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

（6）第5章　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(1)
(6) Chapter 5 Seismic Isolation of Bridges (1)

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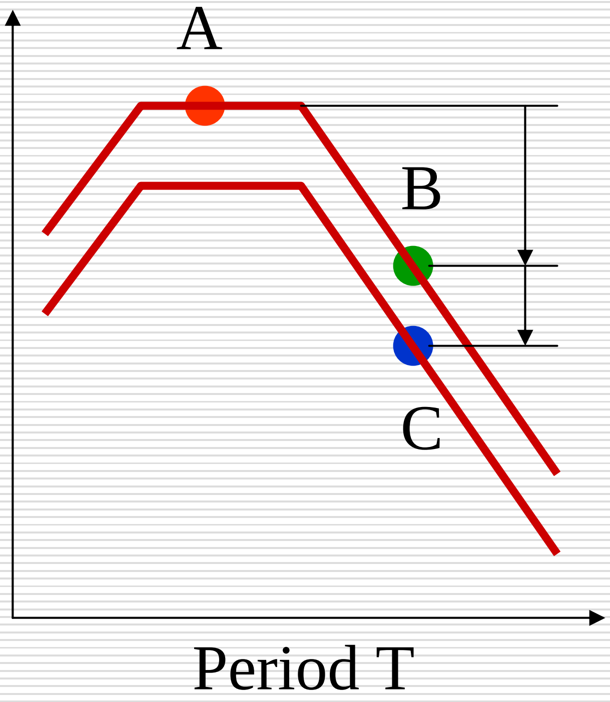
5.1 Basic Principle of Seismic Isolation

(1) Reduction of response displacement and acceleration due to period shift and increasing damping ratio

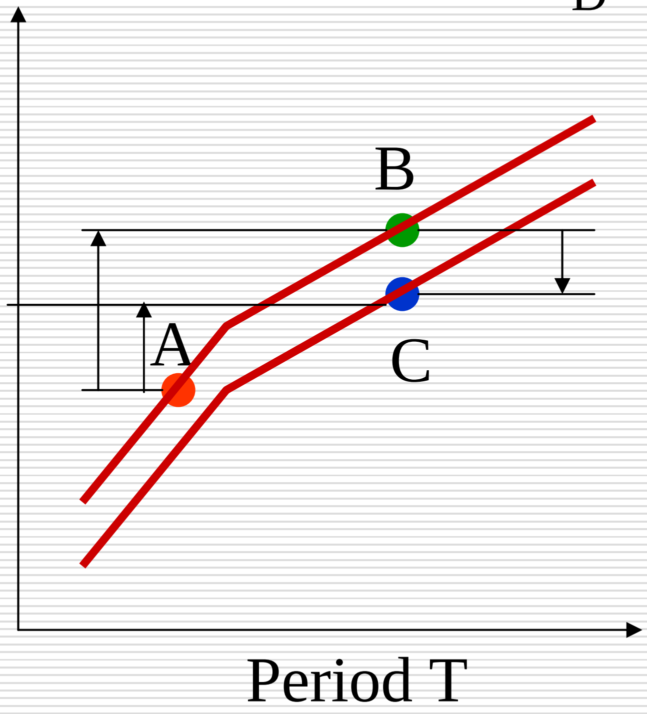
Response Acceleration S_A

加速度応答スペクトルS_A

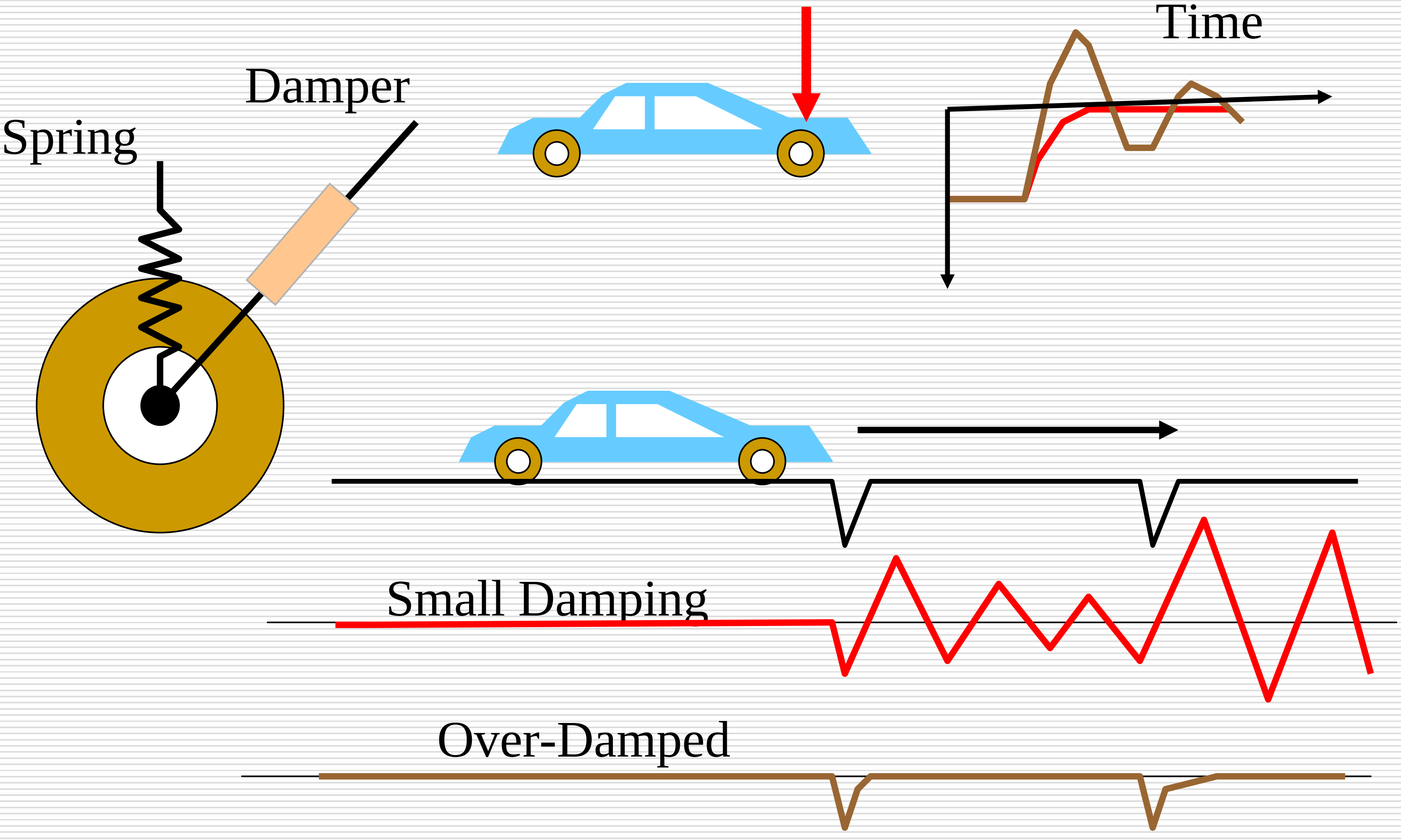


Response Displacement S_D

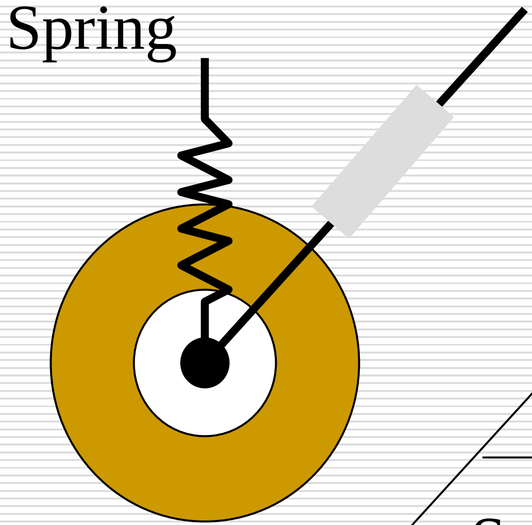
変位応答スペクトルS_D

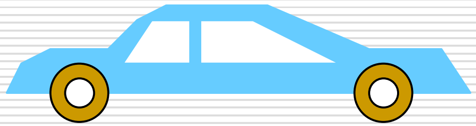


(2) Why is the Energy Dissipation Required ?

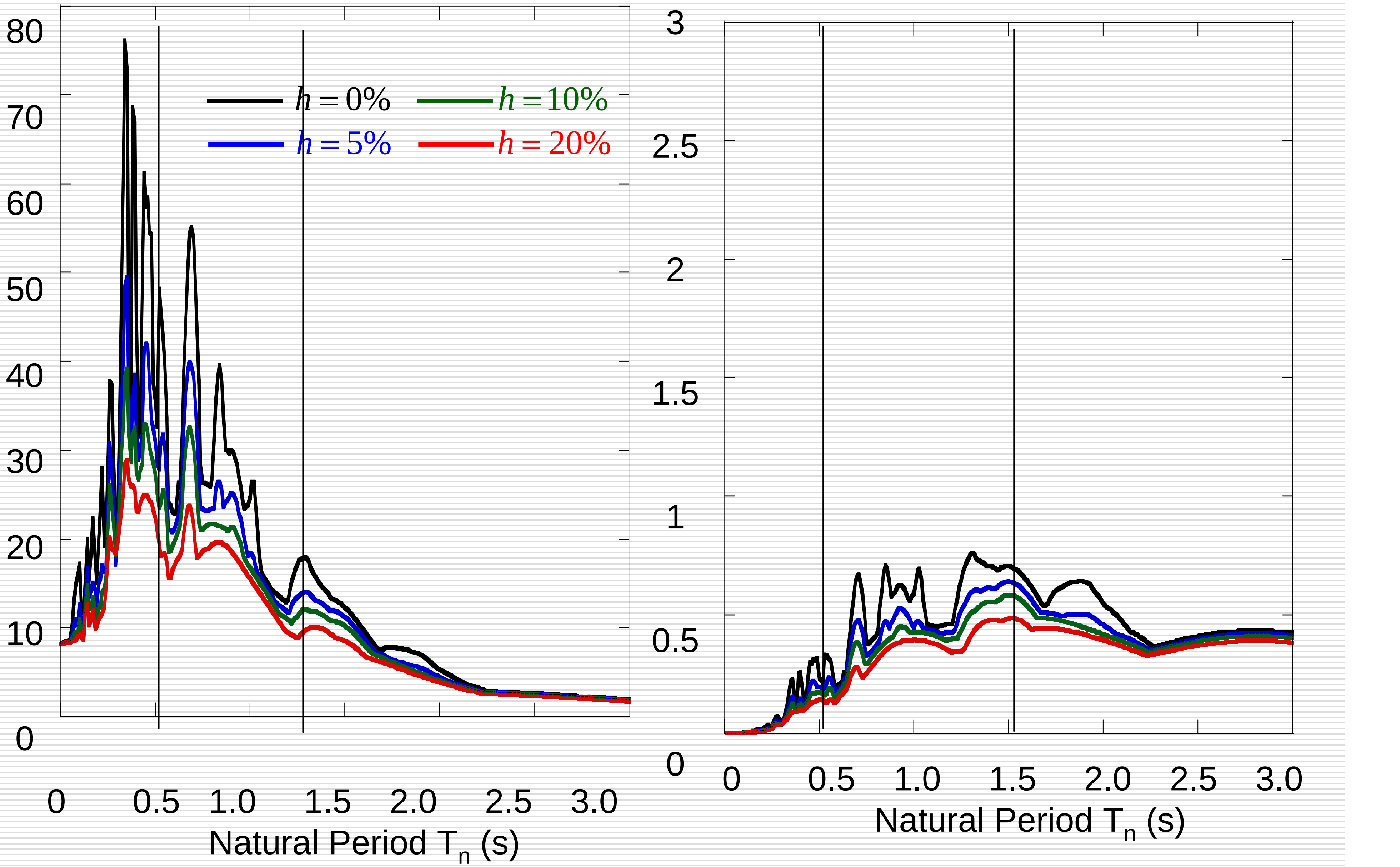


(3) Why is the Increase of Natural Period (Period Shift) Required ?

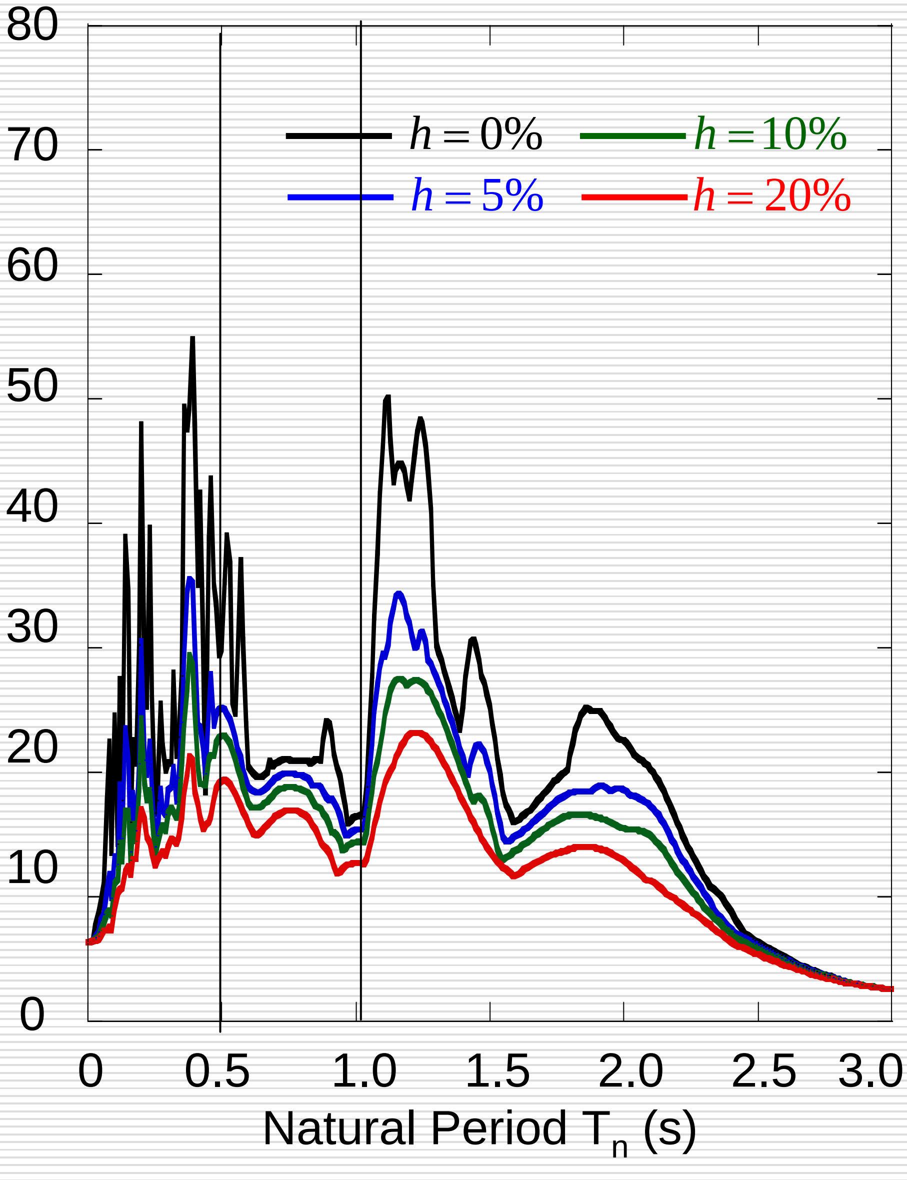


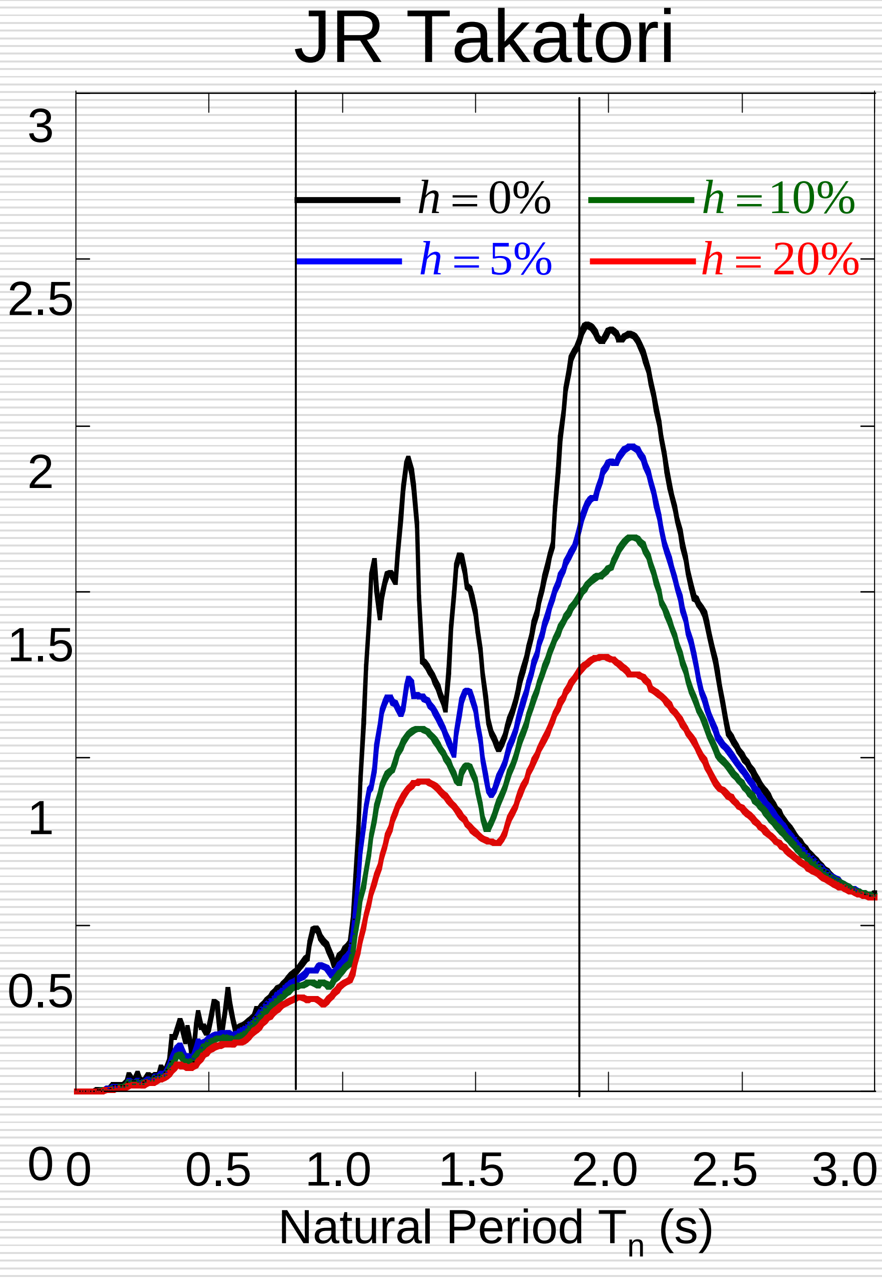
		
Spring	Stiff	Soft
Shock = Acceleration	Strong	Weak = Comfortable
Displacement	Small	Large

JMA Kobe Ground Motion

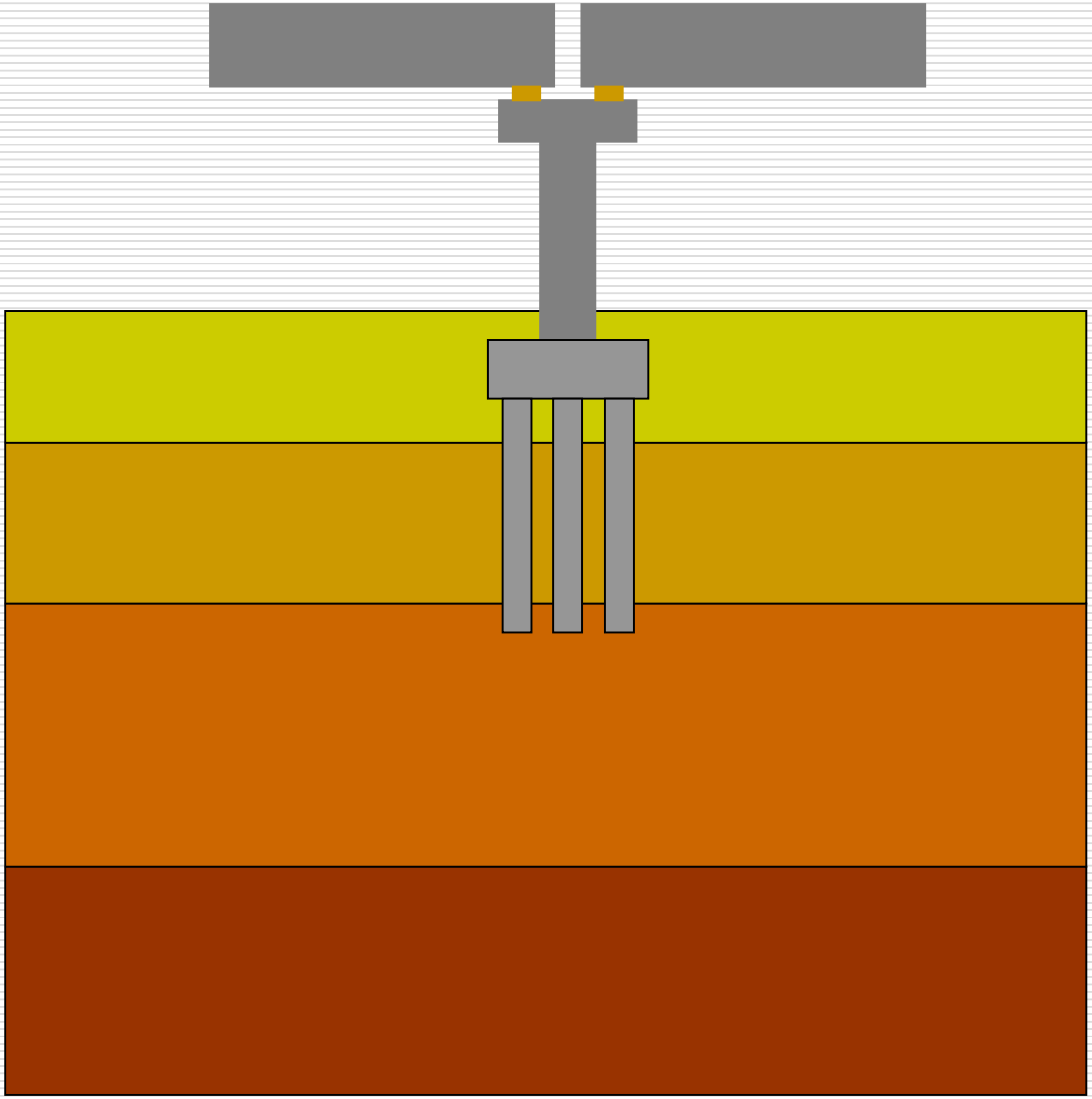


JR Takatori Ground Motion





Natural Period of a Bridge Depends on Various Factors

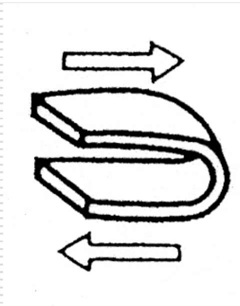


5.2 How can we dissipate energy?
どうすればエネルギー吸収ができるのか？

1) Various principles

- Energy dissipation due to plastic deformation of steel devices

Torsion　　Bending



Mild steel, lead, etc.

- Viscous fluid
- ……

2) Steel dampers

Torsion (ねじり)

Flexural　(曲げ)

Flexural

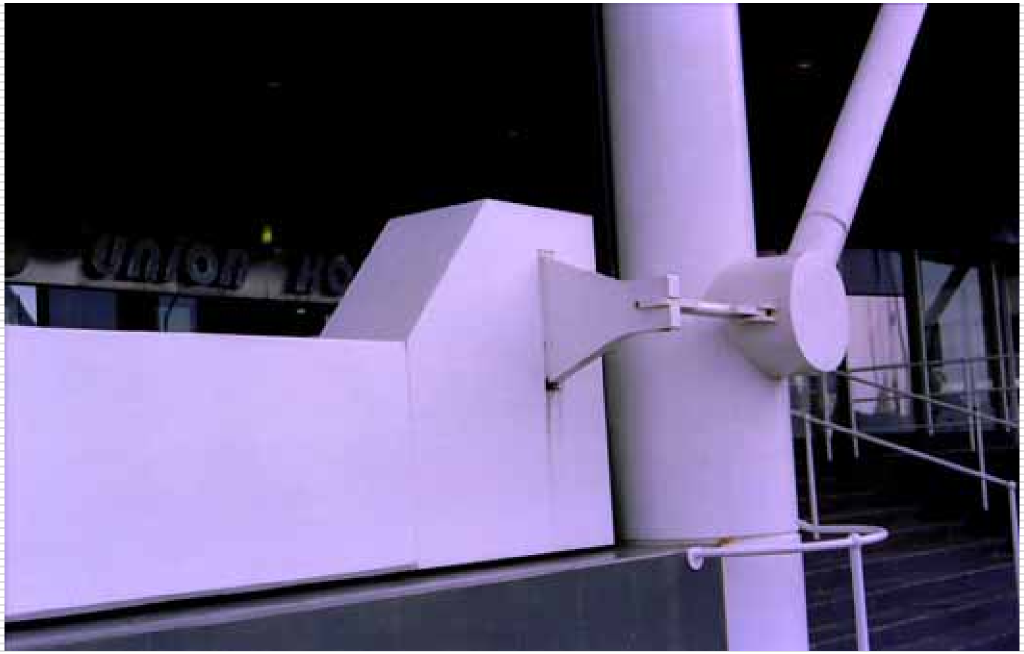
Flexural

Flexural

Fatigue due to repeated plastic deformation?

3) Implementation of Steel Plate Isolators to Buildings

New Zealand



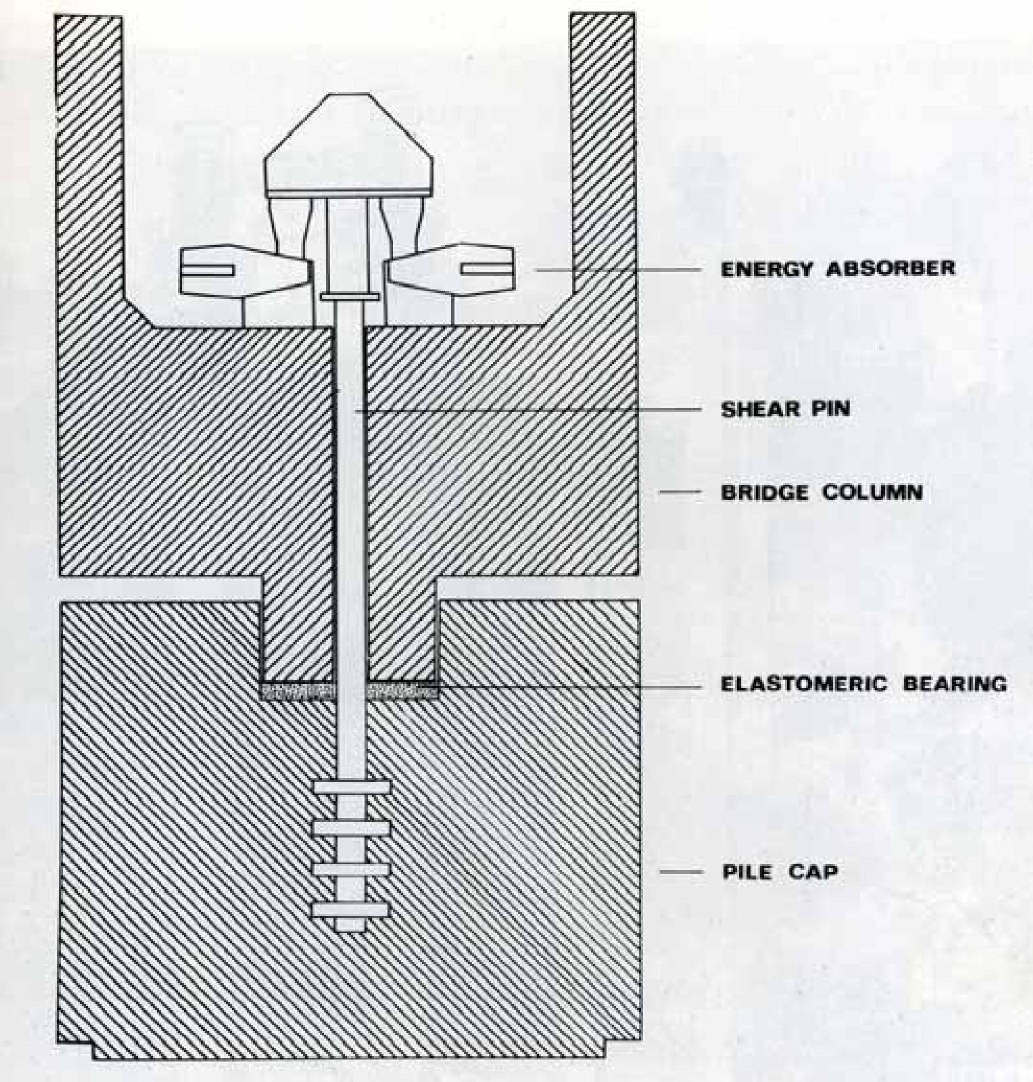
4) Implementation of Torsion Dampers to a Bridge

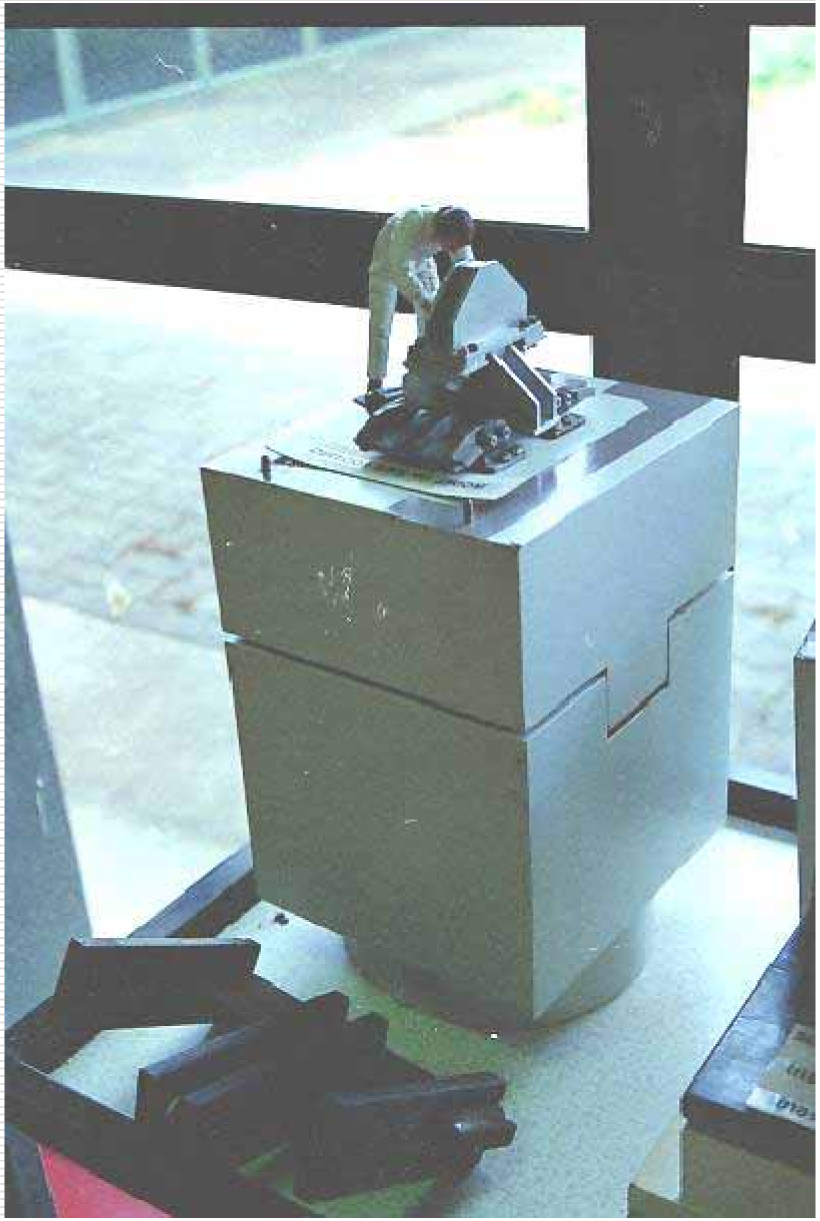
Stepping structure using steel torsion energy dissipators

South Rangitikei Bridge,
New Zealand

1972

Stepping Piers





Skinner, Robinson & McVerry (1993)

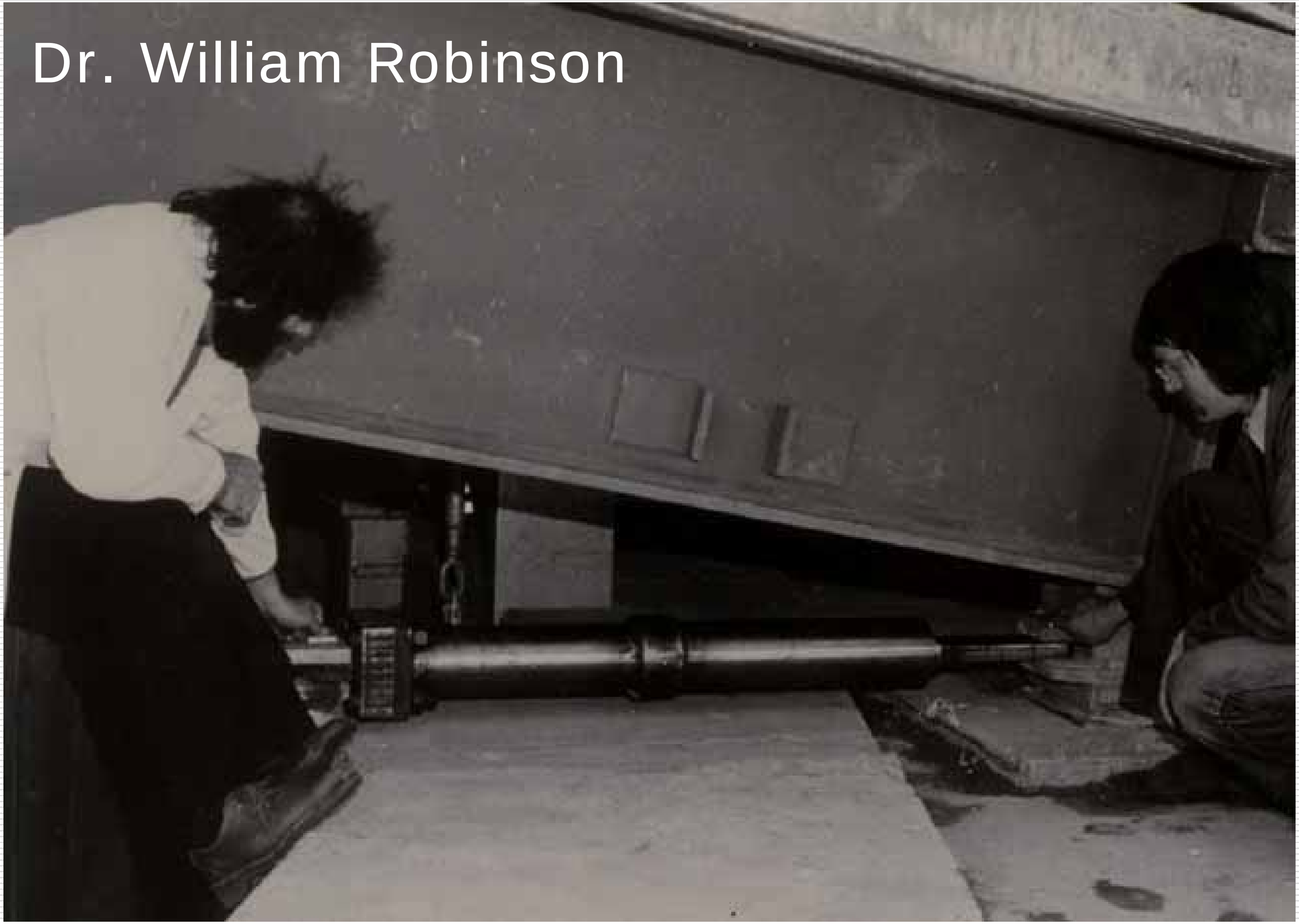
Mechanical Torsion Damper

Torsion Plate Damper

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

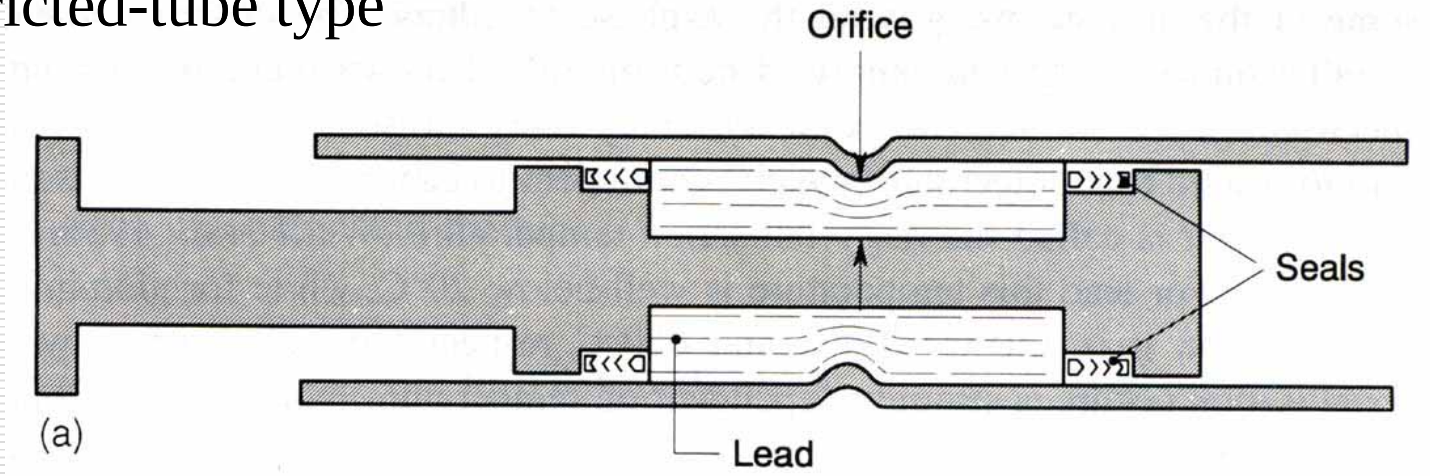
Aurora Terrace Bridge

Lead Extrusion Damper

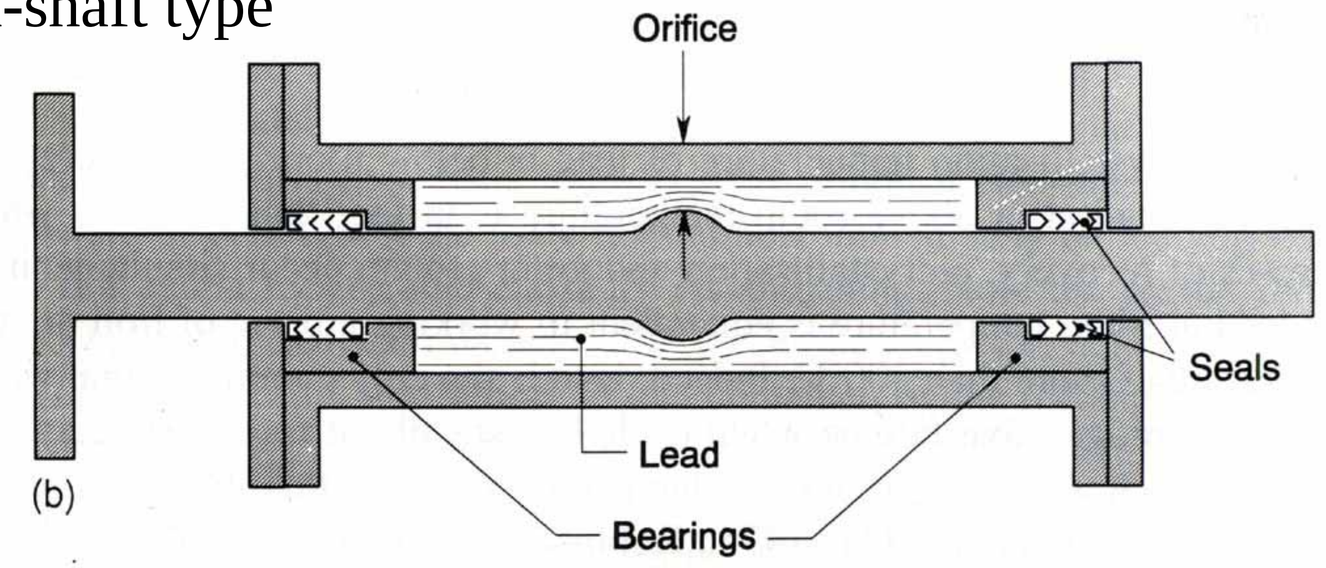


Lead-Extrusion Damper

Constricted-tube type

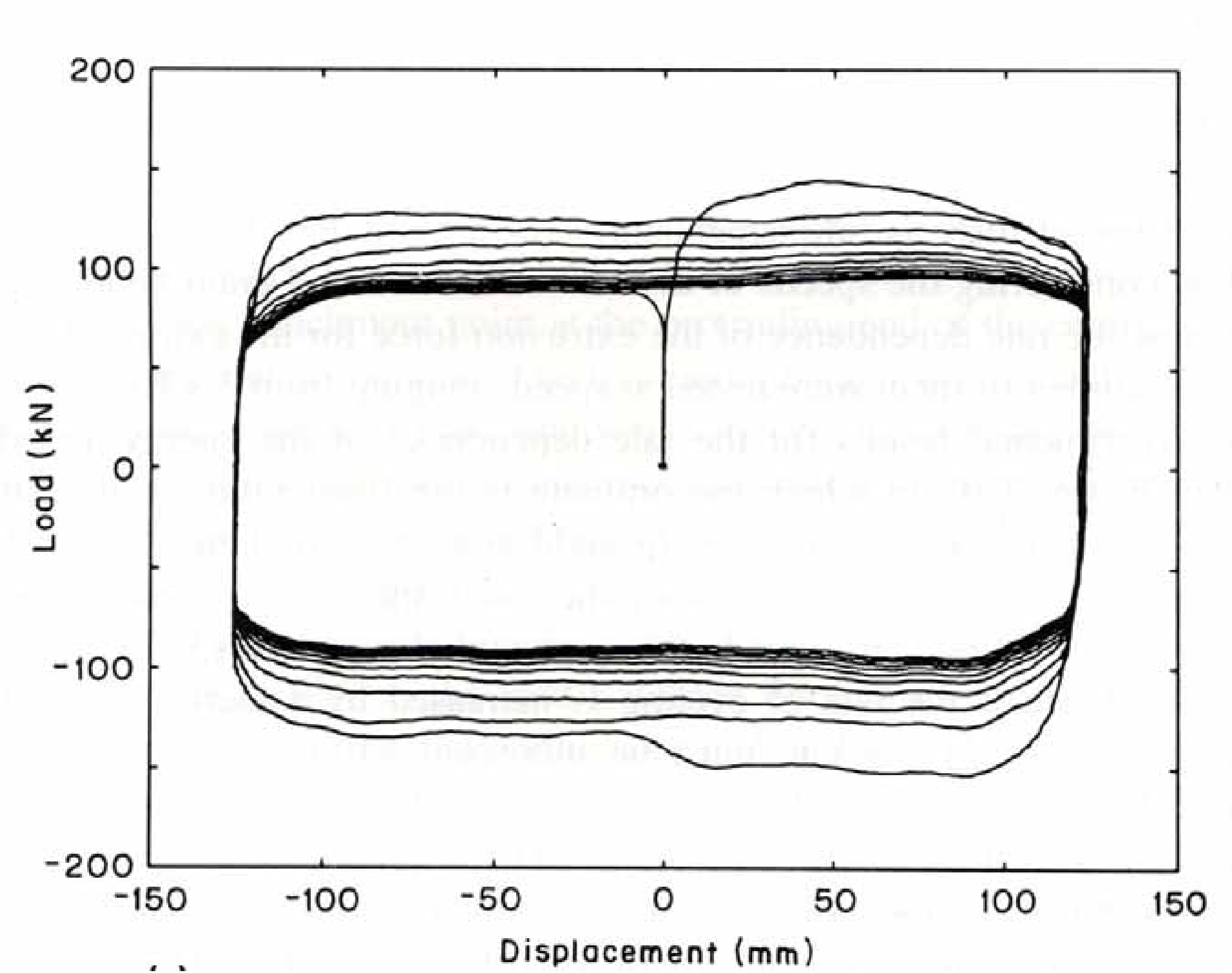


Bulged-shaft type



Skinner, Robinson & McVerry (1993)

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

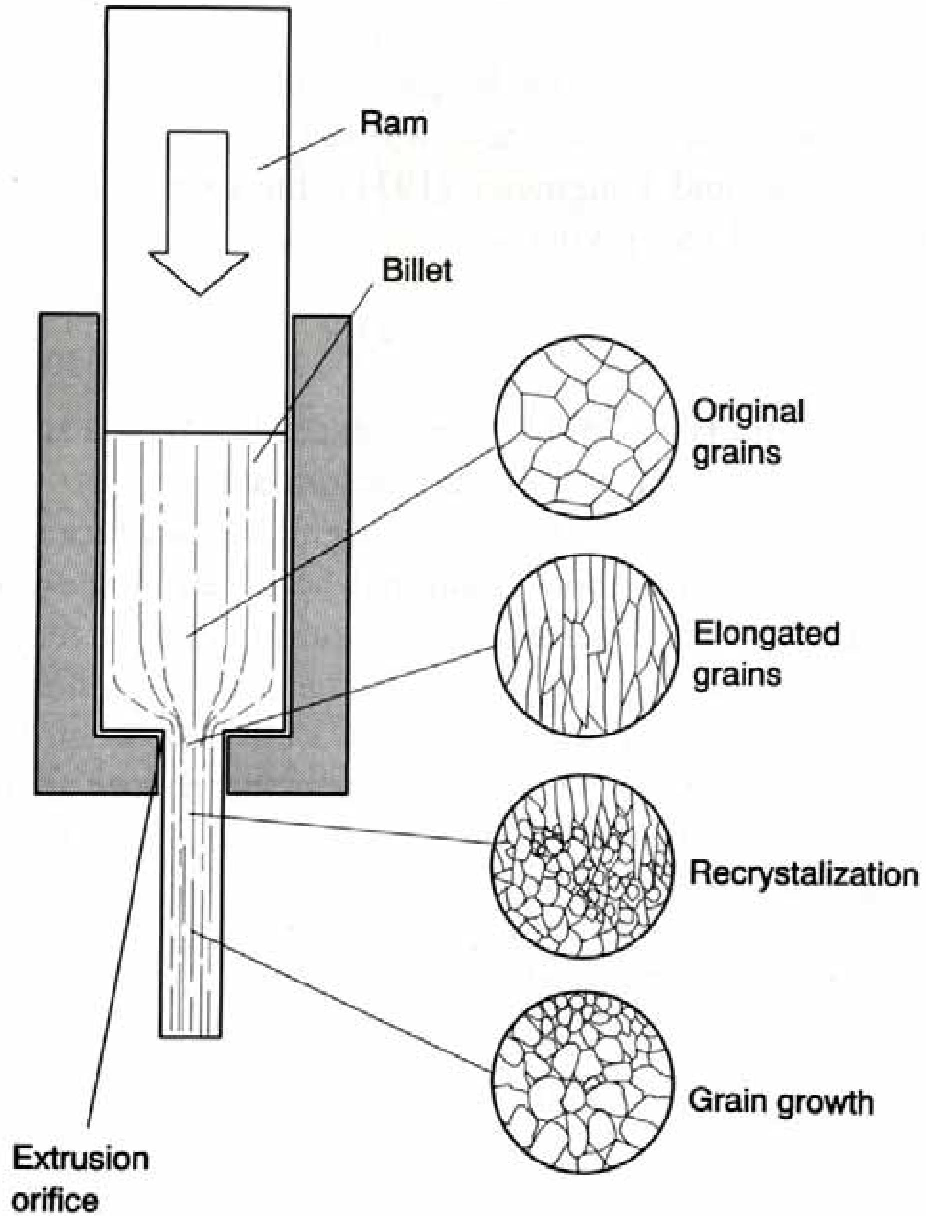


Skinner, Robinson & McVerry (1993)

6) Why is lead appropriate to dampers?

Re-crystallization of Lead after Plastic Deformation

鉛の再結晶



Skinner, Robinson & McVerry (1993)

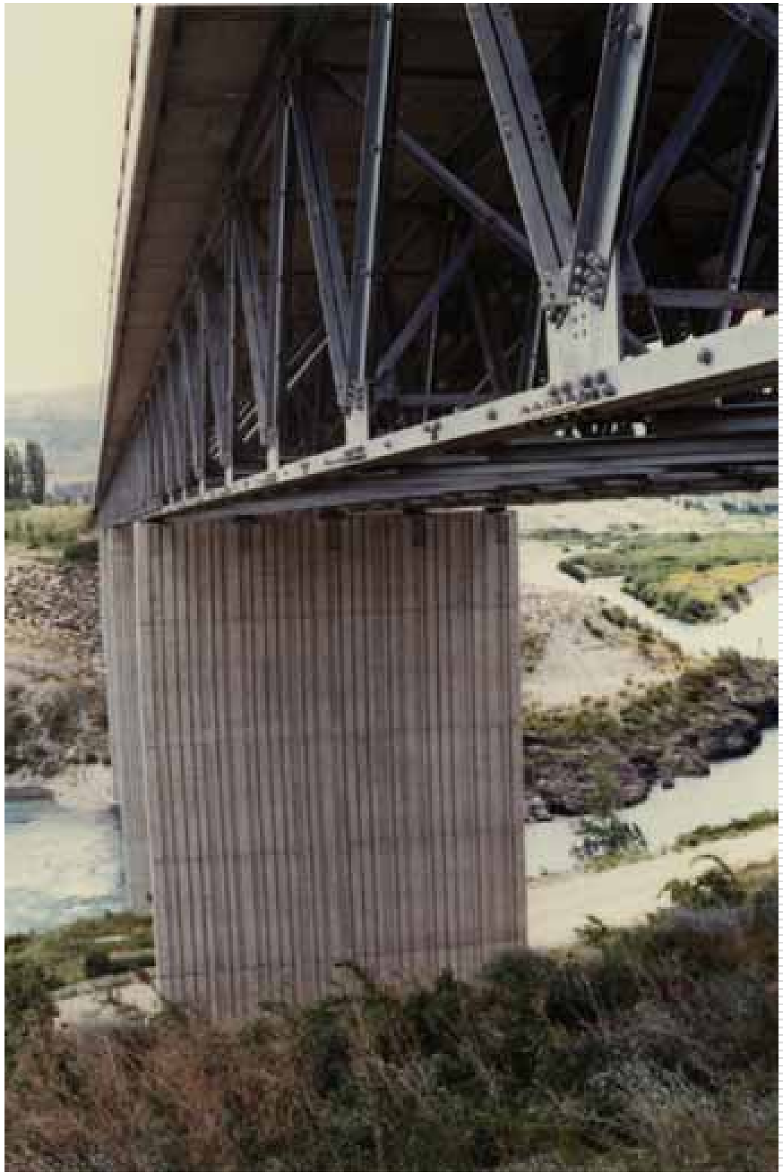
Why is lead appropriate for an energy dissipator?

Re-crystallization of lead 鉛の再結晶

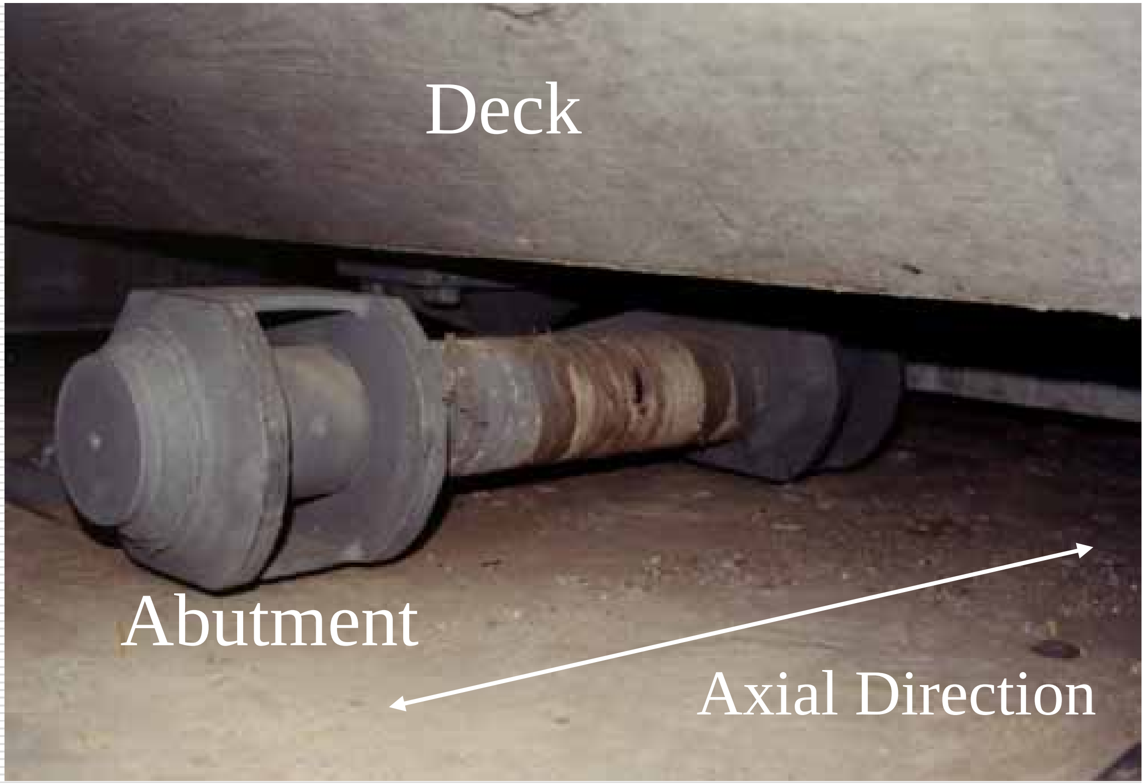
Re-crystallization temperature 再結晶温度
= Temperature which is required for re-crystallization of 50% the lead in an hour

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

7) Implementation of Steel Bar Flexure Energy Dissipators

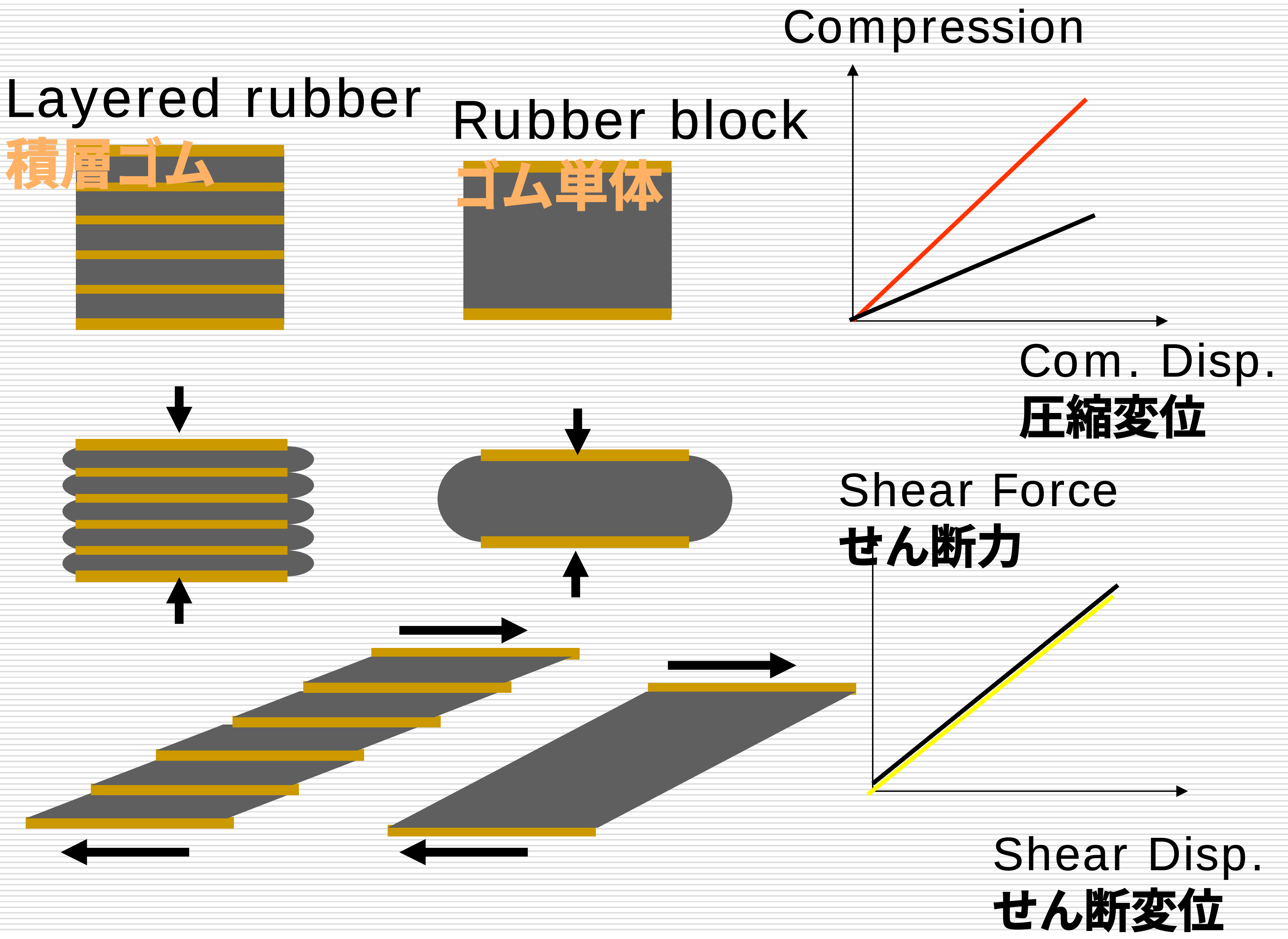


Cromwell Bridge

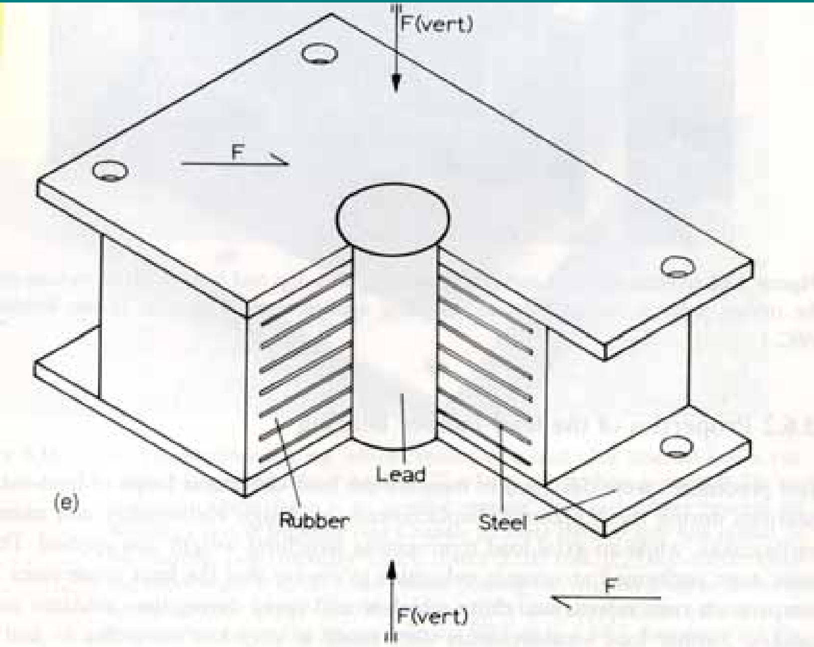


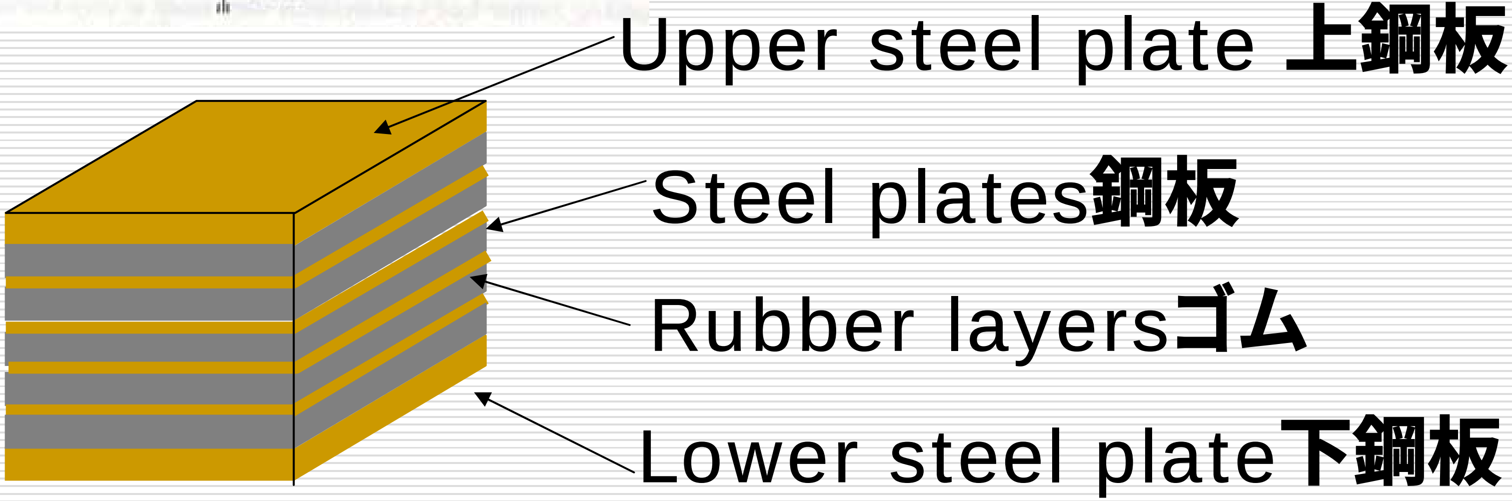
Deformed Mild Steel Flexural Damper

8) Elastomeric bearings 積層ゴム支承



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

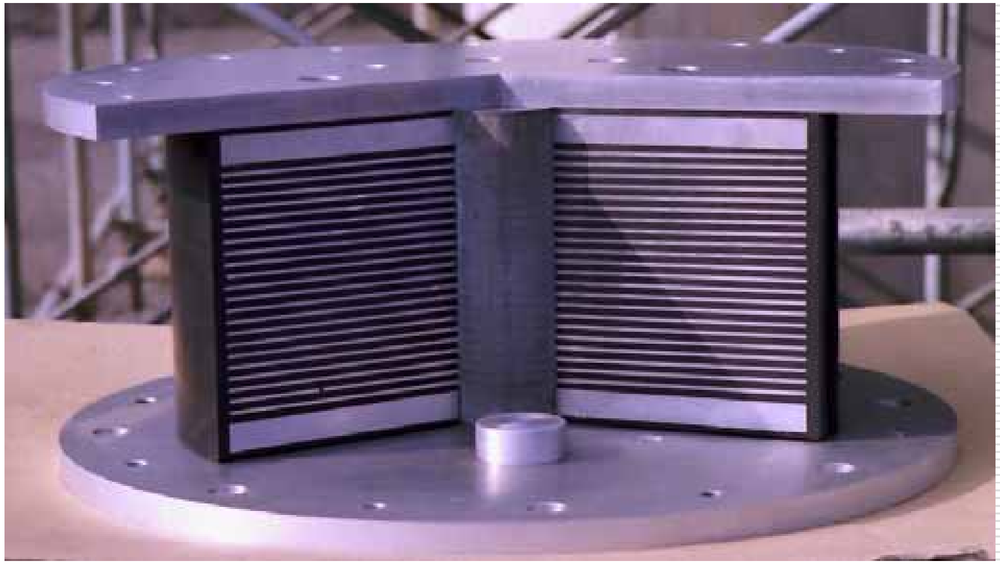




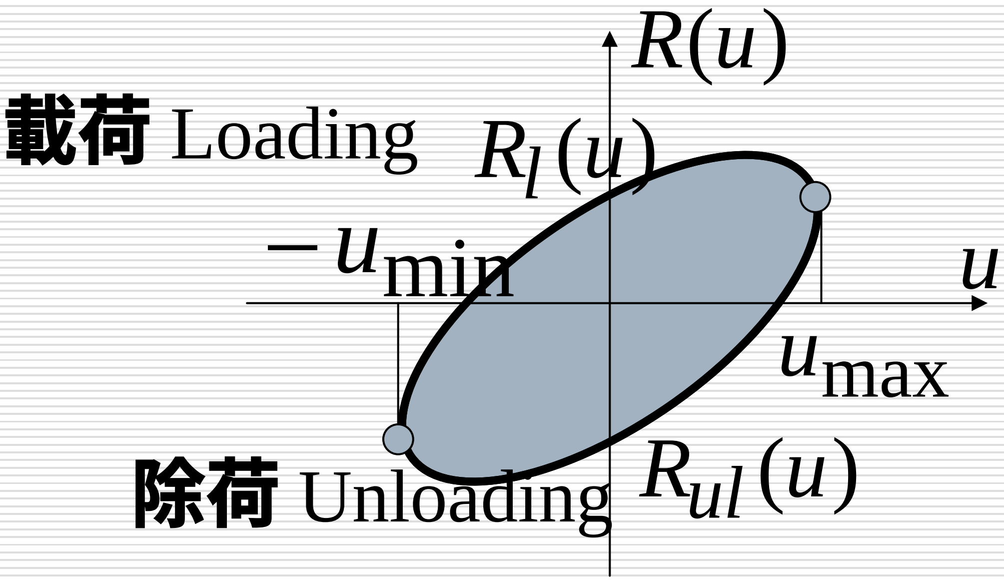
Skinner, Robinson & McVerry (1993)

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



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



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

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

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

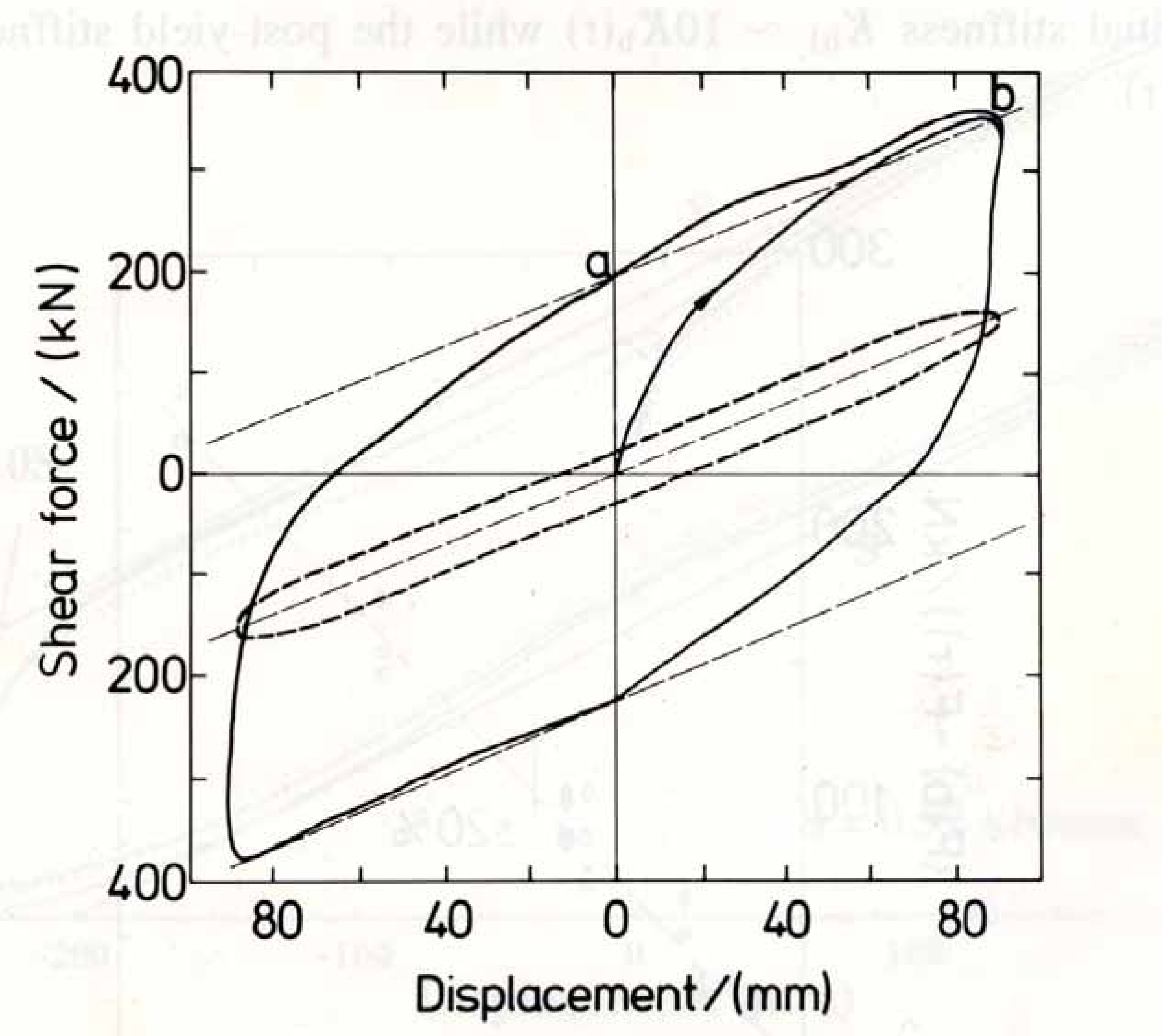
$$= \int_{-u_{\min}}^{u_{\max}} R_l(u)du - \int_{-u_{\min}}^{u_{\max}} R_{ul}(u)du$$

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

where

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

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)

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

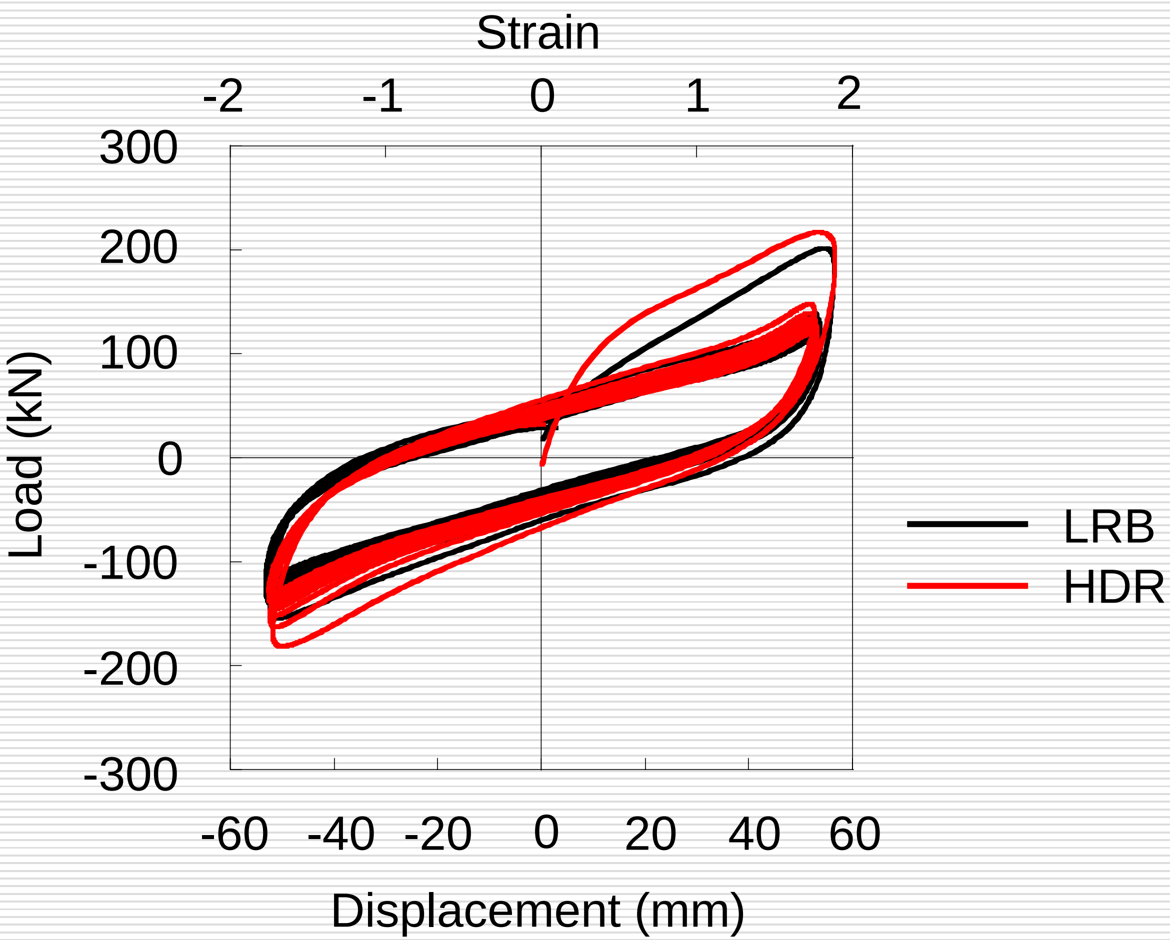
- Use special rubber which dissipates energy when it is subjected to deformation

- 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

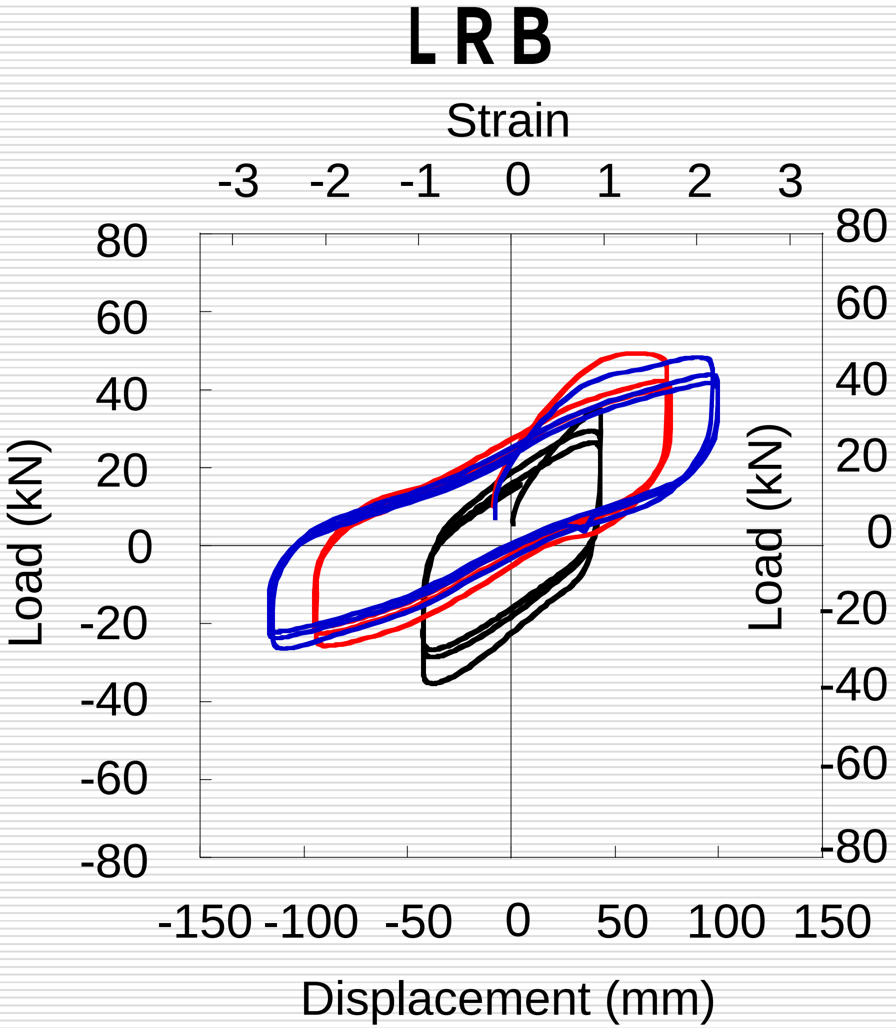
$$G = 1.2MPa$$

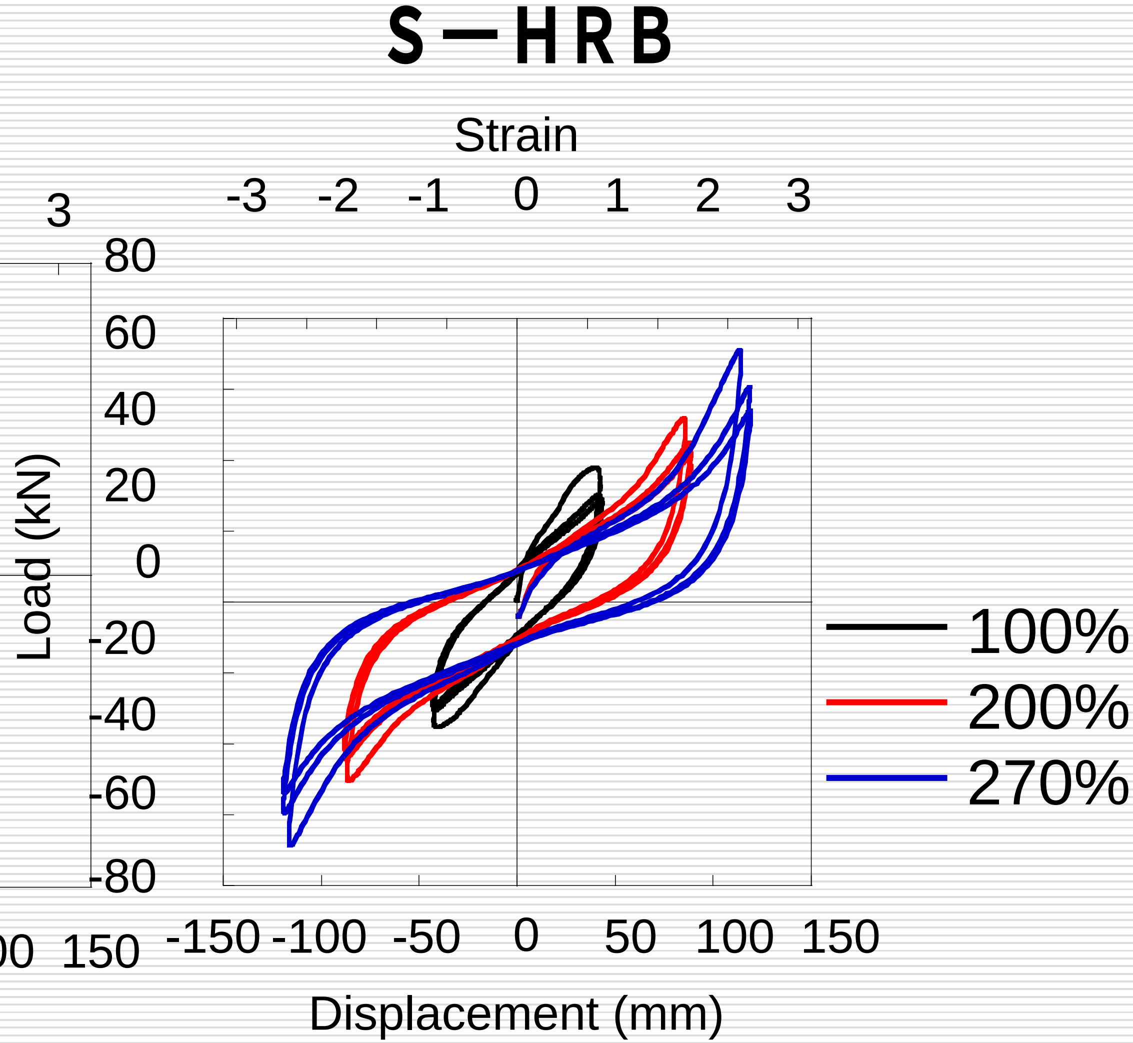


Courtesy of Bridgestone

LRB and HDR for Buildings
建築用LRBとHDR

$$G = 0.4MPa$$





Courtesy of Bridgestone