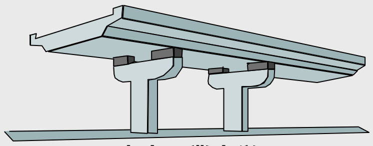
## (5) 長周期化とエネルギー吸収性能の増大に基づく免震設計
## (5) Seismic Isolation of Bridges

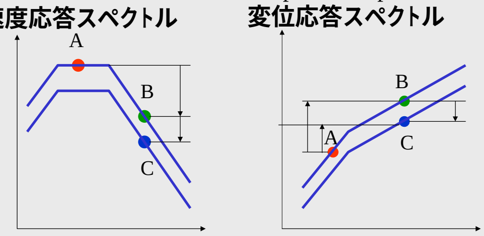


東京工業大学
川島一彦
Kazuhiko Kawashima
Tokyo Institute of Technology

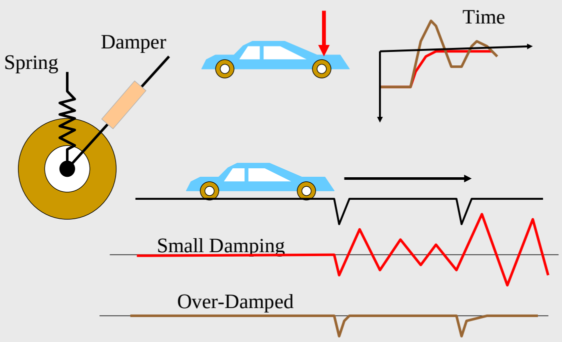
## Basic Principle of Seismic Isolation

Response Acceleration
加速度応答スペクトル

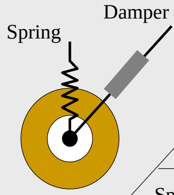
Response Displacement
変位応答スペクトル

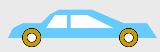



## Why is Energy Dissipation Required ?




## Why is the Increase of Natural Period Required ?




| |  |  |
|---|---|---|
| Spring | Stiff | Soft |
| Shock = Acceleration | Strong | Weak = Comfortable |
| Displacement | Small | Large |

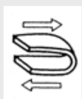
## How can we have energy dissipation?
## どうすればエネルギー吸収ができるのか？

Various principles

●Energy dissipation due to plastic deformation of steel devices

Torsion

Bending



Mild steel, lead, etc.

●Viscous fluid
●……

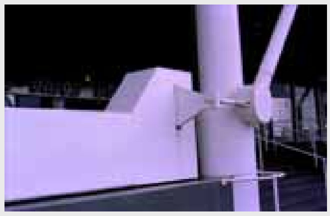
## What devices are available?

Fatigue due to repeated plastic deformation?

## Steel Plate Isolators

## Implementation of Steel Plate Isolators to a Building

New Zealand



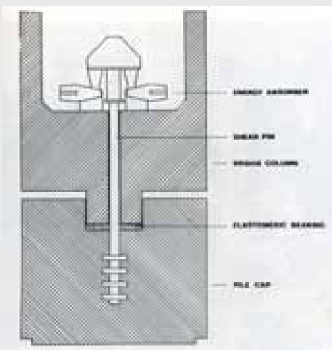
## Steel Torsion Energy Dissipators

## Stepping structure using steel torsion energy dissipators

South Rangitikei Bridge, New Zealand

1972

## Stepping Piers



Skinner, Robinson & McVerry (1993)

## Stepping Columns

Mechanical Torsional Damper

Torsional Plate Damper

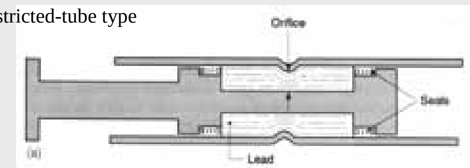
Lead Extrusion Dampers
**鉛押し出し式ダンパー**

Aurora Terrace Bridge

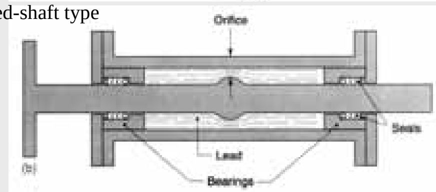
Lead Extrusion Damper


Lead-Extrusion Damper

Constricted-tube type

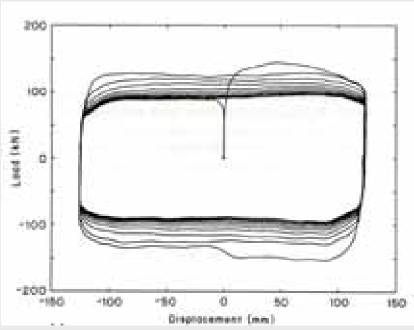



Bulged-shaft type



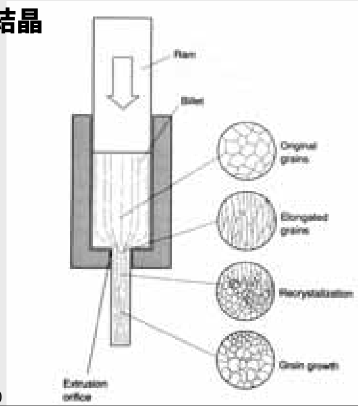

Skinner, Robinson & McVerry (1993)

## Lateral Force vs. Lateral Displacement Hysteresis of a Lead Extrusion Damper




Skinner, Robinson & McVerry (1993)

## Re-crystallization of Lead after Plastic Deformation鉛の再結晶




Skinner, Robinson & McVerry (1993)

## Why is lead appropriate for an energy dissipator?

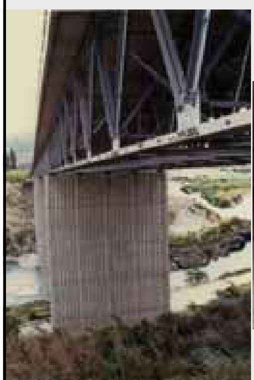
Re-crystallization of lead 鉛の再結晶

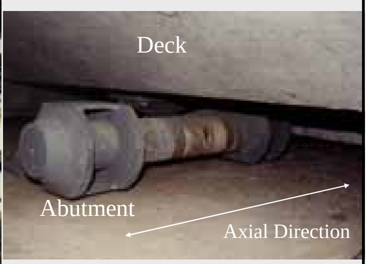
Re-crystallization temperature 再結晶温度
= Temperature which is required for re-crystallization of 50% the lead in an hour

| Material | Re-crystallization temperature |
|---|---|
| Lead | Lower than 20 C |
| Aluminum | 150 degree C |
| Copper | 200 degree C |
| Steel | 450 degree C |

## Steel Bar Flexure Energy Dissipator

## Cromwell Bridge

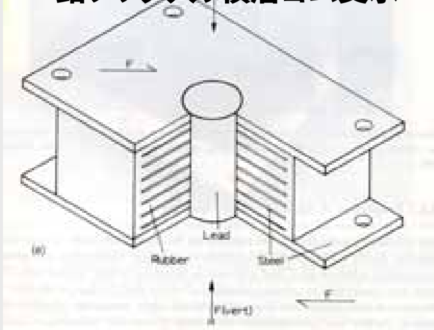





## Deformed Mild Steel Flexural Damper

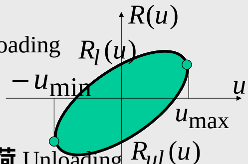
Lead Rubber Bearings
**鉛プラグ入り積層ゴム支承**

Lead Rubber Bearings
**鉛プラグ入り積層ゴム支承**




Skinner, Robinson & McVerry (1993)

## Hysteretic Energy Dissipation




$$\xi_{eq} = \frac{1}{4\pi}\frac{\Delta W}{W}$$

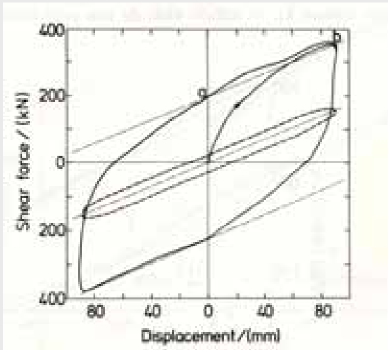
$$\Delta W = \oint R du$$

$$\Delta W = \int_{-u_{min}}^{u_{max}} R_l(u)du + \int_{u_{max}}^{-u_{min}} R_{ul}(u)du$$
$$= \int_{-u_{min}}^{u_{max}} R_l(u)du - \int_{-u_{min}}^{u_{max}} R_{ul}(u)du$$
$$= \int_{-u_{min}}^{u_{max}} R(u)du$$

where

$$R(u) = R_l(u) - R_{ul}(u)$$

Lateral Force vs. Lateral Displacement
Hysteresis of a Lead Rubber Bearing

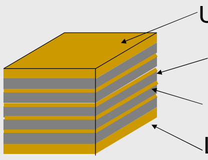



Skinner, Robinson & McVerry (1993)

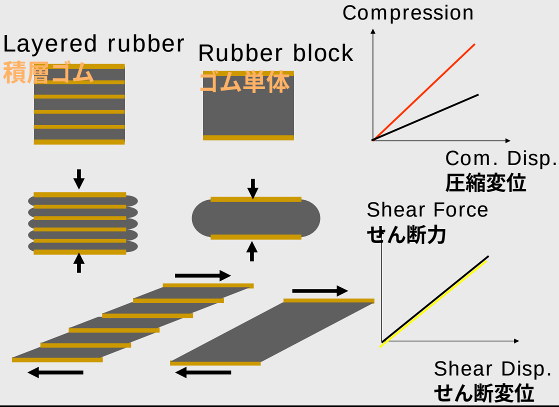
How can we implement the seismic isolation? **具体的には、どうするのか？**

●Period shift (=Increase natural period)**長周期化**

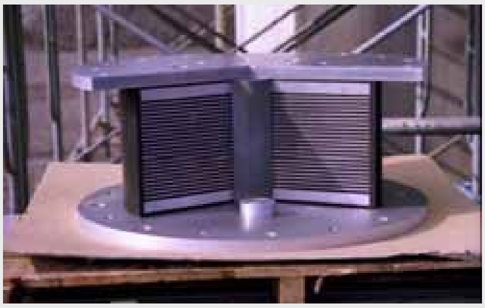
●Support a structure using elastomeric bearings
**水平方向に柔らかい支承（一般には、積層ゴム支承）で支持する**




**なぜ、積層化するのか？**



Lead Rubber Bearings
**鉛プラグ入り積層ゴム**



Large Lead Rubber Bearing used for O-Ghishima Viaduct, Metropolitan Expressway

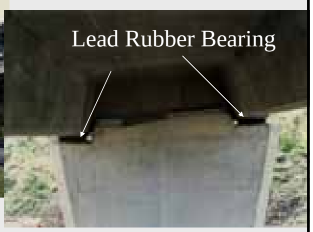
**東扇島橋**
**首都高速道路**

Toe Toe Bridge, New Zealand

Lead Rubber Bearing

Moonshine Bridge, New Zealand

Grafton Bridge, Auckland

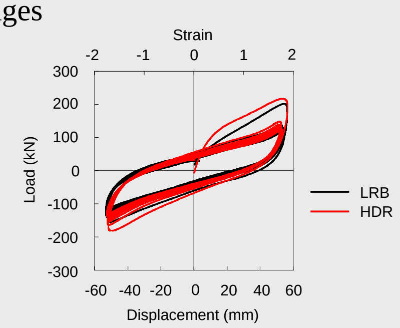



**高減衰積層ゴム支承**
High Damping Rubber Bearings
HDR

- Use special rubber which dissipates energy under deformation
- High damping rubber sheets are laminated with steel plates (elastomeric bearings)
- Because lead is hazardous material in LRB, HDR bearings are preferred in the implementation in seismic isolation in recent years

**橋梁用**
For Bridges

$G = 1.2MPa$

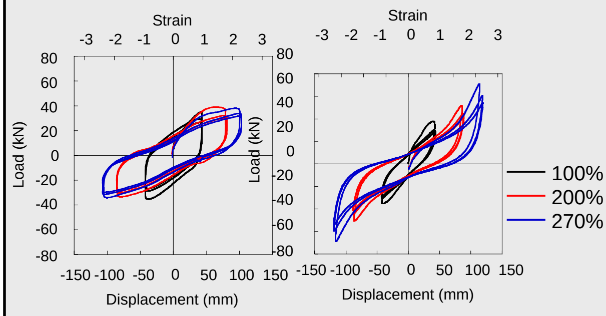



Courtesy of Bridgestone

**建築用** For Buildings

$G = 0.4MPa$

LRB S−HRB

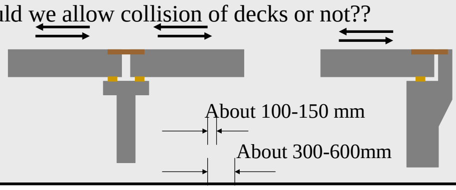



Courtesy of Bridgestone

**けたの地震応答変位が増大することに伴う問題**
Treatment of Deck Collision

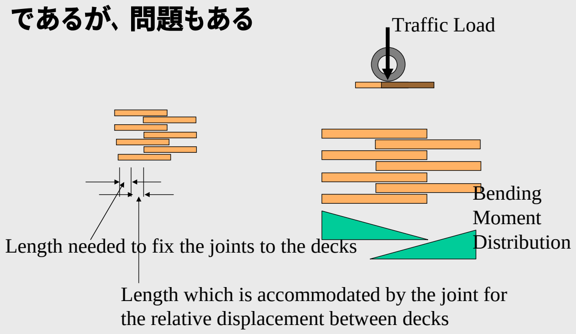
## Difficulty in the Treatment of Large Deck Displacement

- ●Deck displacement easily exceeds +/- 0.5m even in the standard bridges subjected to a near-field ground motion
  - ✓Extreme ground motions
  - ✓Soft soils
- ●Should we allow collision of decks or not??

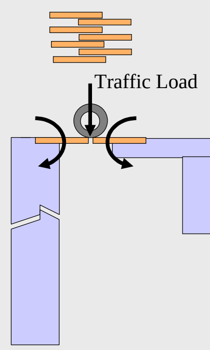



## Problems associated with expansion joints which can accommodate large relative displacement

**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**

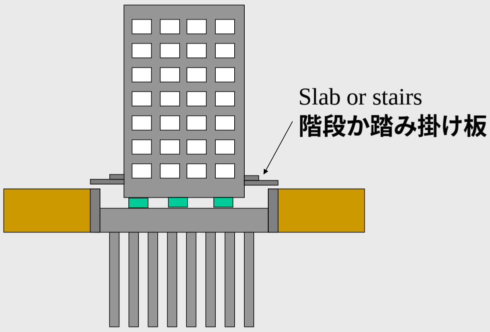



## Problems associated with expansion joints which can accommodate large relative displacement

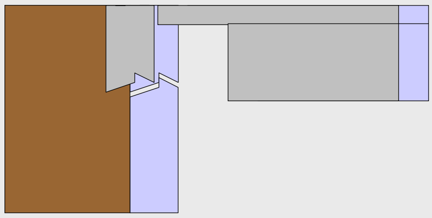



- ●Shock & noise induced by traffic loads result in vibration & noise pollution in city areas
- ●Large bending moment & shear with shock results in damage at the connection. This results in maintenance problems.

Gap is not 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




Knock off Abutment
ノックオフ橋台 (ニュージーランド)



Knock-off Abutment

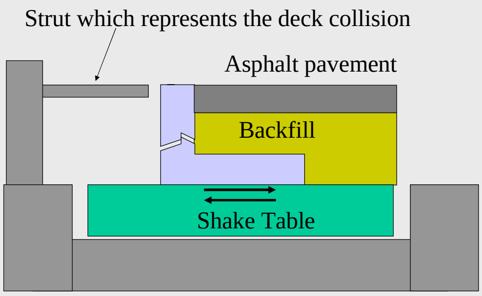

交通量が少ないため、ニュージーランドでは比較的簡単な伸縮継ぎ手が使用されている
Simple Expansion Joints used in New Zealand

Is the Knock-off Abutment effective for implementation 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



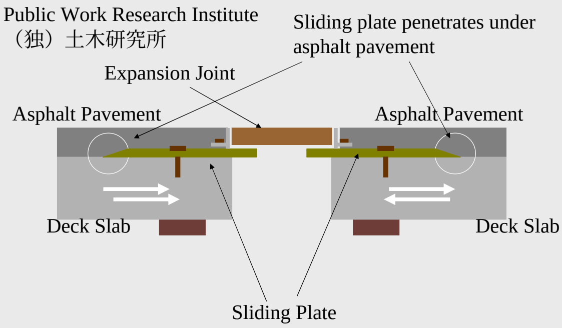
## Impact Load Test using a Shake Table for the Effectiveness of Knock-off Abutment


## Buckling of asphalt pavement

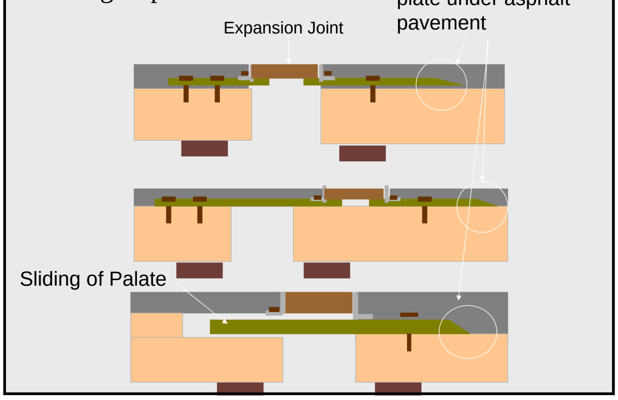

## Tilting of lower parapet wall underneath the asphalt pavement


Courtesy of Dr. Y. Goto, Obayashi Construction

## Sliding Expansion Joints
いろいろな伸縮装置が開発されてきた



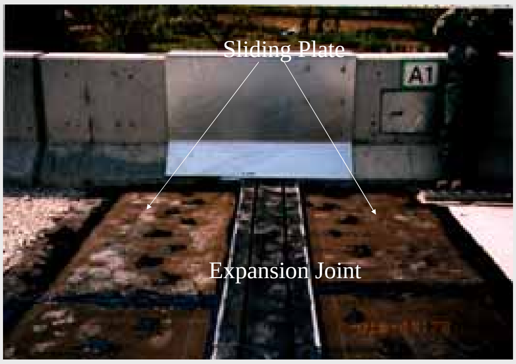

## Sliding Expansion Joint




## Implementation of a New Expansion Joint System to Amano Viaduct, Maibara

423m long 17-span continuous viaduct

## Sliding Expansion Joint




Public Works Research Institute

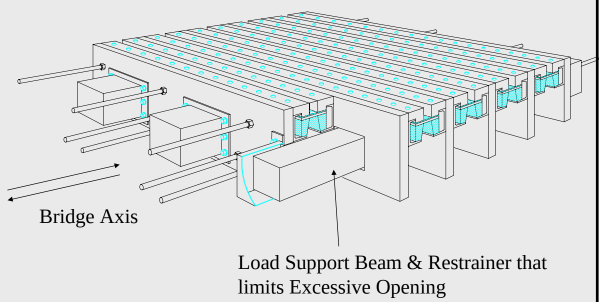
Public Works Research Institute

## 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**

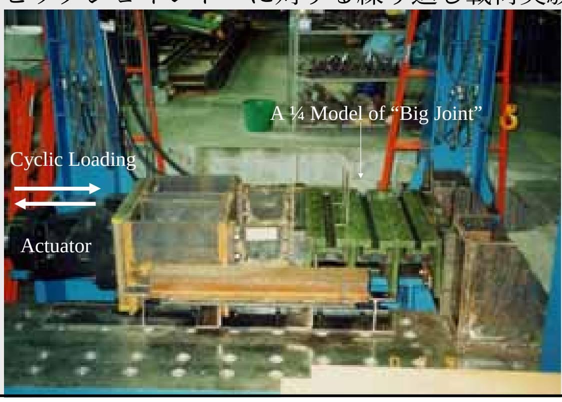
## Big Joint大変位を吸収可能な伸縮装置

An Expansion Joint with Function of a Restrainer

Yokohama Rubber Ltd.




## 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

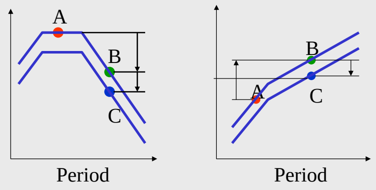



## Expected Natural Period of Isolated Bridges
**免震橋では固有周期をどの程度伸ばせばよいか？**

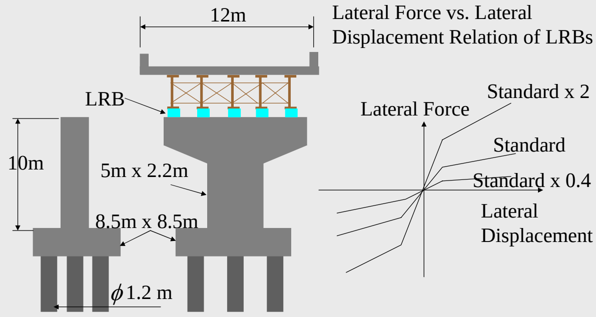
## Expected Natural Period of Isolated Bridges

- Increase of natural period results in larger deck displacement having stronger impact force
- What is the appropriate level of increase of natural period?

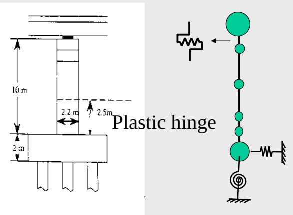
Response Acceleration Response Displacement




## Isolated Bridges Analyzed

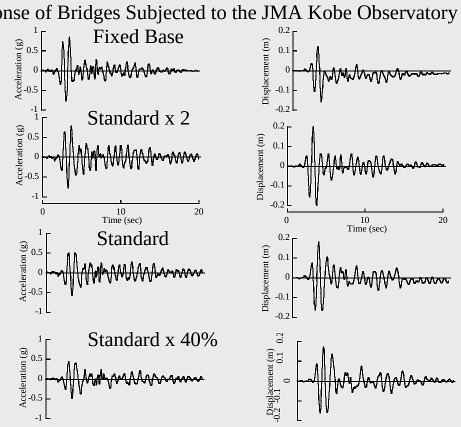



## Idealization of the Isolated Bridge

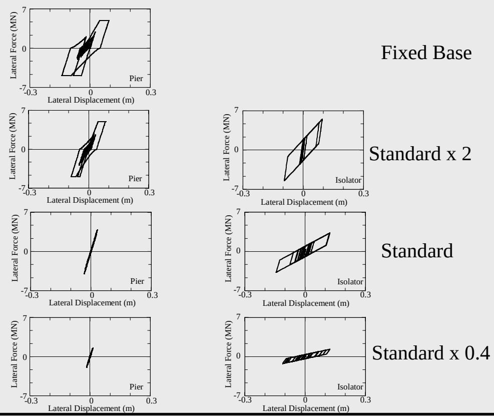



- ✓Lump the mass of a deck at the mass center of the deck
- ✓ Idealize the isolator by a lateral spring element with a bilinear hysteresis
- ✓ Idealize the hysteretic behavior of the column at the plastic hinge by a rotational spring with Takeda degrading model
- ✓ Idealize the stiffness of a foundation and the soil-structure interaction by a set of translational and rotational linear spring elements

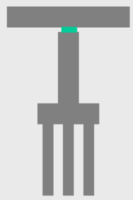
## Response of Bridges Subjected to the JMA Kobe Observatory Record




## Response of Bridges Subjected to the JMA Kobe Observatory Record




## 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**

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

✓ Fixed Base Bridge**一般橋**

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

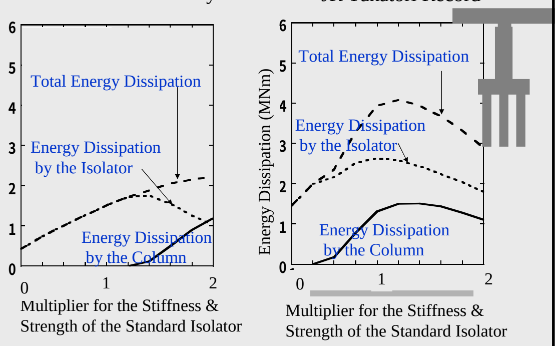
Energy Dissipation Ratio of the Column

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

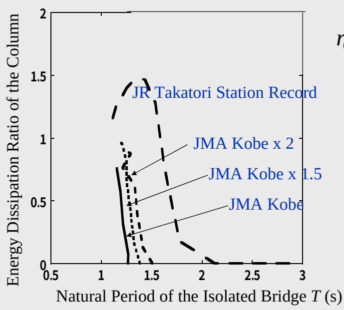
Seismic isolation is beneficial if $r_C < 1.0$

## Energy Dissipation of Isolators & Columns

JMA Kobe Observatory | JR Takatori Record

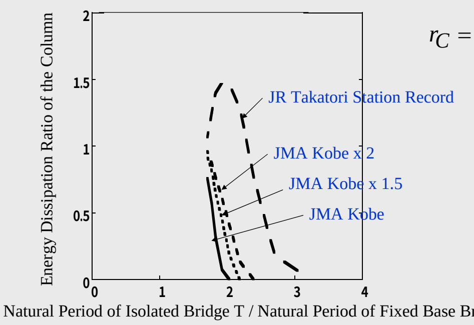



## Energy Dissipation Ratio of the Column




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

## Energy Dissipation Ratio of the Column




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

## Natural Period of an Isolated Bridge

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