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

第4章　免震設計(1)
Chapter 4 Seismic Isolation (1)

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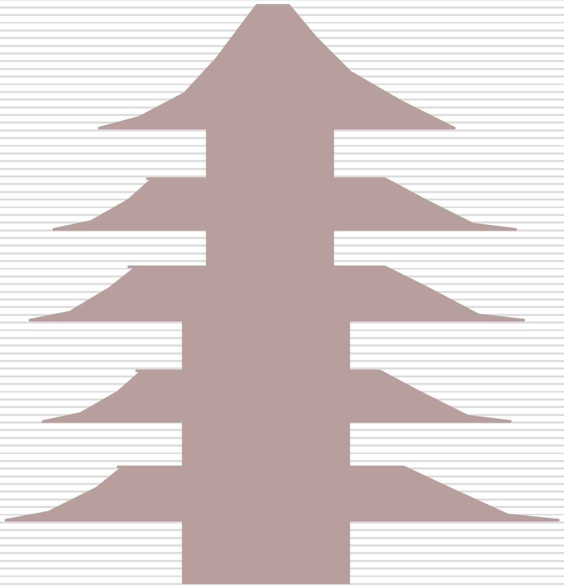
4.1 There was a concept of “isolation” from the early days

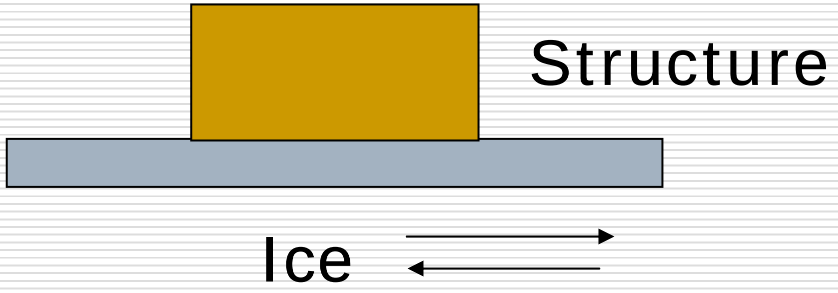
A wooden 4-5 story tower in the 7 century



Modern seismic isolation was unable to implement before 1970s. Advancement of computer technology made it possible to realize implementation of seismic isolation.

1) Initial Concept of “Isolation”

Isolation



- Lateral shaking is not transferred from the ice to a structure
- Structure does not come back to the original position
- Add a weak spring to overcome this deficiency

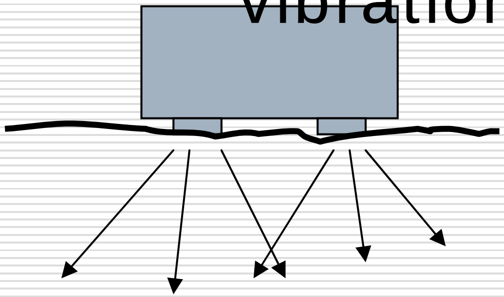
Patents related to “isolation”

- Calanterient (UK) (1909)
- Kenzaburo Kito (1924), Kosho Yamashita (1924)

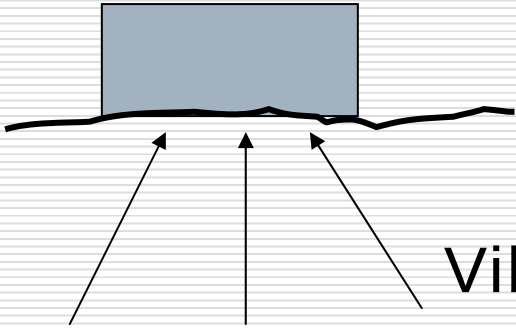
2) Isolation based on Period shift

Machineries

Source of vibration



Machines fragile to micro tremor



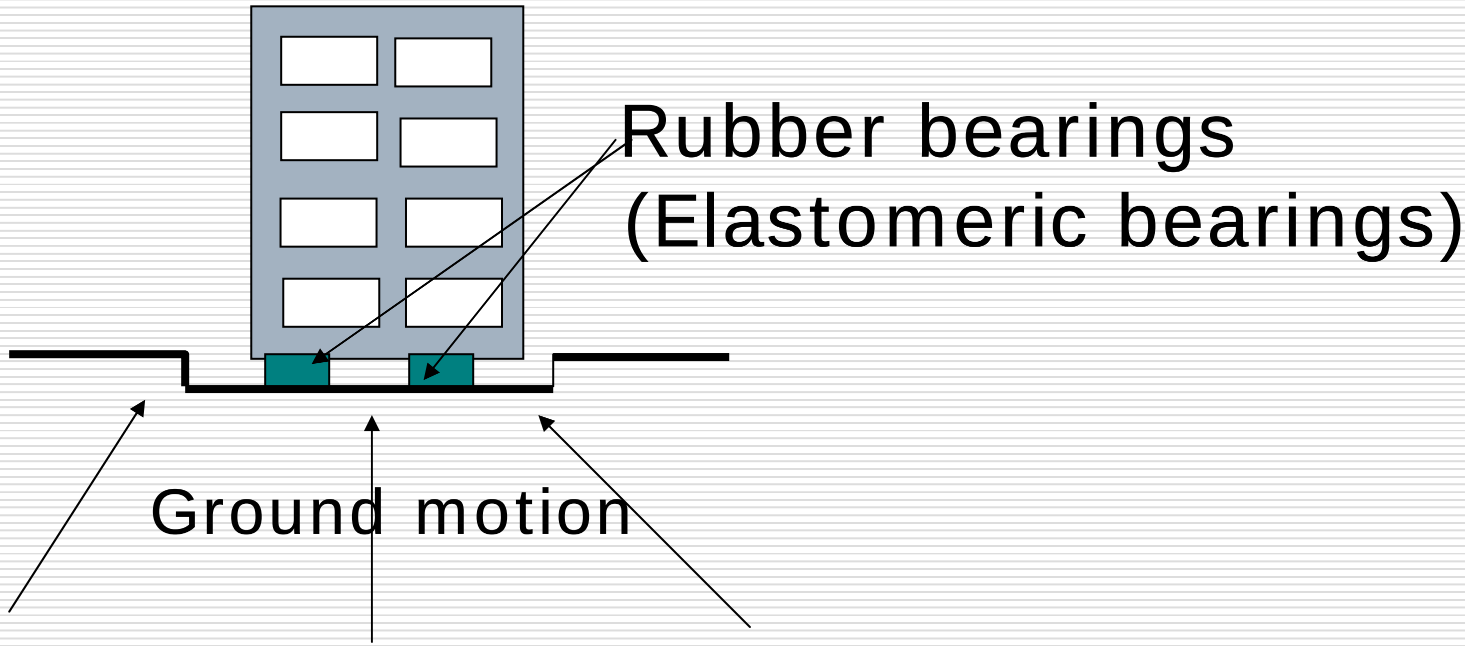
Vibration

- Predominant period of vibration
- Natural period of machines
- Natural period of ground

Shift the period so that resonance can be mitigated

2) Isolation based on Period shift (contd.)

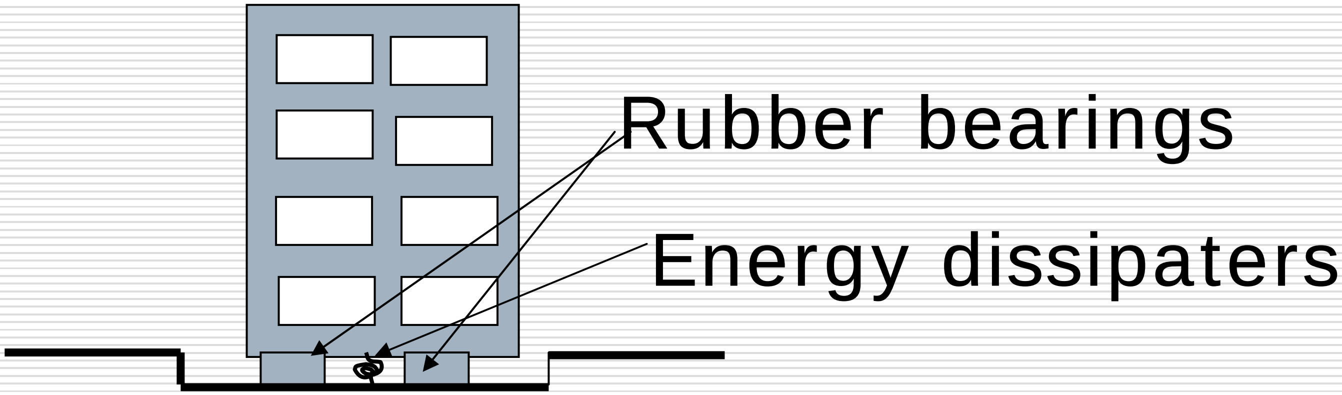
Application of “Period Shift” to structures



Support a structure by soft rubber bearings so that the natural period of a structure shift from the predominant period of ground motion

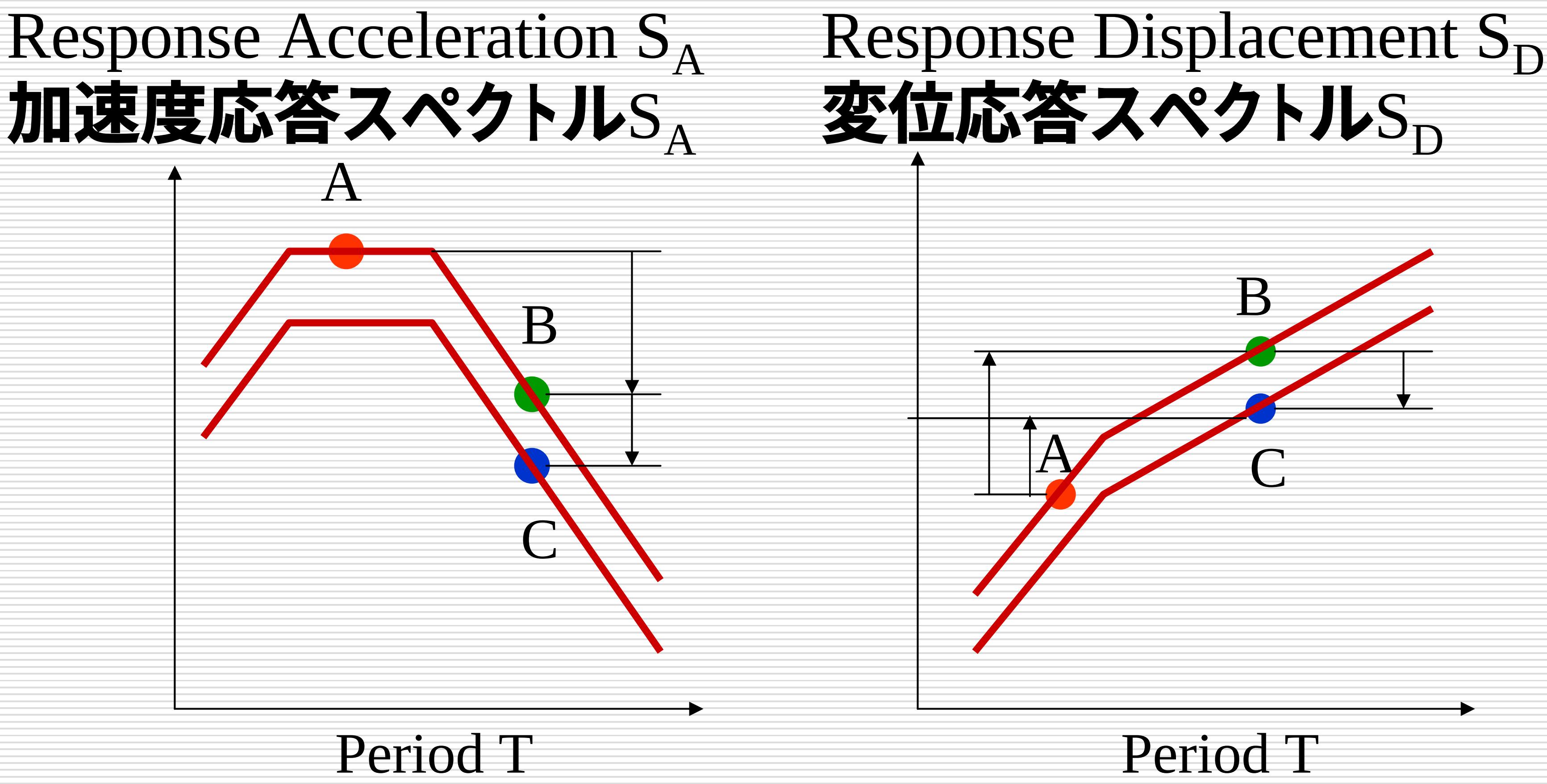
3) Modern Definition of “seismic Isolation” of Structures

- Shift the period of a structure so that resonance can be mitigated
- Set energy dissipaters to a structure so that vibration energy of a structure can be dissipated

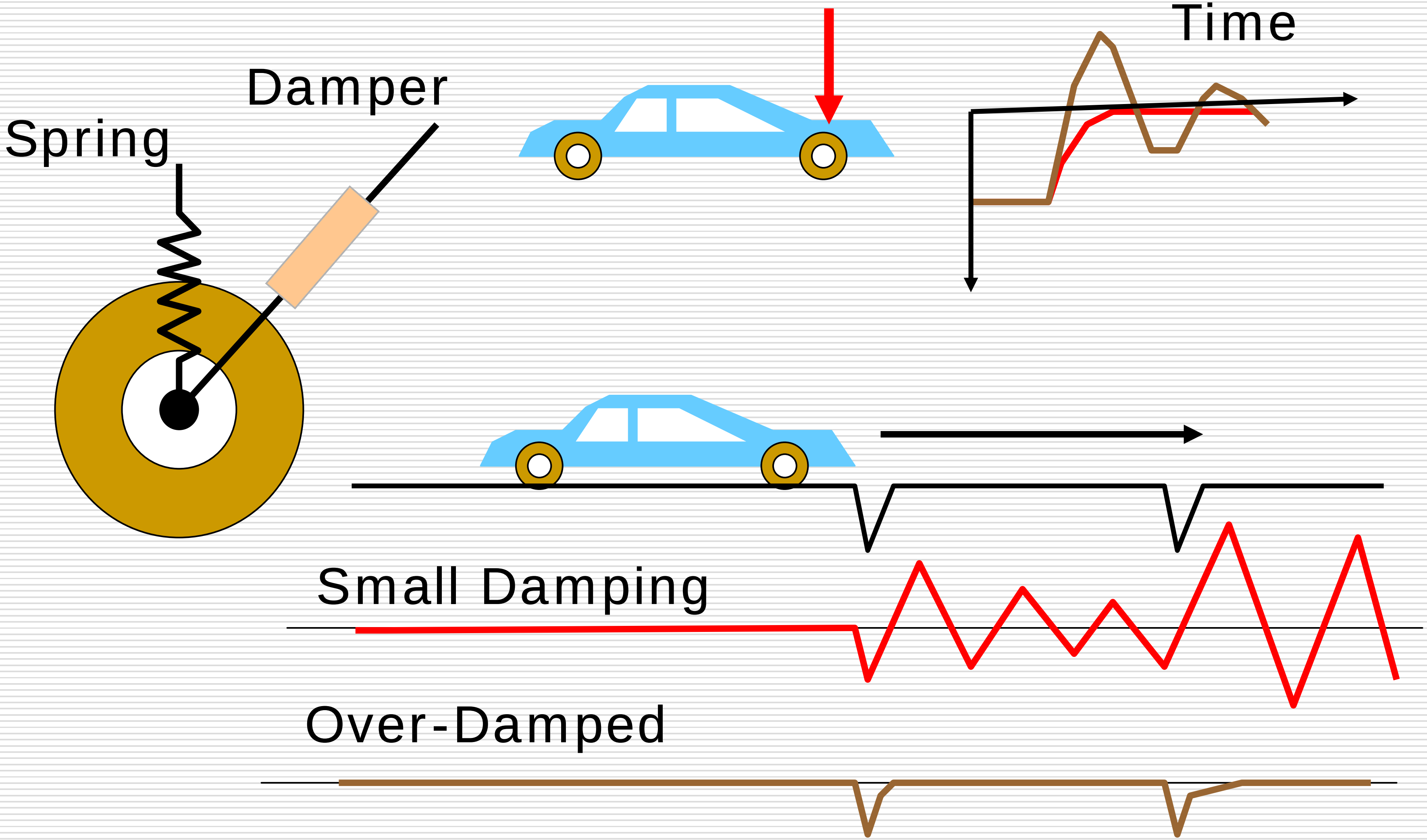


4.2 Basic Principle of Seismic Isolation

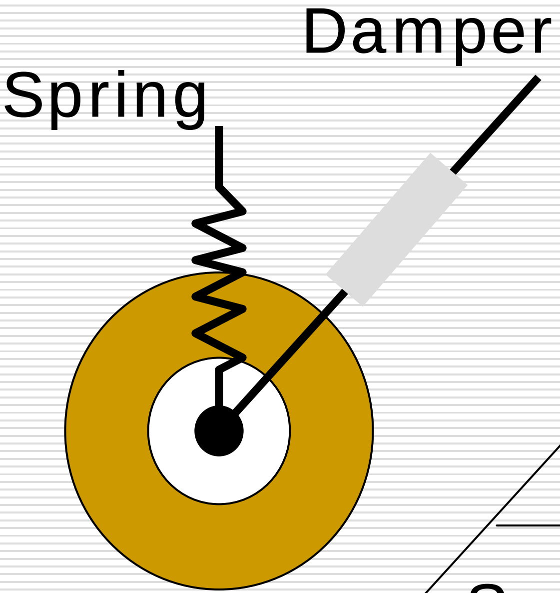
(1) Reduction of response displacement and acceleration due to period shift and energy dissipation

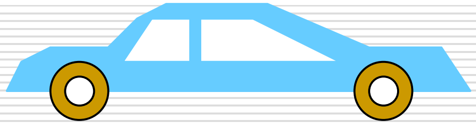


(2) Why is the Energy Dissipation Required ?



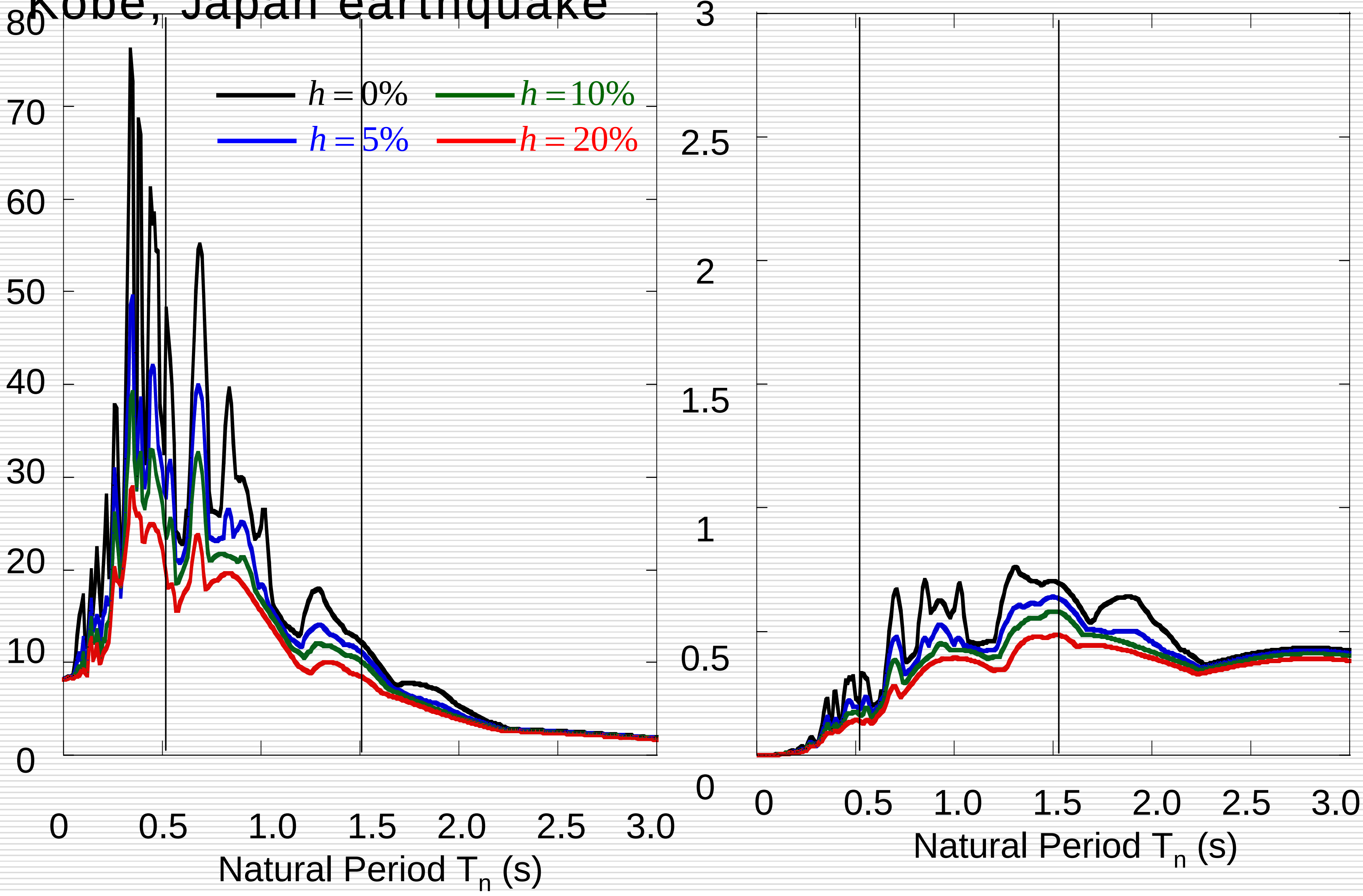
(3) Why is the Increase of Natural Period (Period Shift) Required ?



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

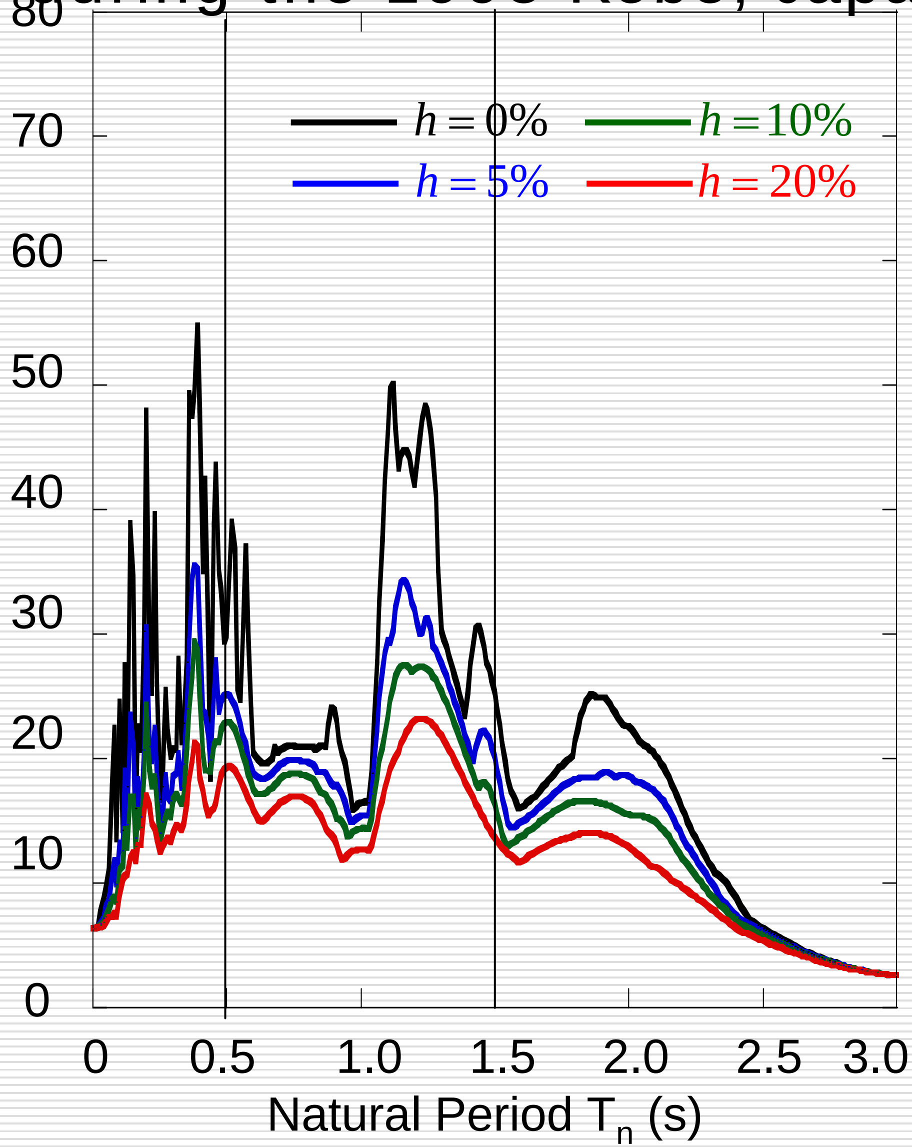
Predominant Period of Ground Accelerations

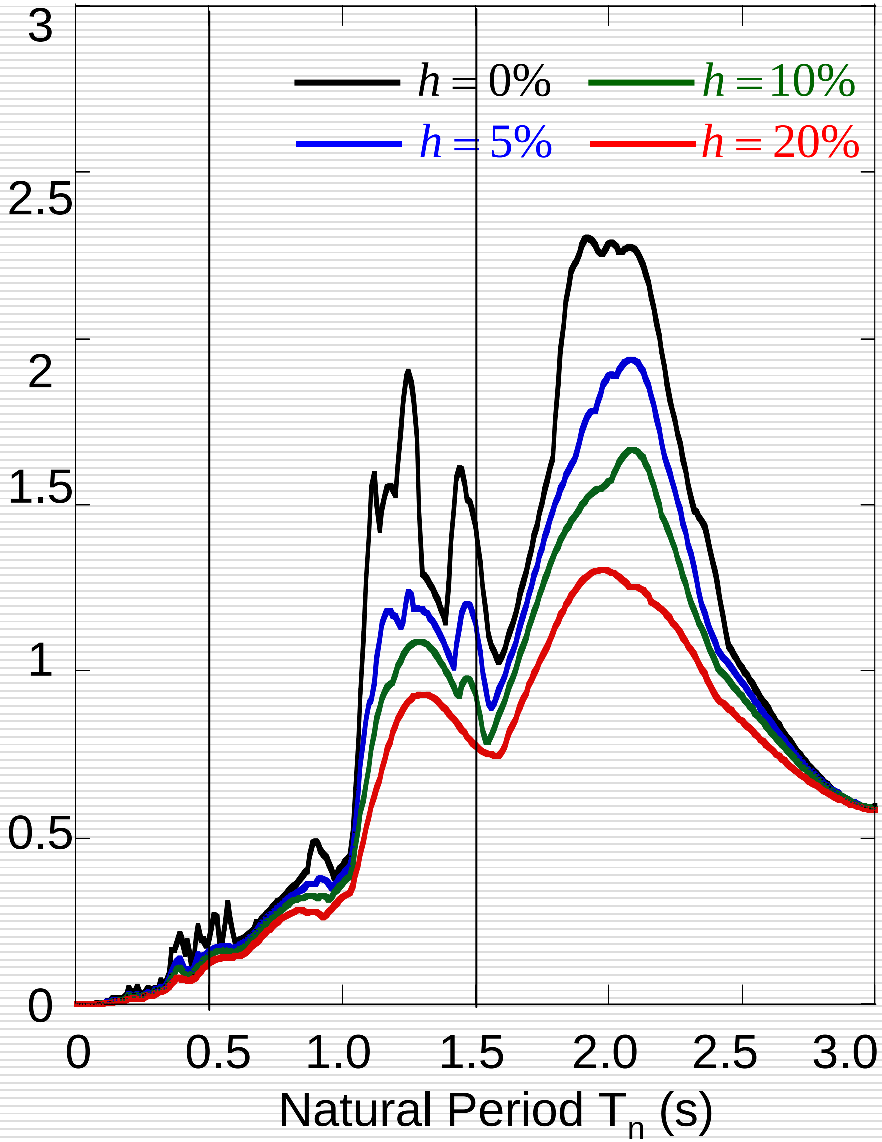
Ground accelerations recorded at JMA during the 1995 Kobe, Japan earthquake



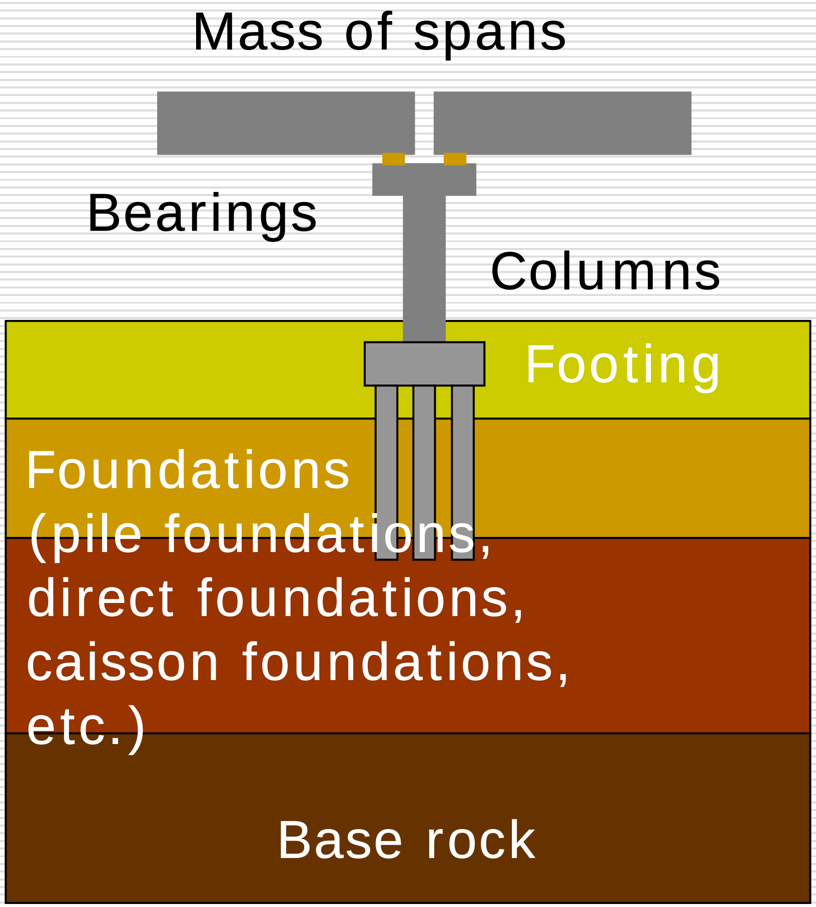
Predominant Period of Ground Accelerations

Ground accelerations recorded at JR Takatori Station during the 1995 Kobe, Japan earthquake





Natural Period of a Bridge Depends on Various Factors



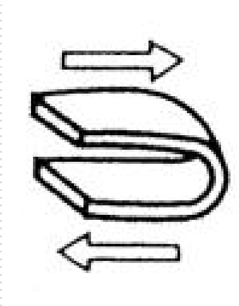
- Mass of spans
- Stiffness of piers
- Stiffness of bearings
- Stiffness of soils
- Stiffness of piles

4.3 How can we dissipate energy?
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

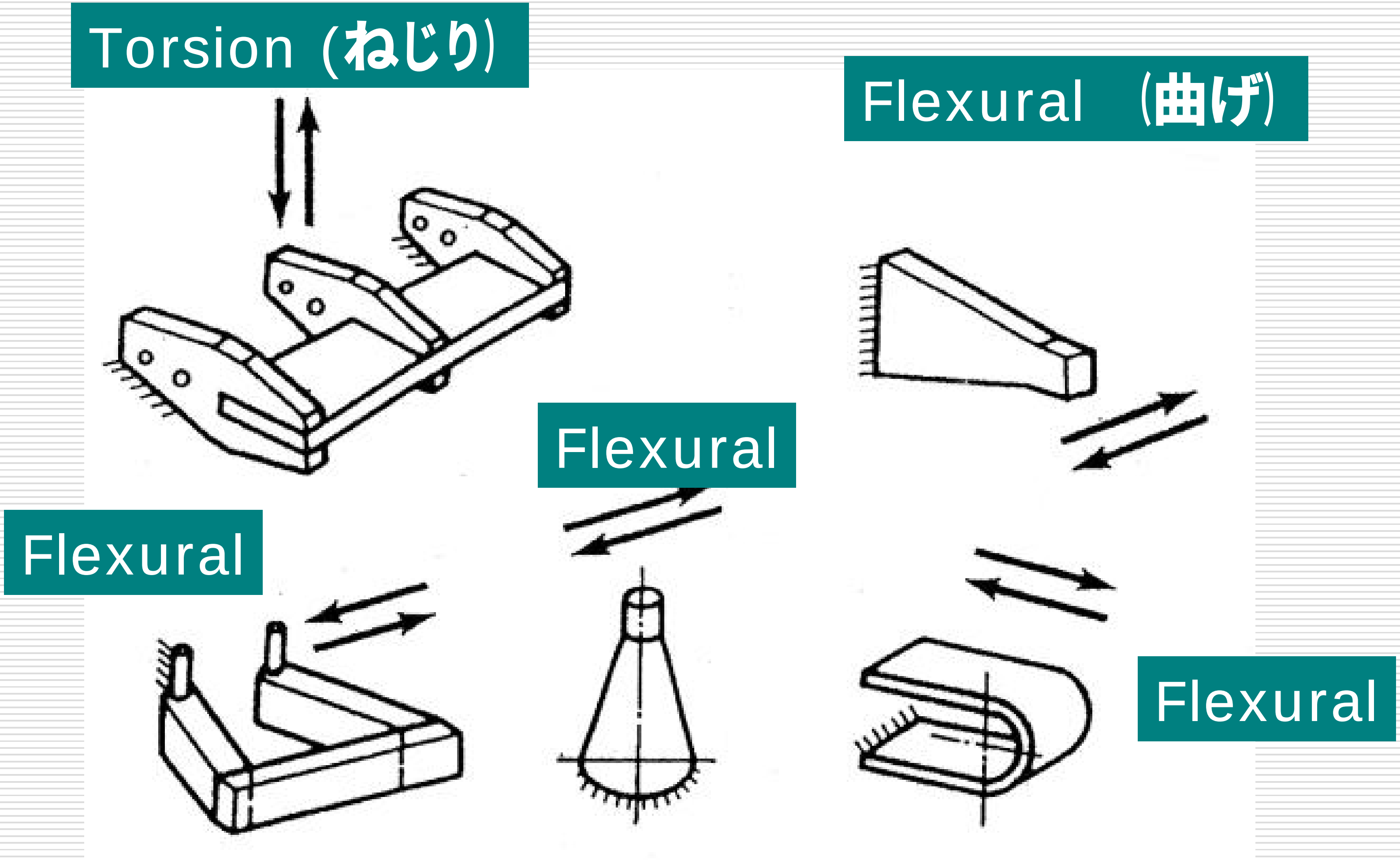


Mild steel, lead, etc.

- Energy dissipation due to plastic deformation of lead
- Viscous fluid (Viscous damper)
- ....

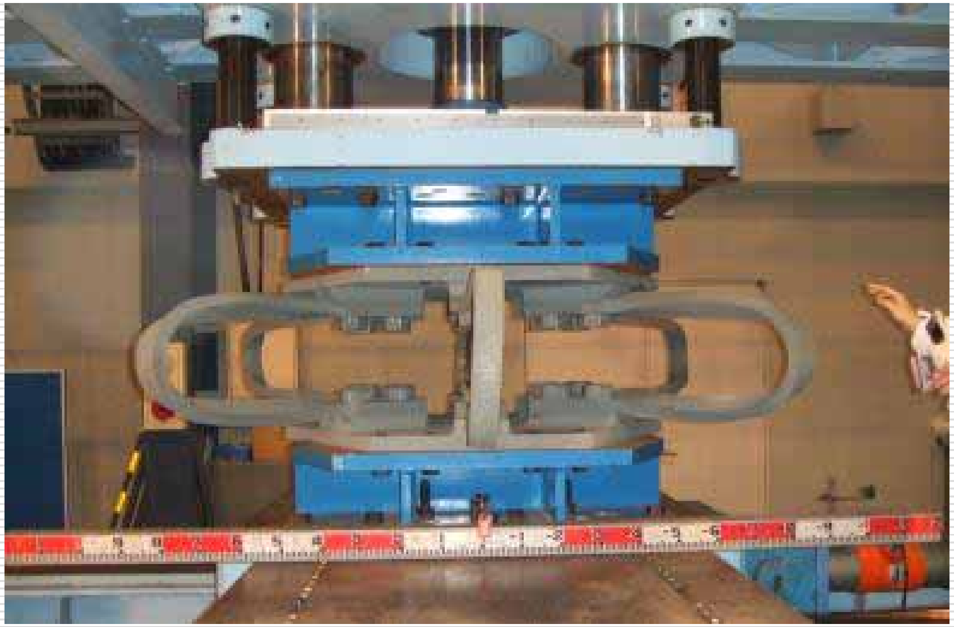
4.4 Energy Dissipaters by Mild Steel

1) Steel dampers



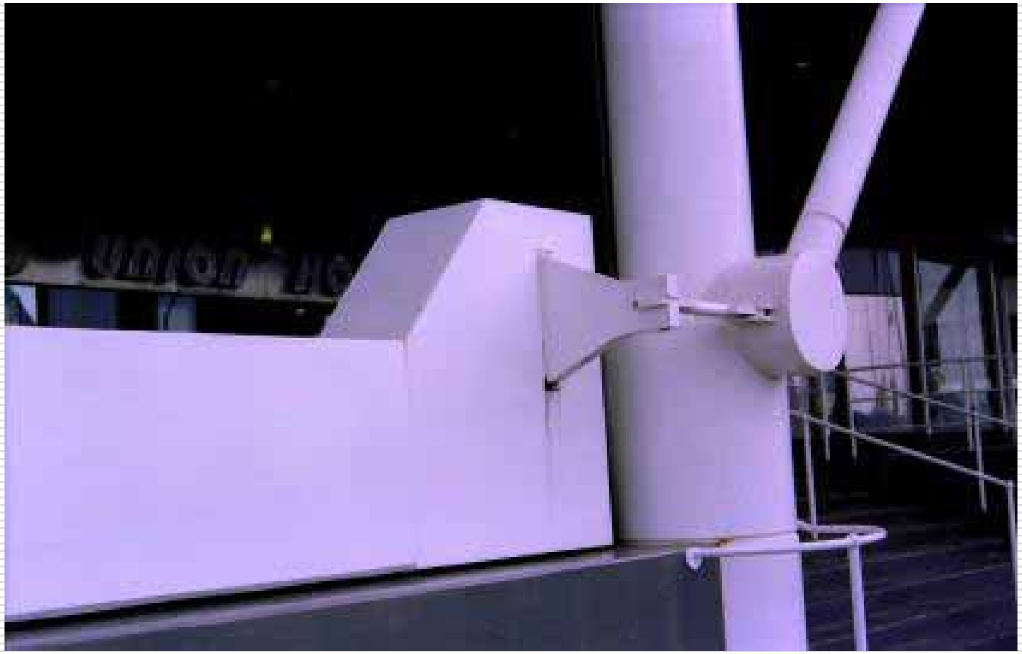
Fatigue due to repeated plastic deformation?

U-damper

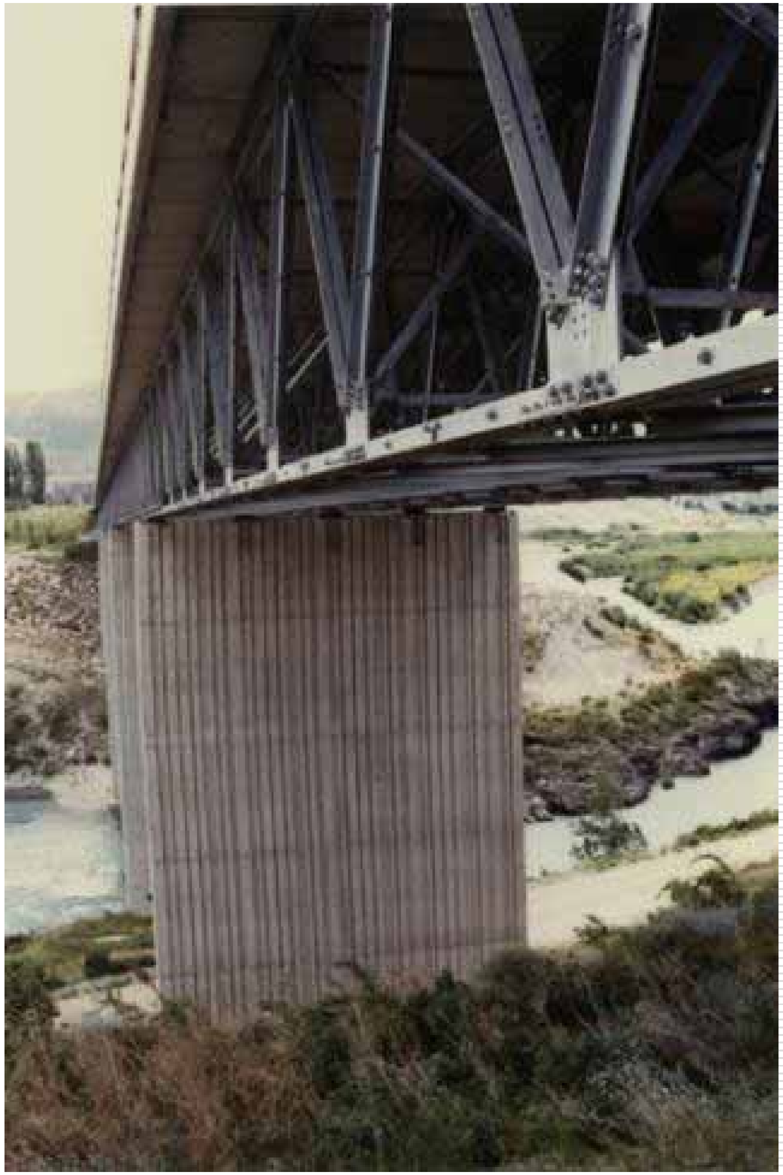


2) Implementation of Steel Plate Isolators to Buildings

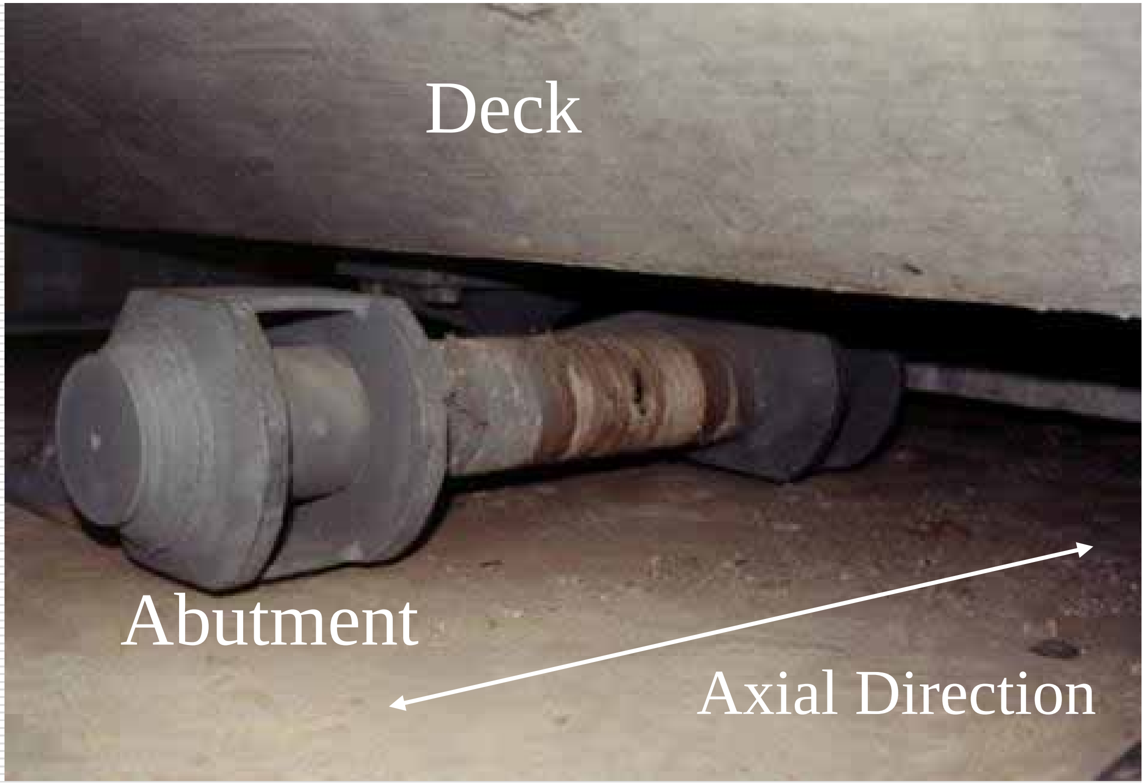
New Zealand



3) Implementation of Steel Bar Flexure Energy Dissipaters to a Bridge



Cromwell Bridge
New Zealand



Deformed Mild Steel Flexural Damper

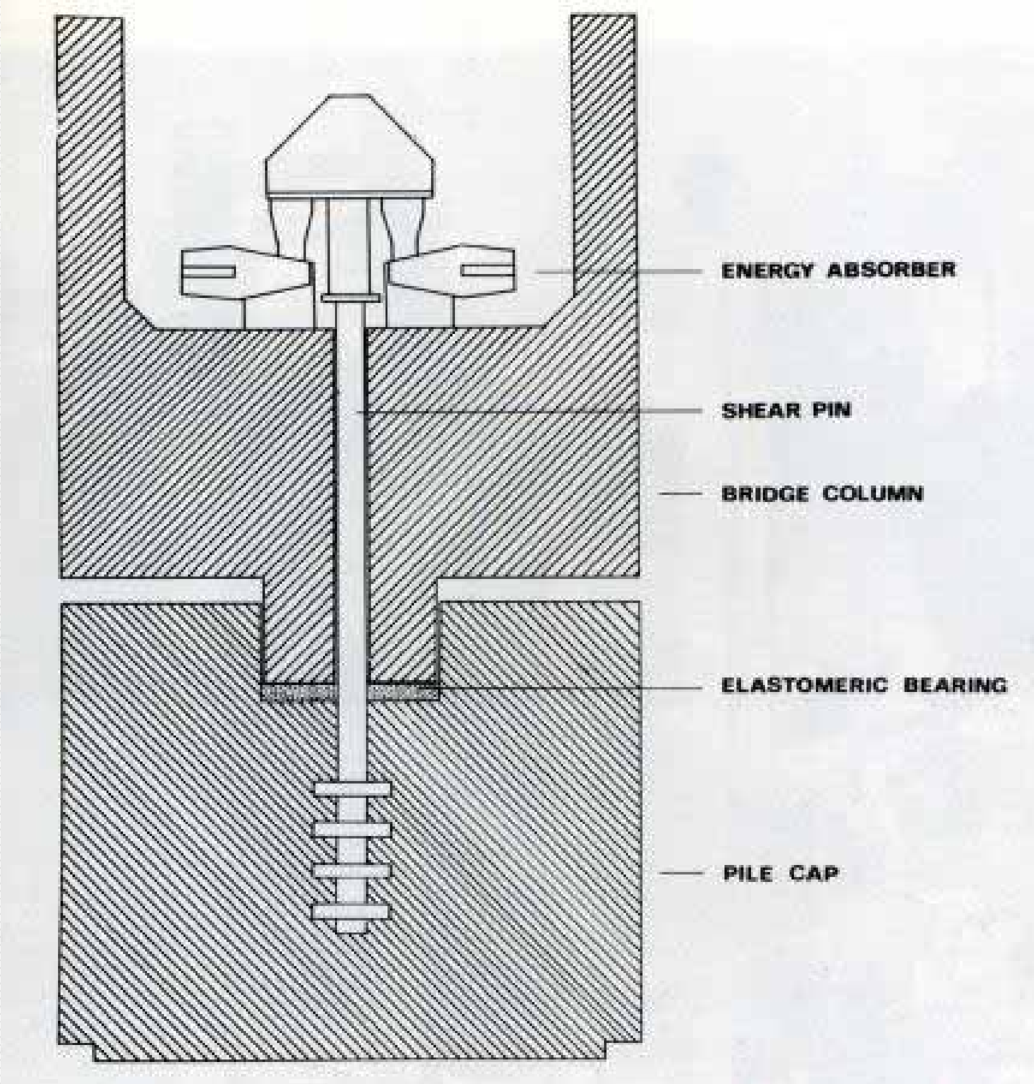
4) Implementation of Torsion Dampers to a Bridge

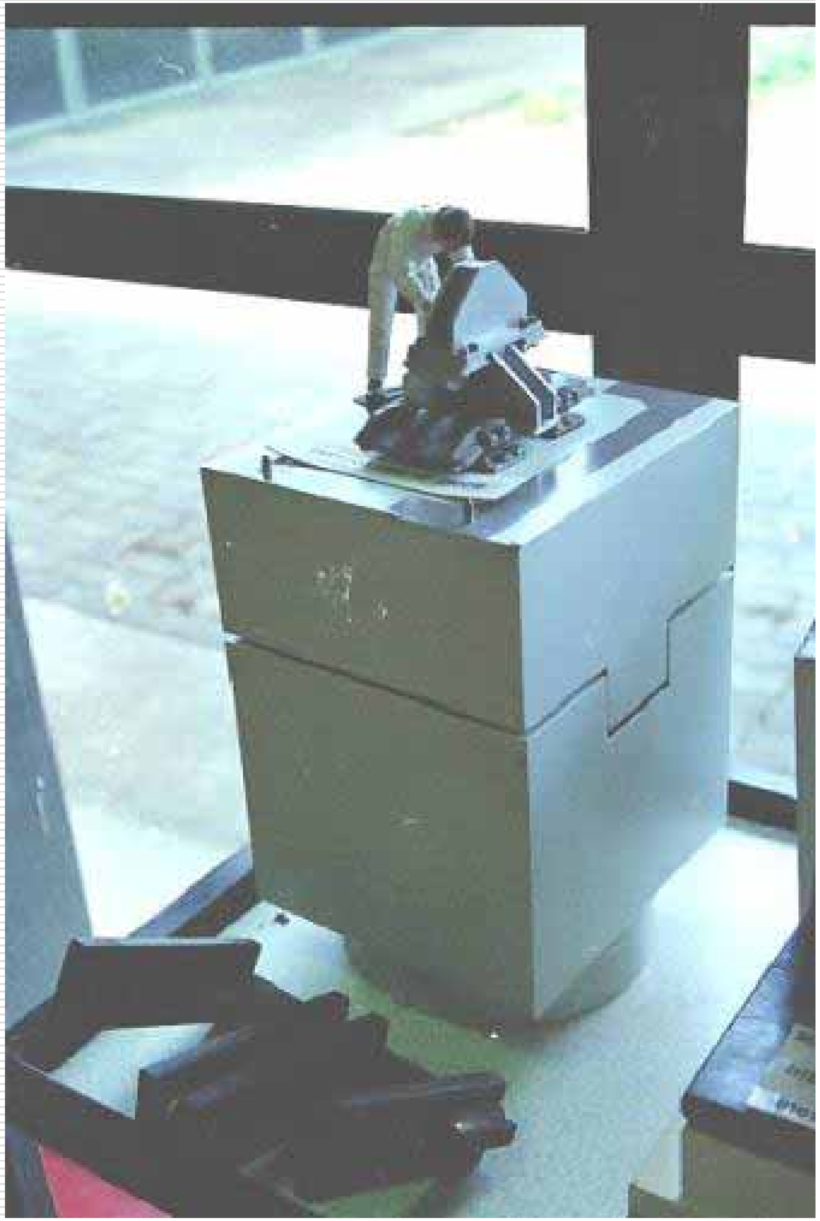
Stepping structure using steel torsion energy dissipators

South Rangitikei Bridge,
New Zealand

1972

Stepping Piers





Skinner, Robinson & McVerry (1993)

Mechanical Torsion Damper

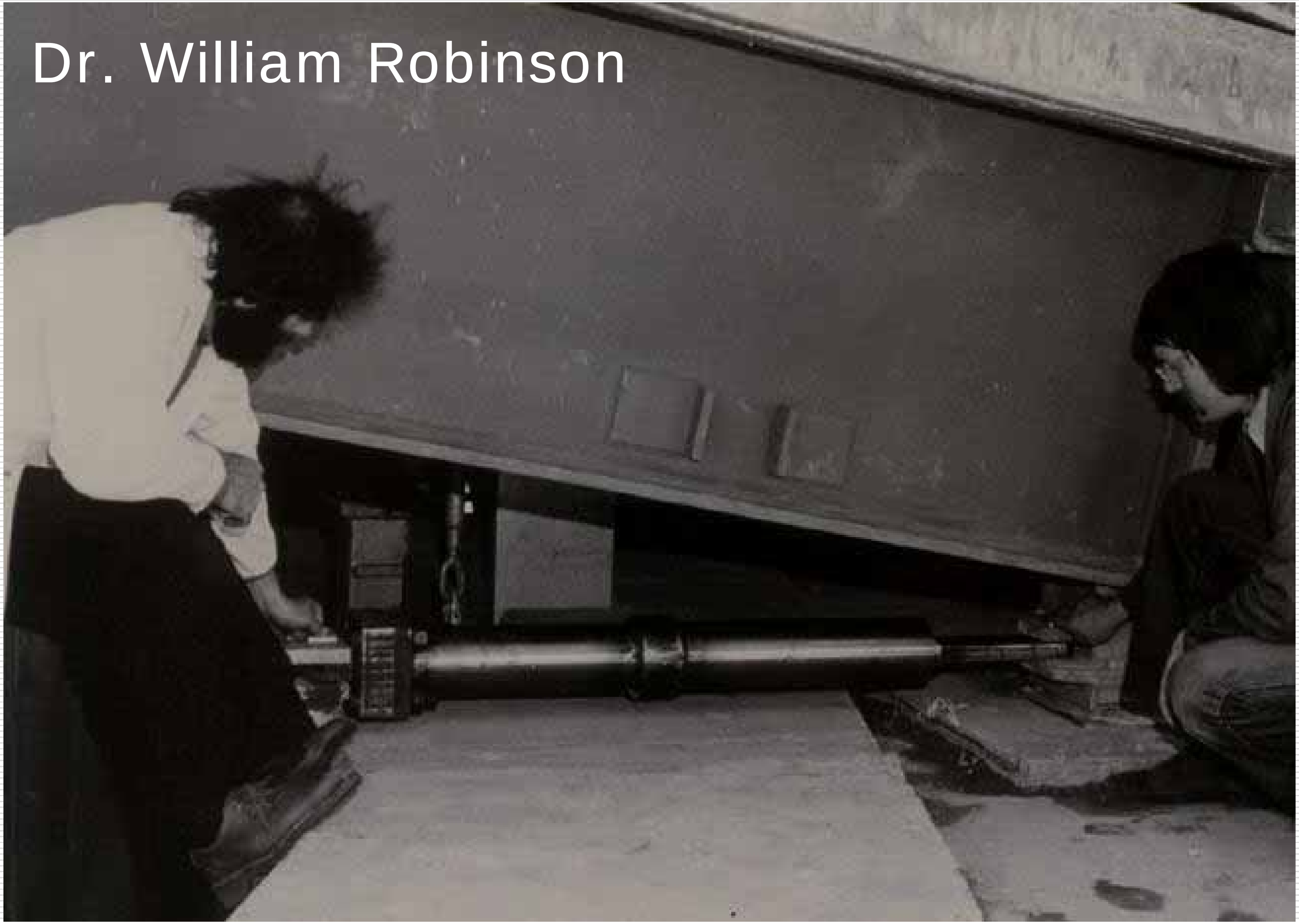
Torsion Plate Damper

4.5 Energy Dissipaters by Lead

1) Implementation of Lead Extrusion Dampers 鉛押し出し式ダンパー

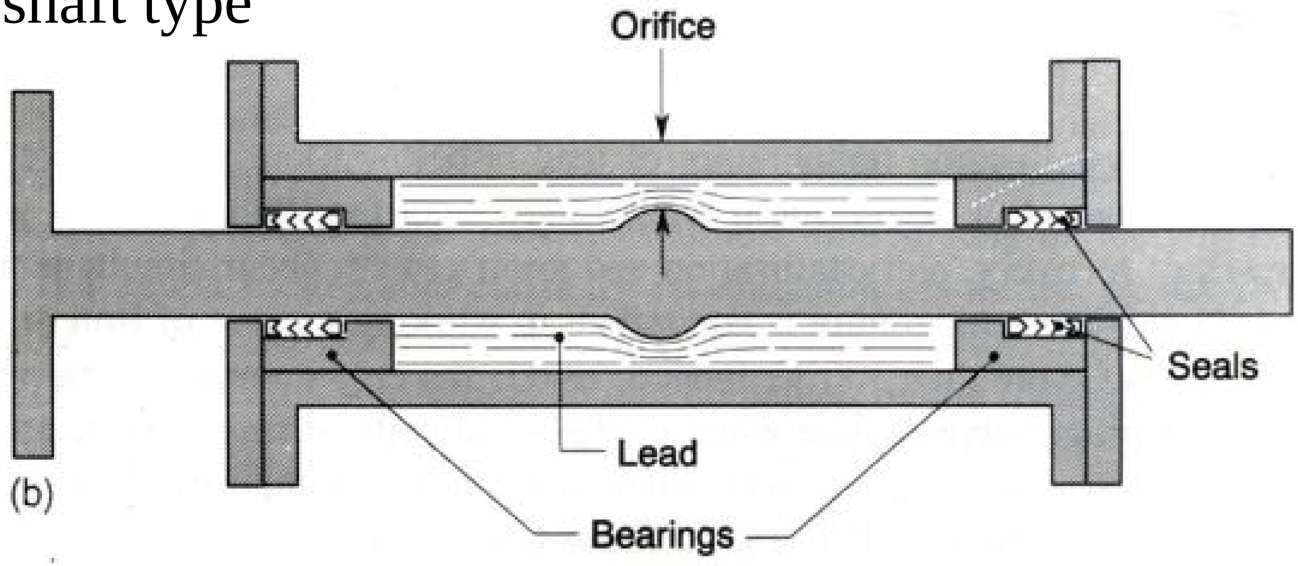
Aurora Terrace Bridge

Lead Extrusion Damper

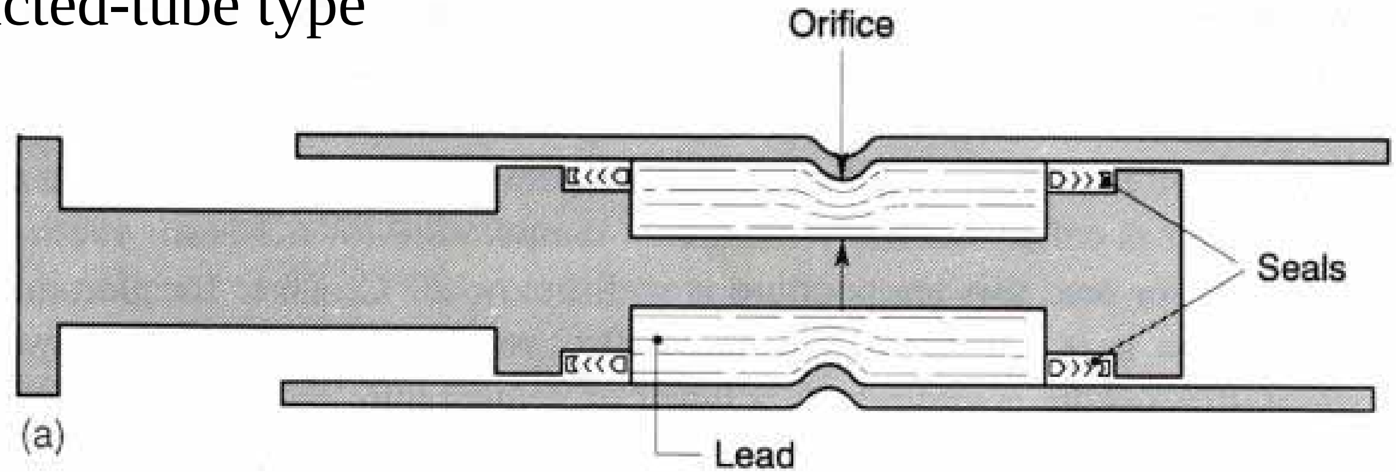


Lead-Extrusion Damper

Bulged-shaft type

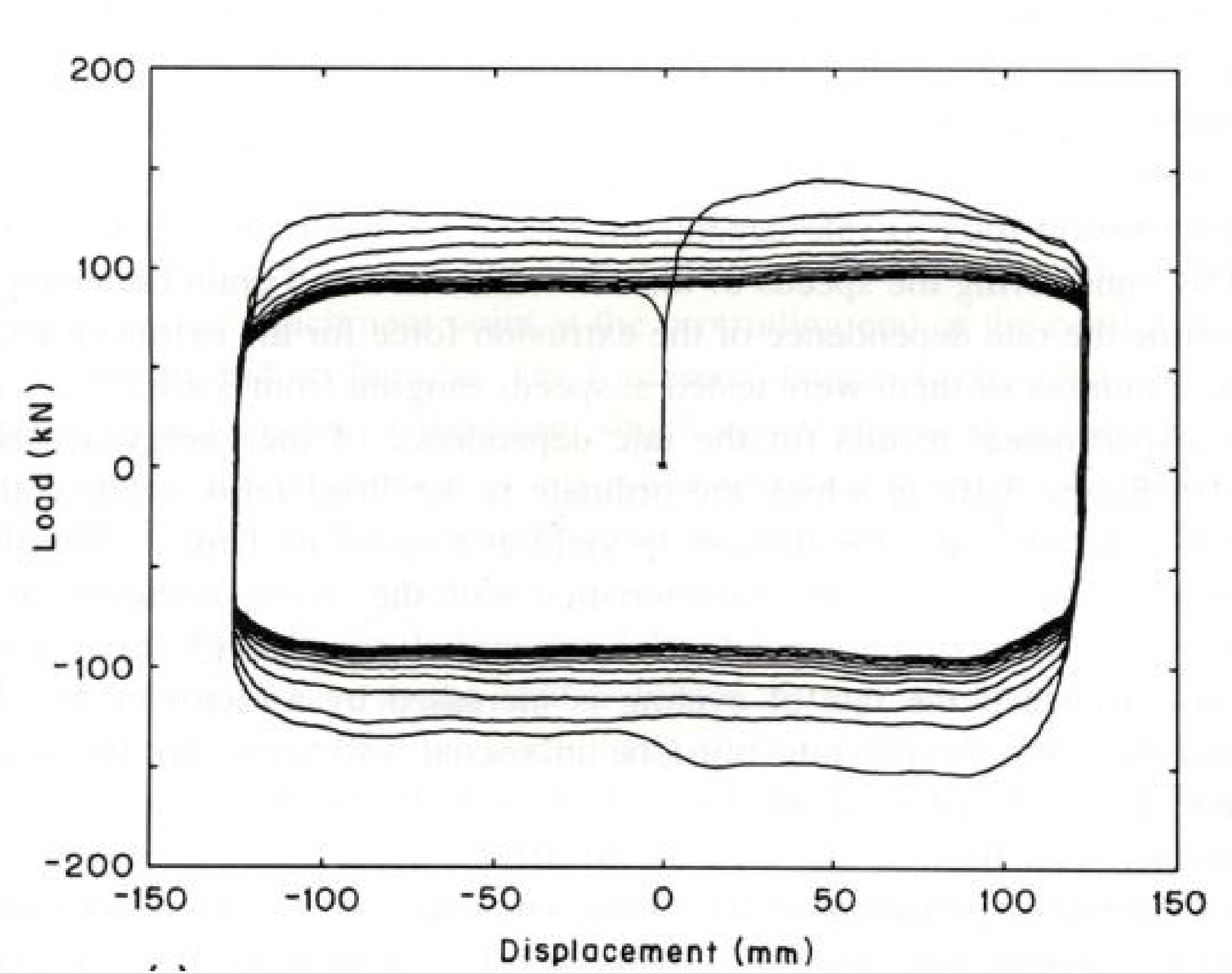


Constricted-tube type



Skinner, Robinson & McVerry (1993)

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

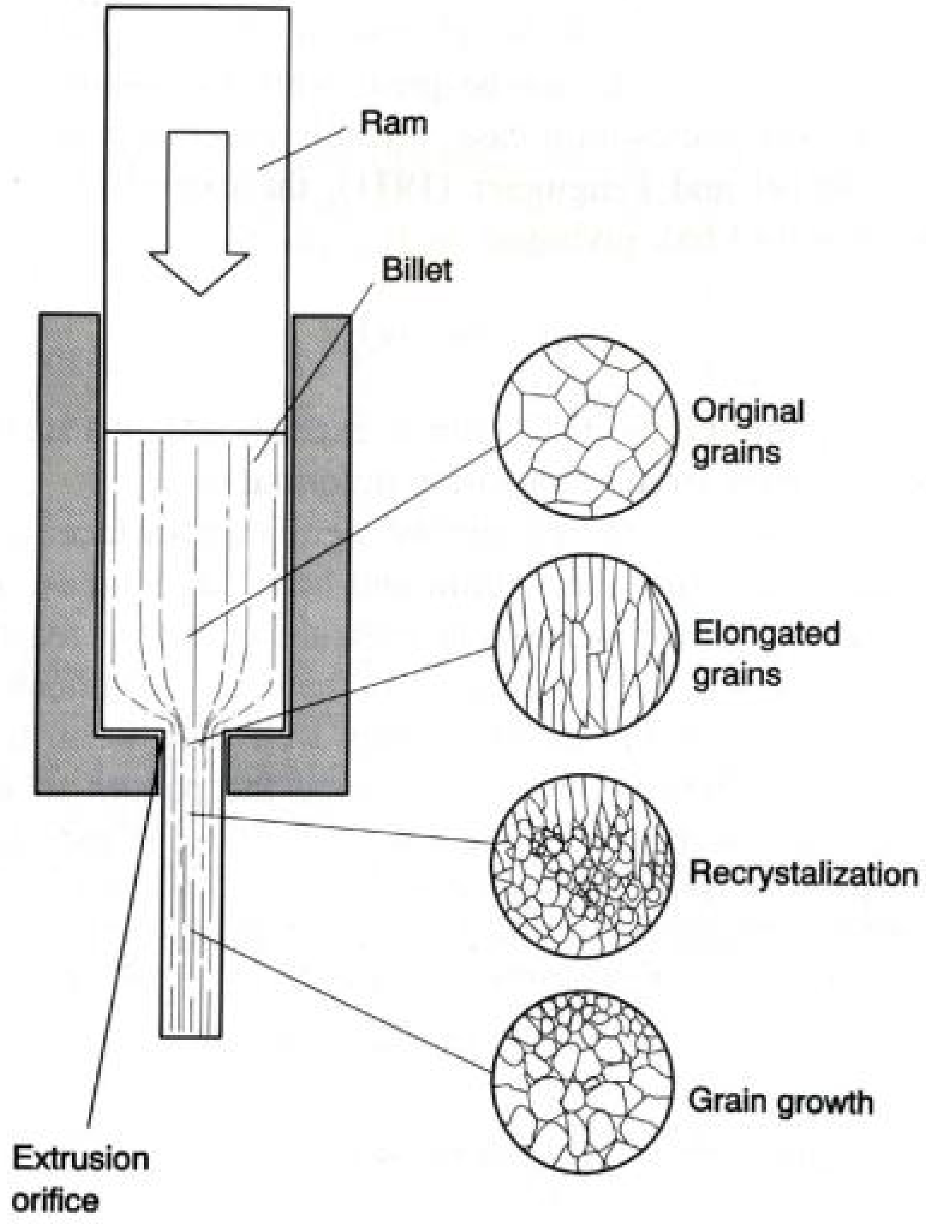


Skinner, Robinson & McVerry (1993)

2) Why is lead appropriate to dampers?

Re-crystallization of Lead after Plastic Deformation

鉛の再結晶



Skinner, Robinson & McVerry (1993)

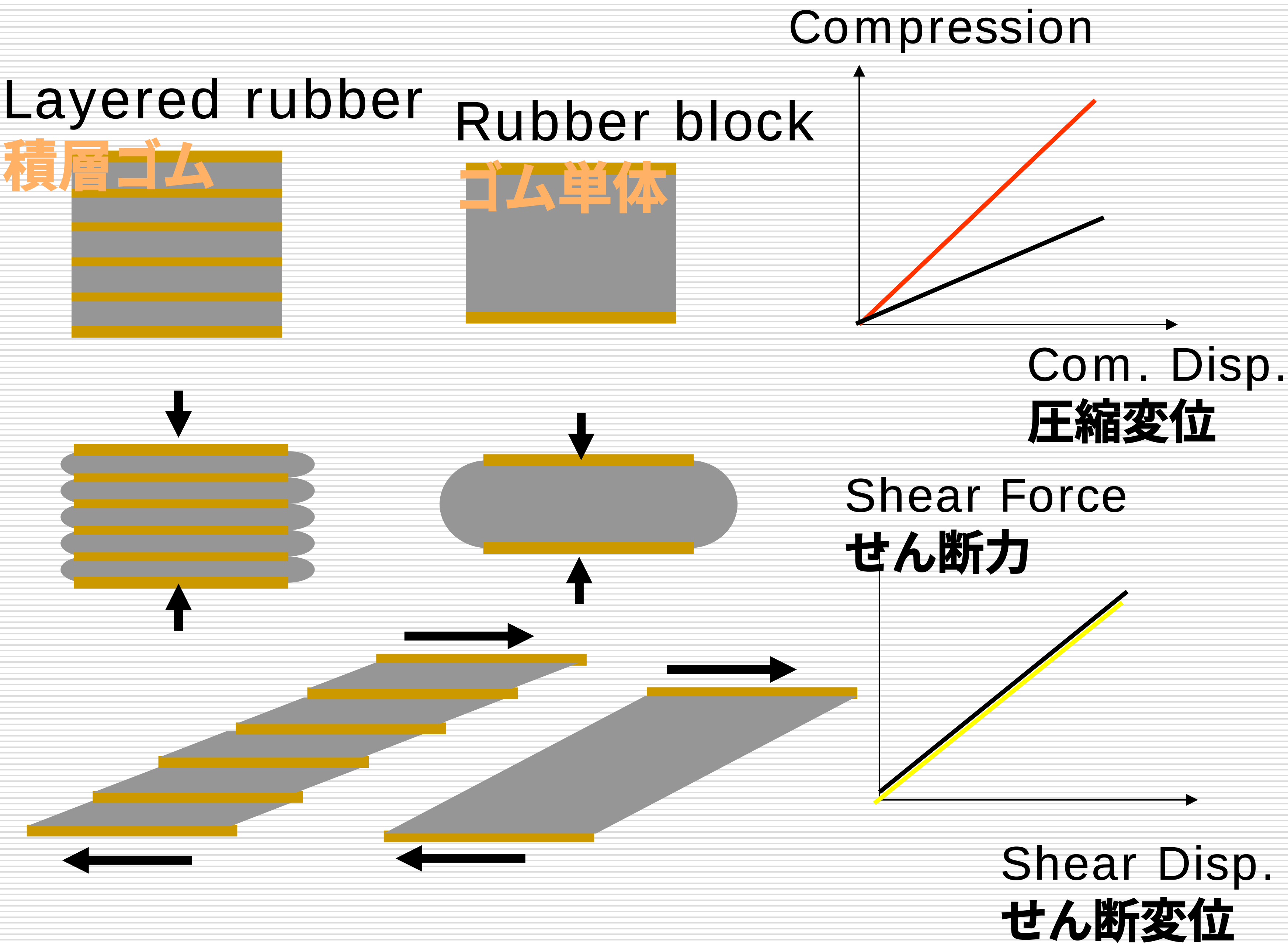
Why is lead appropriate for an energy dissipater?

Re-crystallization of lead 鉛の再結晶

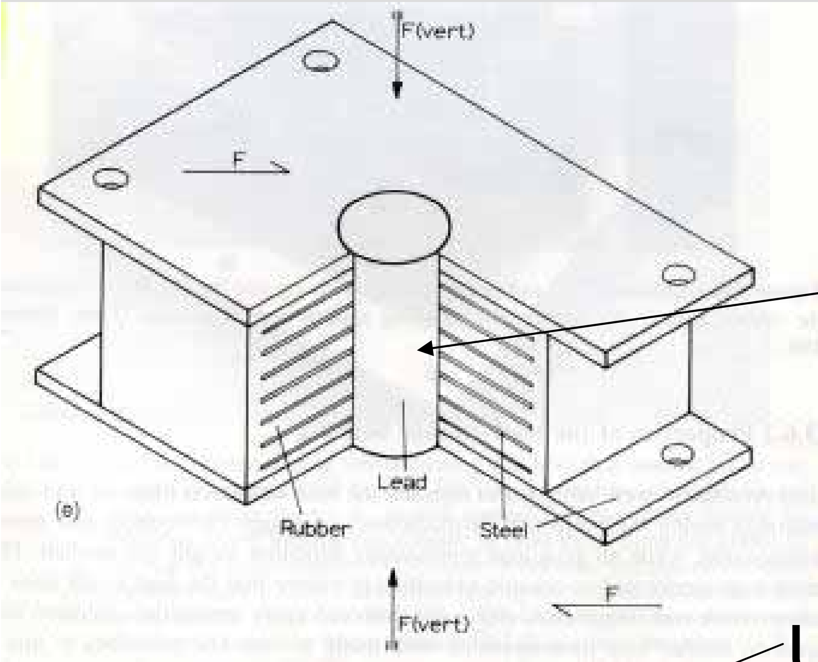
Re-crystallization temperature 再結晶温度
= Temperature which is required for re-crystallization of 50% the lead in an hour

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

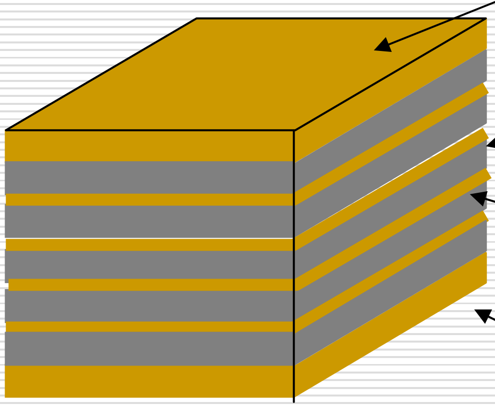
3) Elastomeric bearings 積層ゴム支承



4) Lead Rubber Bearings (LRB)
鉛プラグ入り積層ゴム支承



Lead plug



Upper steel plate **上鋼板**

Steel shims **鋼板**

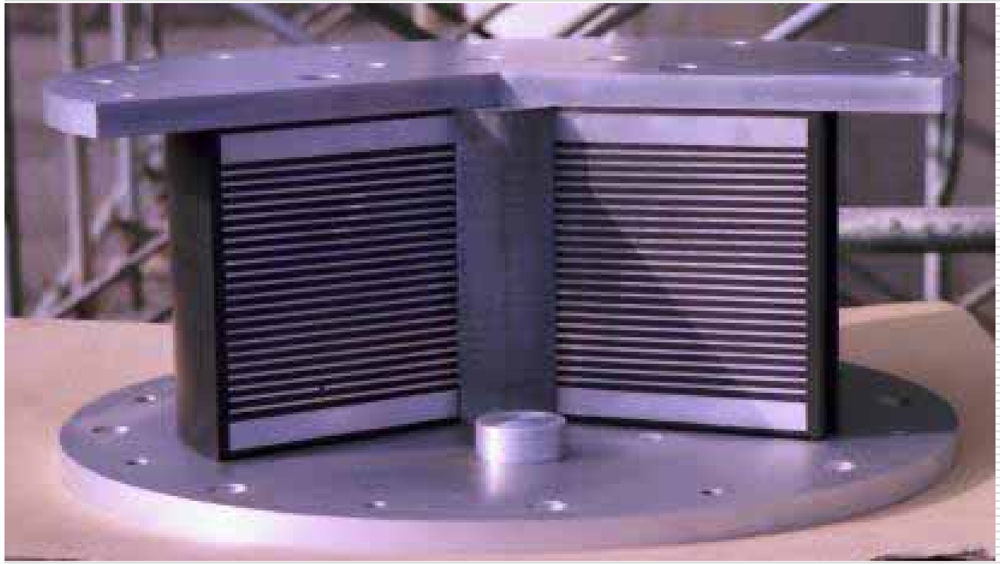
Rubber layers**ゴム**

Lower steel plate**下鋼板**

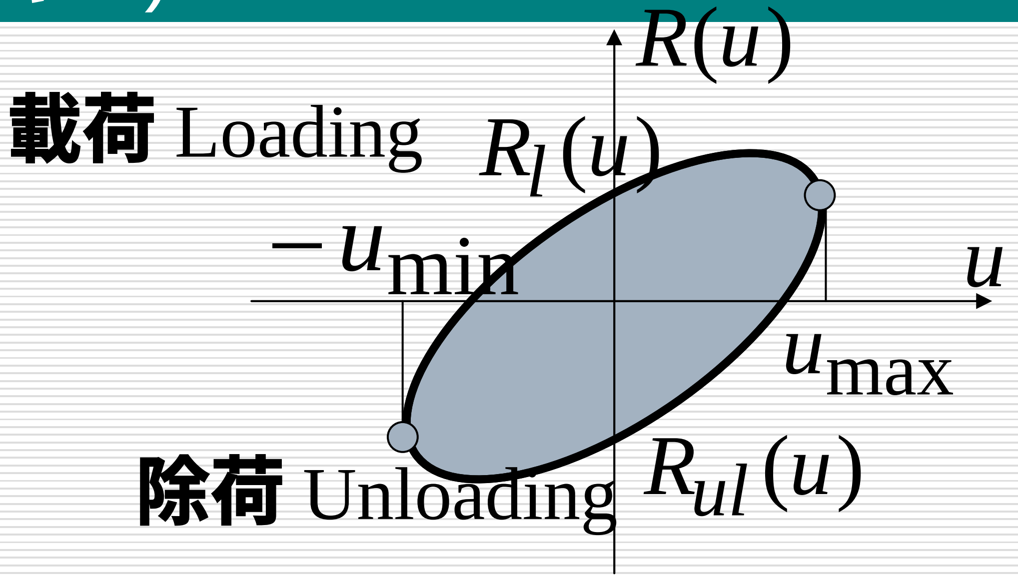
Skinner, Robinson & McVerry (1993)

Lead Rubber Bearings　鉛プラグ入り積層ゴム

Generally, a lead plug is set at middle of an isolator, however several plugs are set as the size of an isolator increases



5) Hysteretic Energy Dissipation (履歴吸収エネルギー)



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

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

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

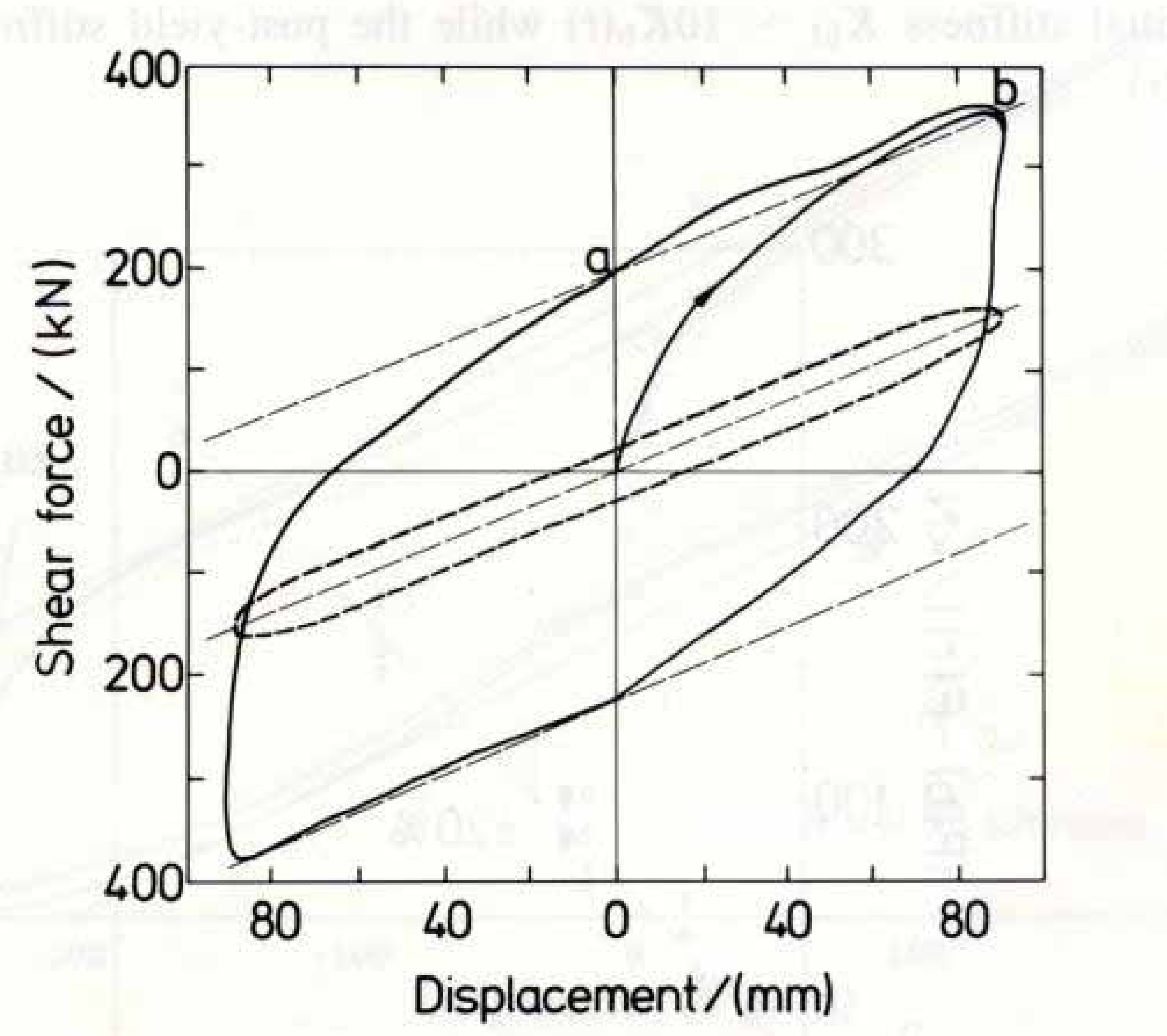
$$= \int_{-u_{\min}}^{u_{\max}} R_l(u)\,du - \int_{-u_{\min}}^{u_{\max}} R_{ul}(u)\,du$$

$$= \int_{-u_{\min}}^{u_{\max}} R(u)\,du$$

where

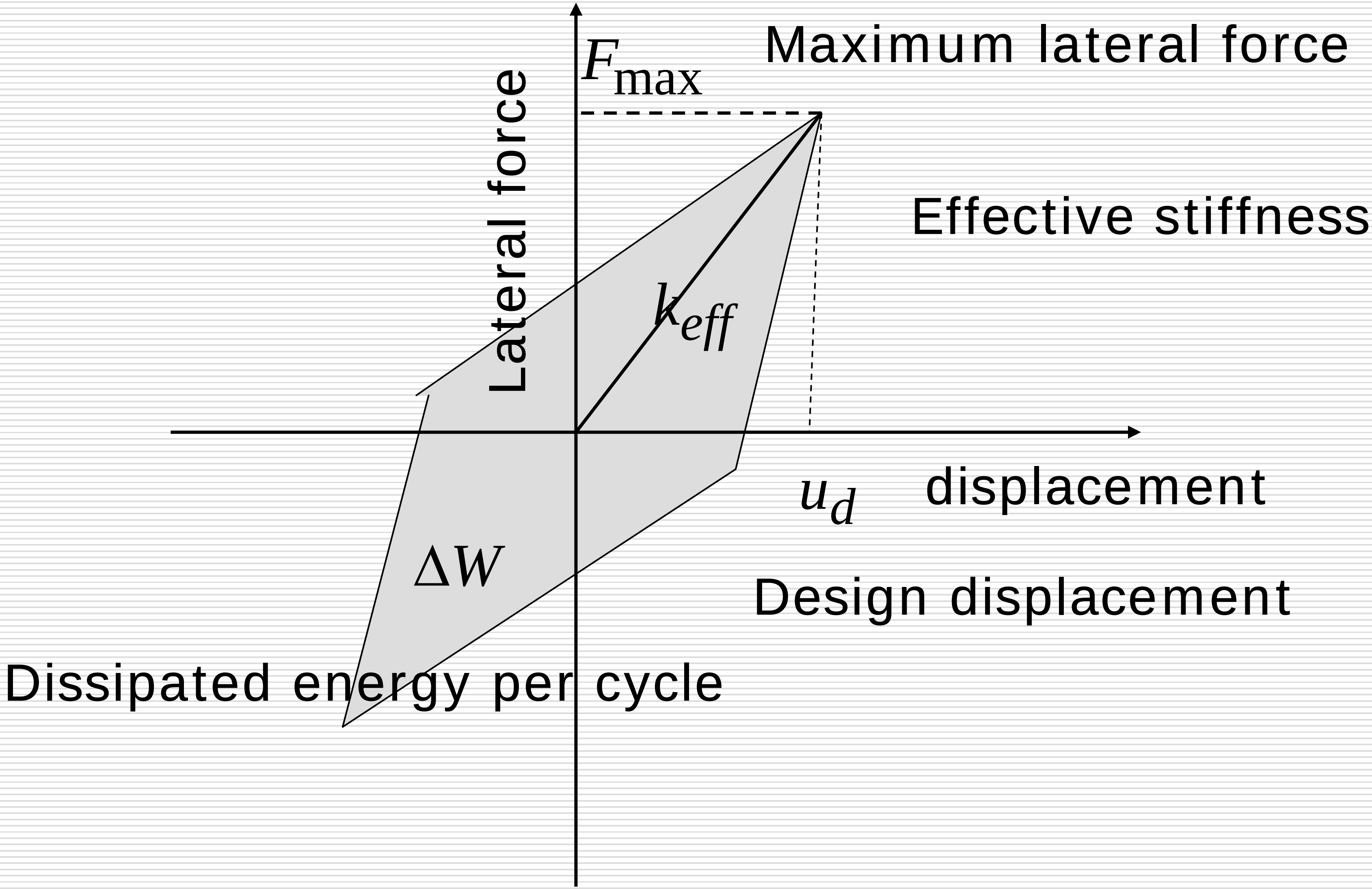
$$R(u) = R_l(u) - R_{ul}(u)$$

6) Lateral Force vs. Lateral Displacement Hysteresis of a Lead Rubber Bearing
水平力～水平変位の履歴曲線



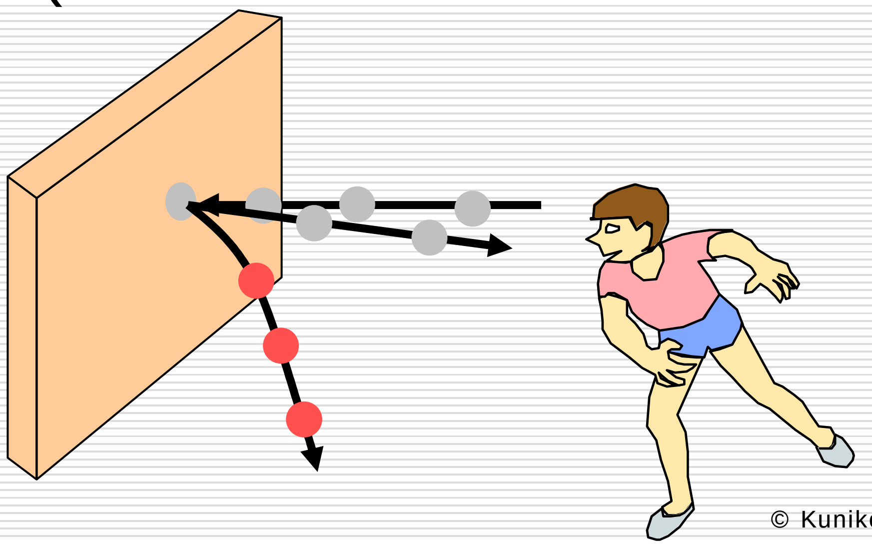
Skinner, Robinson & McVerry (1993)

Well used definition of stiffness, strength and displacement of LRB



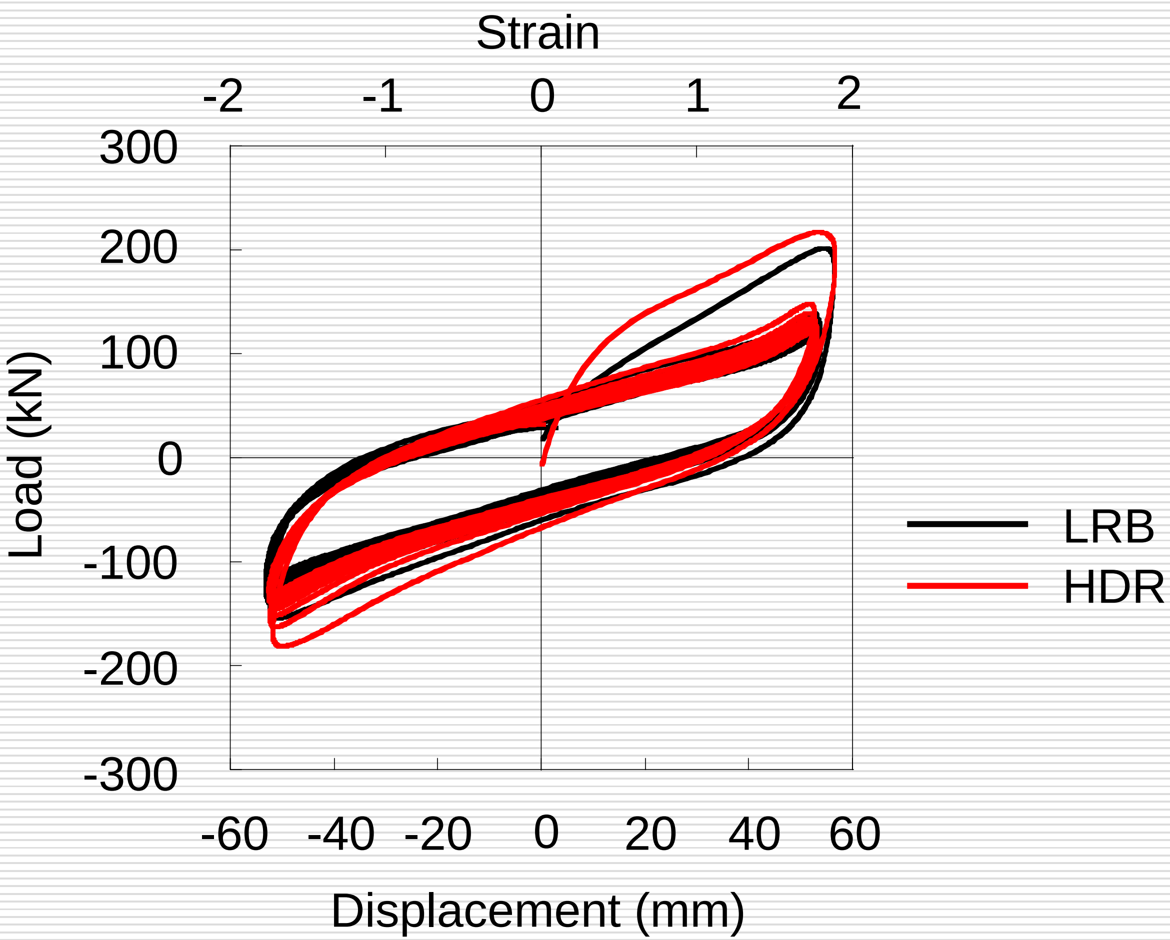
4.6 High Damping Rubber Bearings (HDR)
高減衰積層ゴム支承

- Use special rubber which dissipates energy when it deforms
- High damping rubber layers are laminated with steel plates (elastomeric bearings)
- Because “lead” is hazardous material, HDR bearings are preferred in the implementation in seismic isolation in recent years (Lead confined inside rubber cover is not hazardous)



HDR for Bridges
橋梁用HDR

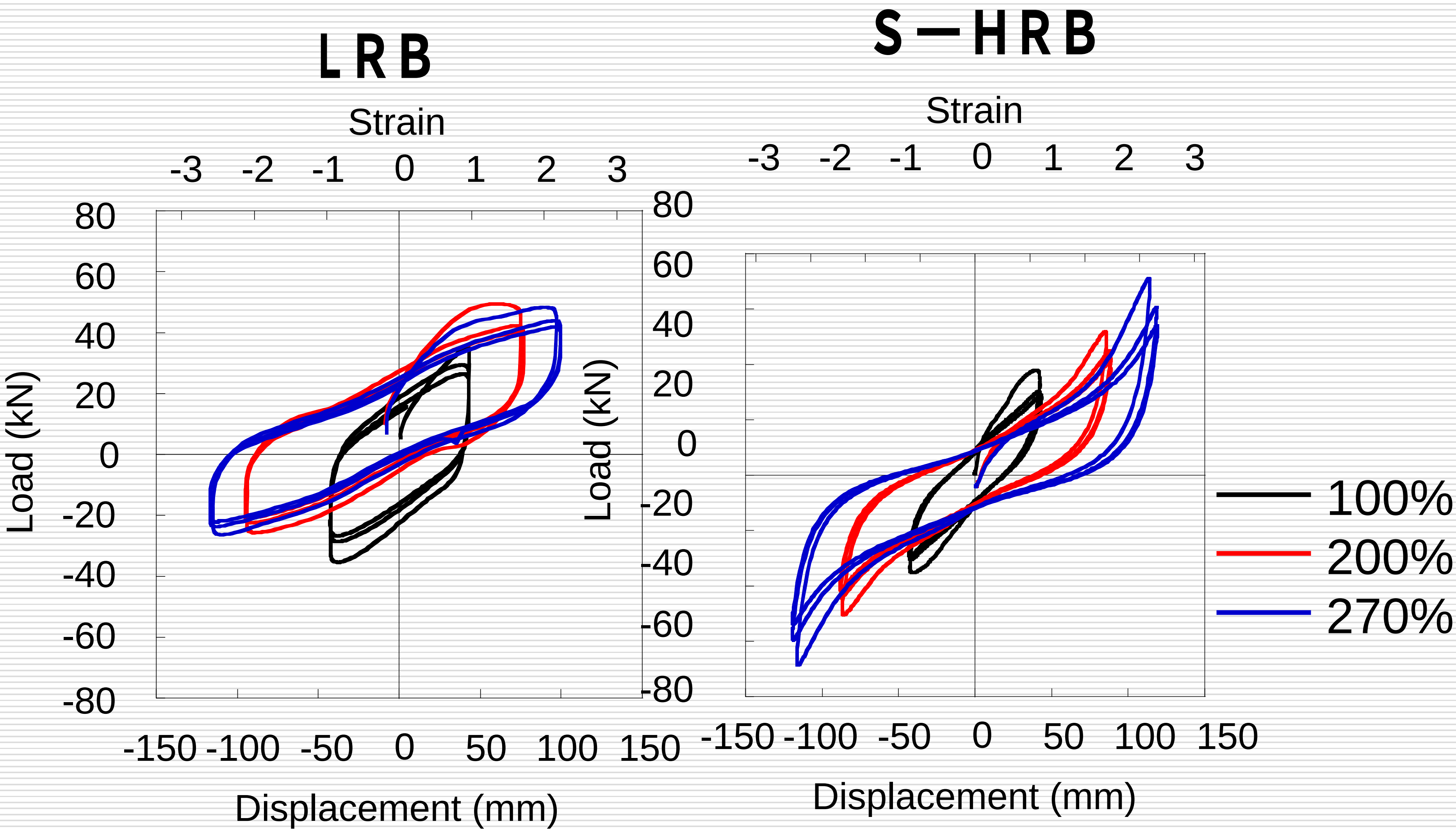
$$G = 1.2MPa$$



Courtesy of Bridgestone

LRB and HDR for Buildings
建築用LRBとHDR

$$G = 0.4MPa$$



Courtesy of Bridgestone

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

1) Basic principle 基本要件

●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

●Set dampers ダンパーを取り付ける

2) Whole-in-one type dives are better for the implementation to bridges
一体型ディバイスの方が橋梁への適用では有利か？

Separate type device
別置き型ディバイス

Whole-in-one type devices **一体型ディバイス**

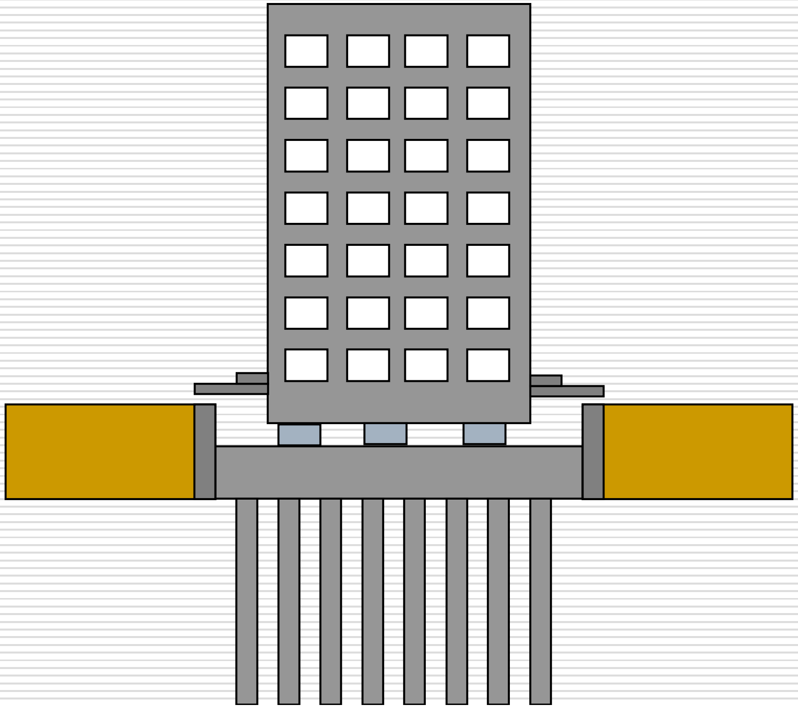
Set Isolators (Period Shifters)
アイソレーター (ピリオドシフター)

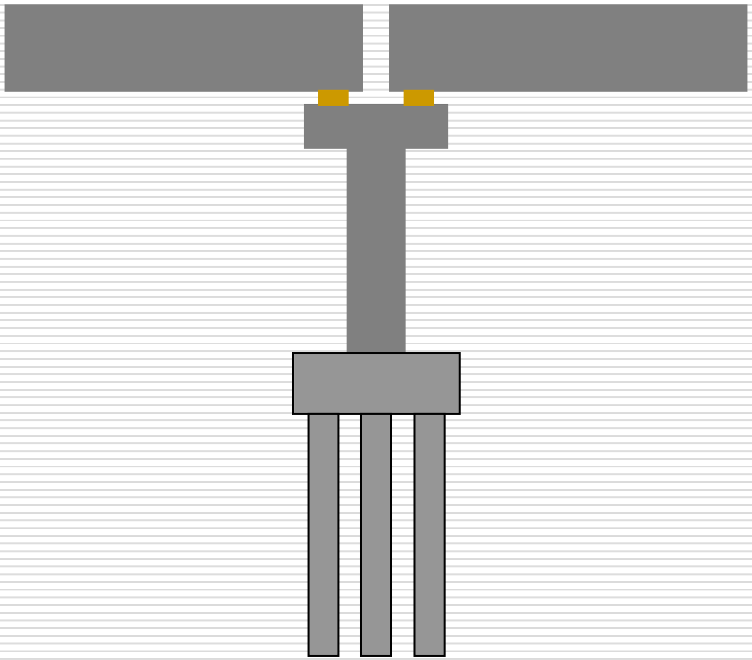
Set Dampers, or Energy Disspators (**ダンパー、あるいは、エネルギー吸収装置**)

Set a devices which have function of isolators and dampers.

3) Space for setting devices is limited in bridges
橋梁では、免震装置を設置するスペースの制約が大きい

●Space between substructures and girders is limited for setting devices in bridges, while the space is generally sufficient in buildings.
●Environmental condition for devices is more strict in bridges than buildings because they are directly exposed to natural environment.





4.8 Implementation of Lead Rubber Bearings to Bridges at the Early Days
鉛プラグ入り積層ゴム支承の橋梁への適用

1) The First Implementation of LRB to Bridges in the World
Toe Toe Bridge, New Zealand
世界最初の橋梁に対するＬＲＢの適用、トエトエ橋

Lead Rubber Bearing

2) Moonshine Bridge, New Zealand

3) Grafton Bridge, Auckland

4) Miyagawa Bridge, The First Isolated Bridge using LRB in Japan　宮川橋、静岡県

Miyagawa Bridge, Shizuoka-ken, 1989

Symbolic “long-nose goblin” at the region was set at the hand-poles of Miyagawa Bridge.

Famous long-nose goblin at the site

Professor Okamoto, S. the 3rd from the left and Principal Engineer Hara in Shizuoka-ken at the right

5) Higashi-Ogi-Shima Bridge 首都高速･東扇島橋

Large LRB

Higashi Ohgishima Bridge
Metropolitan Expressway

4.9 Implementation of High Damping Rubber Bearings to Bridges in the World
The First Implementation of HDR to Bridge
世界初の高減衰積層ゴム支承の橋梁への適用

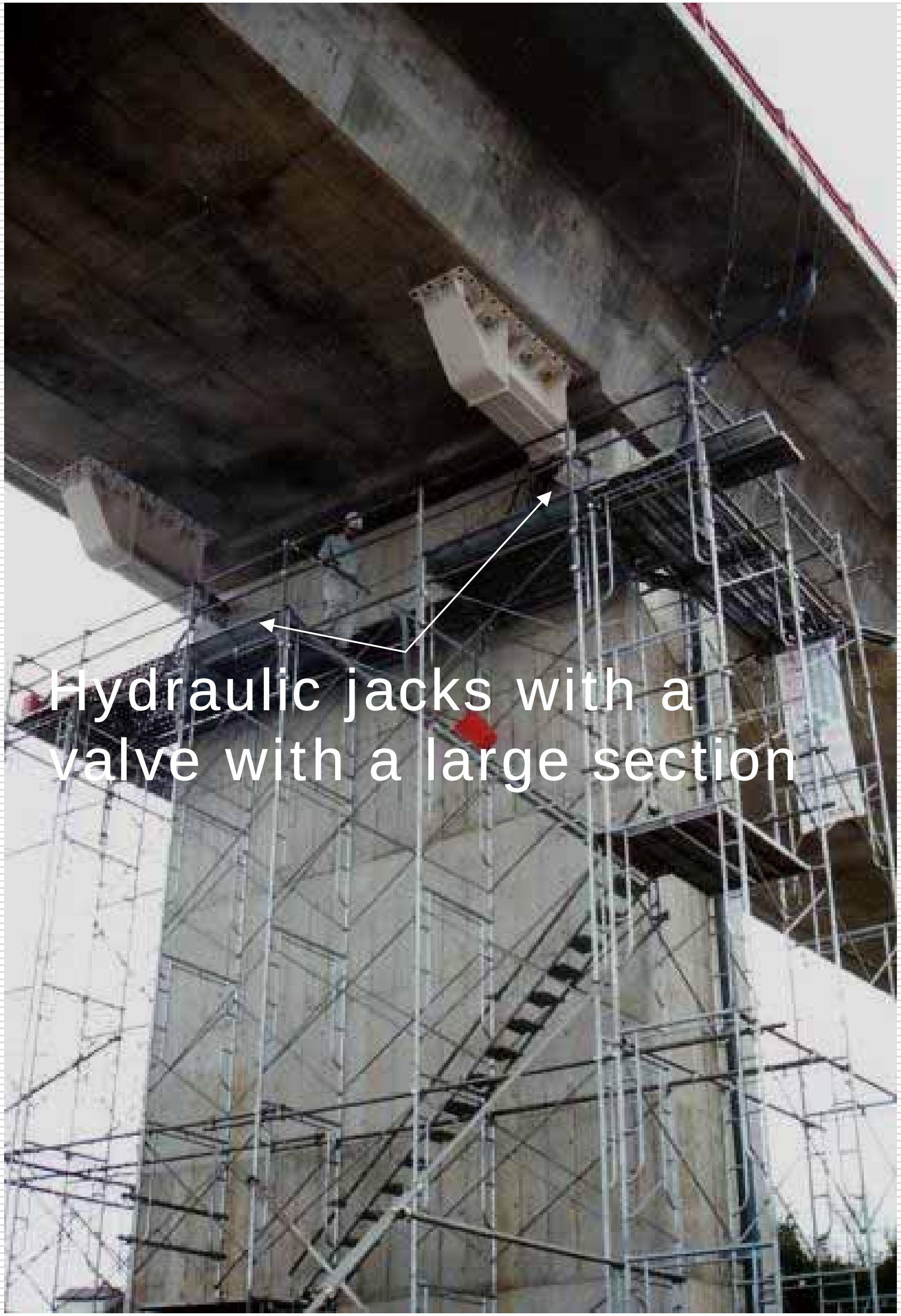
High damping Rubber Bearing used for Yama-age Bridges
山あげ大橋に用いられた高減衰積層ゴム支承

Forced Excitation Test at Yama-age Bridge
山あげ大橋の強制振動実験

Eccentric Mass Shaker

Push-back Test

Hydraulic jacks with a valve with a large


Hydraulic jacks with a
valve with a large section

Implementation of Menshin Design to Super Multi-span Continuous Bridges

Both LRB and HDR were used

超多径間連続橋への適用

Ohito Viaduct

大仁高架橋（静岡県）

Ohito Viaduct

HDR used for Ohito Viaduct

大仁高架橋に用いられたHDR