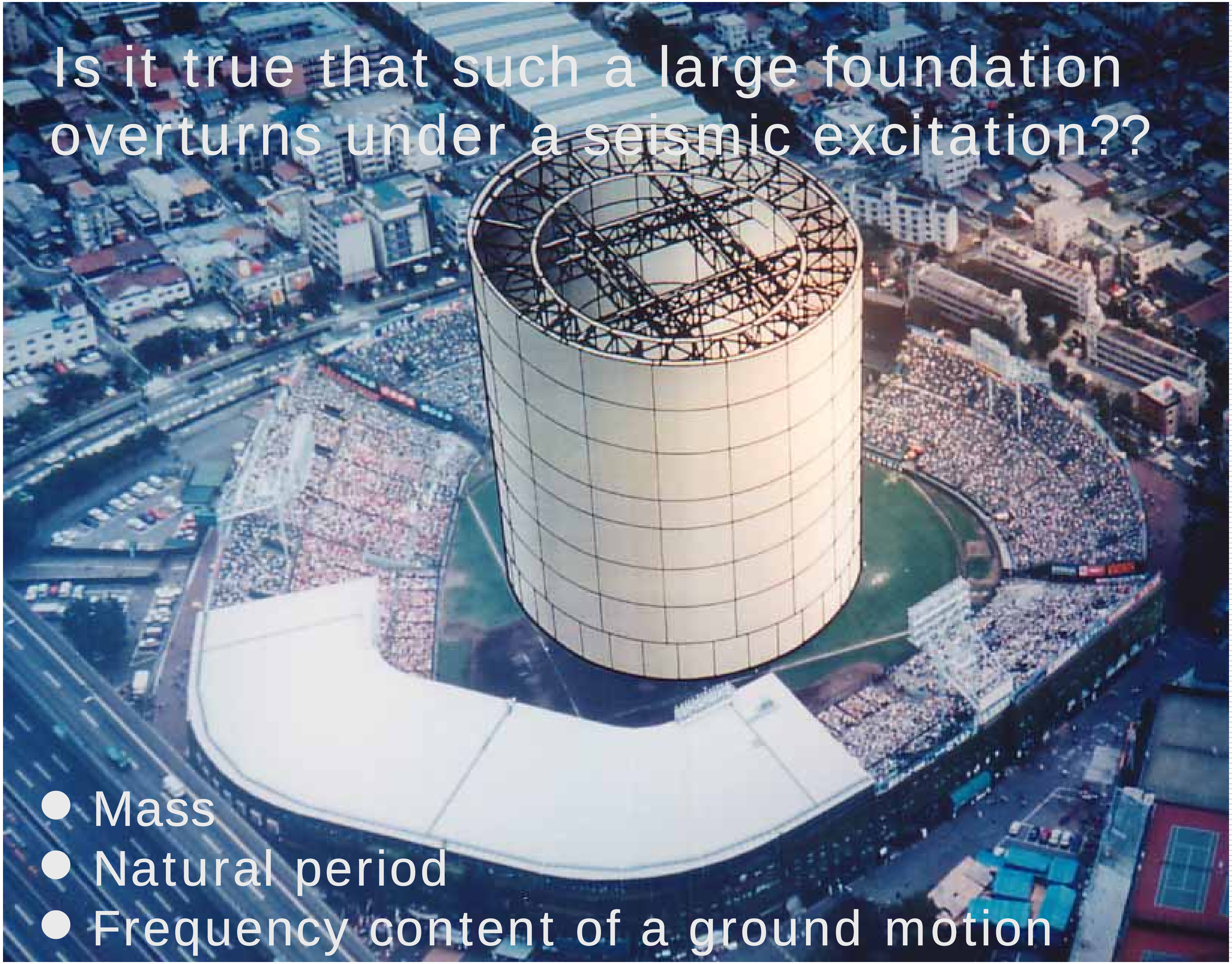
Allowable Eccentricity

$$e_a = \begin{cases} l/3 & \text{— Static} \\ l/6 & \text{— Static +Seismic} \end{cases}$$

Bearing Capacity耐力

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


Akashi Strait Bridge
The World Longest Bridge
In the static design, overturning was
the major factor for sizing those foundations



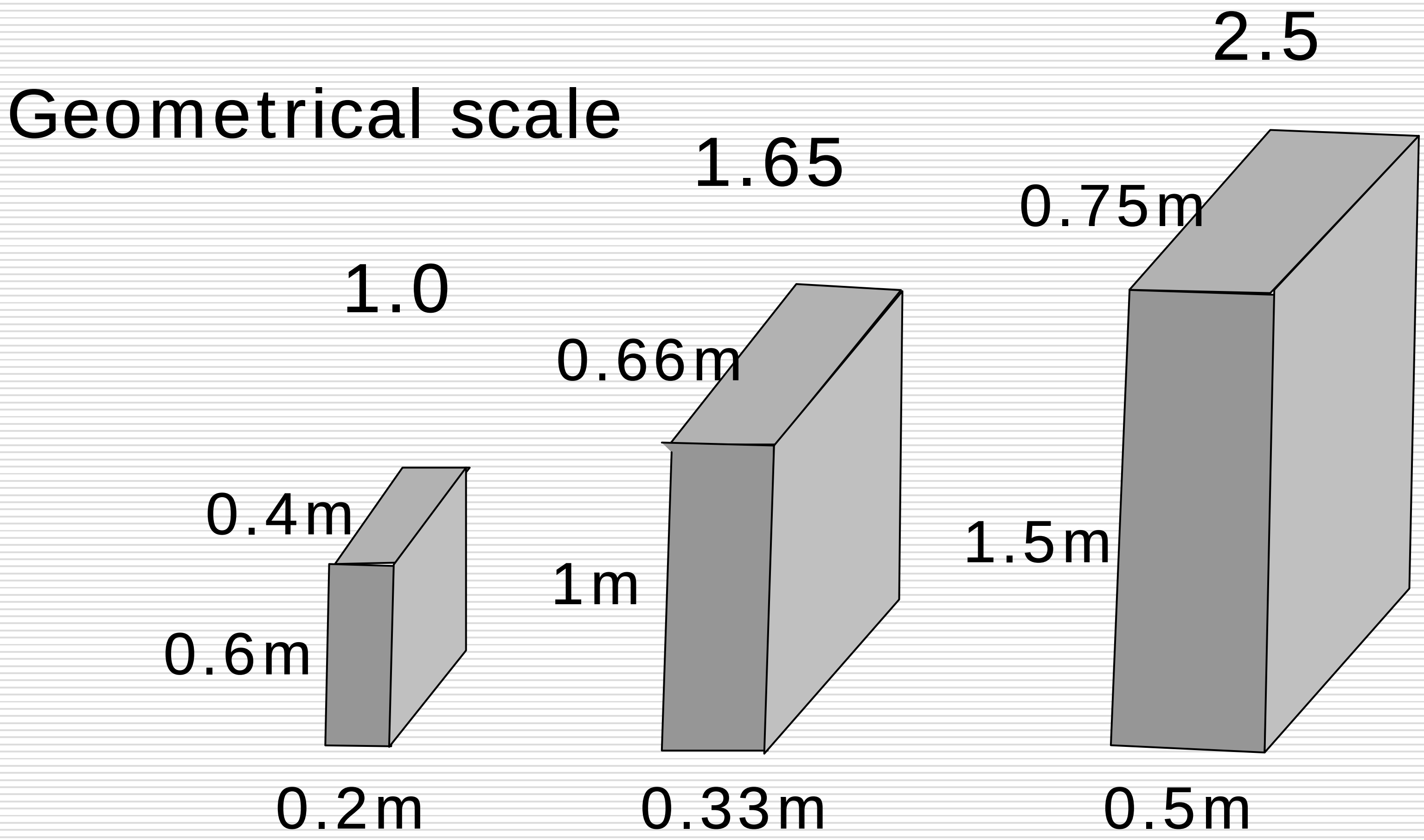
Is it true that such a large foundation overturns under a seismic excitation??

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

Overturning of Foundation-Tower System of Akashi Straight Bridge
明石海峡大橋の耐震設計

- Static Analysis on Overturning of Foundation-Tower System was eliminated from seismic design
- This is because static overturning analysis is unrealistic
- Decision of design was made based on nonlinear dynamic response analysis and a preliminary static design based on critical velocity which results in overturning

Shake Table verification on Overturning of 3 Blocks in 1989



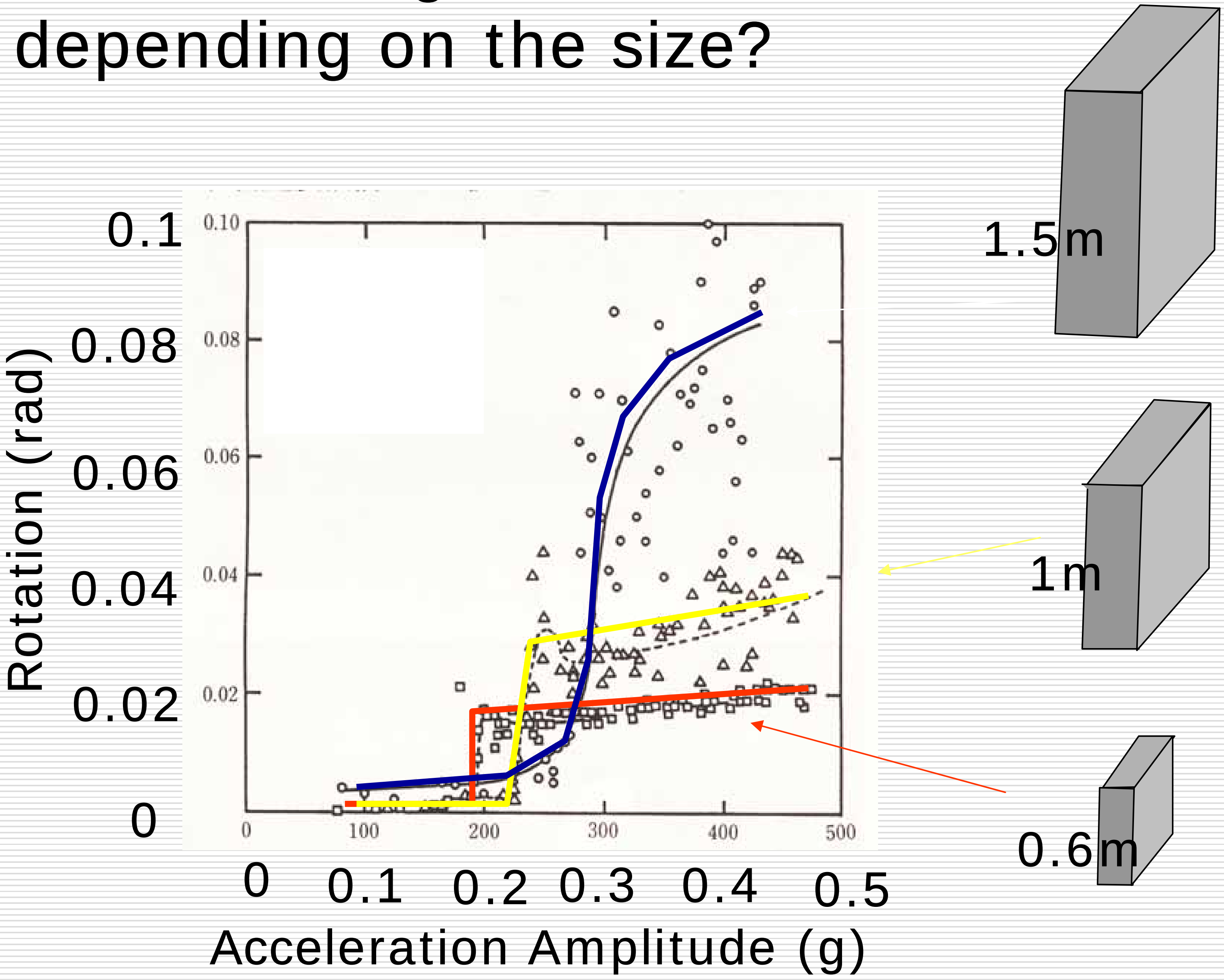
Kawashima & Unjoh (1991)

Shake Table Verification on Overturning of 3 Blocks

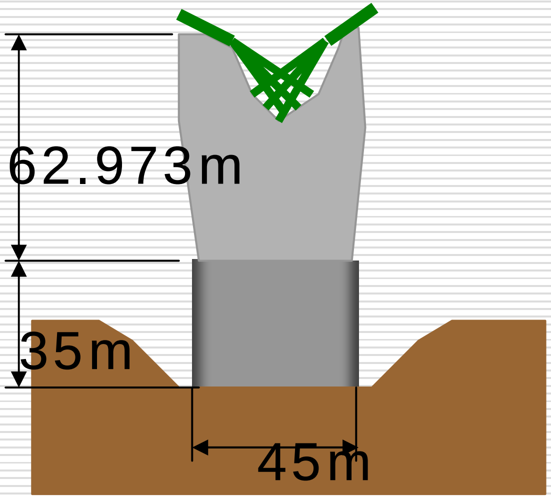
Public Works Research Institute

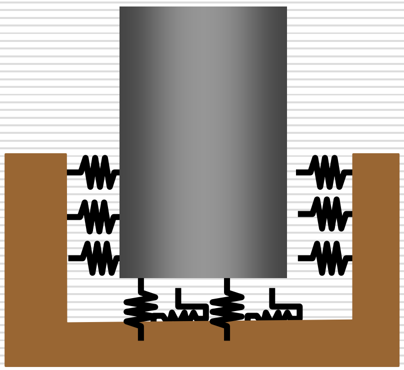
Kawashima & Unjoh (1991)

How did a rigid block rotation depending on the size?

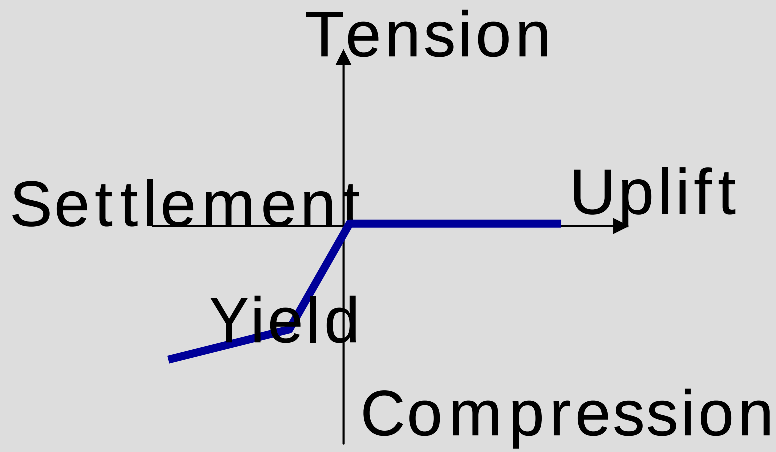


Analytical Idealization of 2 Anchorage of a Suspension Bridge

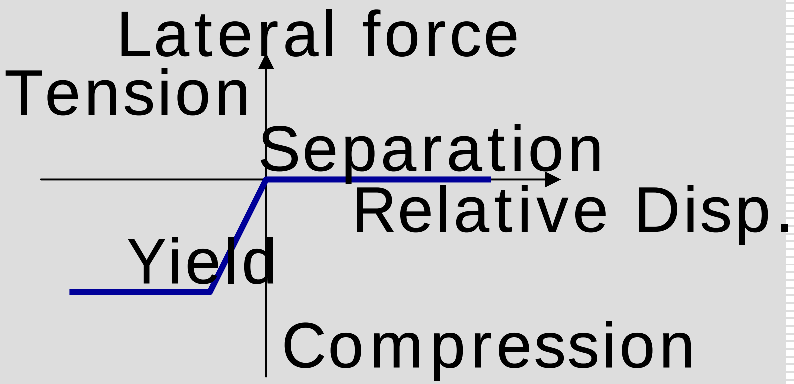




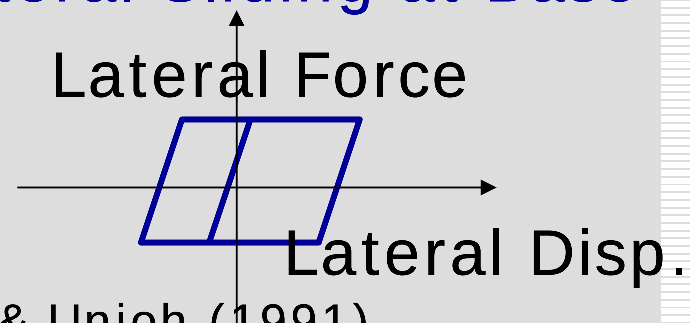
Base Vertical Springs



Side Soils

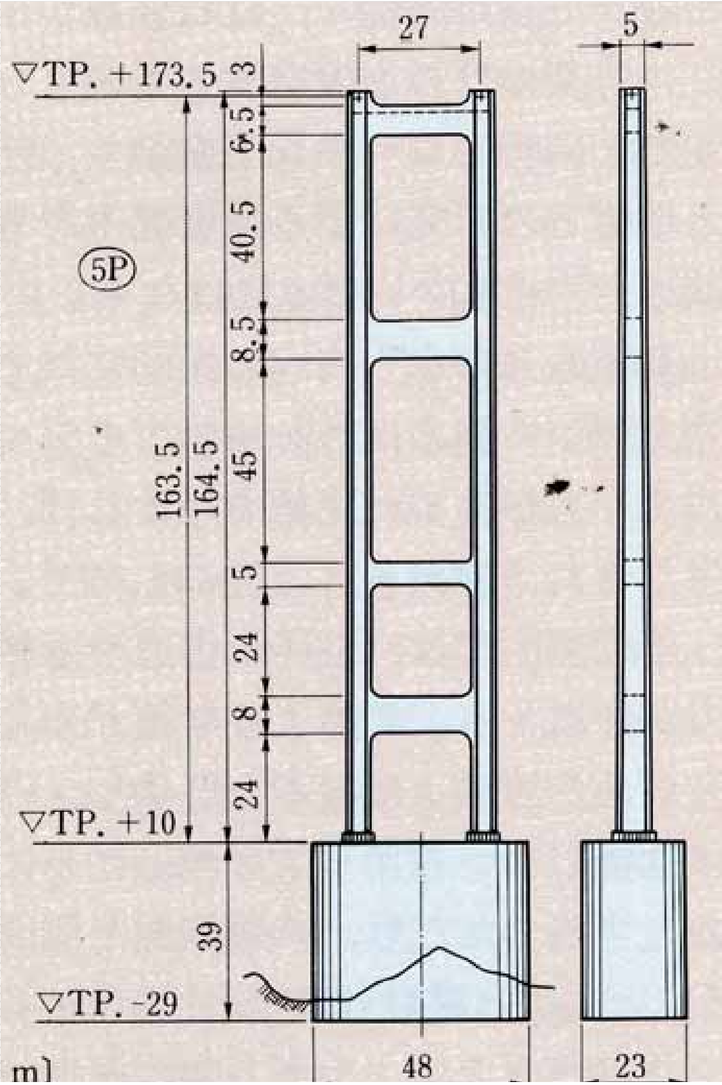


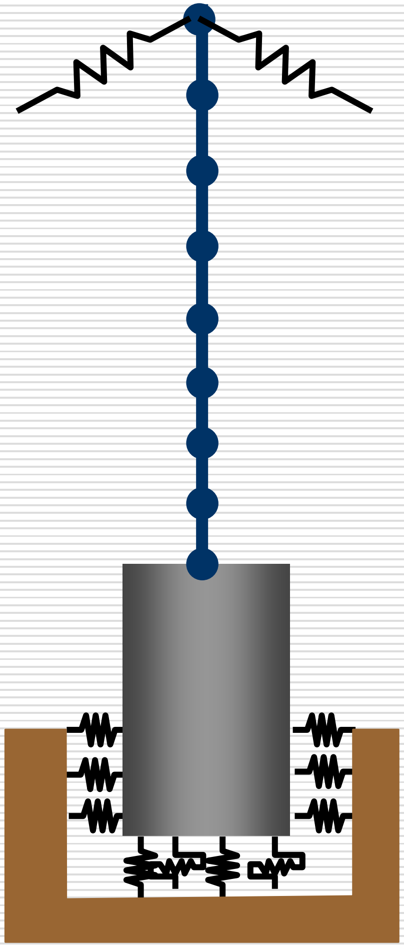
Lateral Sliding at Base



Kawashima & Unjoh (1991)

Analytical Idealization of a tower, cables, and a rigid footing





Kawashima et al (1994)

Seismic Rocking Isolation

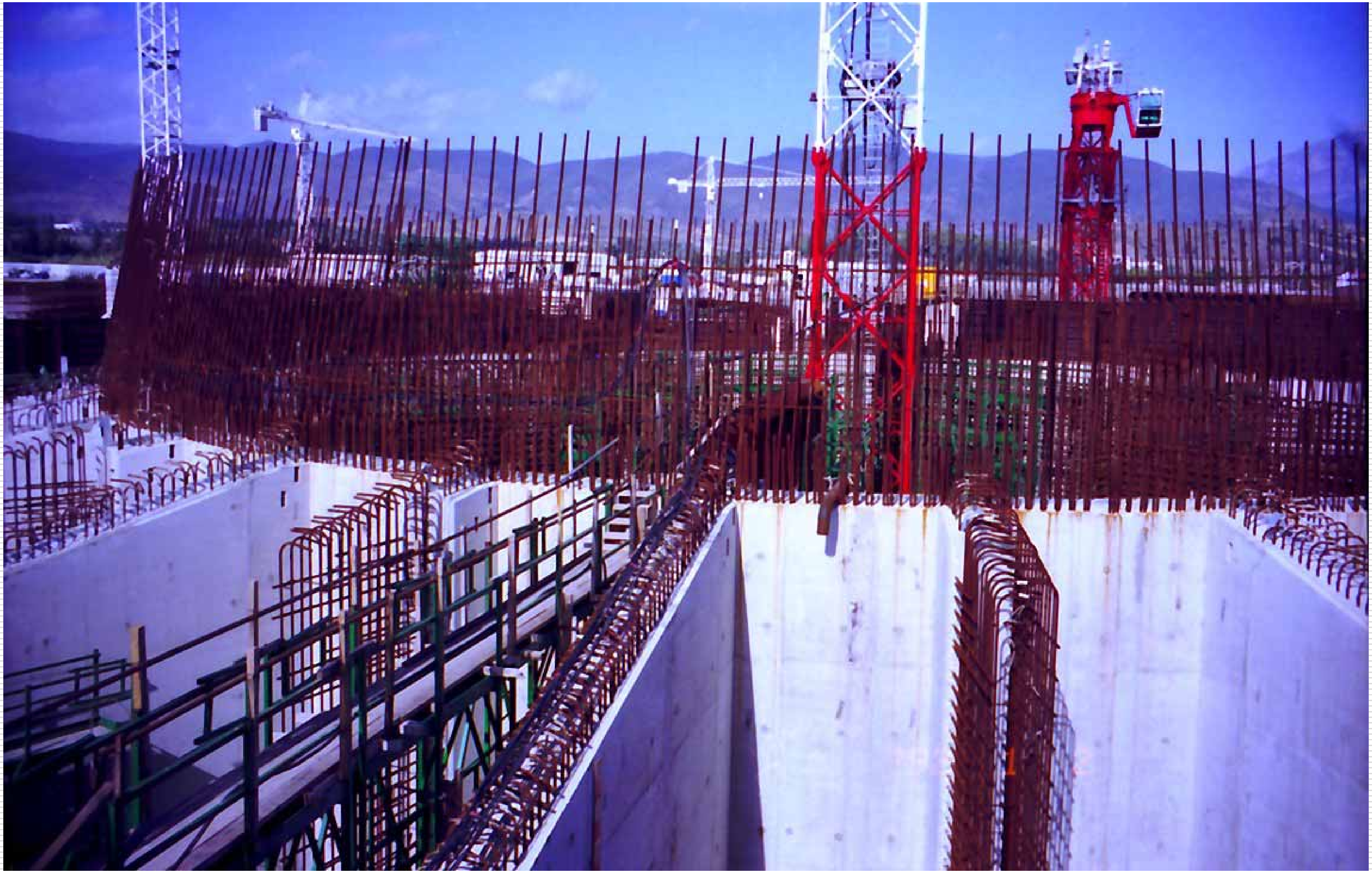
Rion Antirion Bridge, Greece

Courtesy of Dr. Alain Pecker

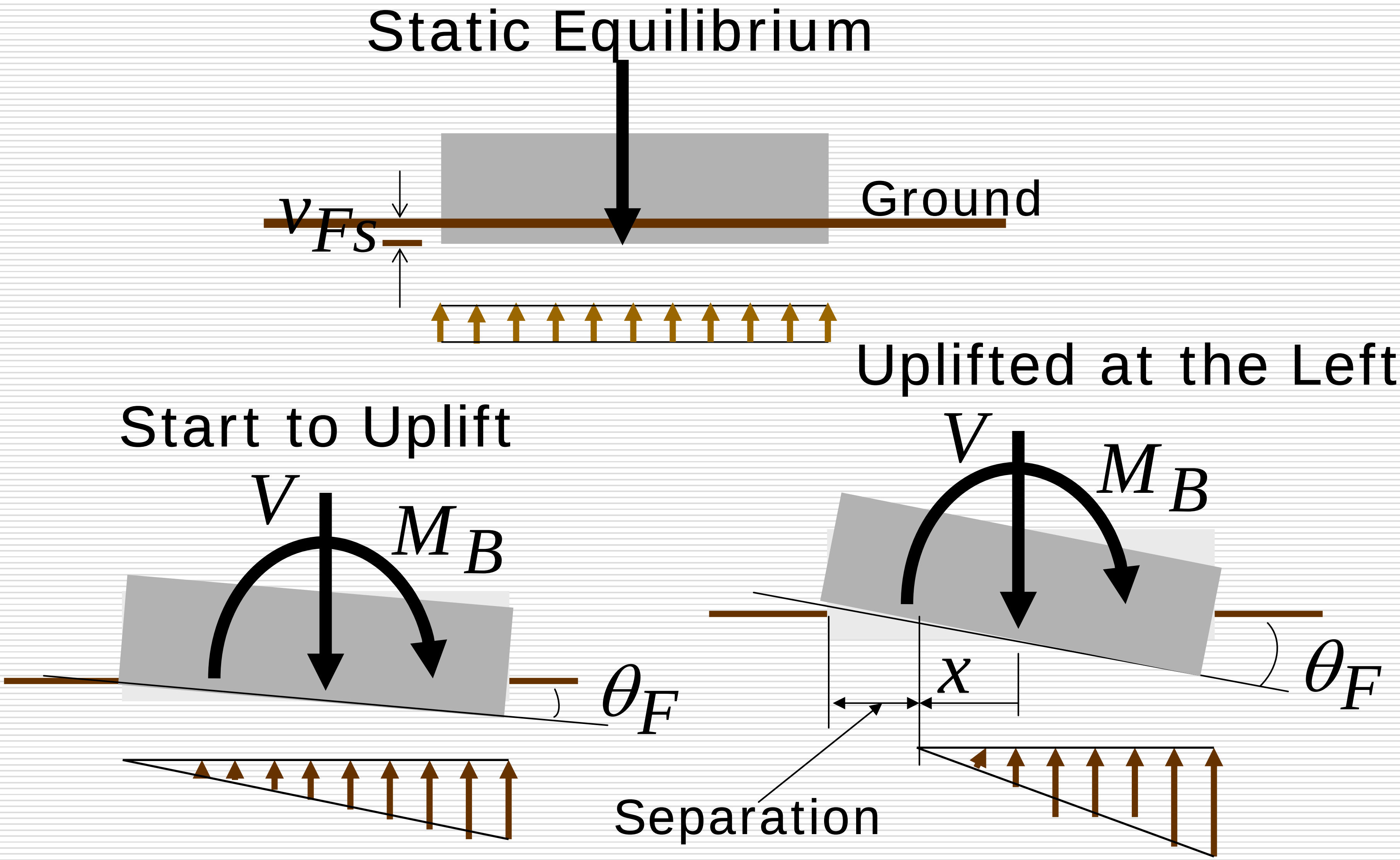
Concept of Rocking Isolation of Rion Anti-Rion Bridge

- Fault dislocation as large as 2 m is anticipated although the location of fault is not known.
- Rocking isolation reduces bridge response.

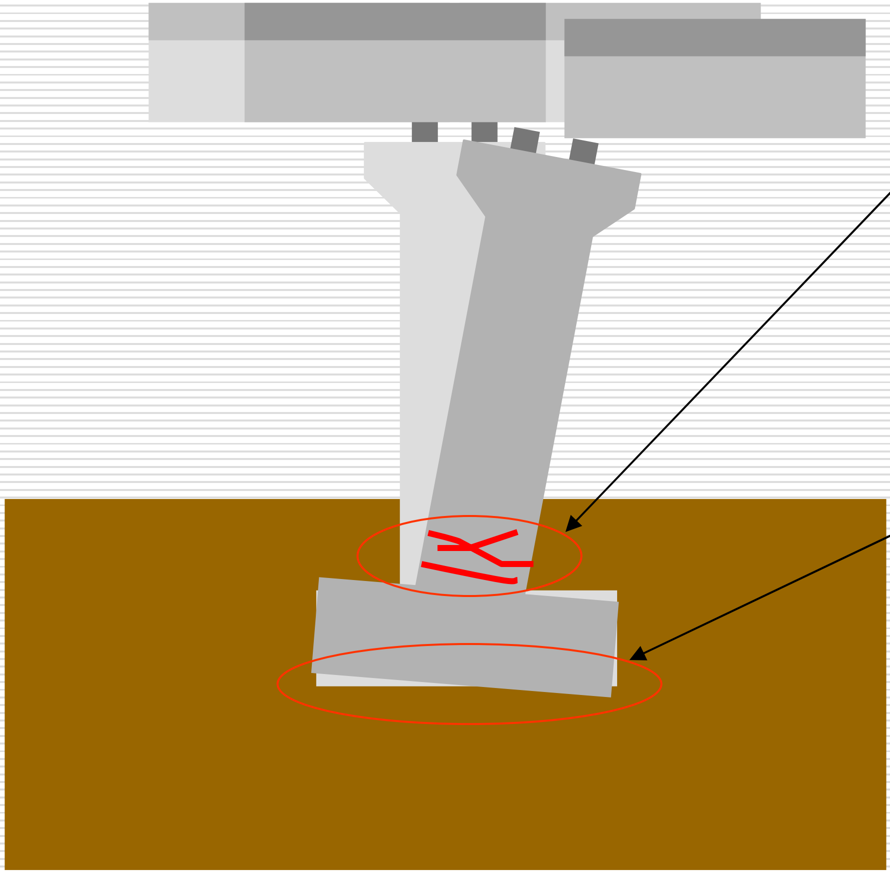
Rion Antirion Bridge



Requirements for Rocking Response in the Static Design



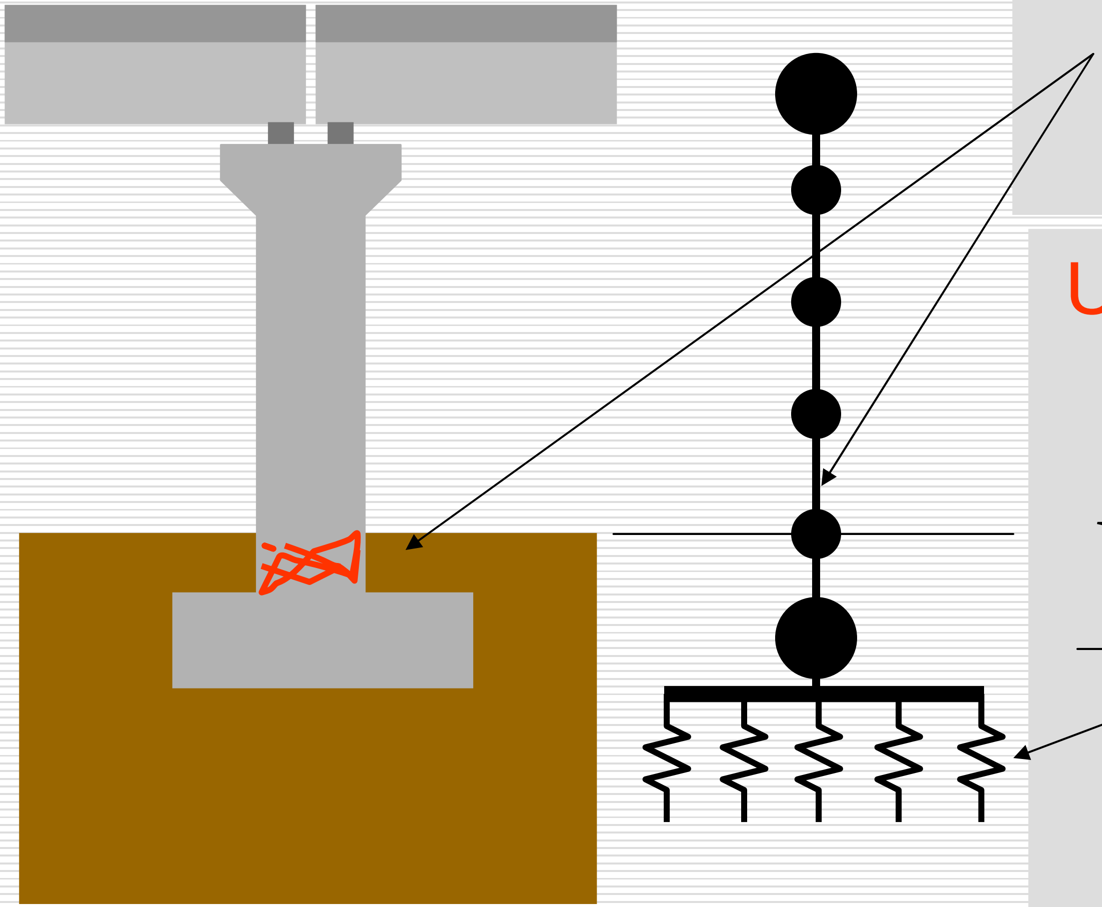
Nonlinear Interaction between a Column Plastic Hinge and a Foundation

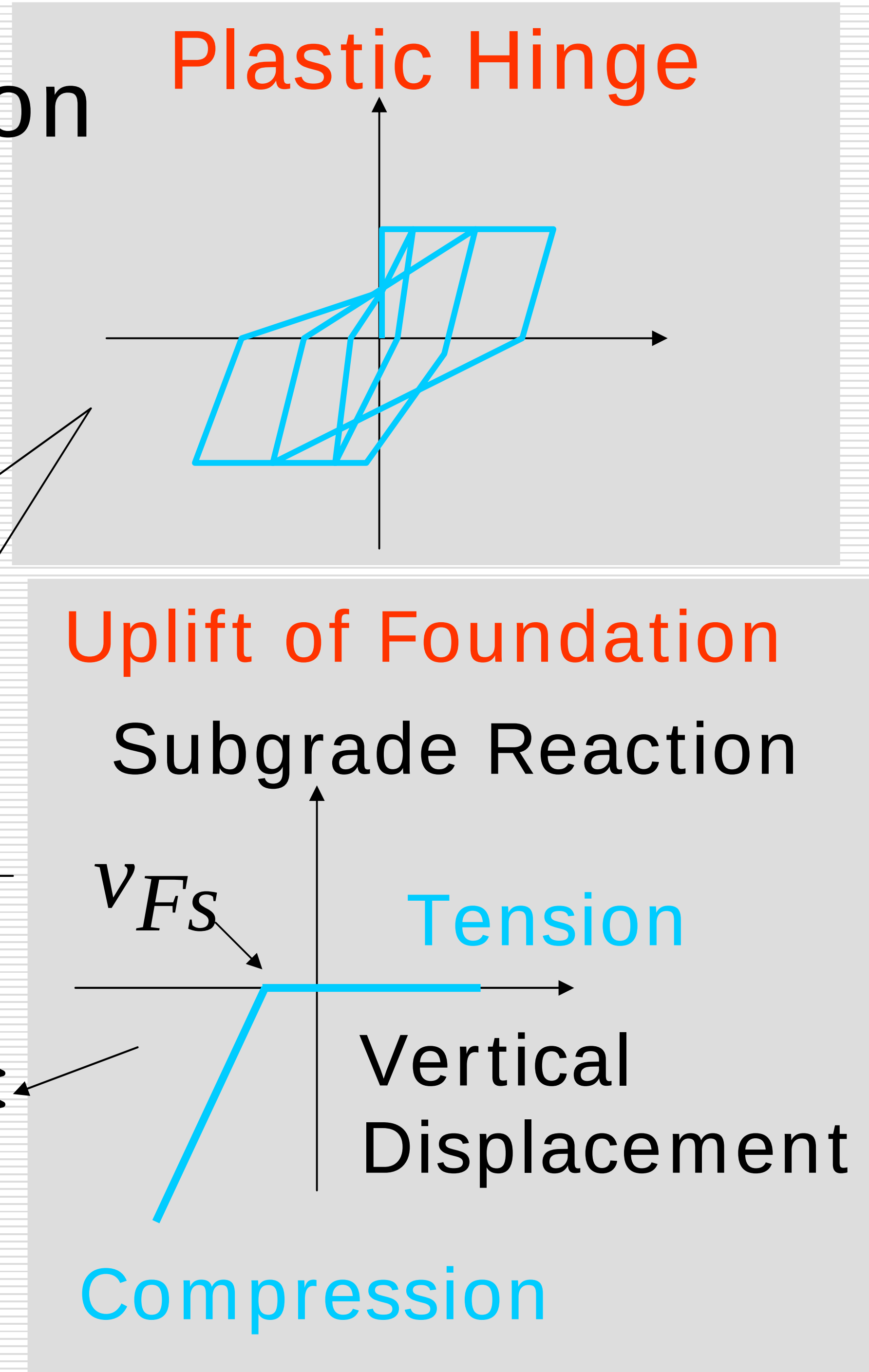


Plastic deformation of a column

Rocking response of a foundation

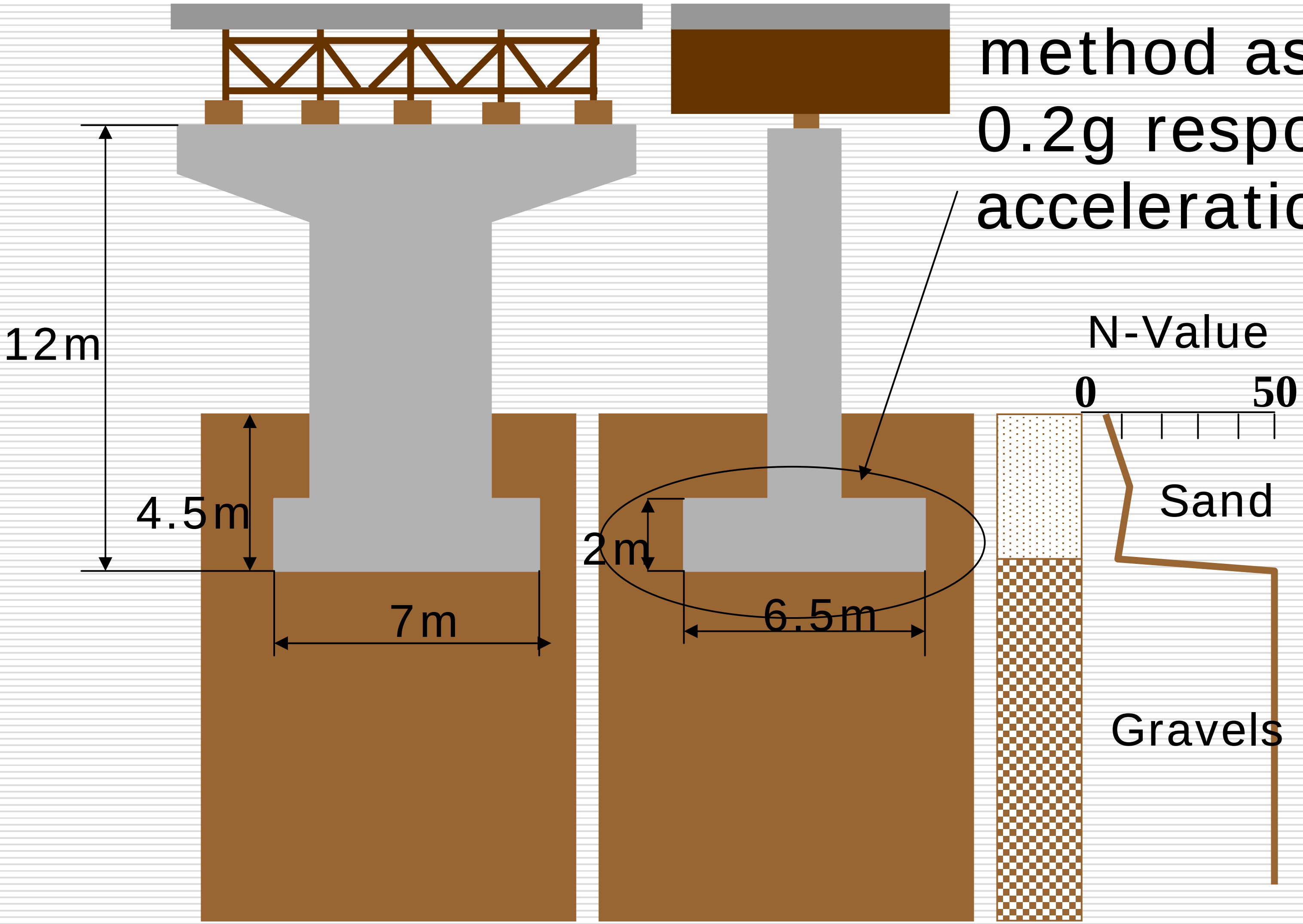
Analytical Idealization





Bridge Analyzed

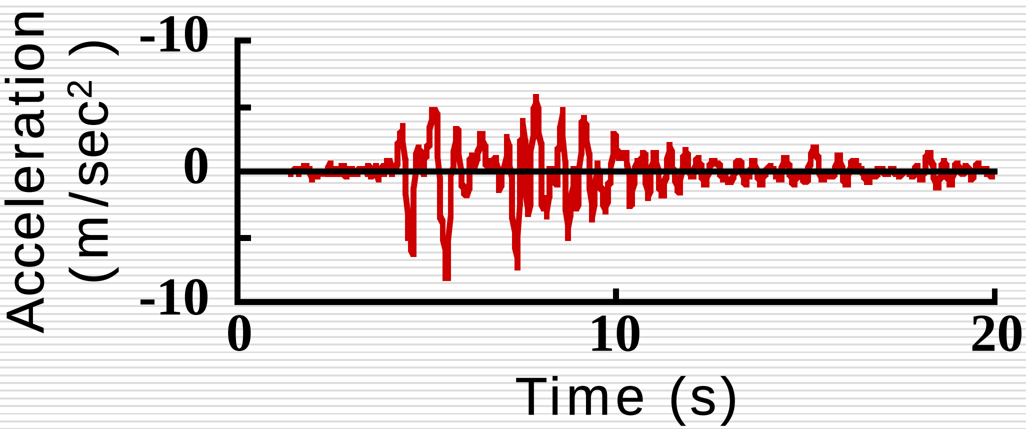
Designed based on the static design method assuming 0.2g response acceleration



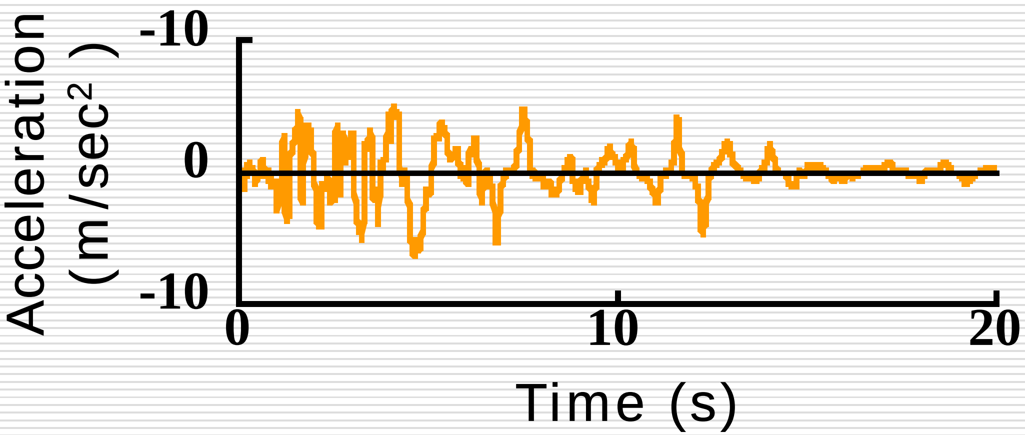
Ground Accelerations Subjected to Bridge

1995 Kobe, Japan earthquake

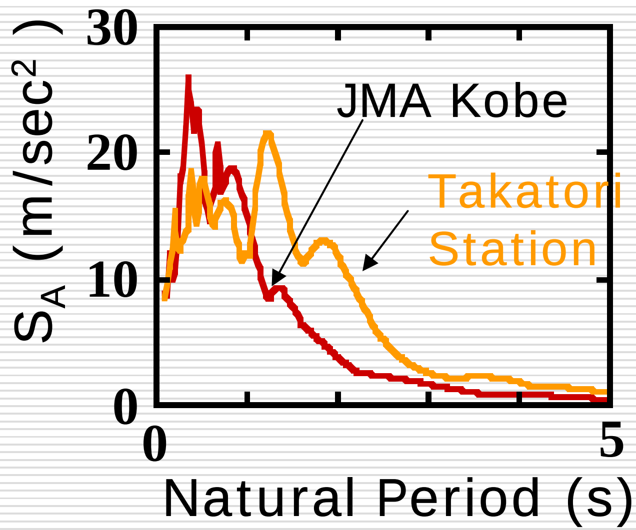
JMA Kobe (NS)



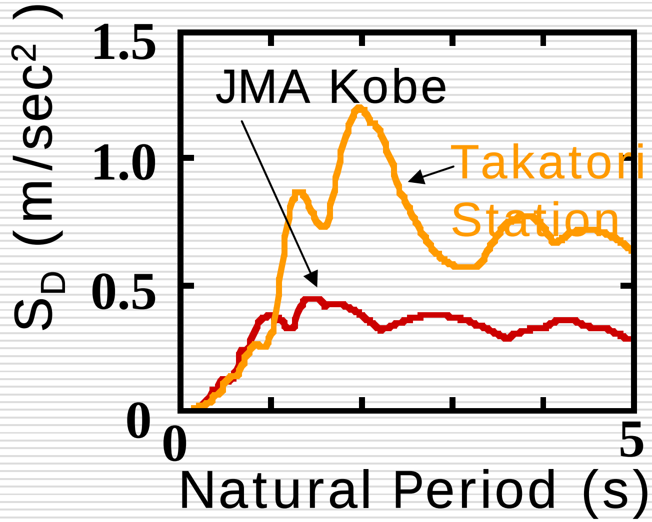
Takatori Station (NS)



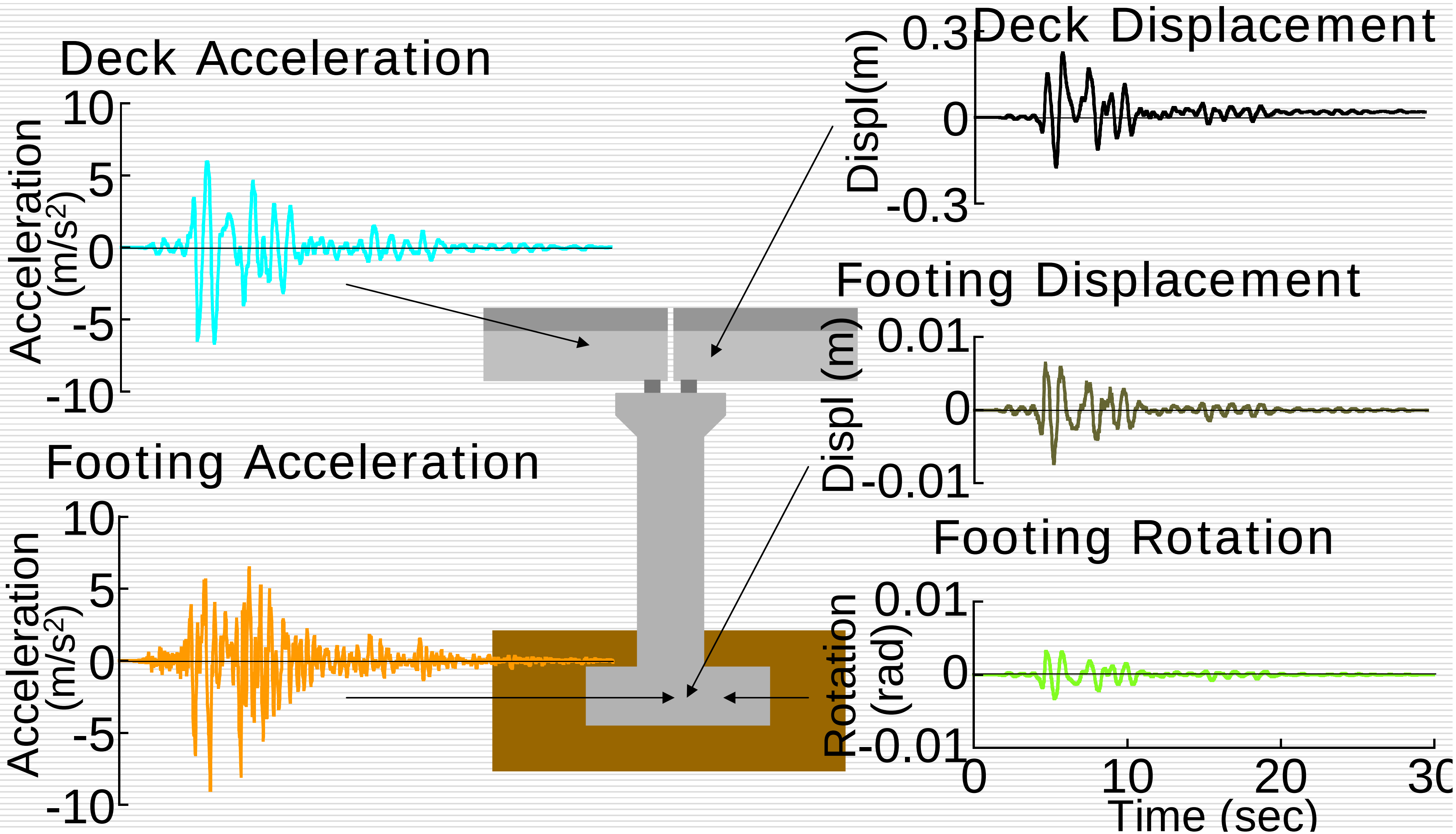
Response Acceleration



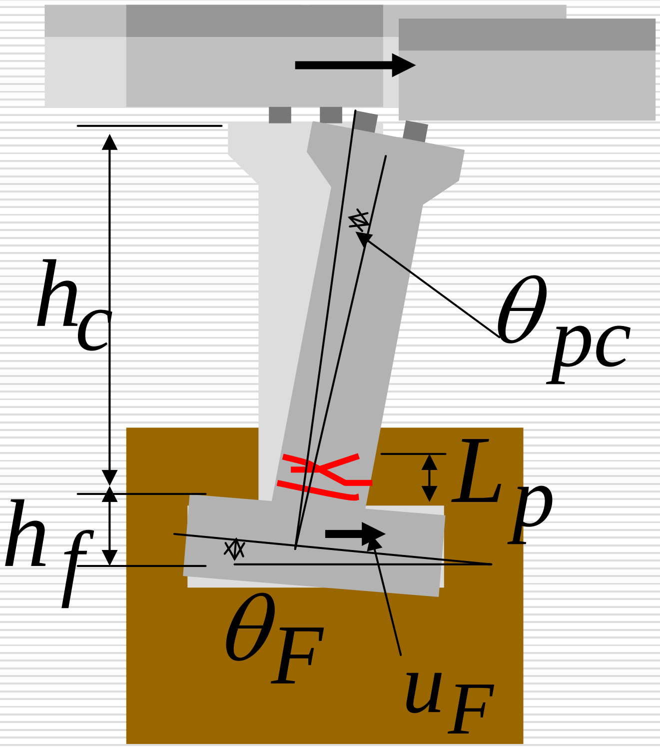
Response Displacement



Seismic Response of the Bridge When Supported by Soil Springs Which Resist Tension一般の解析



Contribution of Footing Displacement and Column Displacement to Deck Response
桁の応答変位には何が寄与するか？

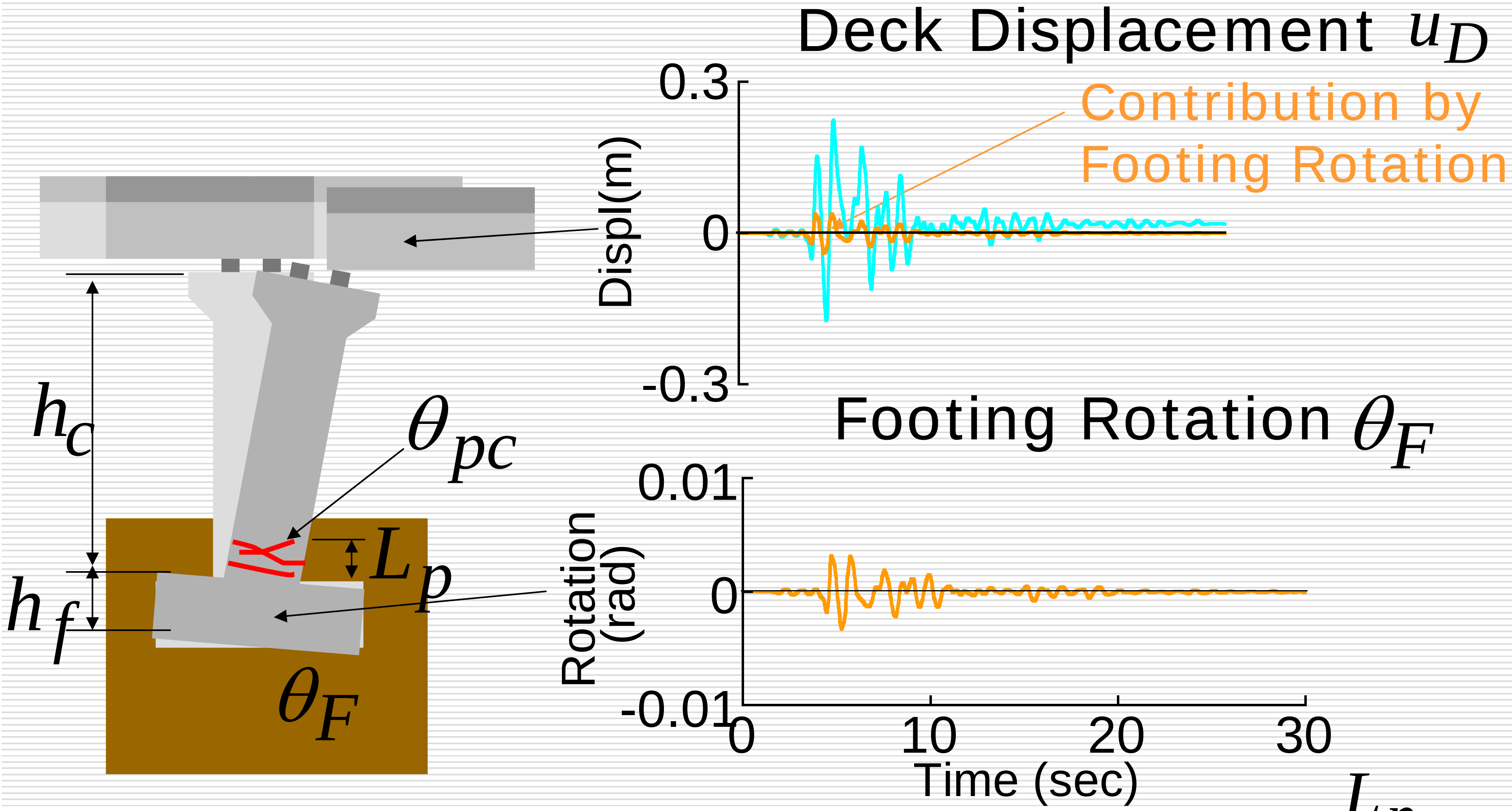


$$u_D = u_F + \theta_F (h_c + h_f) + u_{Cf} + \theta_{pc}\left(h_c - \frac{L_p}{2}\right)$$

u_{Cf} ：displacement due to column (elastic) flexural deformation

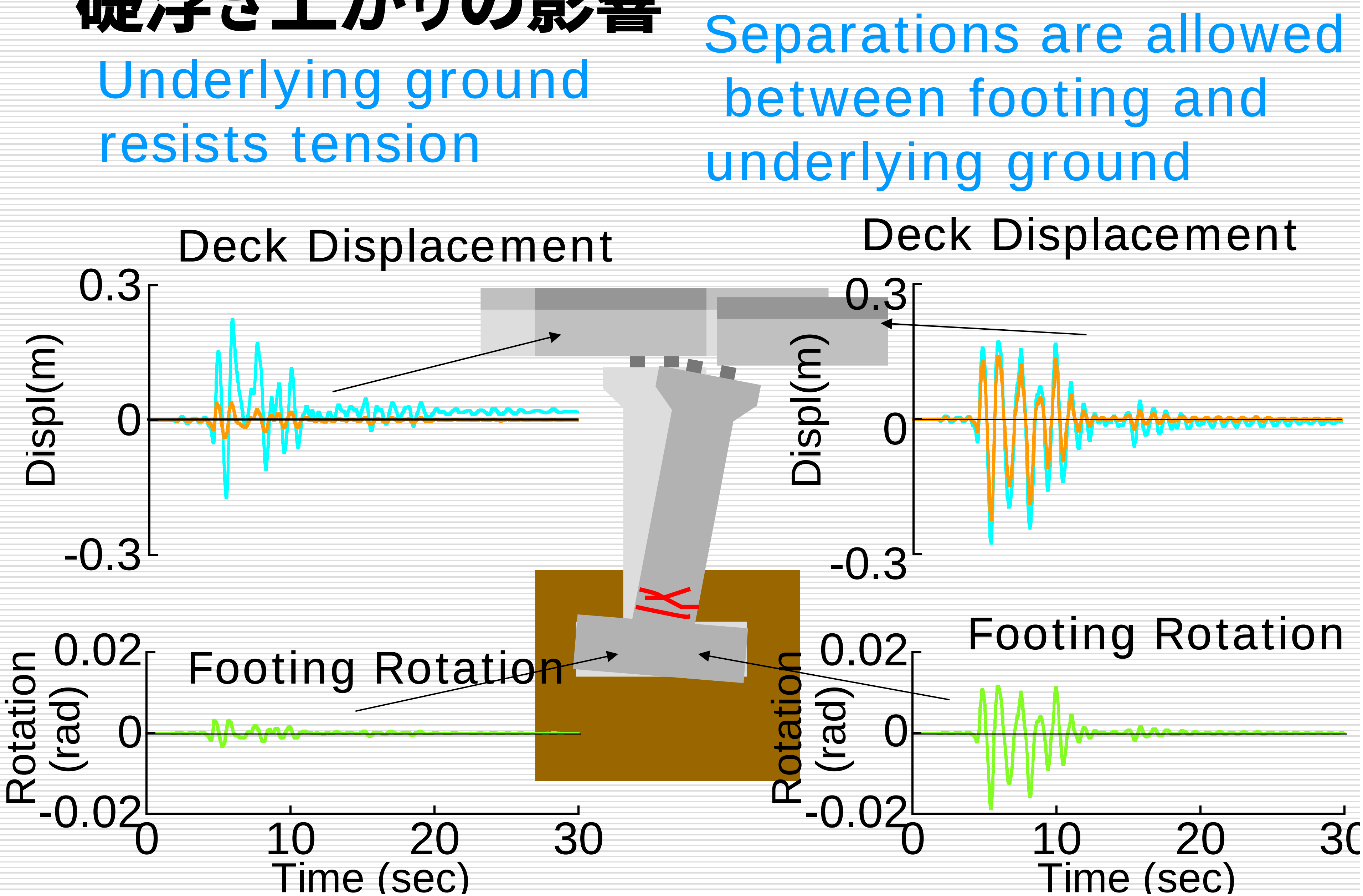
θ_{pc} ：rotation due to plastic deformation at the plastic hinge

Contribution of Footing Rotation to the Deck Displacement

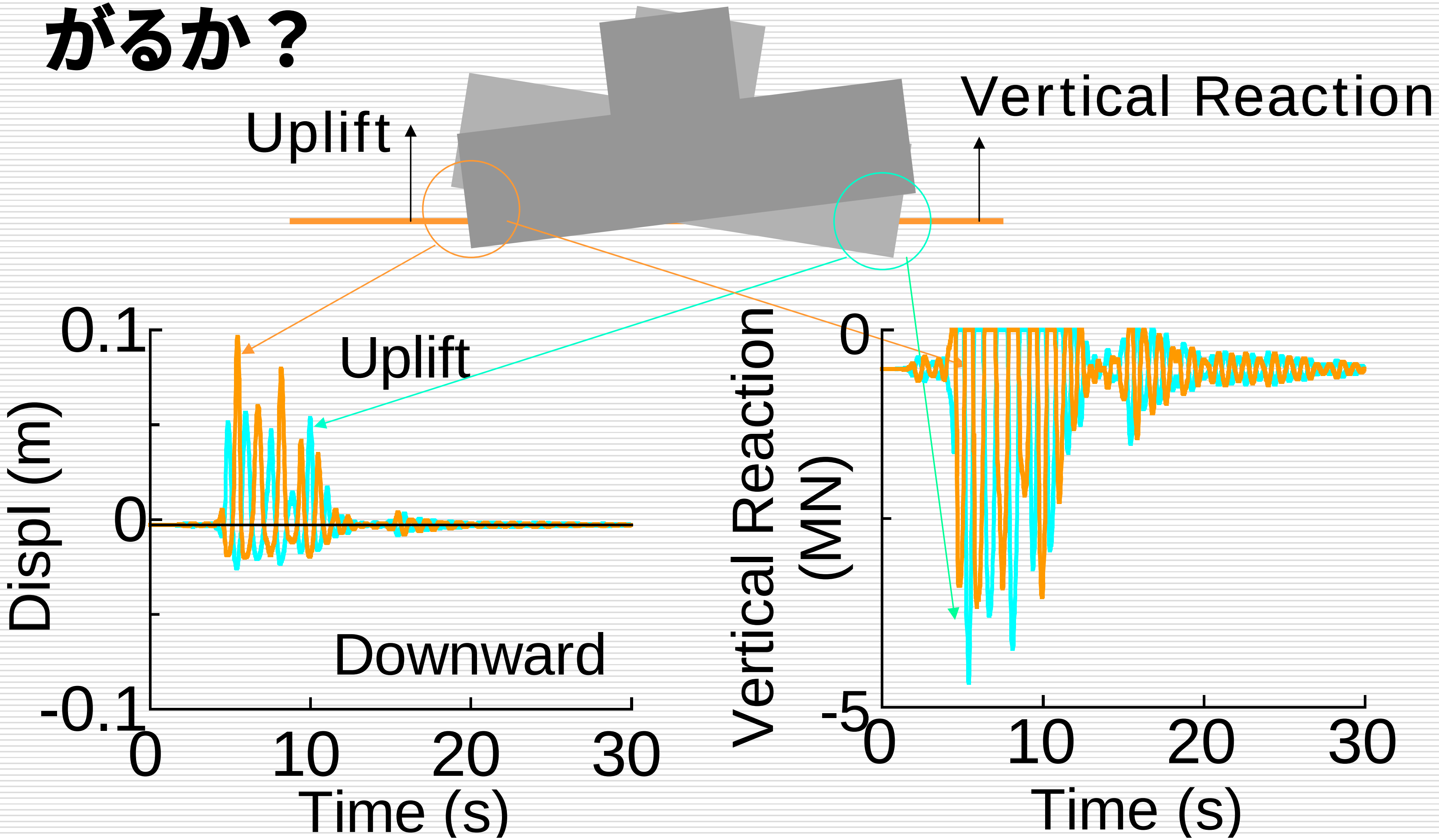


$$u_D = u_F + \theta_F(h_c + h_f) + u_{cf} + \theta_{pc}(h_c - \frac{L_p}{2})$$

Effect of the Uplift of Foundation基礎浮き上がりの影響

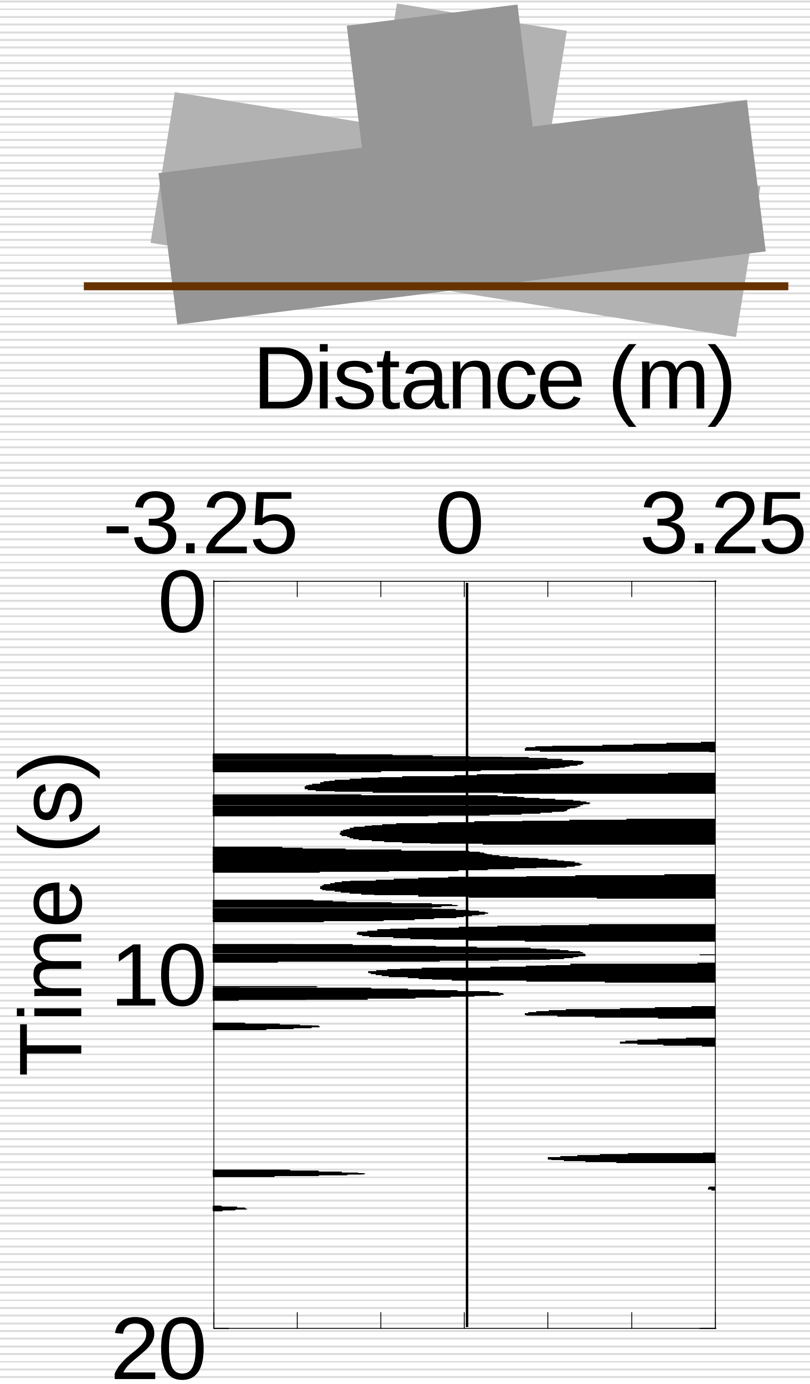


Uplift of the Foundation from the Underlying Ground基礎はどれだけ浮き上がるか？

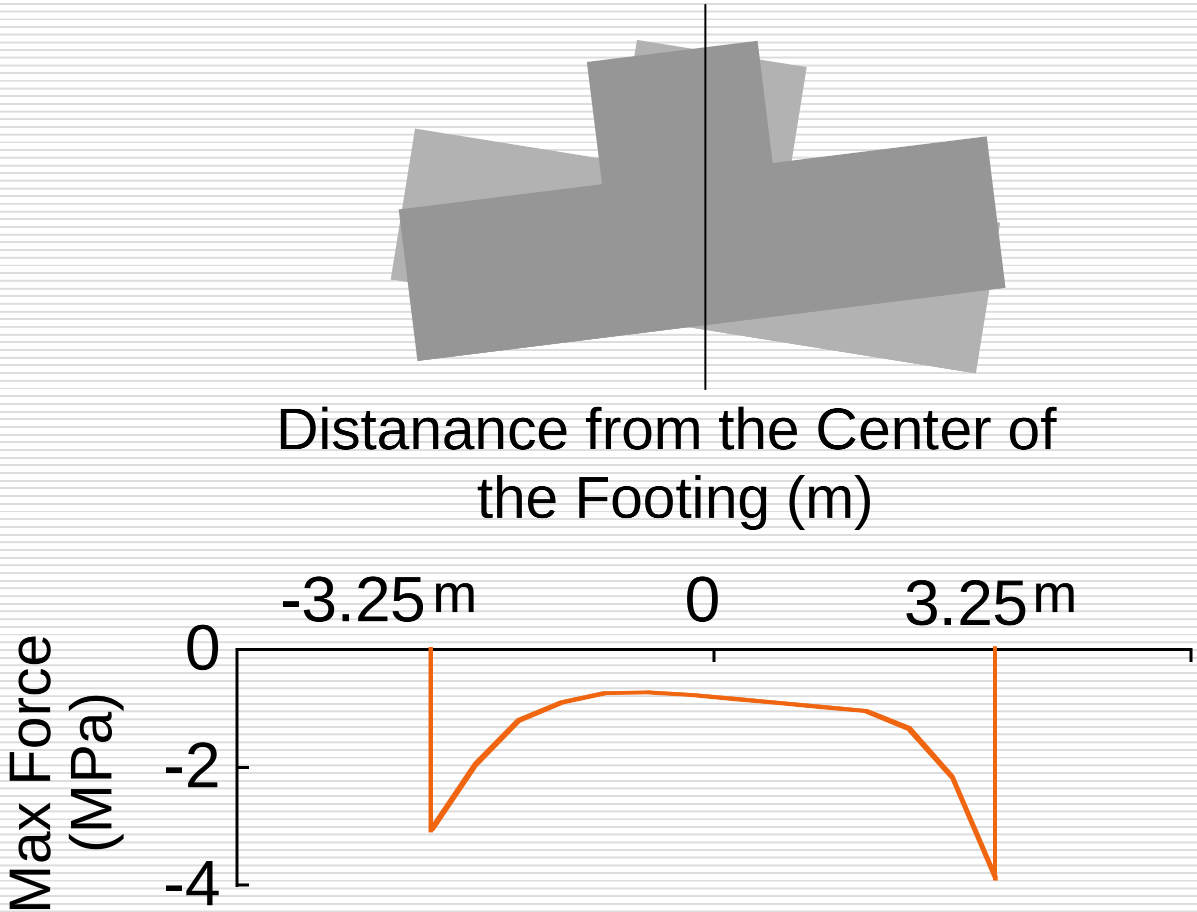


Separations between the Foundation and the Underlying Ground

基礎の浮き上がり量の時間履歴



Peak Subgrade Reaction under the Footing基礎底面の最大反力

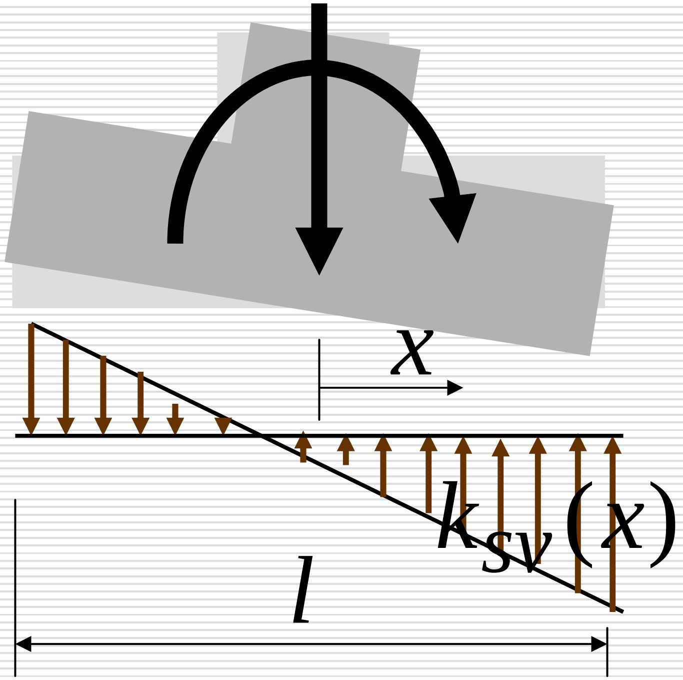


- Effect of local softening
- Effect of yield of the underlying ground

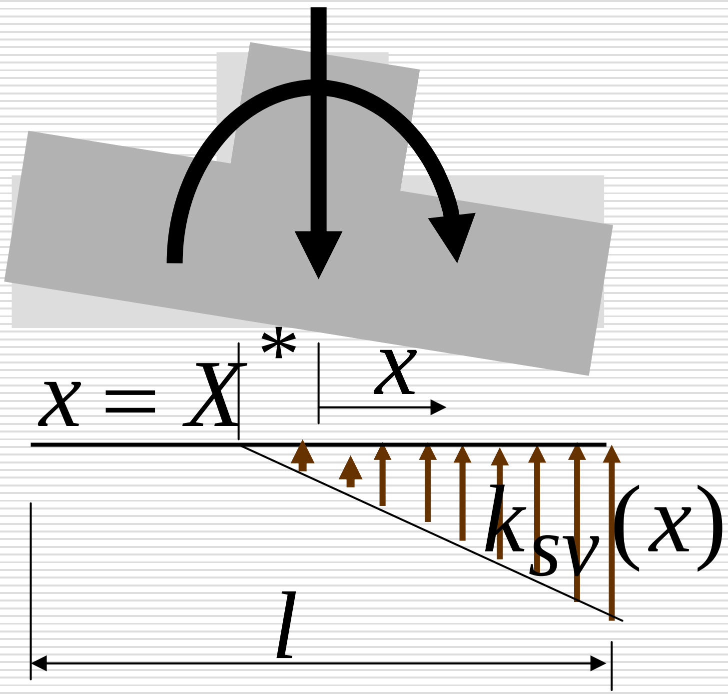
Moment vs. Rotation Relation of the Foundation

Underlying ground resists tension

Separations are allowed between the footing and the underlying ground

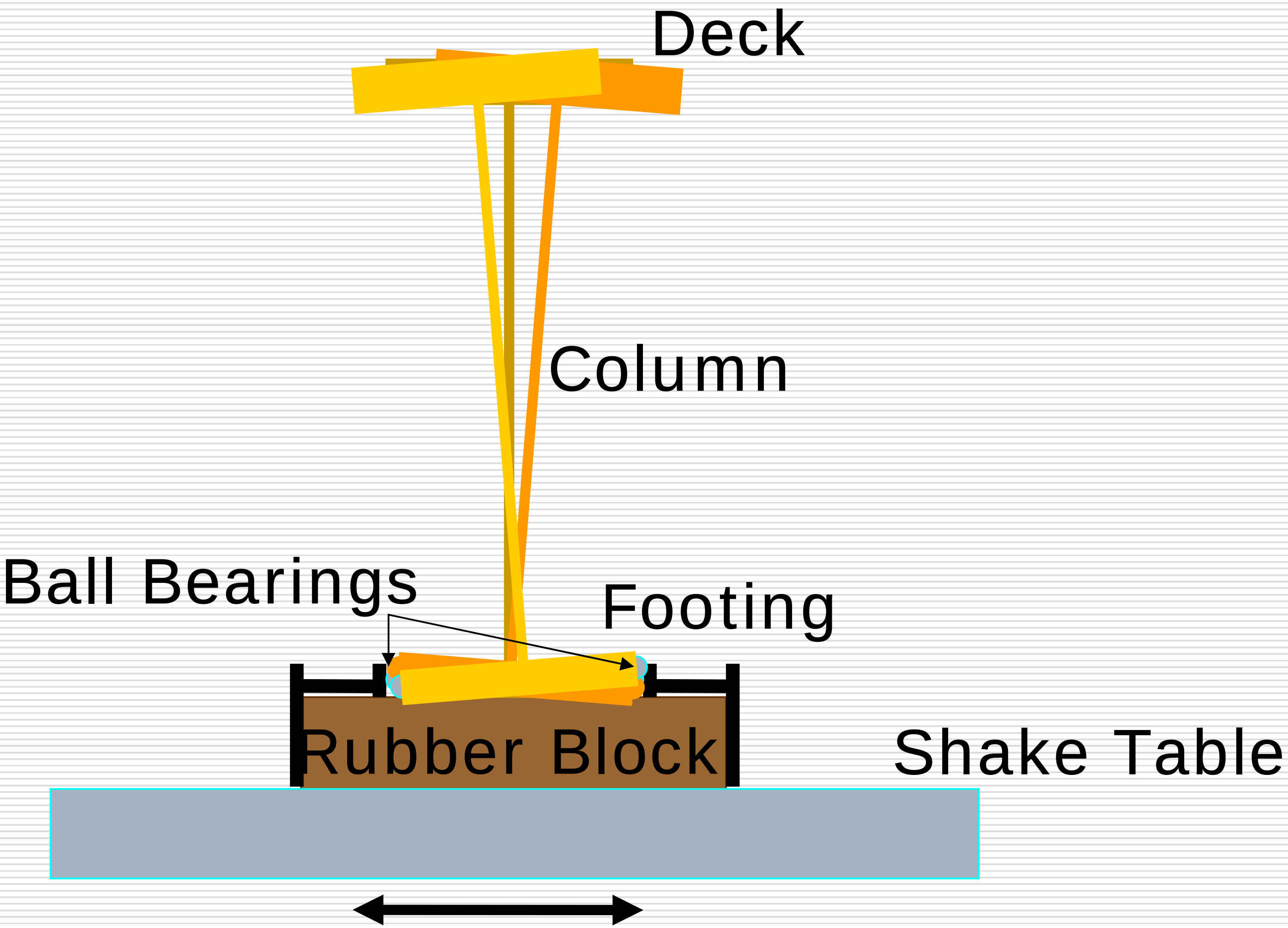


$$K_{F\theta} = \int_{-l/2}^{l/2} k_{sv}(x) \cdot x^2 dx$$

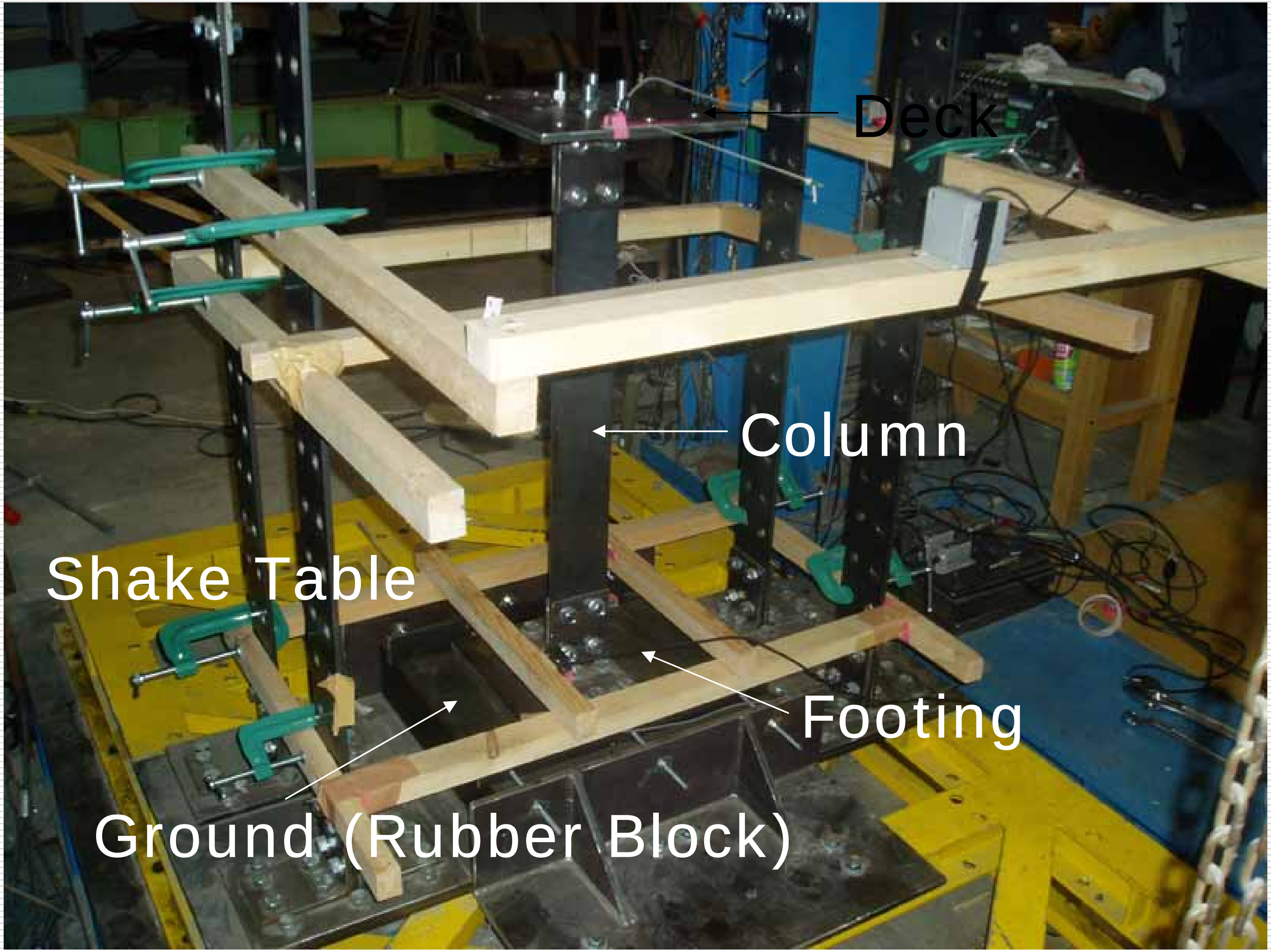


$$K_{F\theta} = \int_{X^*}^{l/2} k_{sv}(x) \cdot x^2 dx$$

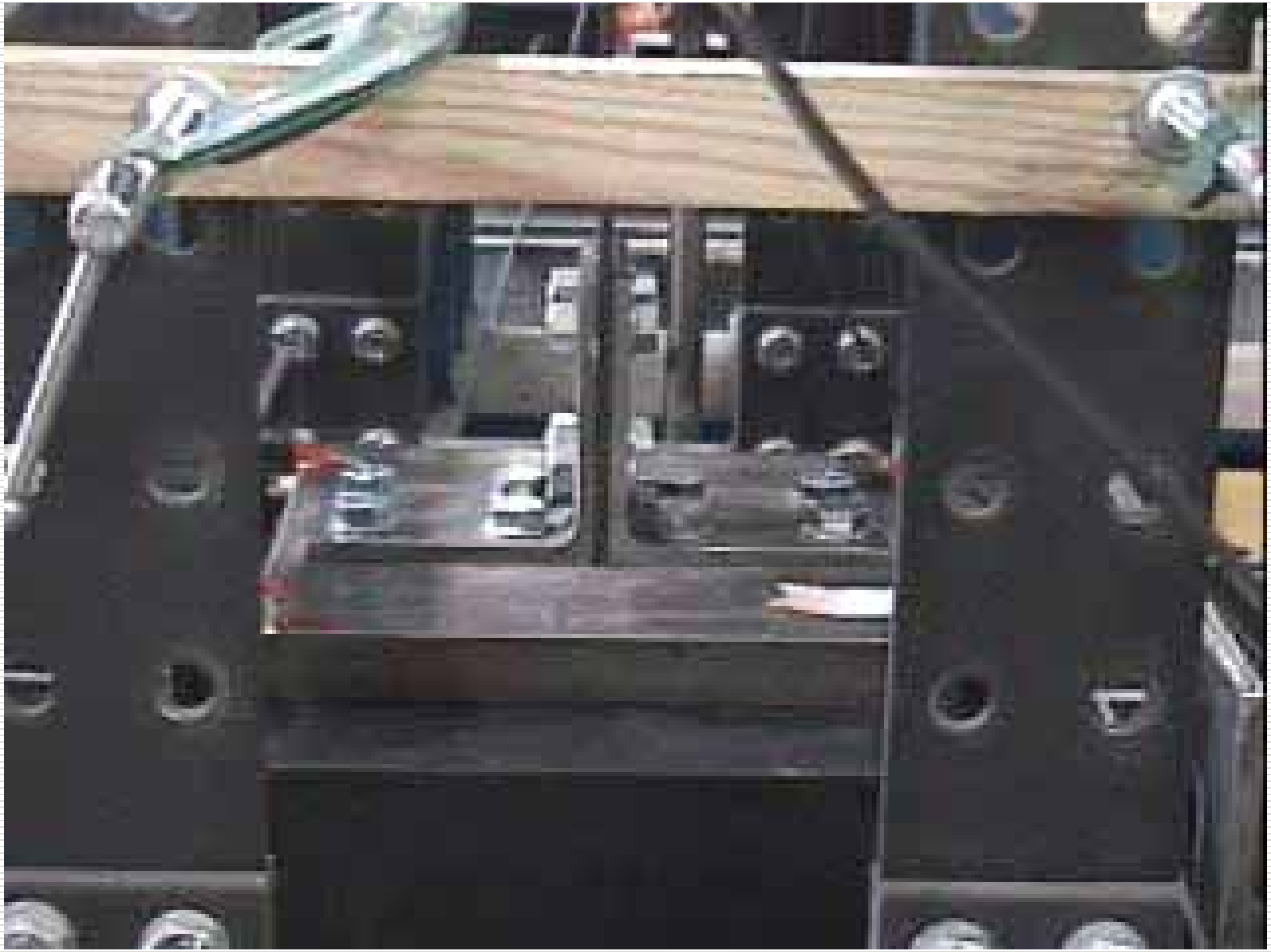
Verification of Seismic Rocking Isolation by Shake Table Test



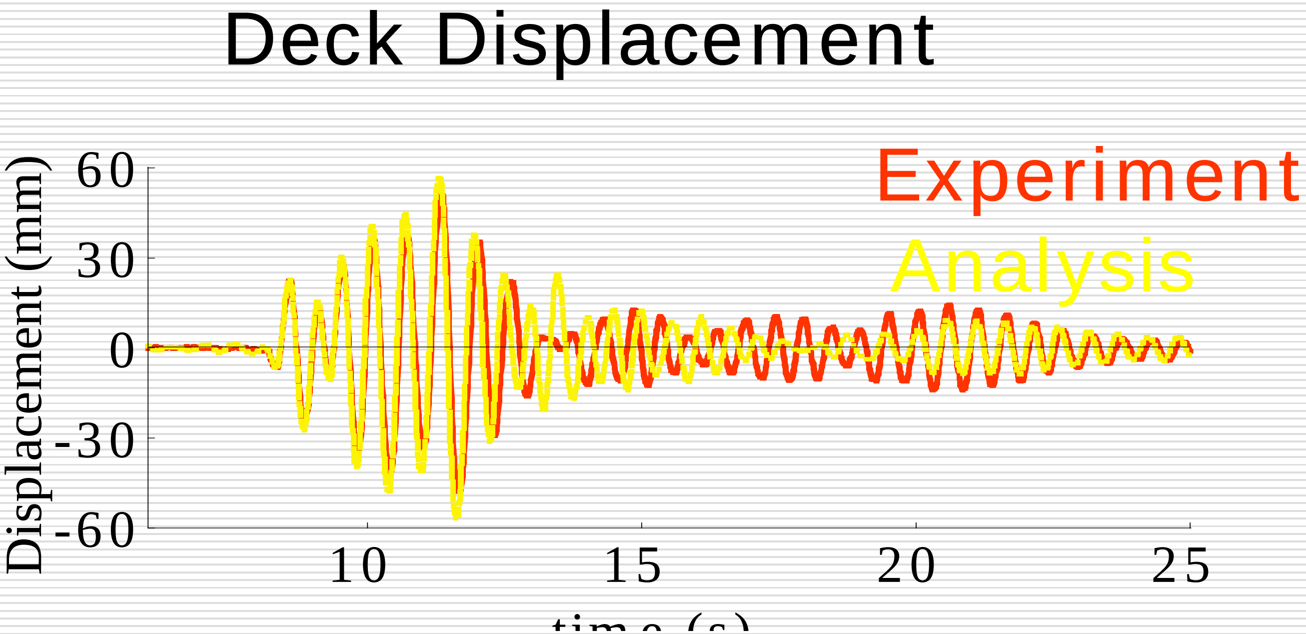
Experimental Model

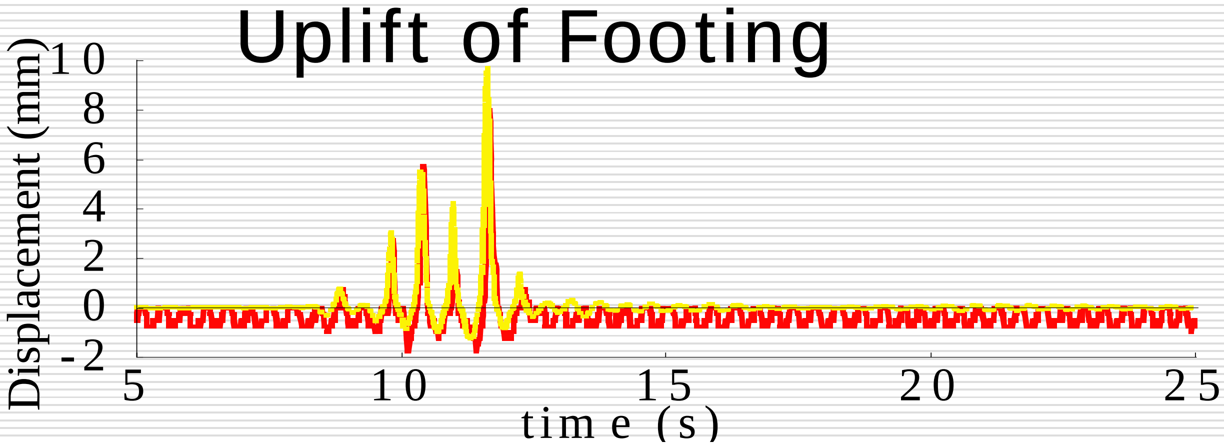


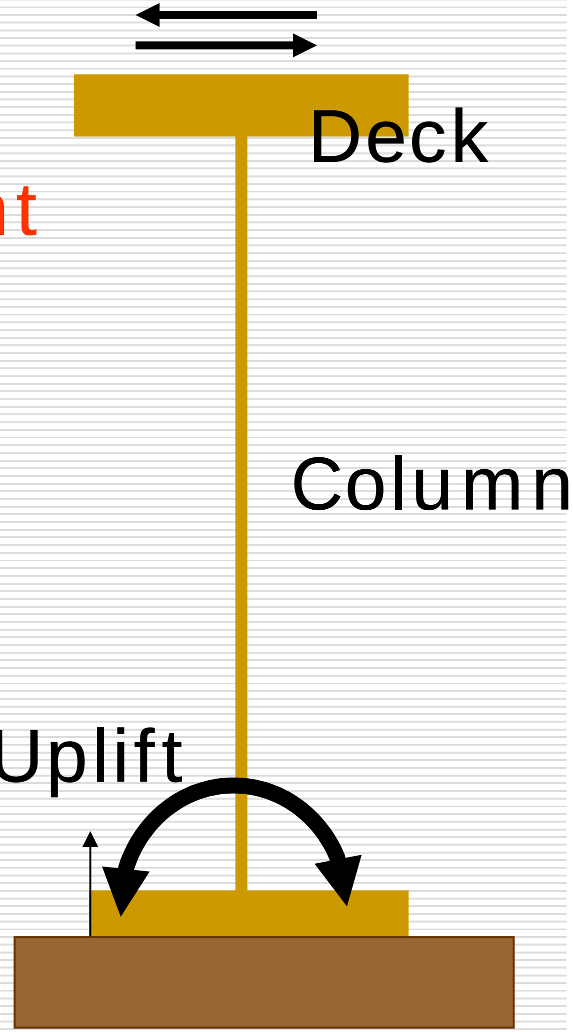
Excitation of Model Foundation under a Ground Acceleration Recorded during the 2007 M6.8 Niigata Chuetsu Earthquake



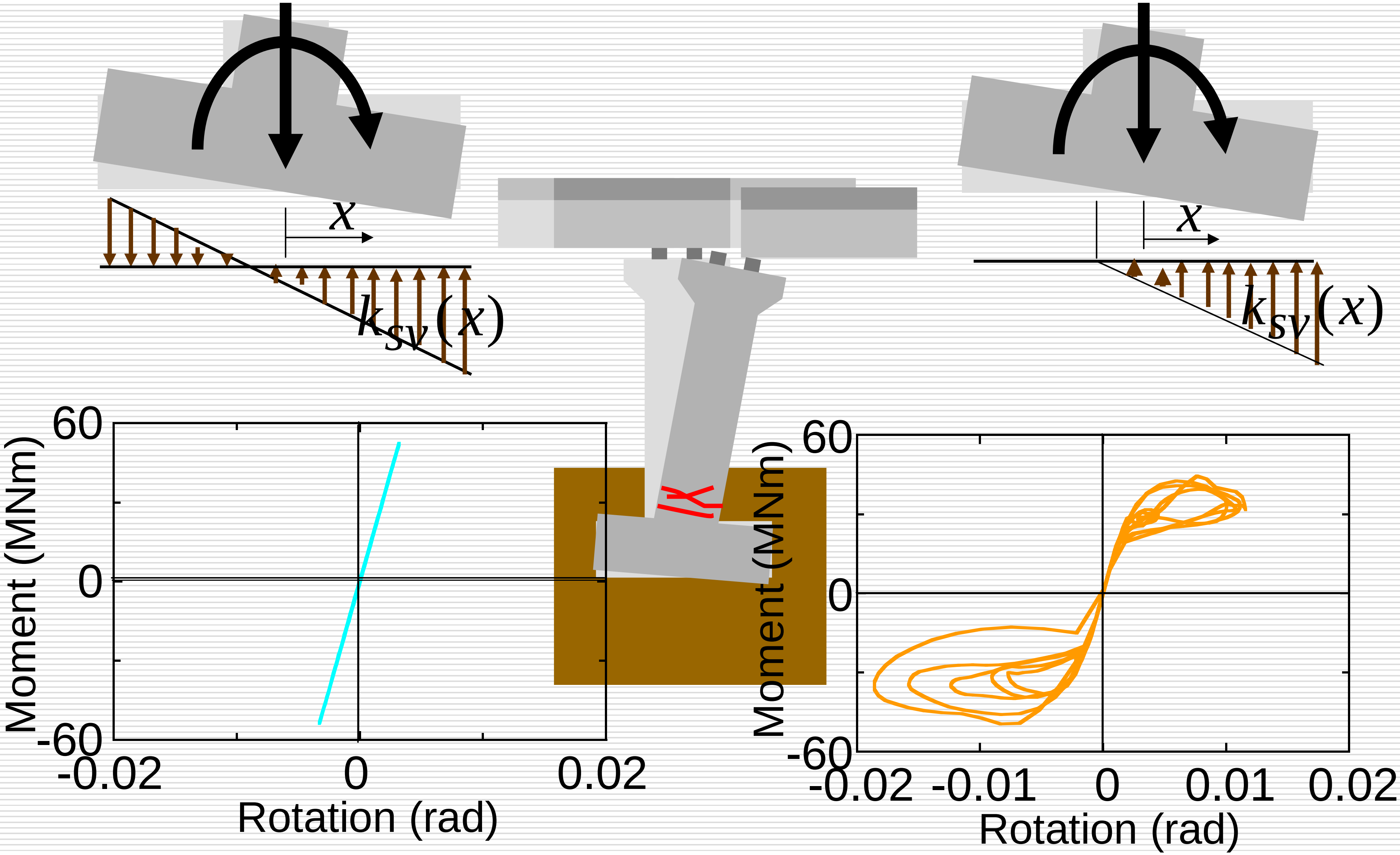
Correlation of the Experimental Response by Analysis







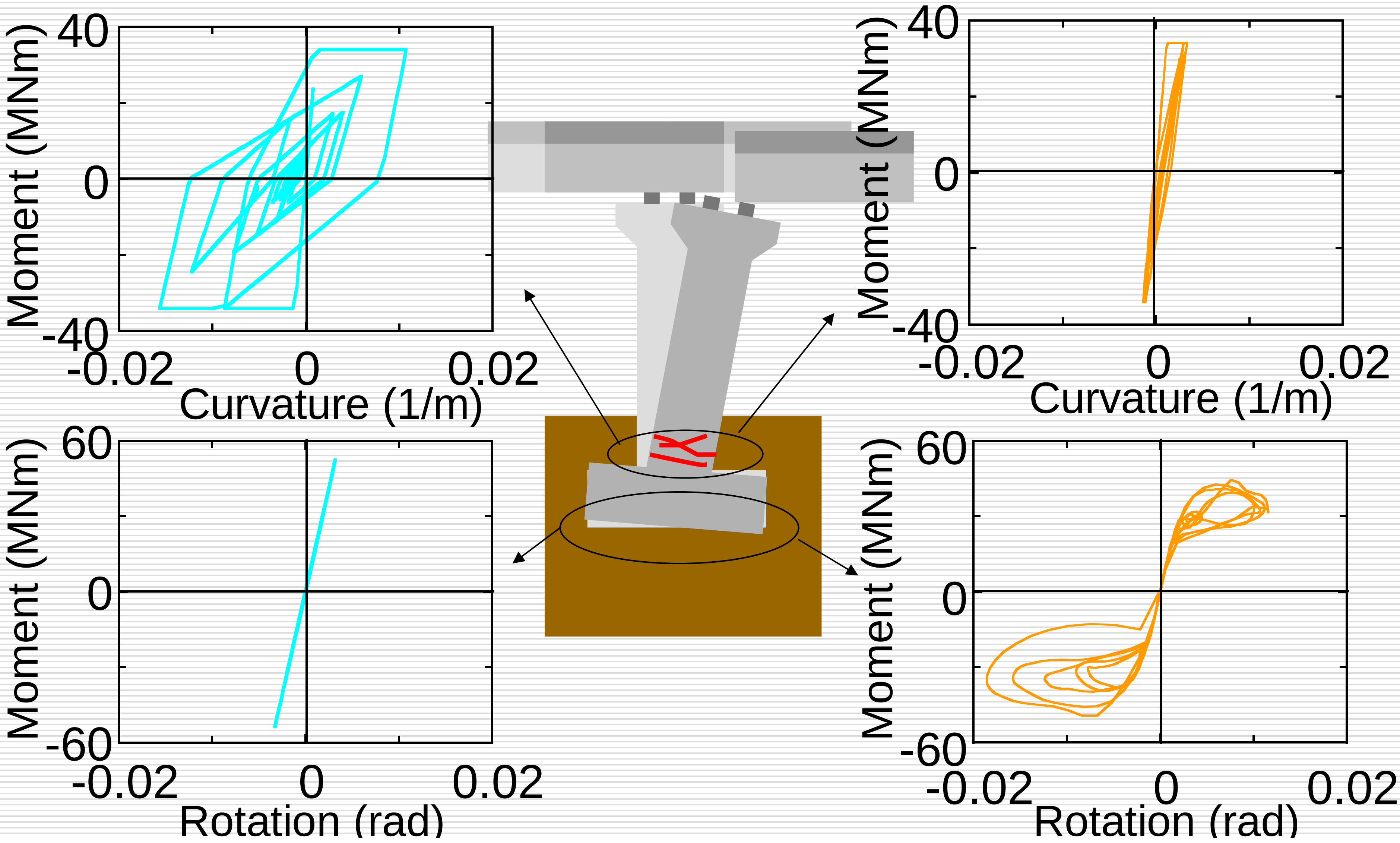
Moment vs. Rotation of the Footing
曲げモーメント～回転角の履歴



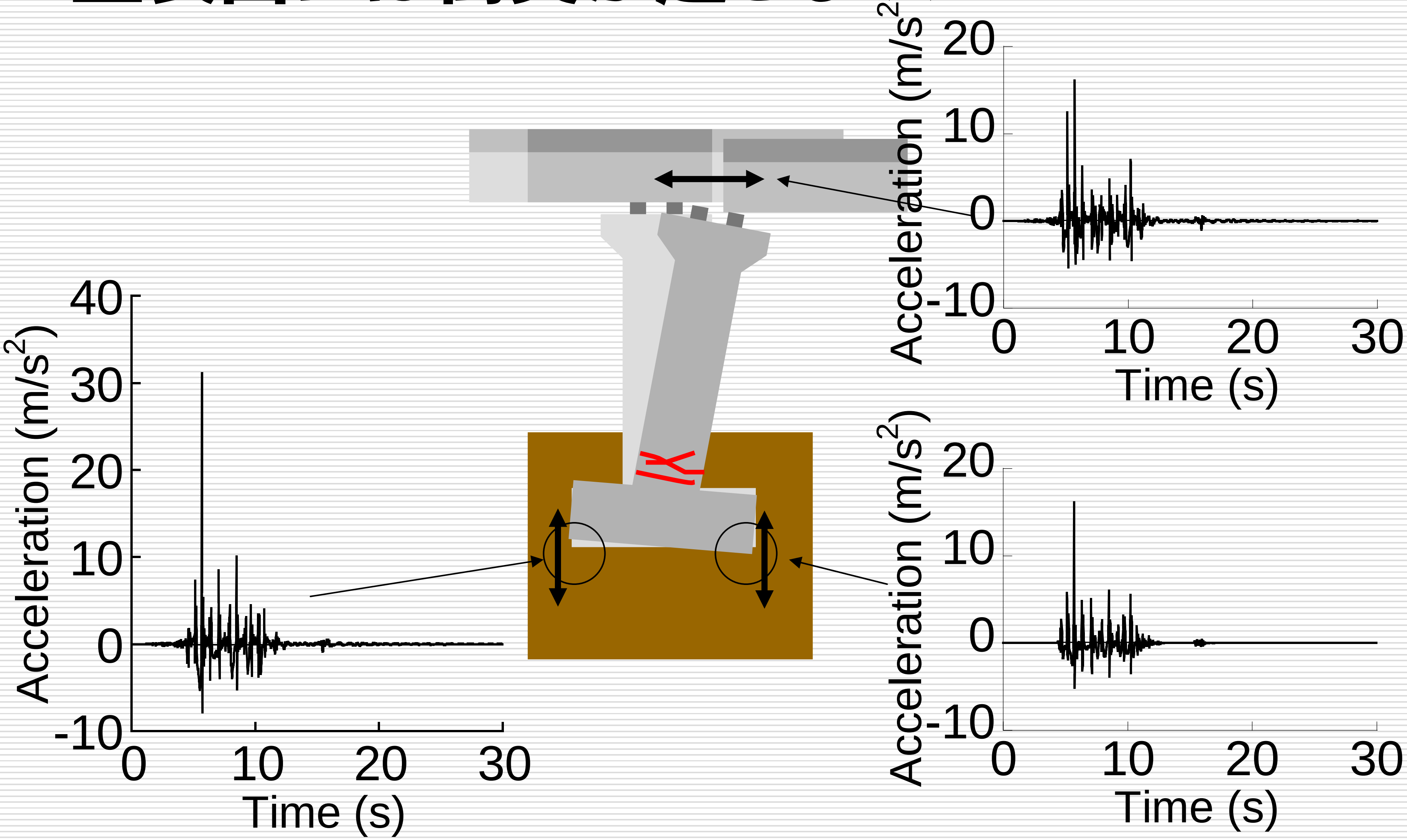
Column and Foundation Interaction

Underlying ground resists tension

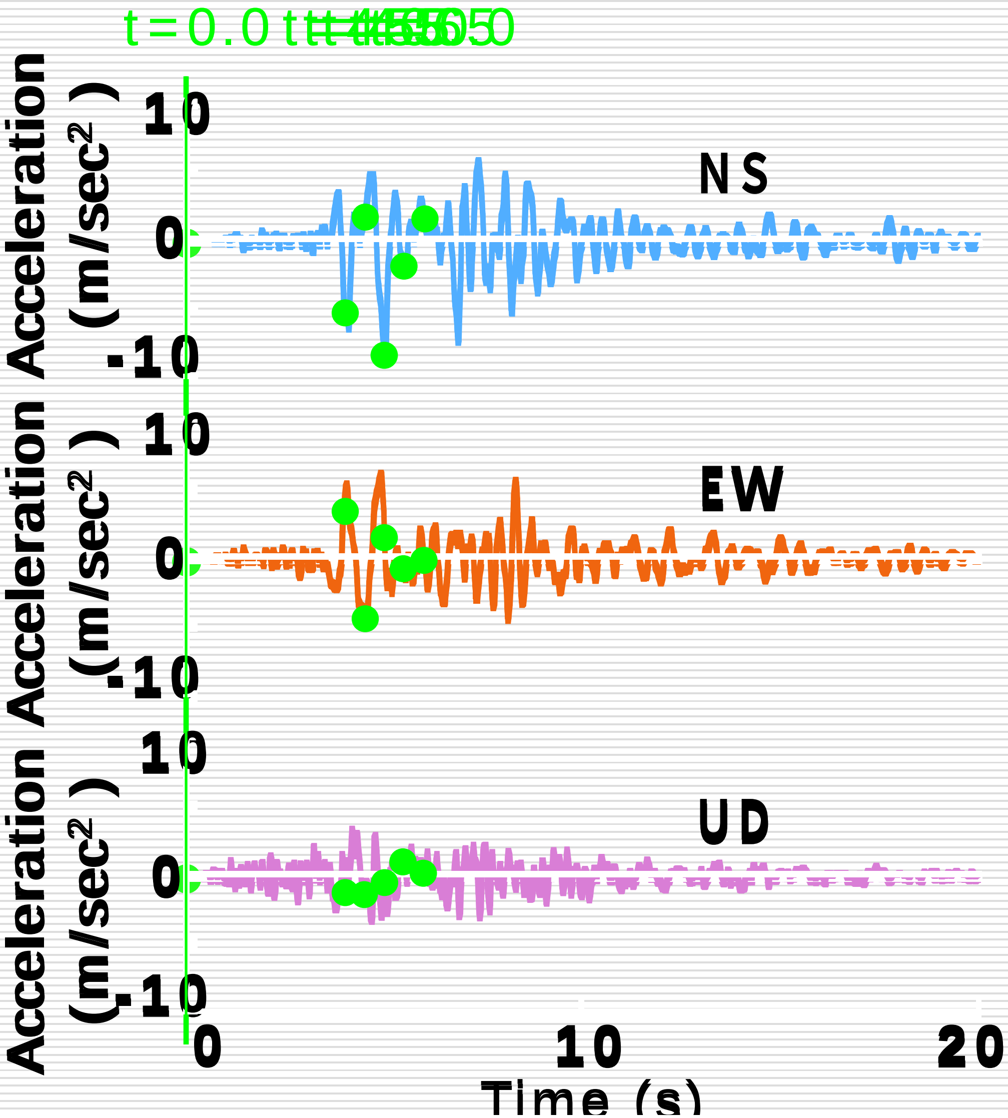
Separations of the footing from the underlying ground

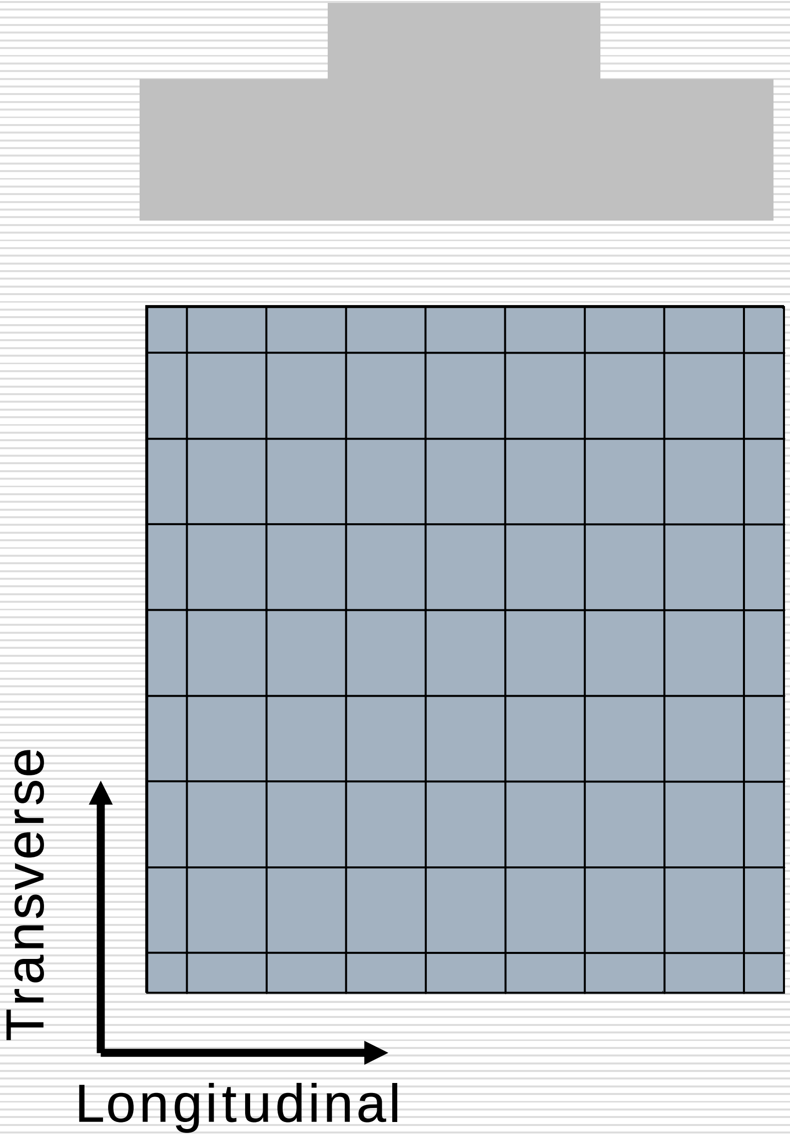


Collision between the Footing and the Underlying Ground基礎底面と地盤表面には衝突が起こる

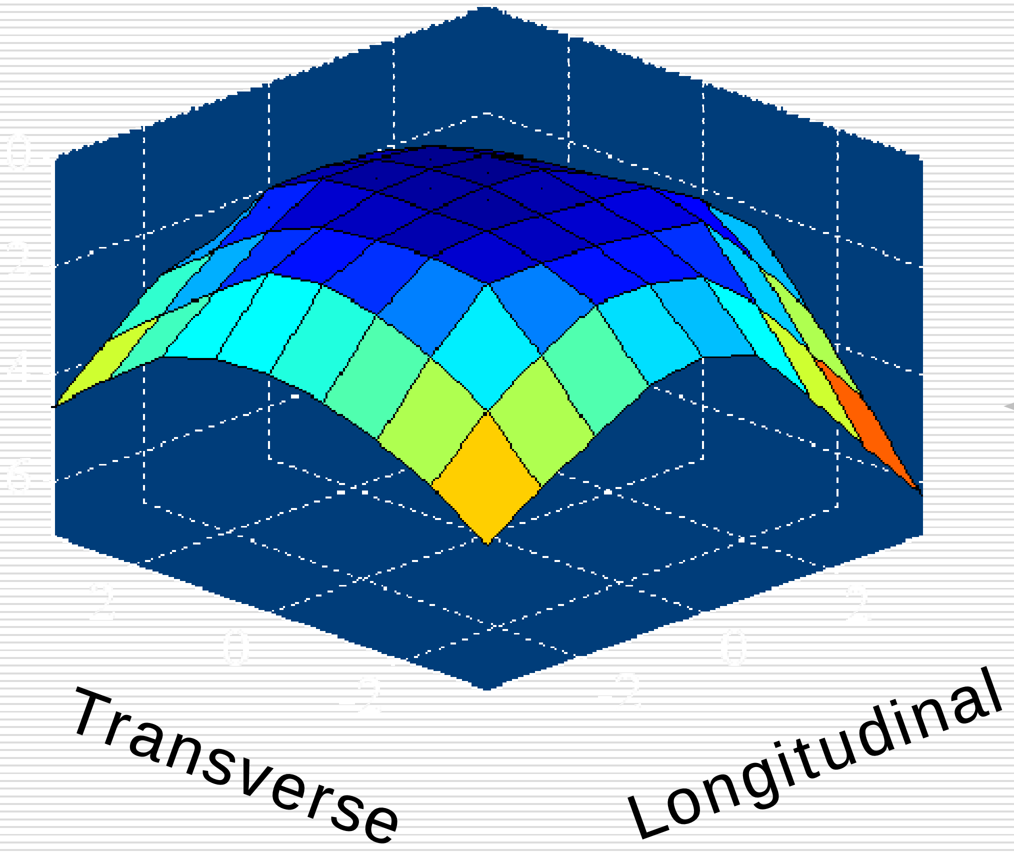


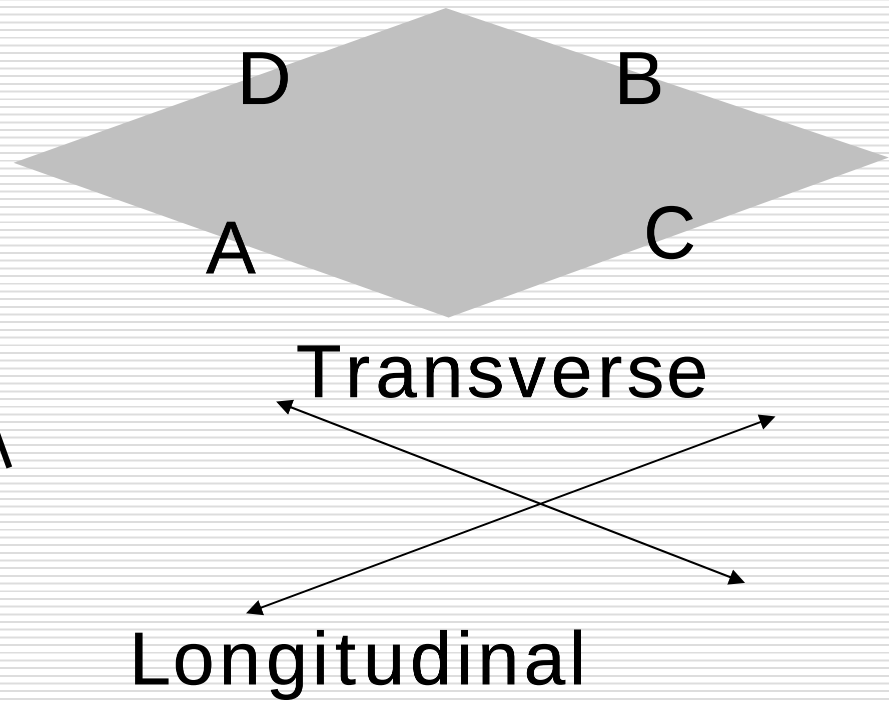
Uplift of the Footing from the Underlying Ground





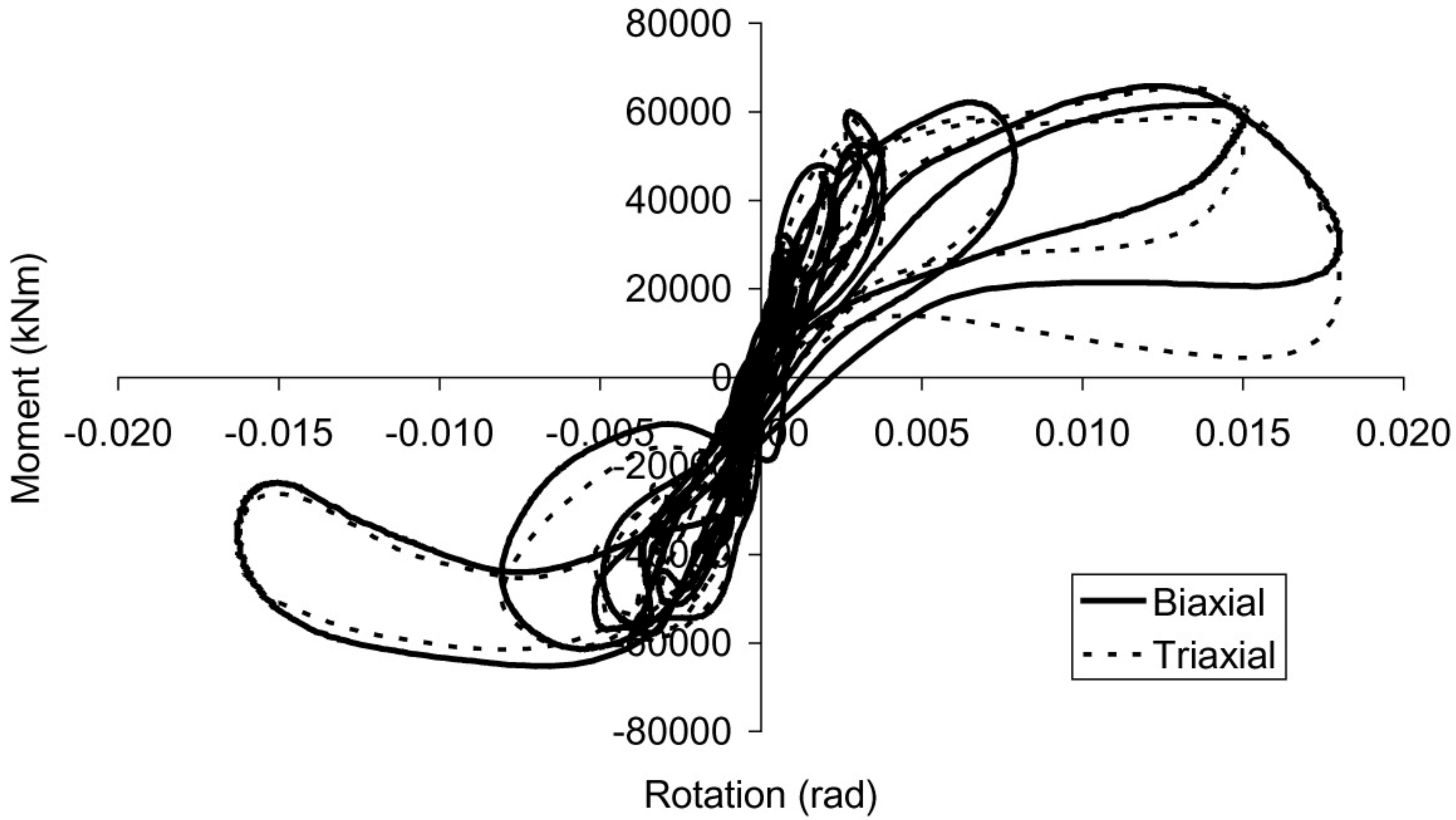
Increase of Reaction Force of the Underlying Ground at Corners





Effect of Bilateral Excitation 2方向載荷の影響

Moment vs. Rotation Hysteresis of the Foundation

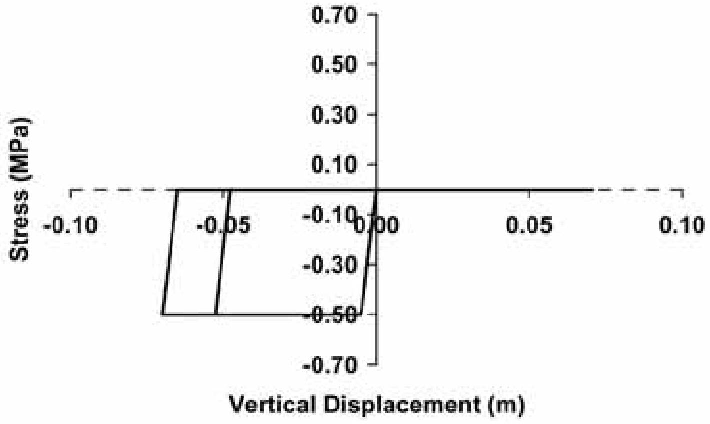


Mergos, P.E. and Kawashima, K.: Rocking Isolation of a typical Bridge pier on Spread Foundation, Journal of Earthquake Engineering, 9(2), 395-414, 2005

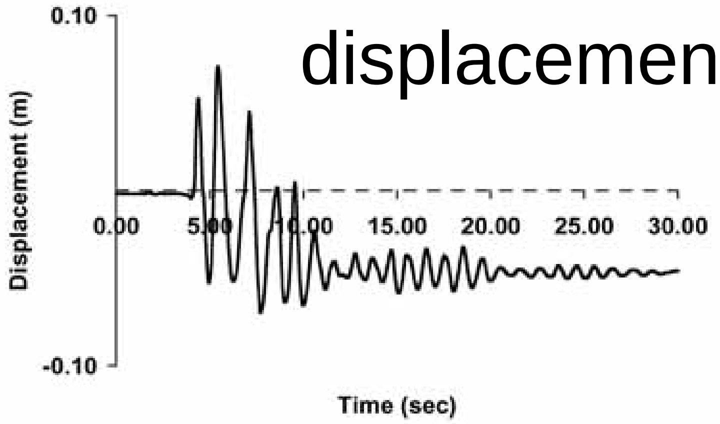
Effect of Yield of Underlying Ground基礎底面地盤が降伏すると、どうなるか？

Vertical displacement vs. stress

Vertical displacement

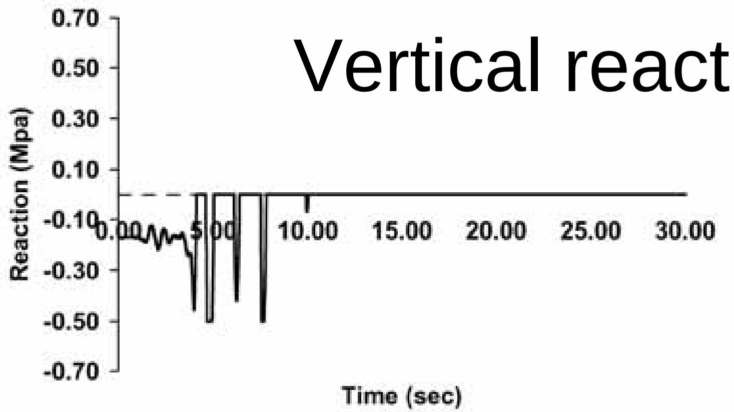


(a)



(b)

Vertical reaction



(c)