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

第4章　免震設計(2)
Chapter 4 Seismic Isolation (2)

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

4.10 Technical Challenges in the Implementation of Seismic Isolation to Bridges
4.5 橋梁の免震設計を適用する際の問題点

1) Unstable ground sites

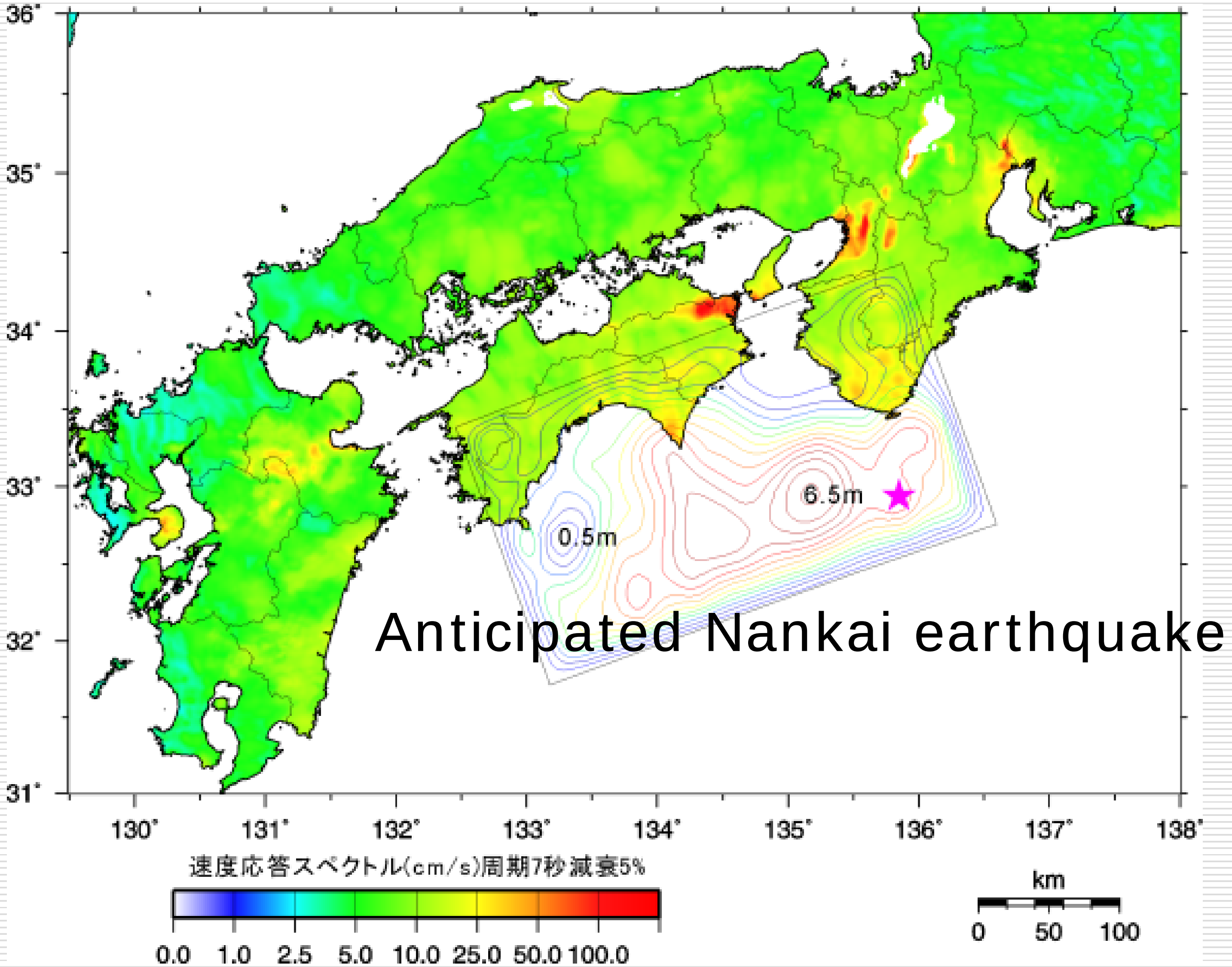
- Since connection of span and substructures is weak in an isolated bridge, the seismic isolation should not be adopted at the sites where soil instability (sliding, slippage, liquefaction, lateral spreading caused by liquefaction) occurs.
- In such locations, structures with a large number of static determinant is preferred.
- It is feasible to construct an isolated bridge if unstable surface soils are removed or strengthened and large and deep foundations are constructed.

2) Resonance of Isolated Bridge resulting from Period Shift due to Long Period Ground Motions

- It is likely that long-period ground motions are generated by a large magnitude earthquake.
- At soft soil sites, ground accelerations tend to have long period components due to ground amplification effect.
- It is often the case that response accelerations and displacements are larger in an isolated bridge than a fixed base bridge at soft soil sites.

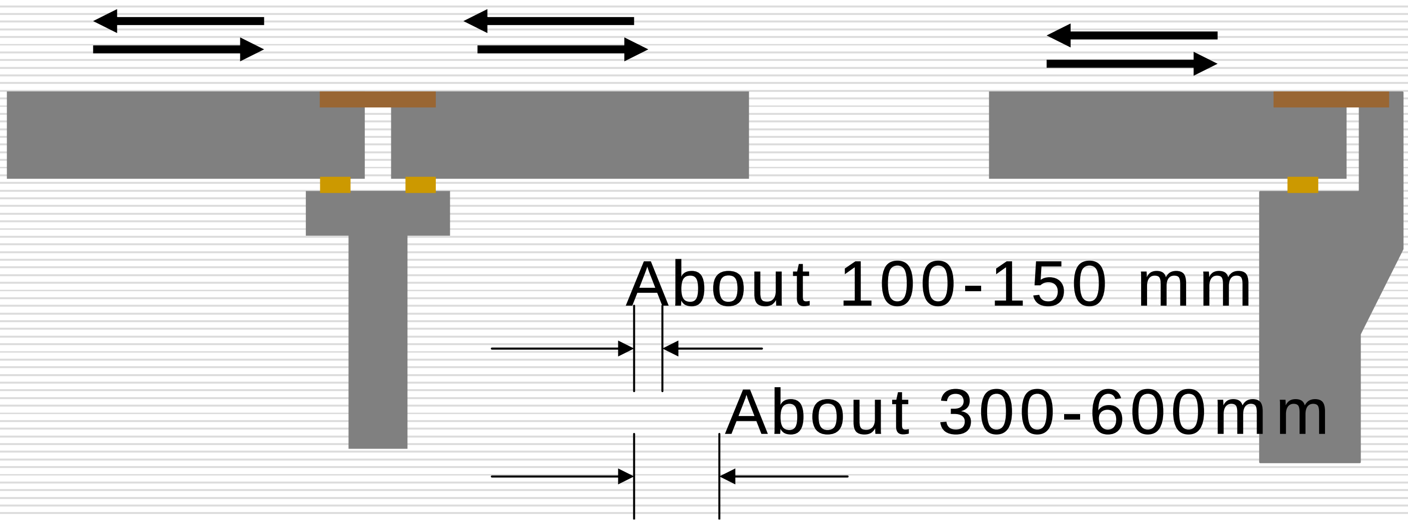
Long-Period Ground Motions

Velocity response at 7 second



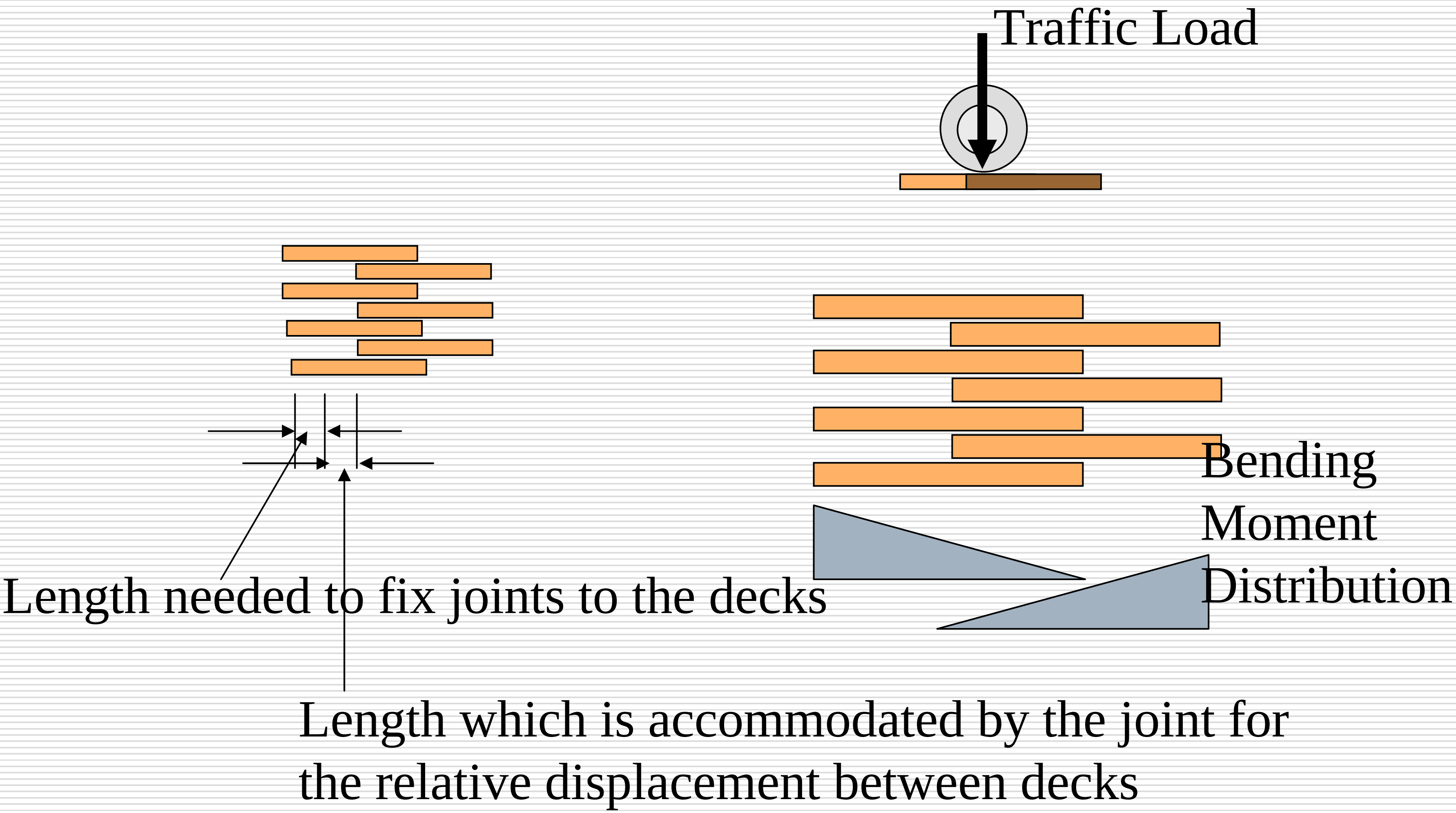
3) Difficulty of the Treatment for Increased Deck Displacement due to Increased Natural Period
長周期化することによる桁の応答変位の増大

- Deck displacement easily reaches +/- 0.5m even in a standard bridge under an extreme near-field ground motion
    - ✓Extreme ground motions
    - ✓Soft soils
- Should we allow collisions between decks or not?

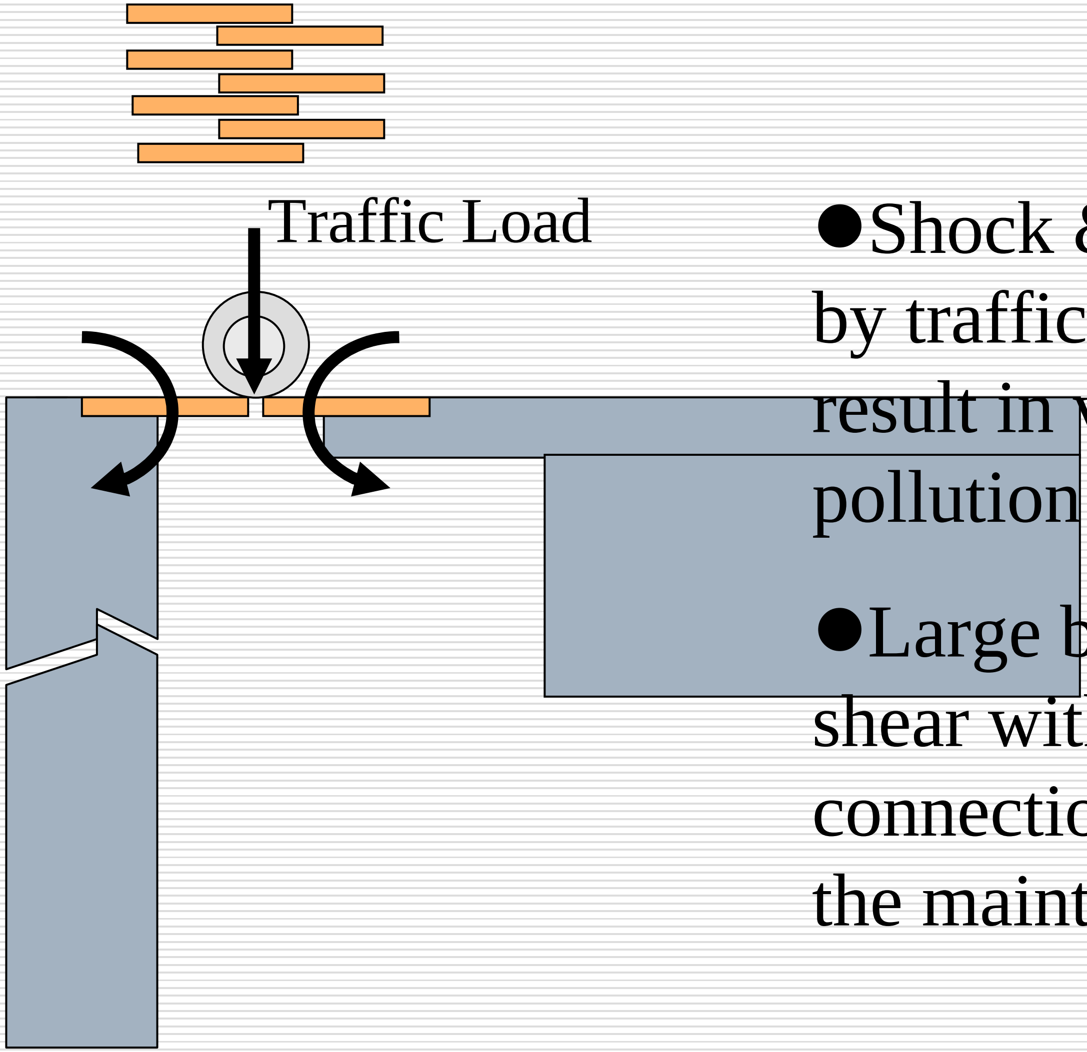


Problems associated with expansion joints which accommodate large relative displacement

大変位を吸収可能な伸縮継ぎ手の採用は可能であるが、問題もある



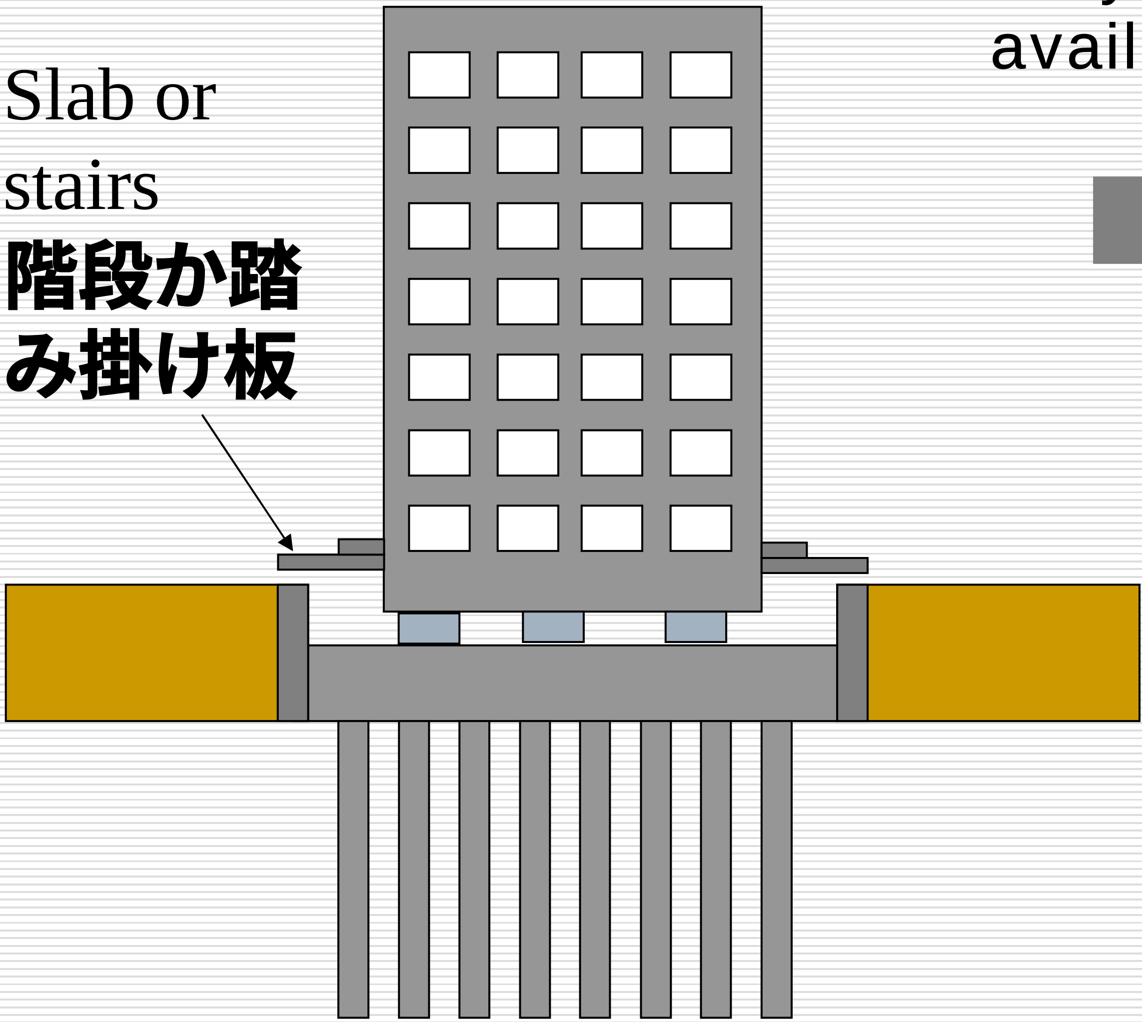
Problems of adopting an expansion joints which accommodate large relative displacement (2)



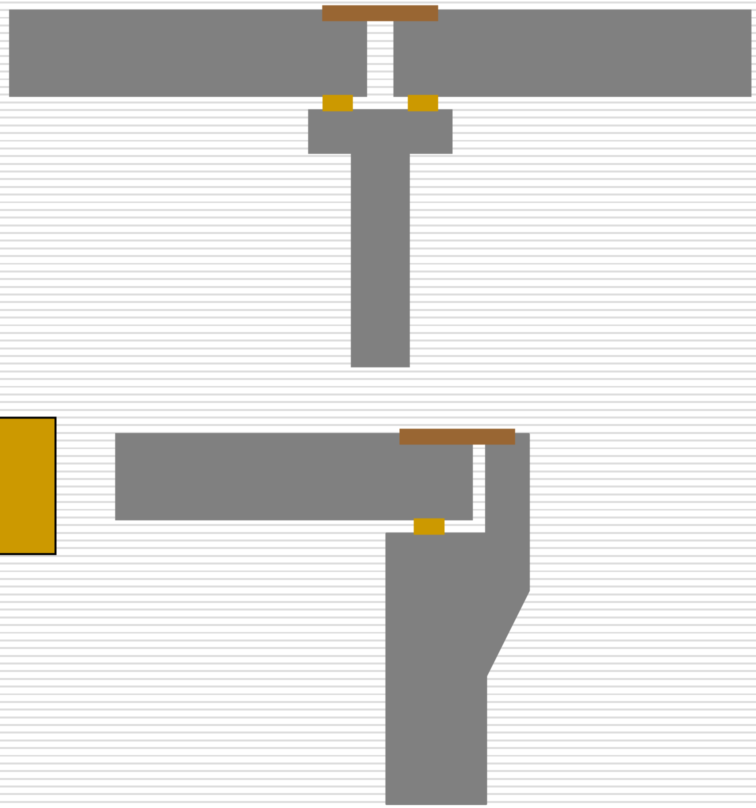
- Shock & noise induced by traffic loads are likely to result in vibration & noise pollution in city areas
- Large bending moment & shear with shock damage connections. This results in the maintenance problems.

Gap is not generally problem in buildings
建物外周の遊間は建築物では一般に問題にならない

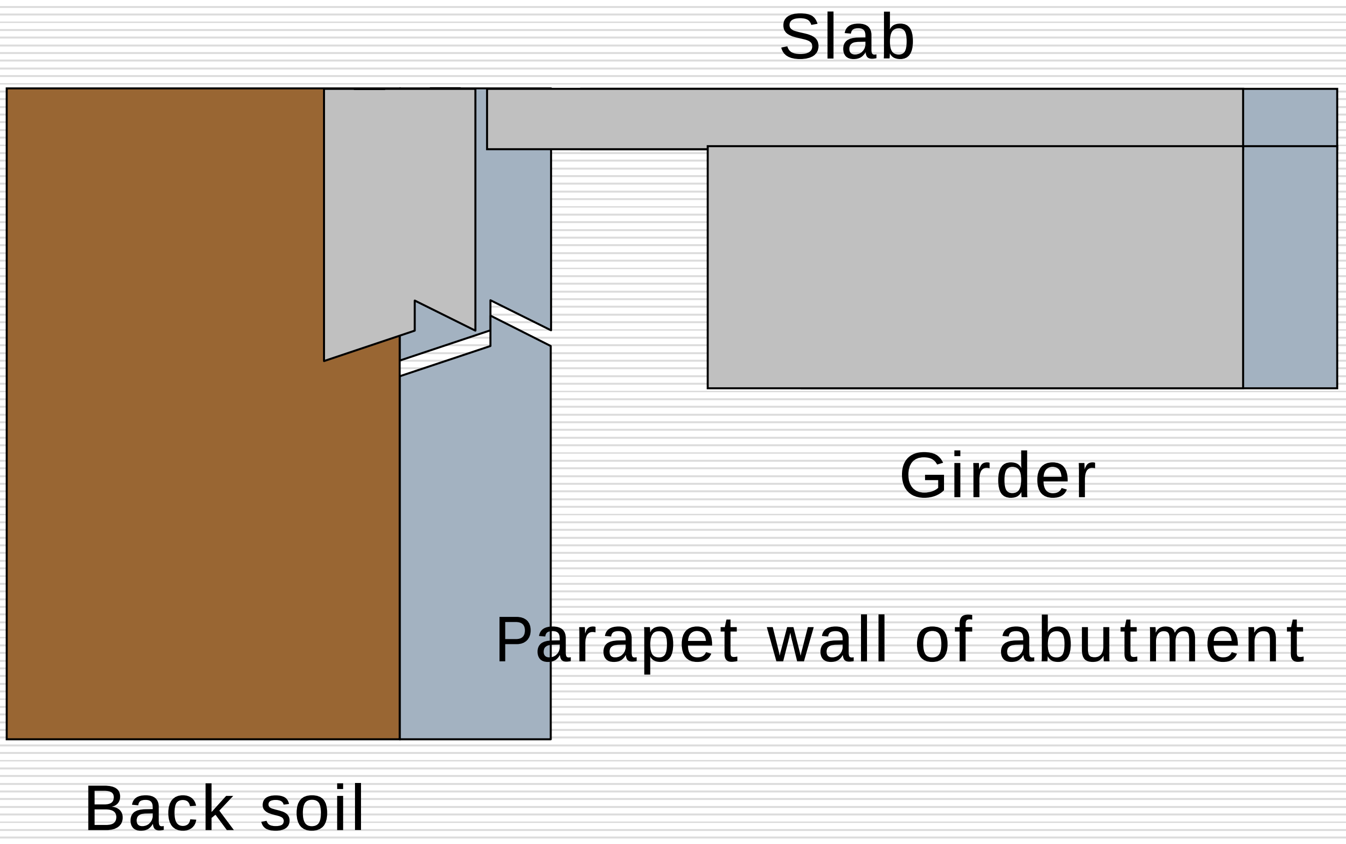
Slab or stairs
階段か踏み掛け板



Only limited space is available on bridges



4) Knock off Abutment Developed in New Zealand
ノックオフ橋台 (ニュージーランド)



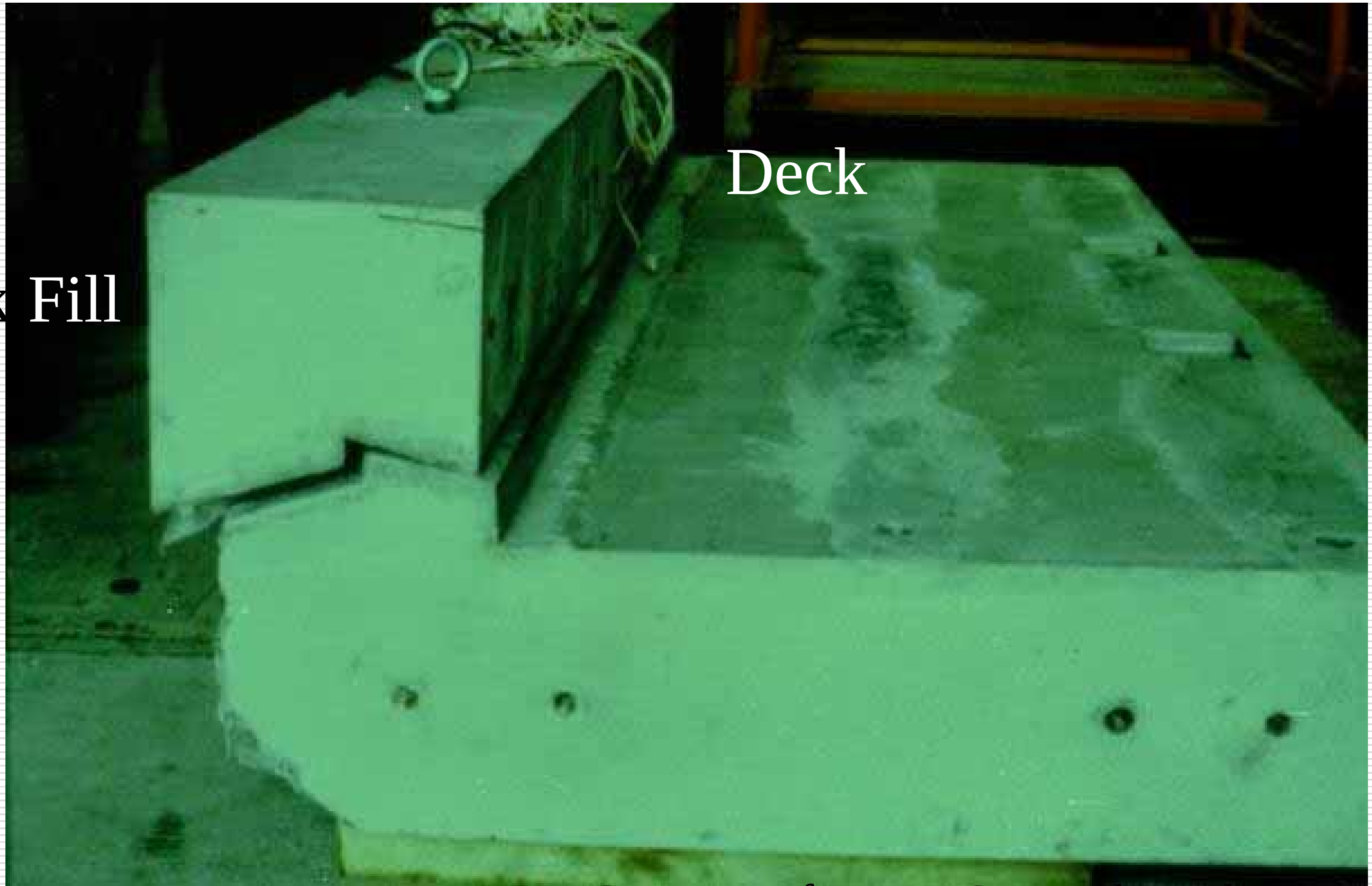
Knock-off Abutment

交通量が少ないため、ニュージーランドでは比較的簡単な伸縮継ぎ手が使用されている

Simple Expansion Joints used in New Zealand

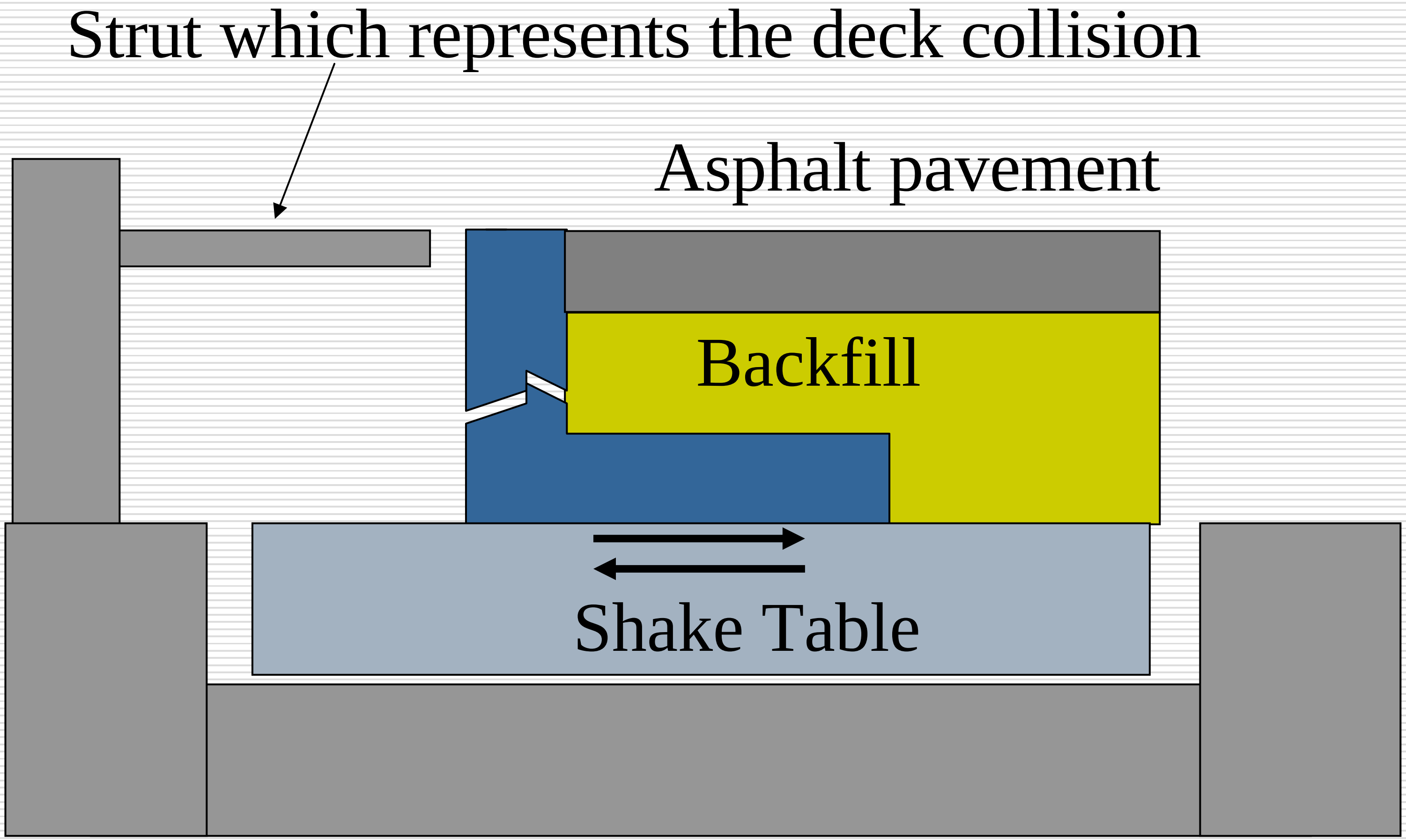
Is Knock-off Abutment effective in Japan?

Shake able experiments on Knock-off Abutment



Courtesy of Dr. Y. Goto, Obayashi Construction

Shake table experiments on Knock-off Abutment
ノックオフ橋台に対する振動台実験



Impact Load Test using a Shake Table for the Effectiveness of Knock-off Abutment

Knock-off Abutment

Courtesy of Dr. Y. Goto, Obayashi Construction

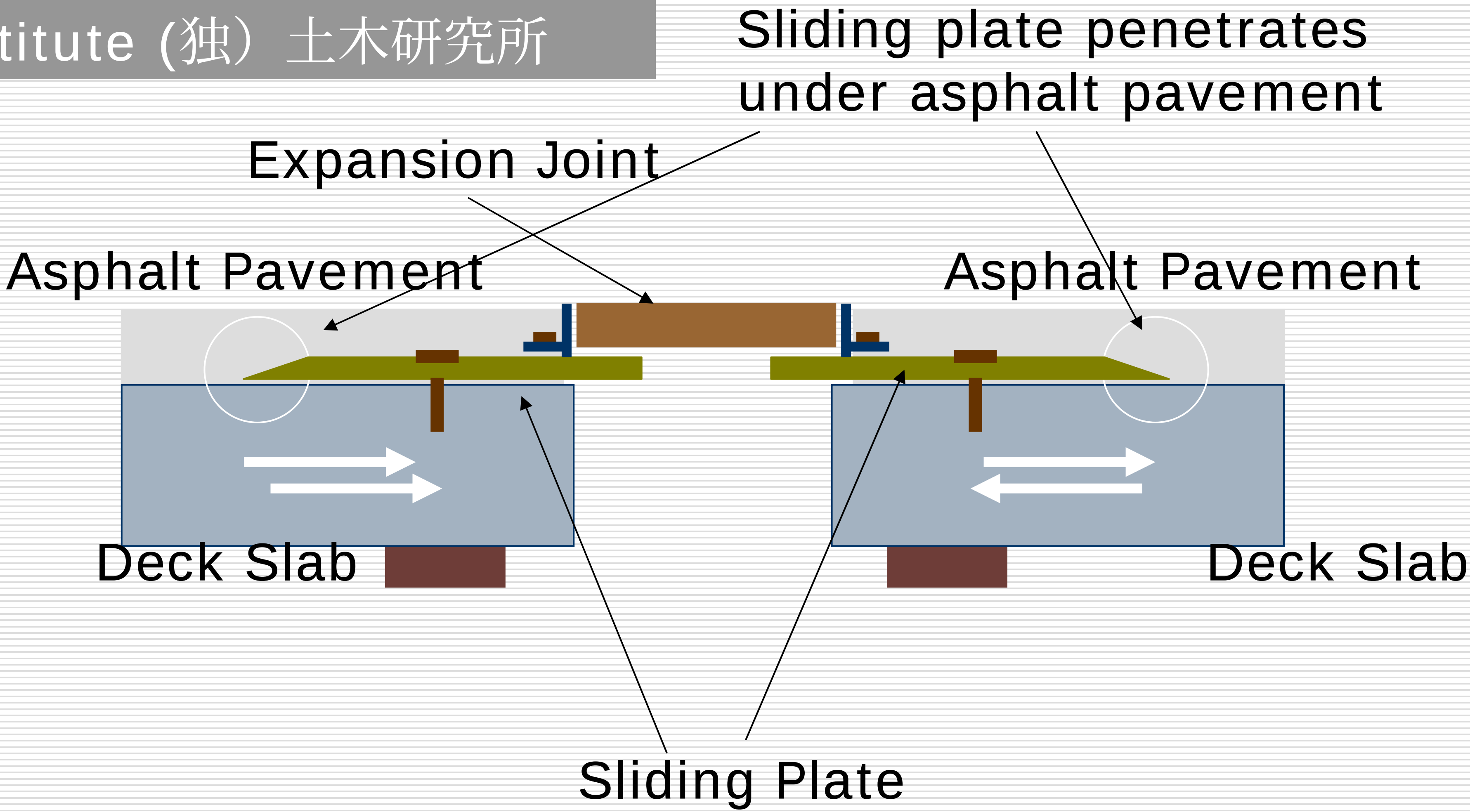
Buckling of asphalt pavement

Tilting of lower parapet wall underneath the asphalt pavement

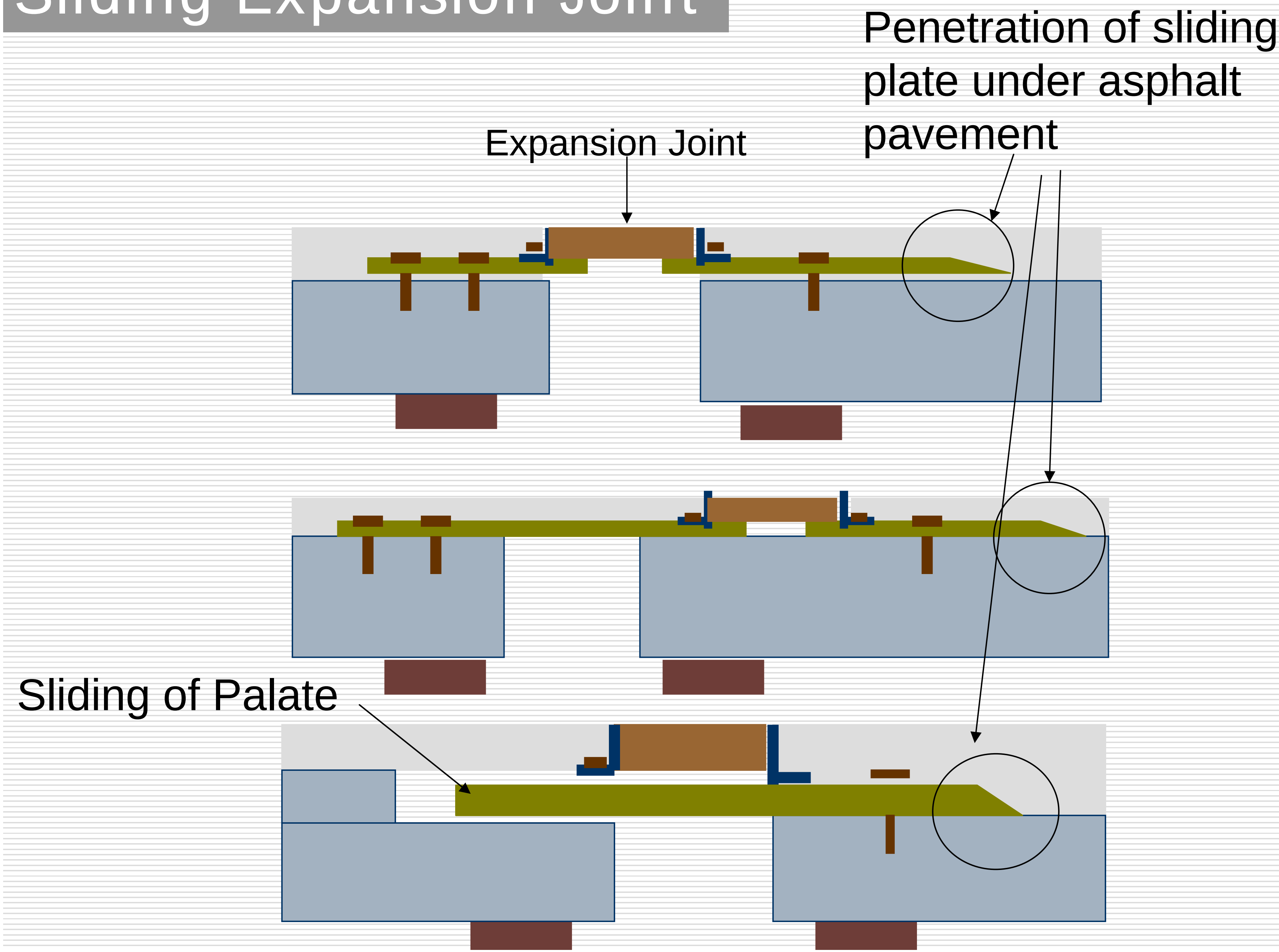
Courtesy of Dr. Y. Goto, Obayashi Construction

5) Development of Various Sliding Expansion Joints
いろいろな伸縮装置が開発されてきた

Public Work Research Institute (独）土木研究所

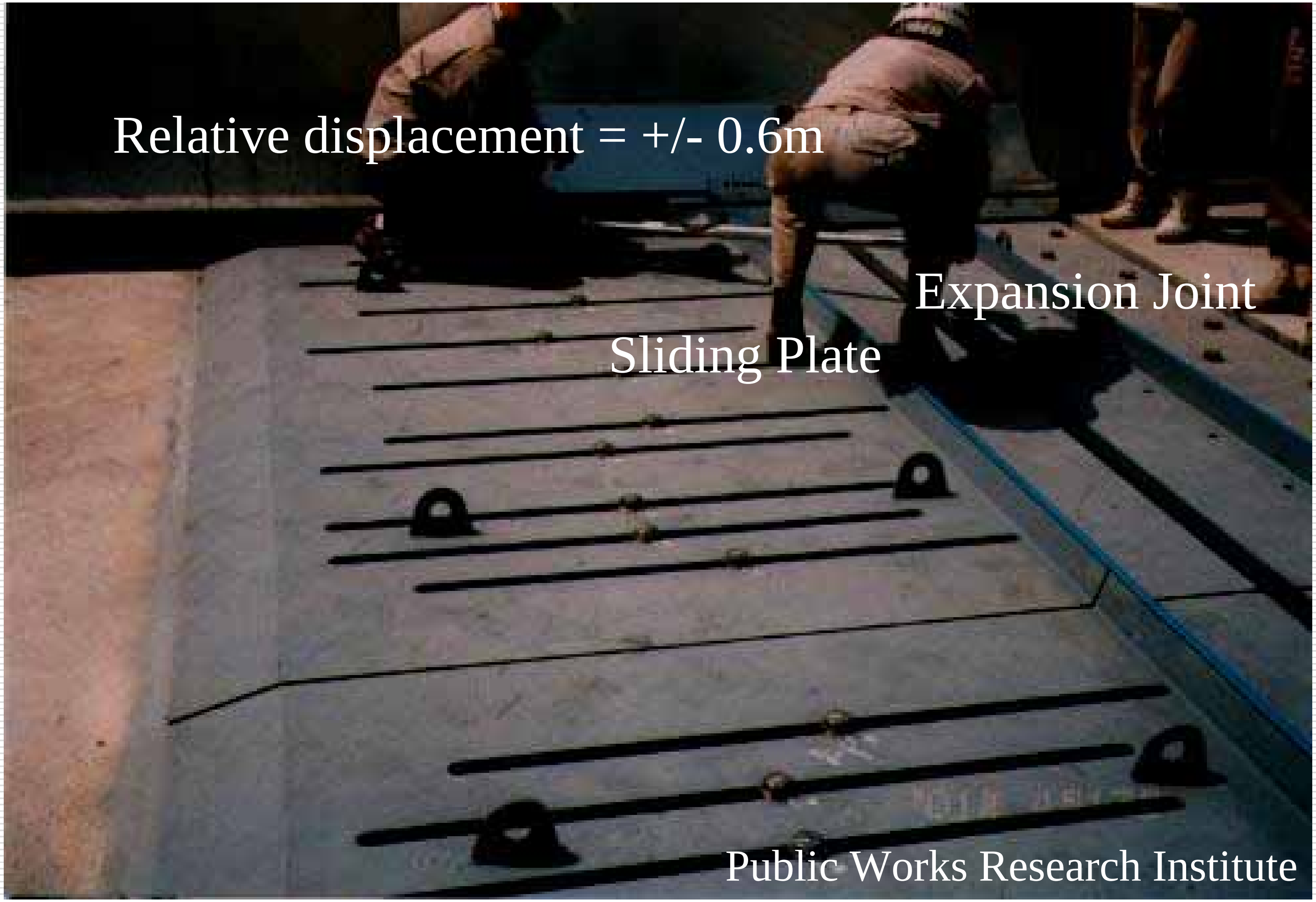


Sliding Expansion Joint



Implementation of a Set of Sliding Expansion Joint System to Amano Viaduct, Maibara

423m long 17-span continuous viaduct



Sliding Expansion Joint

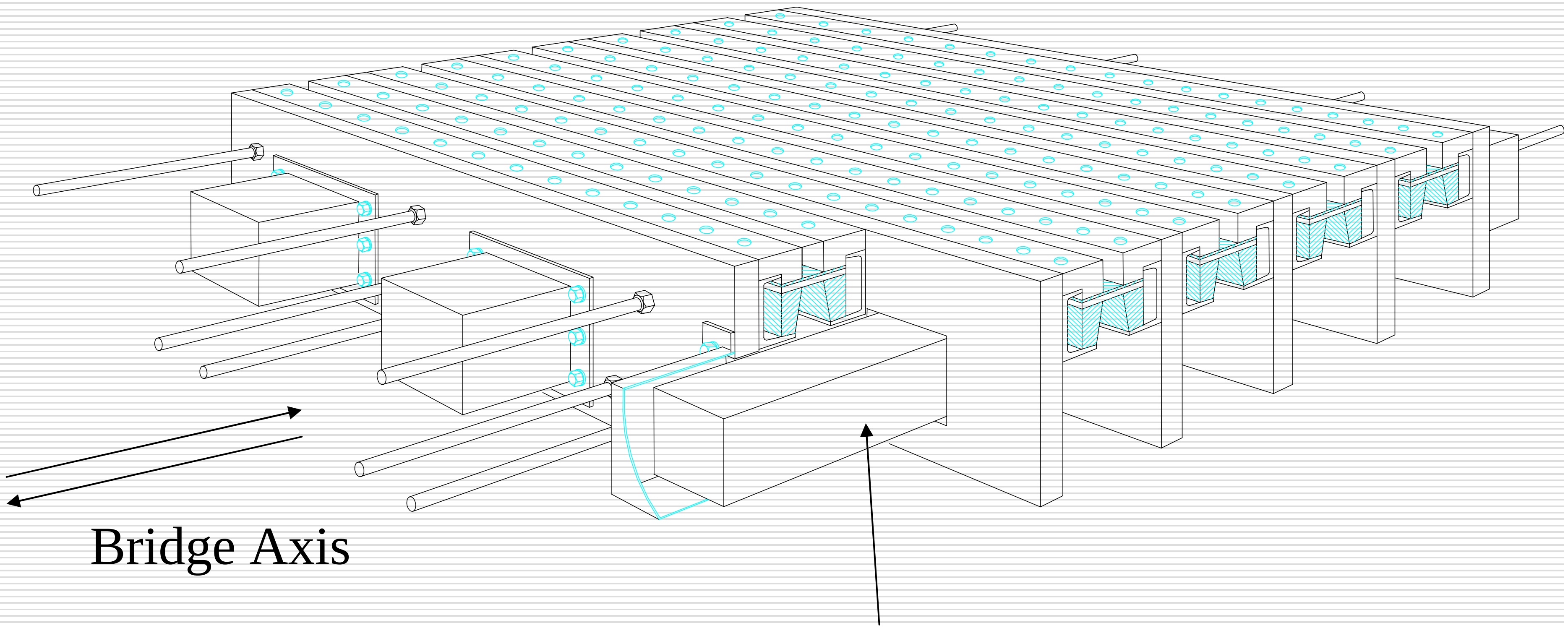
Sliding Expansion Joint Ready for Pavement

6) Development of 2 Directional Expansion Joint
2方向に相対変位を吸収可能な伸縮装置の開発

7) Big Joint 大変位を吸収可能な伸縮装置

An Expansion Joint with Function of a Restrainer

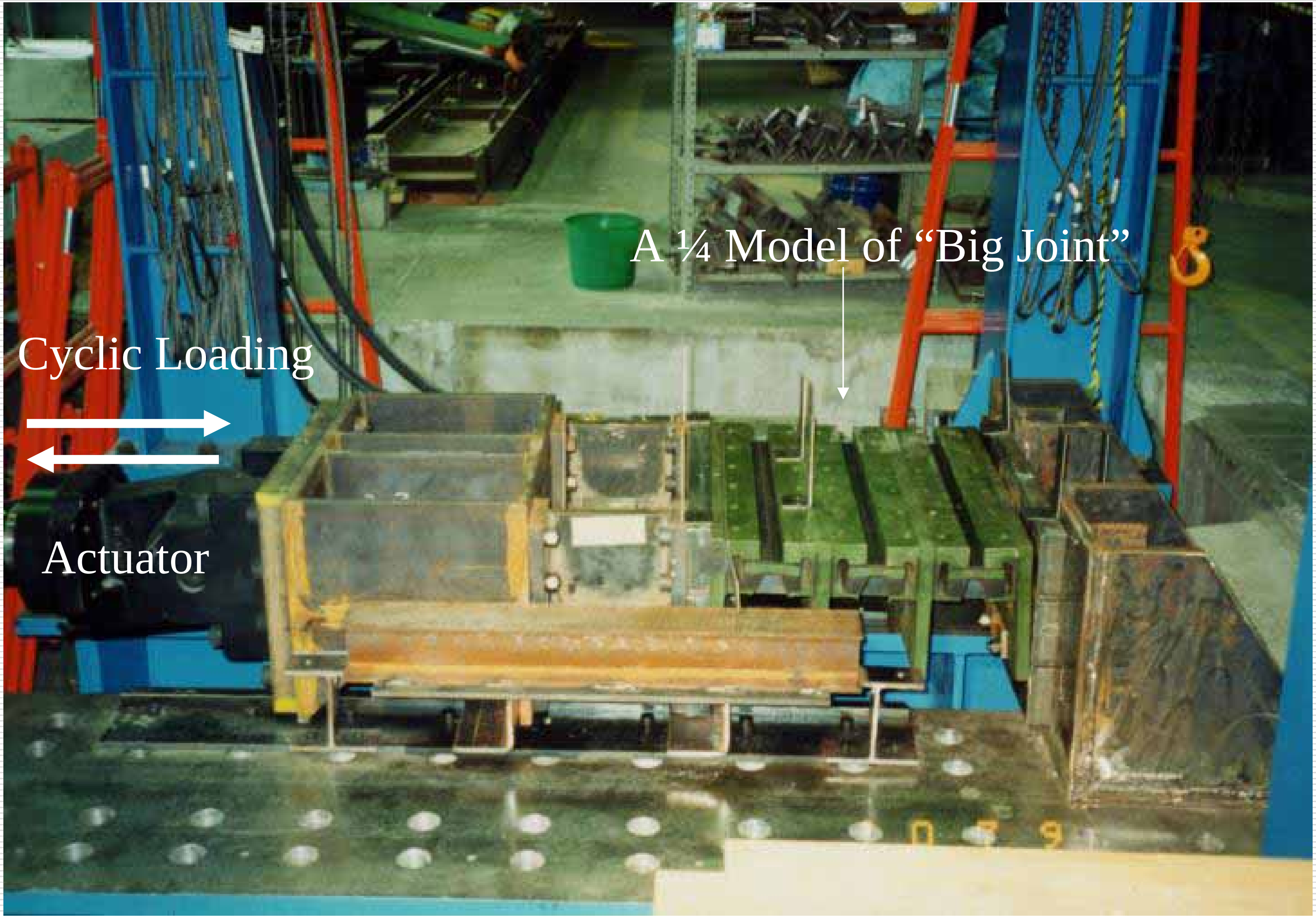
Yokohama Rubber Ltd.



Bridge Axis

Load Support Beam & Restrainer that limits Excessive Opening

Cyclic Loading Test for a Big Joint
"ビッグジョイント"に対する繰り返し載荷実験



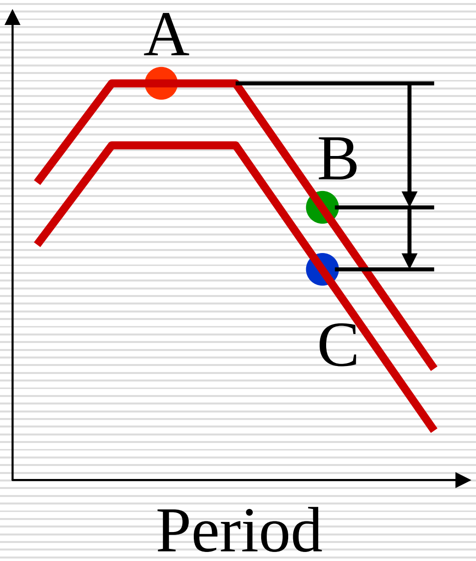
4.11 How Should the Natural Period of an Isolated Bridge be set?
免震橋では固有周期をどの程度伸ばせばよいか？

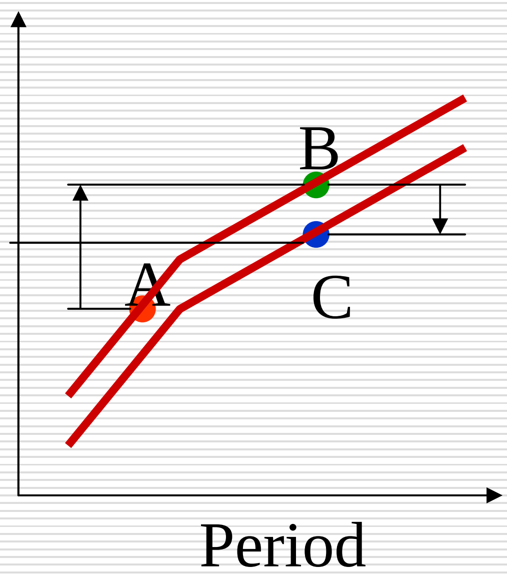
1) Expected Natural Period of Isolated Bridges

- Increase of natural period results in larger deck displacement at expansion jnoints, which is likely to develop strong impact force

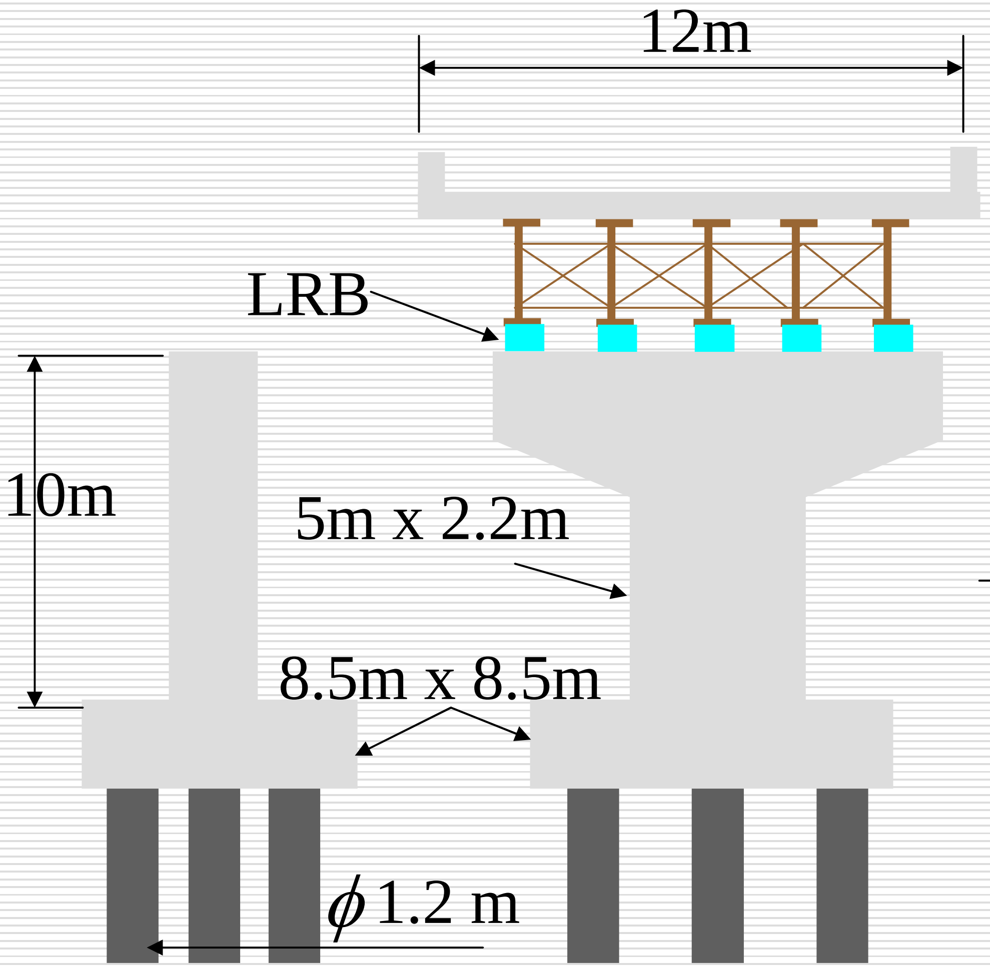
- What is the appropriate level of increase of natural period?

Response Acceleration Response Displacement

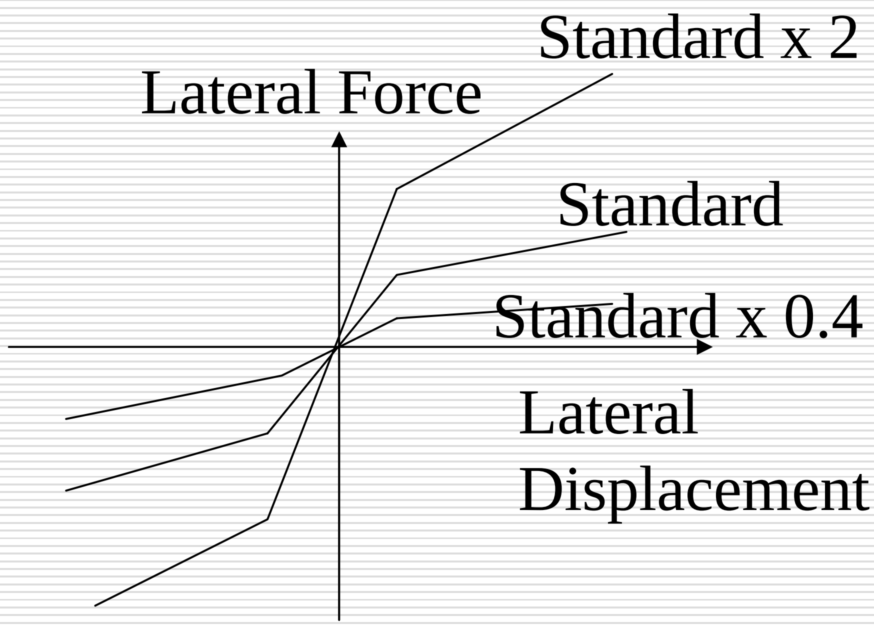




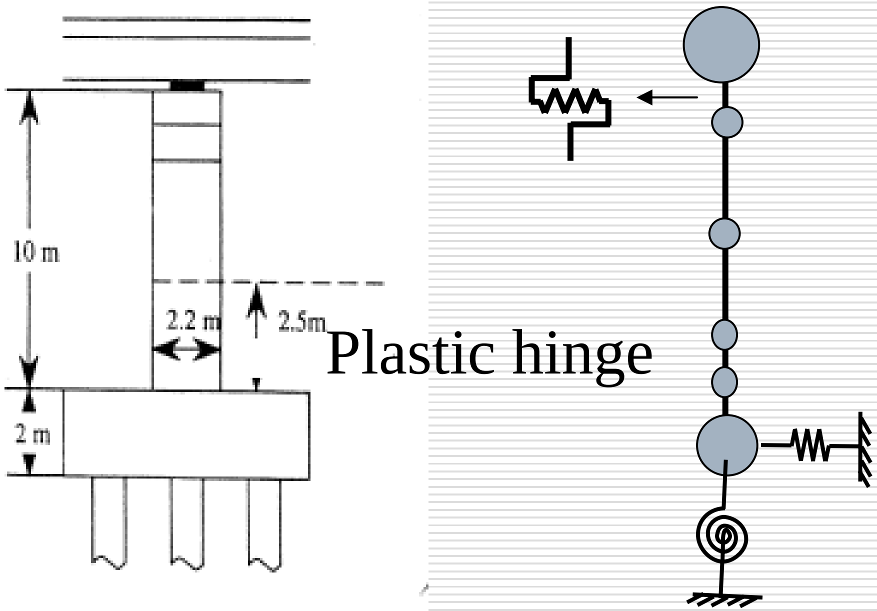
2) Analytical Example-Isolated Bridges Analyzed



Lateral Force vs. Lateral Displacement Relation of LRBs



3) Idealization of the Isolated Bridge



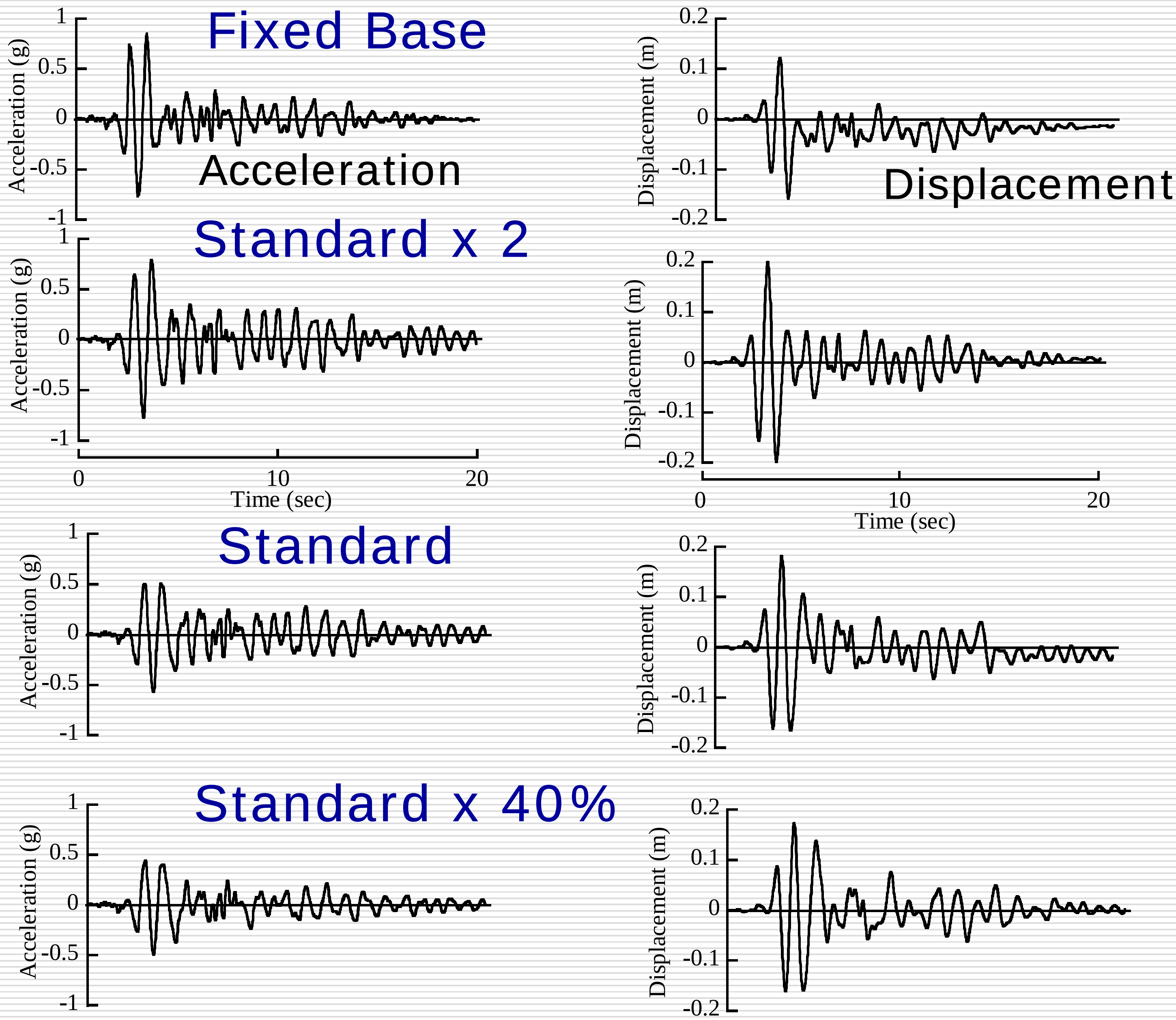
✓Lump the mass of a deck at the mass center of the deck

✓ Idealize the isolator by a lateral spring element with a bilinear hysteresis

✓ Idealize the hysteretic behavior of the column at the plastic hinge by a rotational spring with Takeda degrading model

✓ Idealize the stiffness of a foundation and the soil-structure interaction by a set of translational and rotational linear spring elements

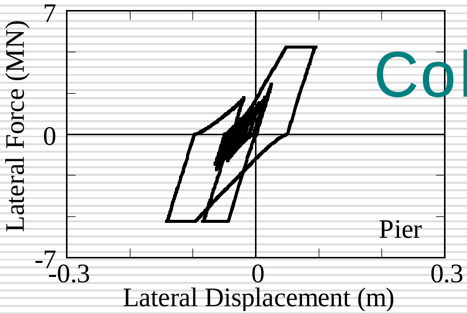
4) Deck Responses under JMA Kobe Observatory Record



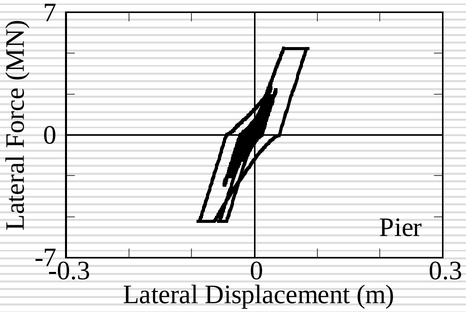
5) Column Moment vs. Curvature Hystereses at the Base

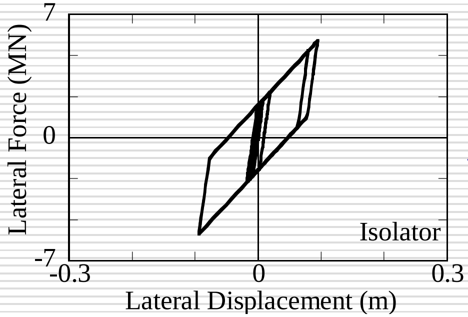
Column

Fixed Base

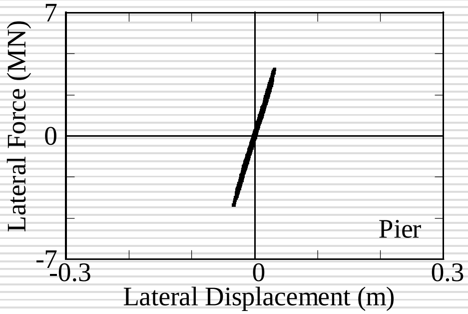


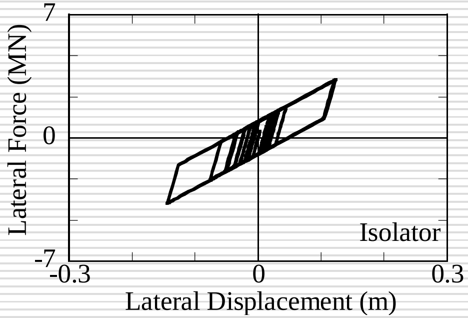
Isolator



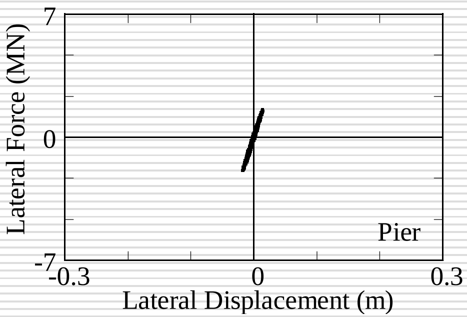


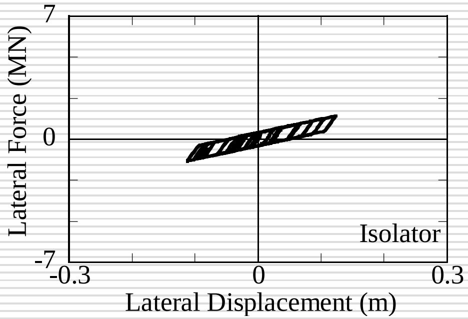
Standard x 2





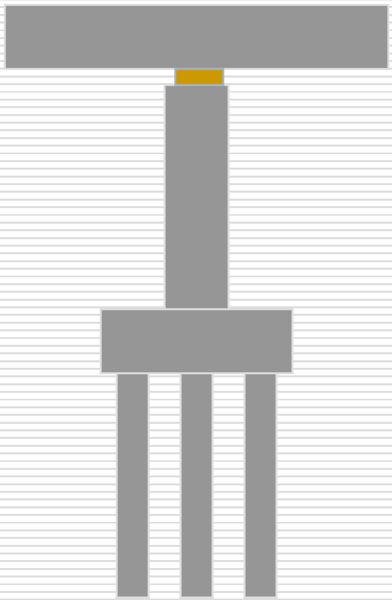
Standard





Standard x 0.4

6) Energy Dissipation of Isolators & Columns
免震装置と橋脚の塑性吸収エネルギー



Energy Dissipation of the Columns

- ✓ Isolated Bridge**免震橋**

$$U_C{}^I = \oint M_C{}^I d\theta_C{}^I$$

- ✓ Fixed Base Bridge**一般橋**

$$U_C{}^F = \oint M_C{}^F d\theta_C{}^F$$

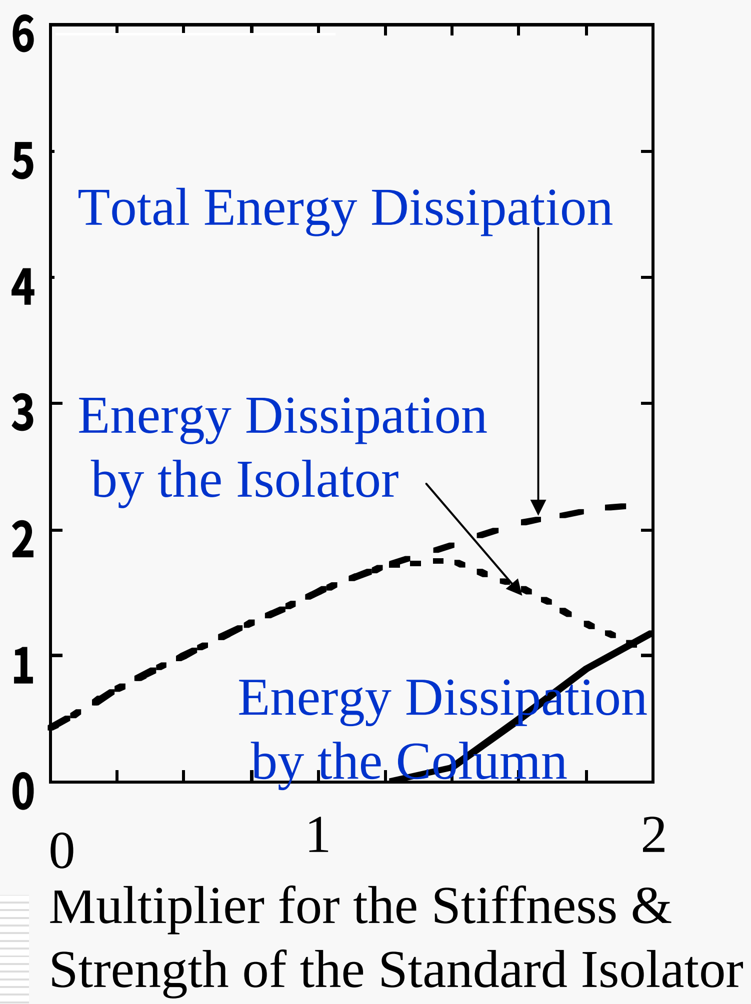
Energy Dissipation Ratio of the Column

$$r_C = \frac{U_C{}^I}{U_C{}^F}$$

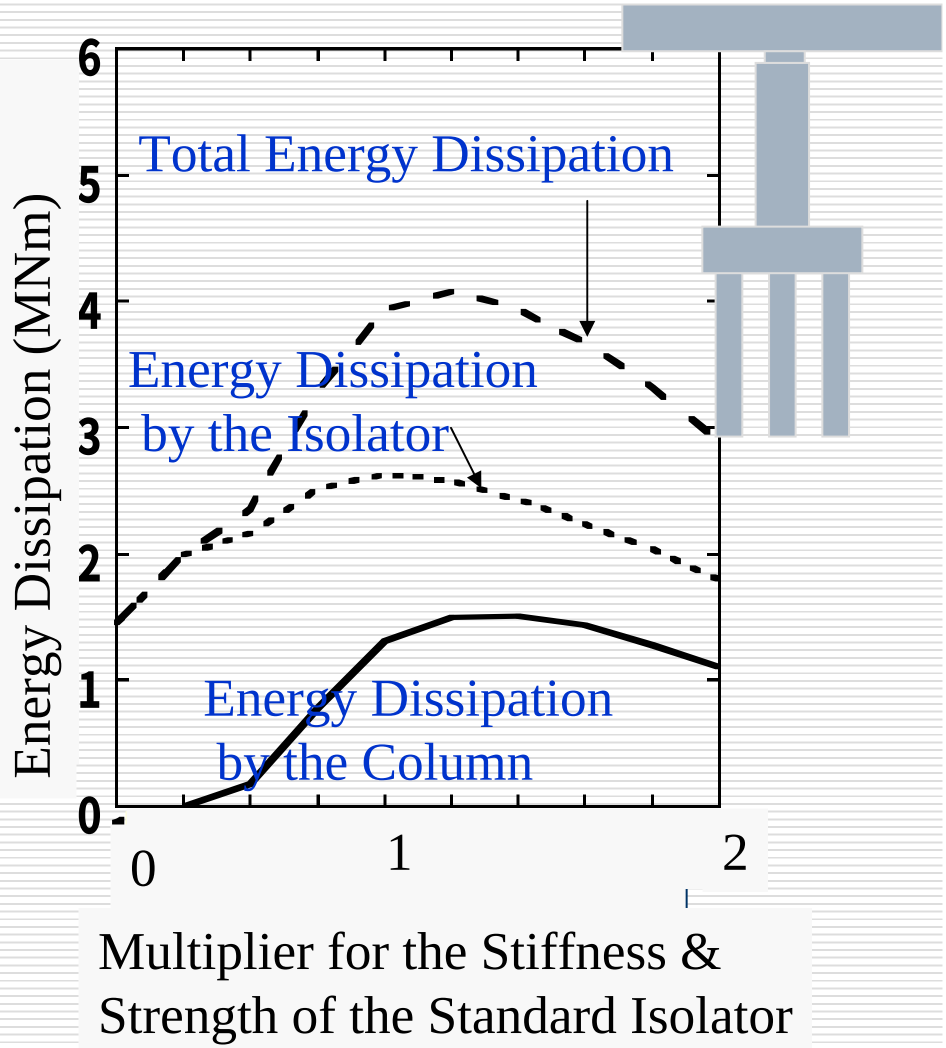
Seismic isolation is beneficial if $r_C < 1.0$

7) Energy Dissipation of Isolators & Columns

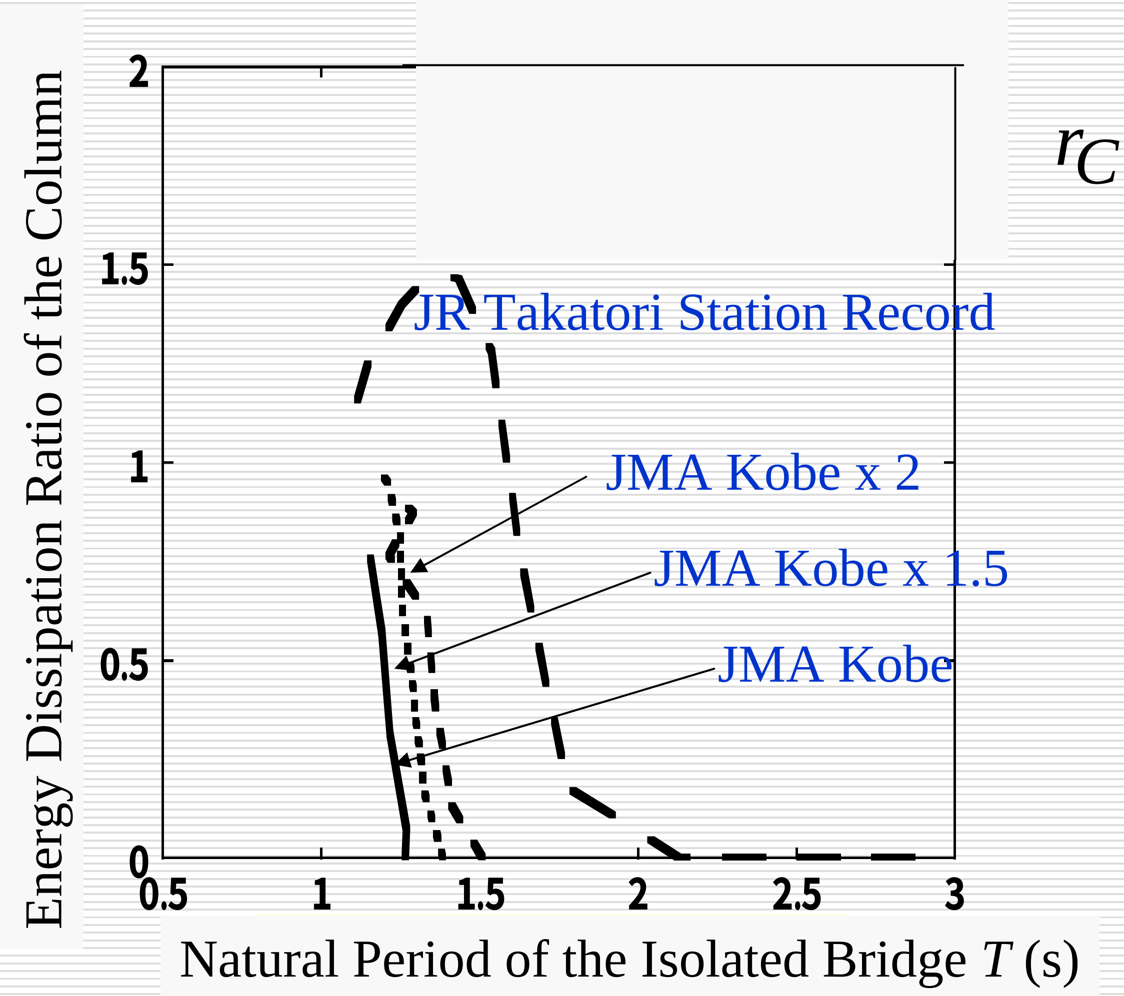
JMA Kobe Observatory



JR Takatori Record

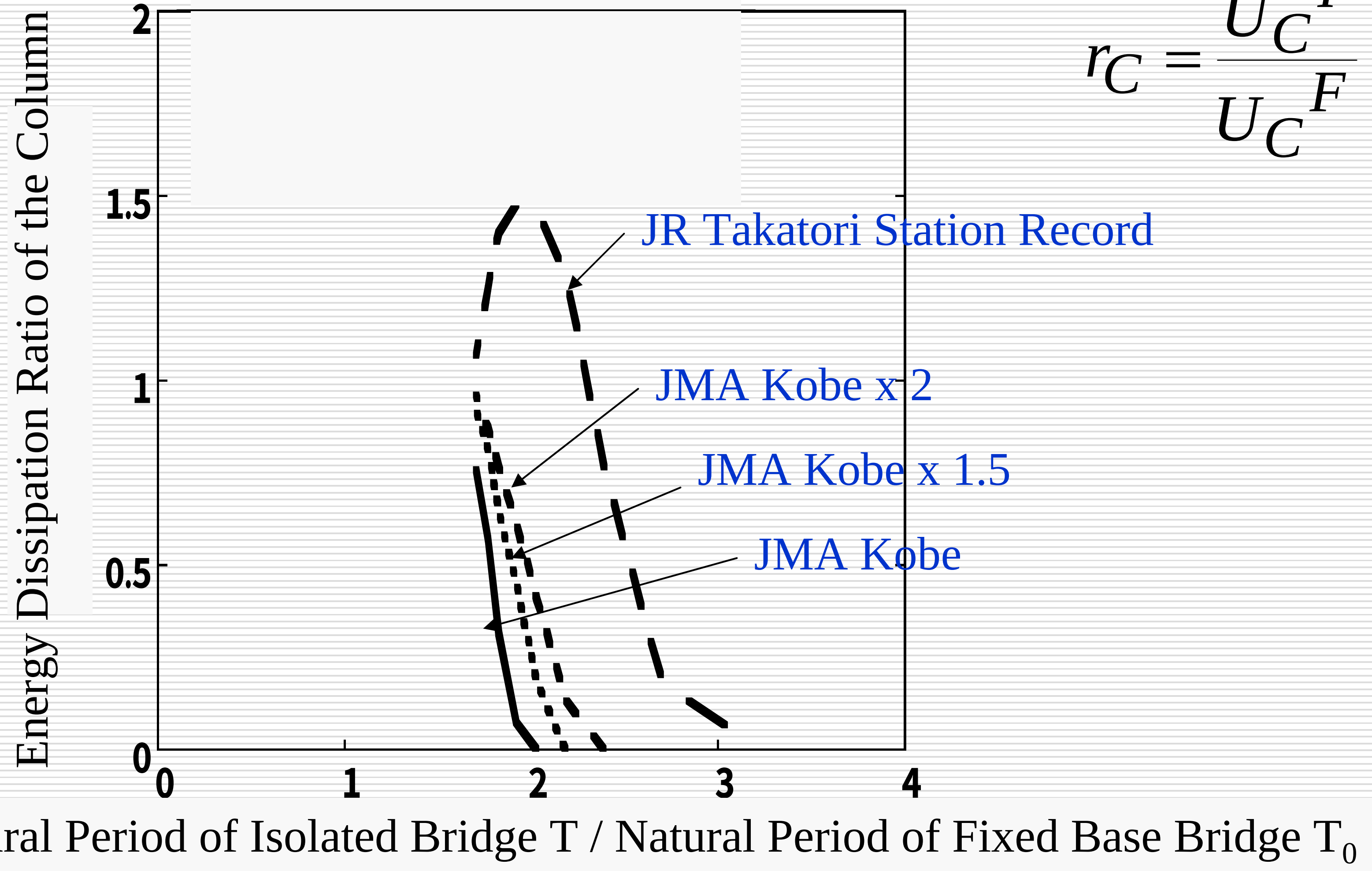


8) Energy Dissipation Ratio of the Column



$$r_C = \frac{U_C{}^I}{U_C{}^F}$$

Energy Dissipation Ratio of the Column



$$r_C = \frac{U_C{}^I}{U_C{}^F}$$

9) Summary-How should the Natural Period of an Isolated Bridge be Set?

Part V Seismic Design Specifications of Highway Bridge
Japan Road association, 2002, 2007 **道路橋示方書**

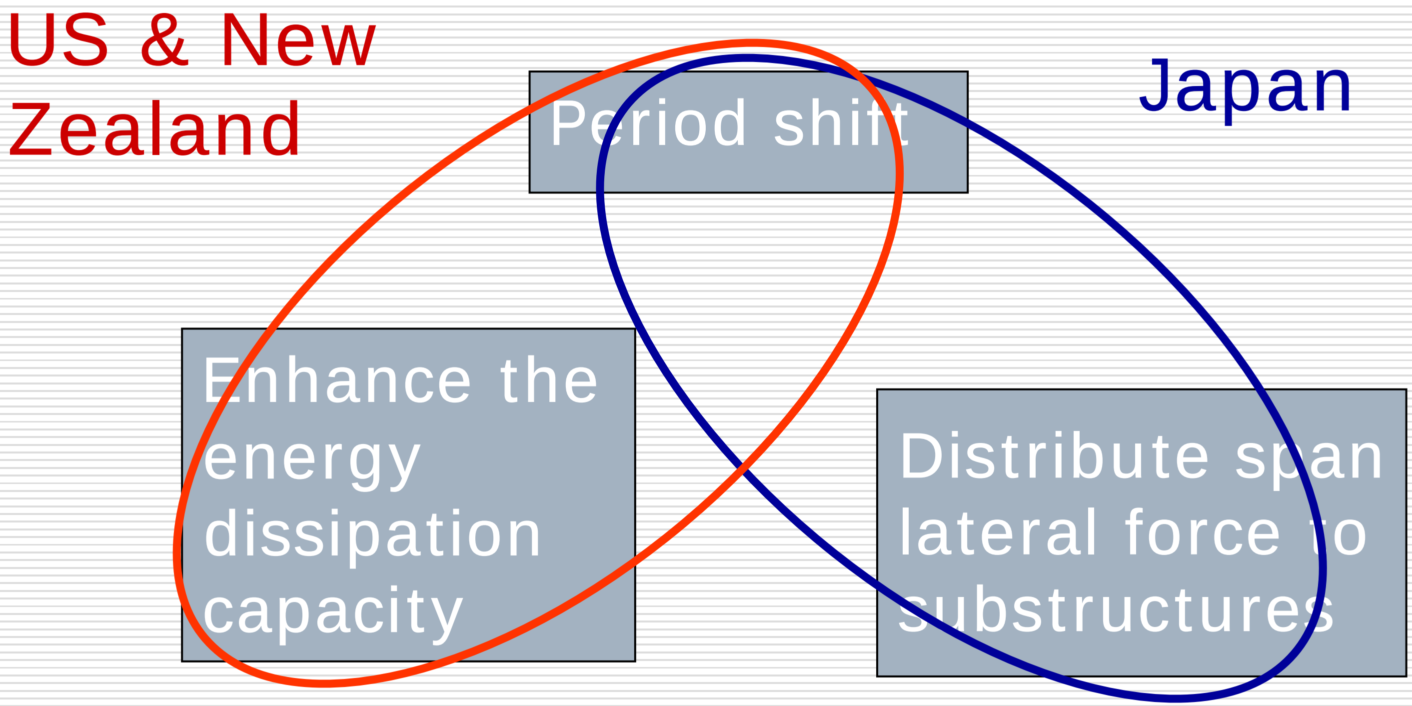
$$\frac{T}{T_0} \approx 2$$

✓ T should not be extremely long so that the deck response displacement does not become excessively large = Menshin Design

✓ Careful evaluation on the site condition and site specific ground motions are required

9) Summary-How should the Natural Period of an Isolated Bridge be Set? (contd.)

Different approach to "Period Shift"



4.12 How should we use the benefit of seismic isolation?

- Compared to a fixed base bridge, the seismic force can be reduced in an isolated bridge under the same condition
- Thus, there are various options
  - ✓ (a) Reduce construction cost
  - ✓ (b) Enhance the seismic performance
  - ✓ (a)x40% + (b)x60%
- How we should use the benefit of seismic isolation has to be carefully studied. Since the history of seismic isolation is short and since we have few experience on response measurement and seismic damage, it should be principally used to enhance the seismic performance

4.13 What is the disadvantage of seismic isolation?

- Seismic force (response acceleration) decreases but response displacement increases. Thus excessive period shift (elongation of natural period) should not be conducted.
- Seismic isolation can increase responses at soft soil sites where long-period ground motions are induced.
- Seismic isolation should not be used at the sites where instability of soils (liquefaction & lateral spreading and slippage & slope failure) is likely to occur. In such a condition, a bridge with higher statically determinant such as a moment resisting frame structure should be constructed.

4.14 What is important in implementation of seismic isolation?

- Do not excessively shift the period
  - ✓ It is not appropriate to increase the natural period over 2-3 s. at a standard bridge.
- Pay attention not to have resonance with soil response
- Enhance the damping capacity
- Distribute the inertia force of a superstructure to substructures depending on the lateral capacity of substructures

4.15 What are bridges to which seismic isolation can be favorably implemented?

- Super multi-span continuous bridge (1km long bridge)
  - ✓ Since thermal movement of a superstructure is large, it becomes easier to adopt expansion joints which are capable to absorb large relative displacement
  - ✓ Since elastomeric bearings are laterally flexible, they fit to absorb thermal deformation, creep and shrinkage of a superstructure
- Seismic retrofit of existing bridges
  - ✓ Tie together between adjacent simply supported spans so that they becomes a multi-span continuous bridge under the seismic action
  - ✓ Seismic isolation can be used in stead of seismic retrofit

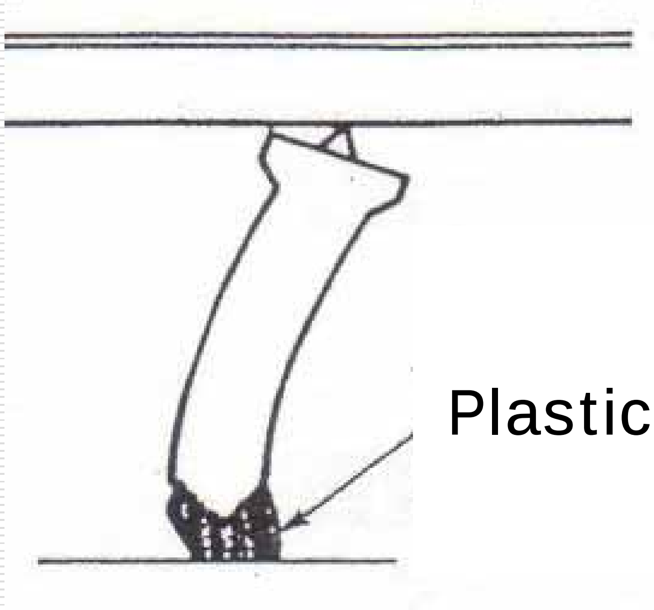
4.16 Is the Seismic isolation and fixed base design completely different?

Fixed base design: Design structure strong enough to withstand the seismic force

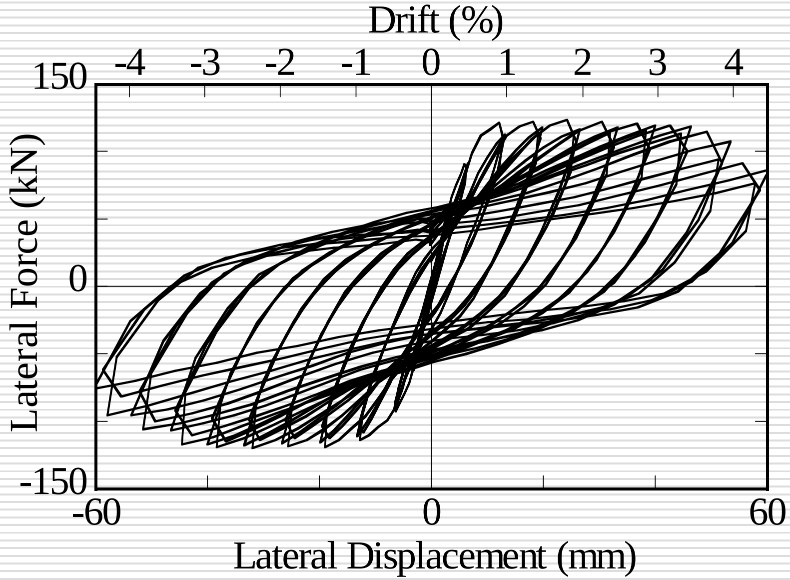
↕ Completely different?

Seismic isolation: Reduce response by period shift and energy dissipating devices

1) What is the concept of ductility design?



Plastic hinge



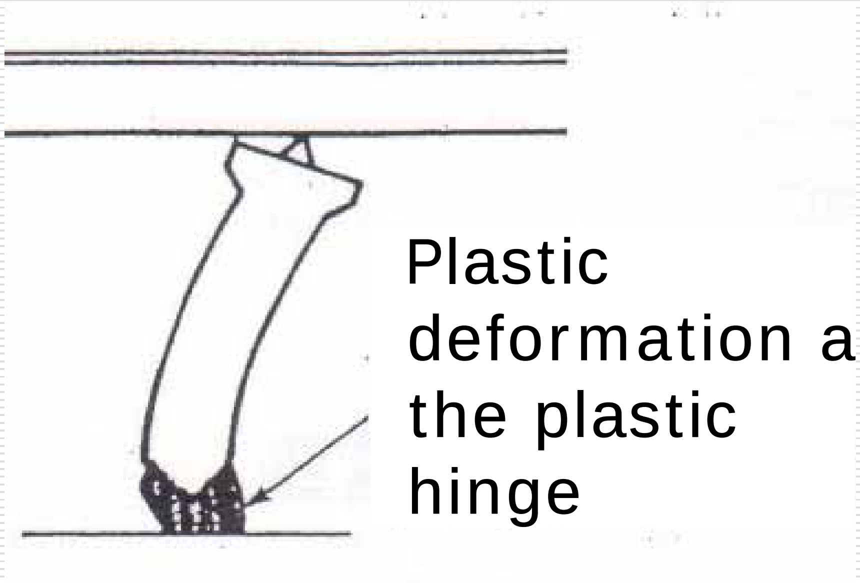
Plastic deformation (=damage) of column at the plastic hinge

Deterioration of stiffness → Period shift

Energy dissipation → Increase damping

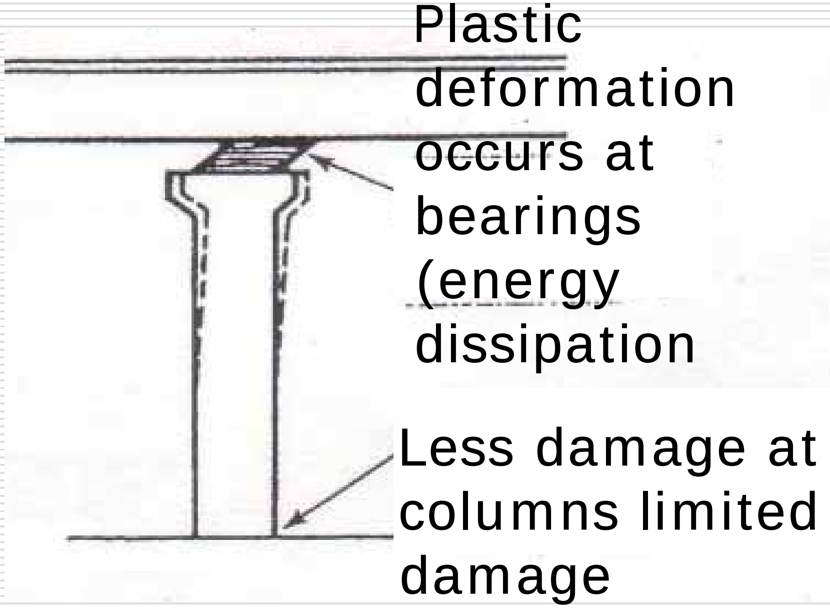
2) Is the Seismic isolation and fixed base design completely different?

Fixed base design



Design column plastic hinge so that stable reduced stiffness (equivalent stiffness) and energy dissipation can be achieved

Seismic isolation



Design isolation bearings and dampers so that the bearings can take a role of column plastic hinge in the fixed base design

3) Fixed base design and seismic isolation have the same concept

- In fixed base bridges, we set sufficient volume of tie bars at column plastic hinges so that sufficient ductility capacity can be achieved
- However having “plastic deformation” at the plastic hinge means that column suffers damage
- The original concept of seismic isolation was developed by seeking a way that no structural components suffer damage
- Seismic isolation is not different with the fixed base design but it is on the same direction extending the fixed based design based on capacity design concept

4.17 Summary of Seismic Isolation

- What is seismic isolation?
  ✓Period shift + Increase energy dissipation capacity
  ✓ Design based on only “period shift” or “increase energy dissipation capability” (response control) is also well used.
- How can we design isolated bridges?
  ✓Support spans by isolators and set energy dissipaters (dampers).
  ✓ LRB (lead rubber bearings) or HDR (high damping rubber bearings) are beneficial to bridges because isolators and dampers are all in one. Space for installation of isolators and dampers is limited in bridges.

4.18 What bridges can seismic isolation be effectively used?

- What bridges are appropriate for seismic isolation?
  - ✓ Multi-span continuous bridges
  - ✓ Bridges resting on stiff and stable soils
- What should we care in design of seismic isolated bridges
  - ✓ Do not excessively elongate the natural period but set the natural period such that response displacement of spans is not too large
  - ✓ Natural period of an isolated bridge should be decided not to have resonance with the surrounding ground.
  - ✓ Note in design that the effectiveness of seismic isolation has not yet been fully verified under an extreme earthquake.