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

(10) 第7章　その他の形式のダンパー
(10) Chapter 7 Other Types of Dampers

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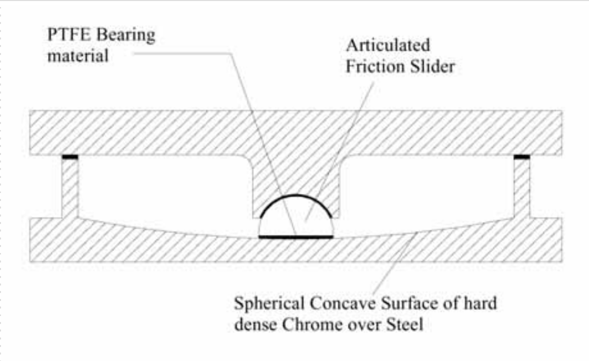
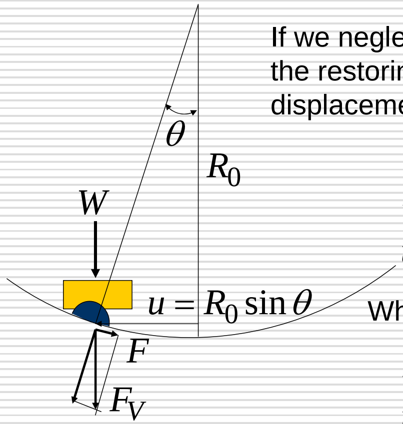
7.1 Friction Pendulum System (FPS)

1) Structure of Friction Pendulum System



After Professor M. Calvi

2) Restoring Force by FPS



If we neglect the friction force, the restoring force and lateral displacement are given as

$$F = F_V \sin\theta$$

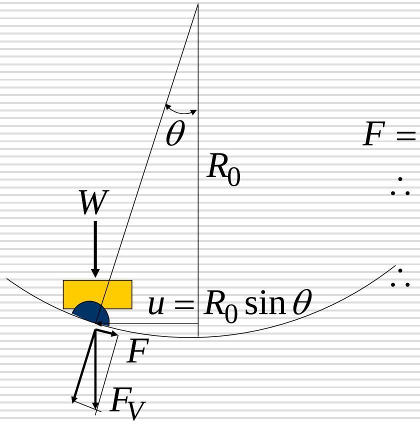
$$u = R_0 \sin\theta$$

When θ is small,

$$F \approx F_V \theta$$

$$u \approx R_0 \theta$$

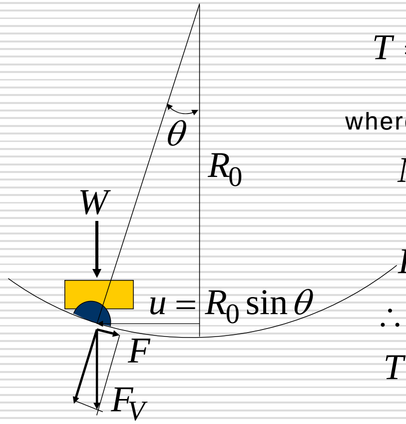
3) Stiffness K



$$F \approx F_V \theta$$
$$u \approx R_0 \theta$$

$$F = Ku$$
$$\therefore$$
$$F_V \theta = K R_0 \theta$$
$$\therefore$$
$$K = \frac{F_V}{R_0}$$

4) Natural Period of a Structure Supported by FPS



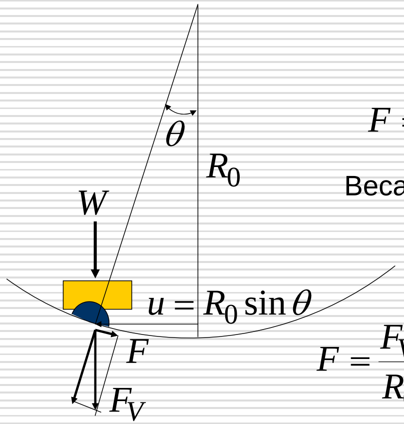
$$T = 2\pi \sqrt{\frac{M}{K}}$$

where

$$M = \frac{W}{g} = \frac{F_V}{g}$$
$$K = \frac{F_V}{R_0}$$
$$\therefore$$
$$T = 2\pi \sqrt{\frac{R_0}{g}}$$

Natural period is independent of mass M

5) Lateral Force vs. Lateral Displacement Hysteresis



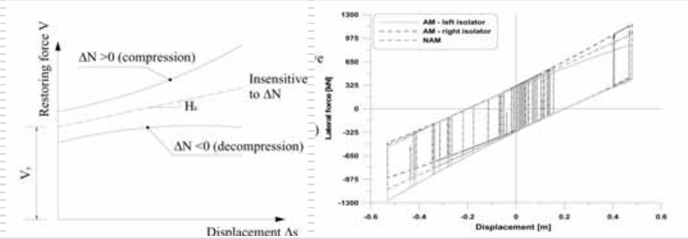
$$F = F_V \sin\theta$$

Because,

$$\sin\theta = \frac{u}{R_0}$$

$$F = \frac{F_V}{R_0} u + sign(\dot{u}) \mu F_V$$

$$F = \frac{F_V}{R_0} u + sign(\dot{u}) \mu F_V$$



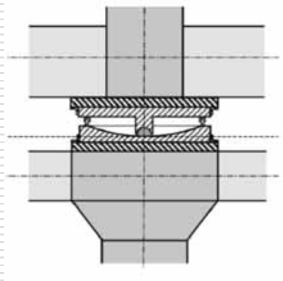
After Professor M. Calvi

6) Summary of Characteristics of FPS

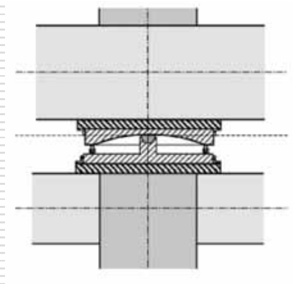
- FPS is governed by 2 parameters
  - ✓Radius of the spherical surface
  - ✓Friction coefficient at the sliding interface
- Neglecting variation of the friction coefficient with velocity and pressure that slightly effect the peak response of the system, the only one parameter is the radius of the spherical surface
- Residual displacements can be reduced due to the self-centering action induced by the concave spherical surface.

7) Two types of FPS

Upward mounting



Downward mounting



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8) Example of FPS

Courtesy of Prof. Steven Mahin, UCB

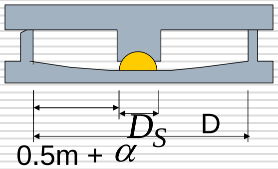
Friction Pendulum System

Courtesy of Dr. Victor Zayas, Engineering Protection System

Friction Pendulum System for Carrying Over 10,000 tf Structure

9) Problems for Implementation of FPS to Bridges

- Large diameter FPS needed to accommodate +/- 0.5 m displacement

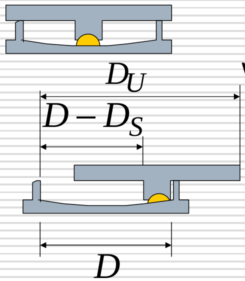


If we consider $\alpha = 0.15m$ and $D_S = 0.2m$

$$D = 2(0.5+\alpha) + D_S$$
$$= 1.5m$$

Consequently, the outer diameter of the FPS becomes nearly 1.8m

In fact, much larger diameter may be needed



Width of the upper steel is

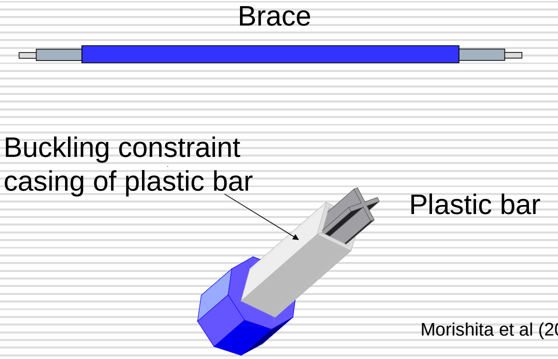
$$D_U = 2(D - D_S) + D_S$$
$$= 2D - D_S$$

If D=1.5m, D_U becomes 2.8m

New types of FPS are being developed for coping with this problem.

7.2 Unbond Brace Dampers

1) Unbond Brace Damper or Damper Brace



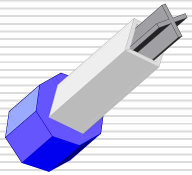
Morishita et al (2004)

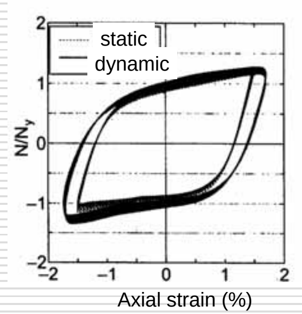
森下邦宏他、土木学会論文集、No. 766/I-68、2004

Damper Brace

Morishita et al (2004)

2) Large and Stable Hysteretic Energy Dissipation by Damper Brace





Morishita et al (2004)

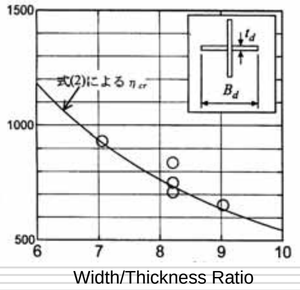
3) Thickness of Plates and Fatigue has to be properly considered in design

- Width-thickness ratio

$$r = \frac{B_d}{2t_d}$$

- Accumulated plastic deformation

$$\eta = \sum_i \frac{\delta_{pi}}{\delta_y}$$



where,

δ_{pi} : plastic displacement of i-th loading

δ_y : yield displacement

$$\eta_{cr} = 17{,}800 r^{-1.52}$$

Morishita et al (2004)

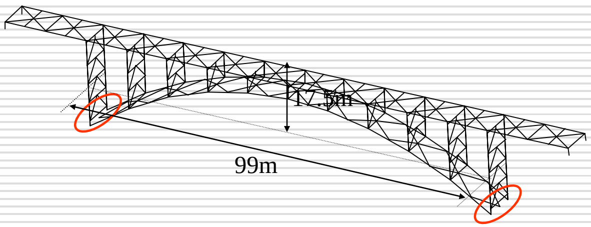
4) Unbond Brace Dampers widely used for Buildings
座屈拘束ブレースダンパー



Courtesy of Shin-Nippon Steel Co. Ltd

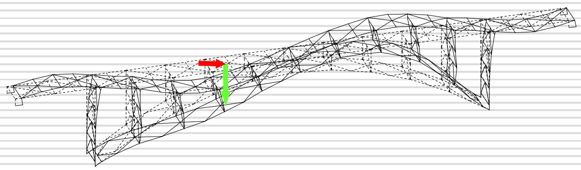
5) An Example of Analysis for Implementation of Damper Braces to Seismic Retrofit of an Arch Bridge

(1) Target bridge



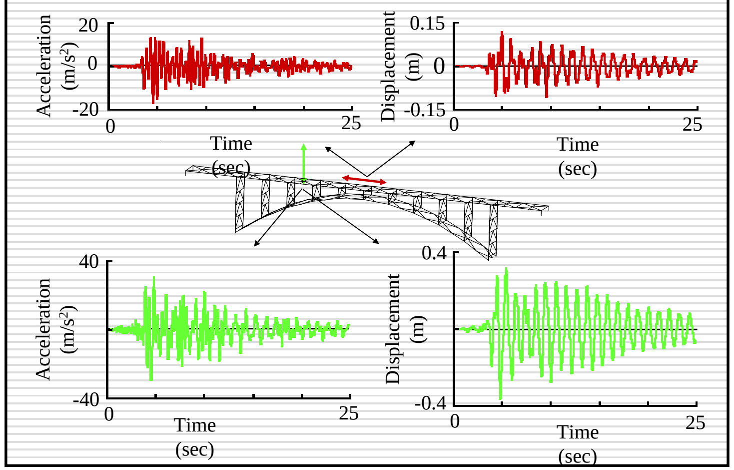
福田、川島、渡辺、構造工学論文集、Vol. 51A、2005

(2) Peculiar Response of Arch Bridges due to Coupling of Longitudinal and Vertical Modes

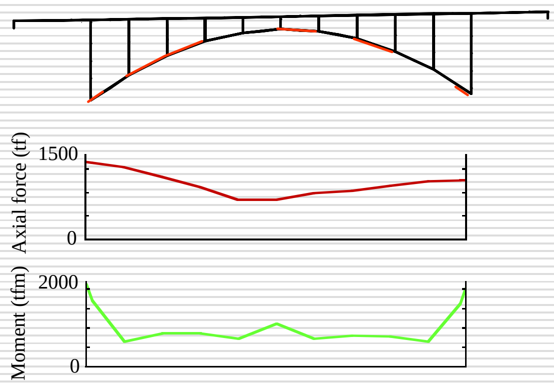


Fundamental Natural Period T=1.1 sec

(3) Seismic Response of As-Built Bridge under JMA Kobe Ground Acceleration, 1995 Kobe EQ



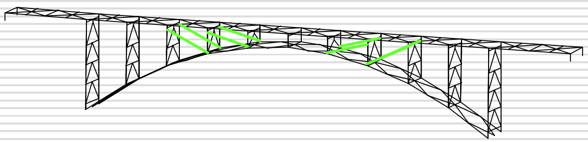
(4) Arch Members which undergo Inelastic Deformation



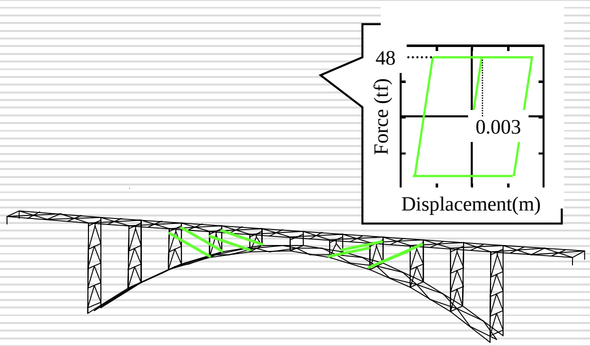
(5) Where should Damper Braces be Installed?

Criteria for deciding where damper braces should be installed

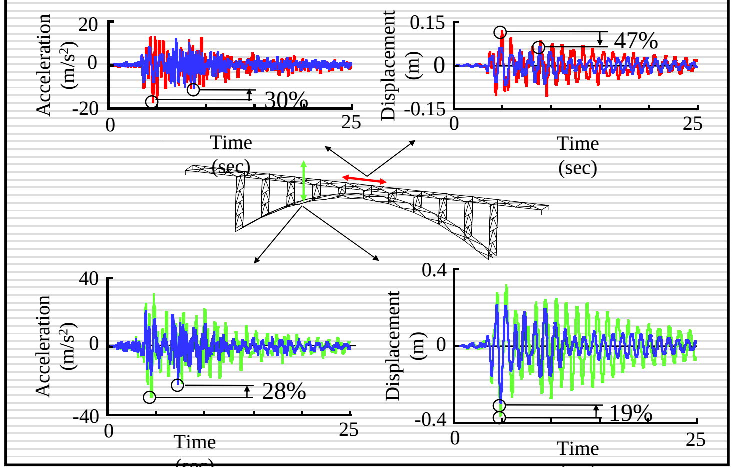
$\varepsilon > \varepsilon_a = 1/100$	Axial strain between 2 nodes
$\Delta u > \Delta u_a = 1/10m$	Relative displacement between 2 nodes
$l_D < 12m$	Length of member



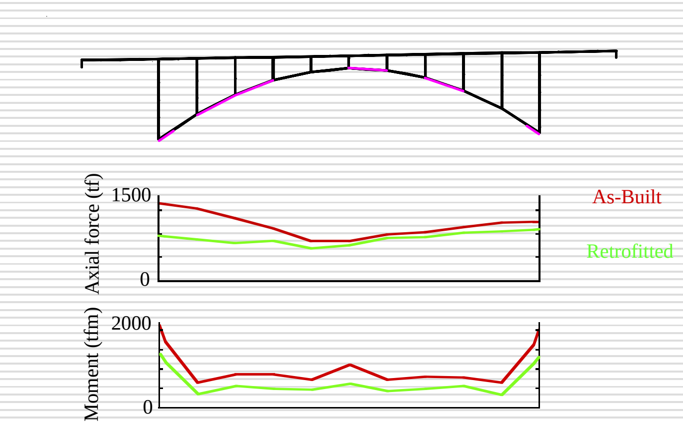
(6) Analytical Idealization of Hysteretic Behavior of Damper Brace



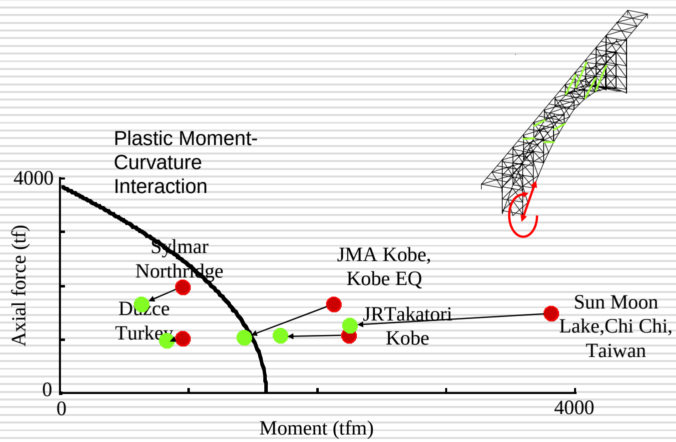
(7) Effect of seismic Retrofit



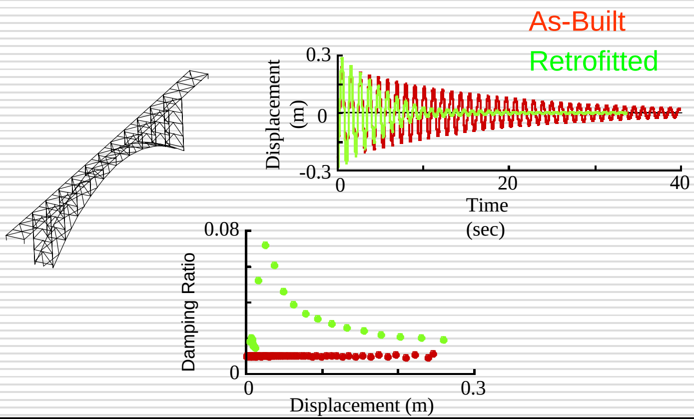
(8) Effect of Seismic Retrofit by Damper Braces



(9) Effect of Seismic Retrofit by Damper Braces

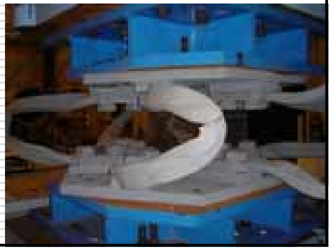


(10) Enhancement of Damping Ratio by Damper Braces



7.3 U-Dampers using Low-yield Mild Steel

1) U Damper U型免震ダンパー



2) U Dampers U型免震ダンパー

●低降伏点鋼を使用
●ほぼバイリニア型の履歴ループ

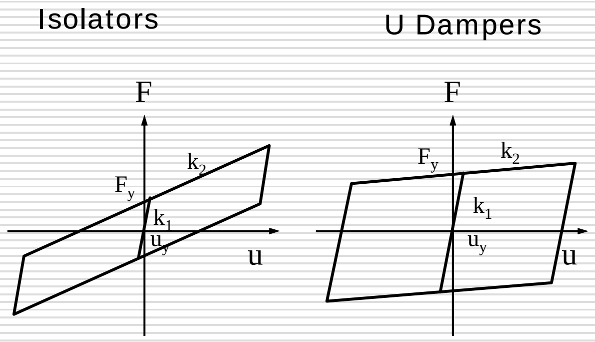
●Provide U-shaped low-yield steel plates so that they can dissipate energy in bilateral directions.

●They were developed for buildings, but they can be effective for bridges. Hysteretic loops can be idealized by bilinear model.

●They can be implemented for not only new bridges but also existing bridges. Because they can be so set that they cover bearings, they are appropriate for implementation to bridges where space around bearings is limited

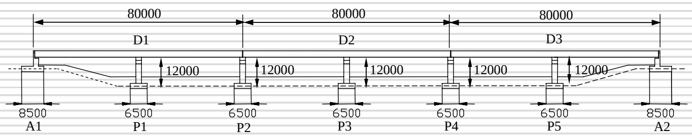
●Amount of energy dissipation and stiffness can be varied by appropriately choosing number and thickness of low-yield steel

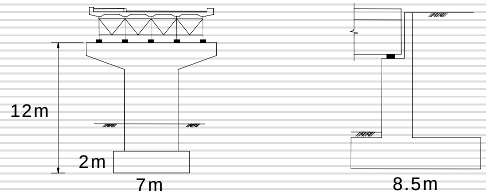
3) Various Combination of Isolators and U Dampers can be implemented



4) Example of analysis for the Effectiveness of U-Dampers

(1) Target bridge

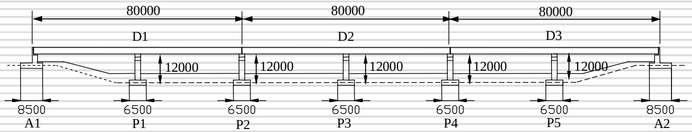




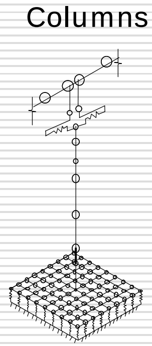
室谷、川島、土木学会地震工学研究論文集、No. 29、2007

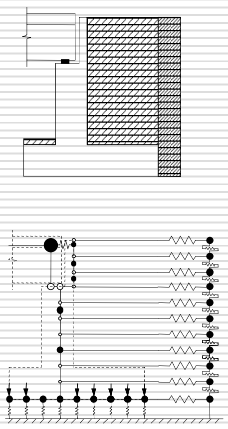
(2) Combinations of Isolators & Dampers

- 3 combinations were assumed
  - ✓Elastomeric bearings
  - ✓Isolation using HDB
  - ✓Isolation using HDB + U Dampers



(3) Analytical Model





(4) U-Dampers used in Analysis

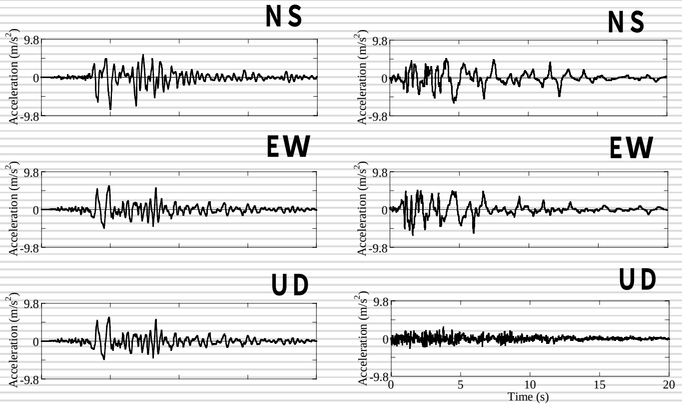
- Yield strength、Yield Displacement ＝24.2 mm
- Design Displacement (Displacement under which U Dampers are stable for at least 20 times loading) ＝450mm
- Ultimate Displacement (Displacement under which U Dampers may rupture under 20 times loadings) ＝650mm
- NSUD45(Shin Nippon Steel Engineering) ×8

(5) Basic Parameters of the Target Bridge

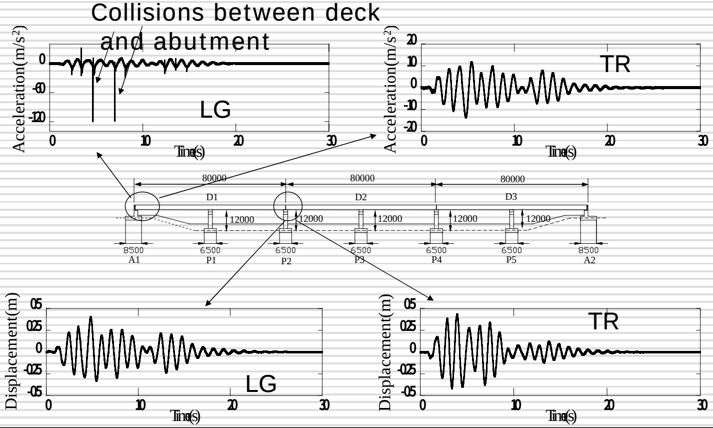
- Fundamental natural period in the longitudinal direction
  - ✓Elastomeric bearings：1.09s
  - ✓HDB：0.85s
  - ✓HDR+U Dampers：0.72s
- Element damping ratio Deck =2%、Column at the plastic hinge ＝2%、Column at other than plastic hinge ＝5%、abutment、footing ＝5%、ground ＝10%

(6) Ground Motions

JMA Kobe Observatory　　JR Takatori Station

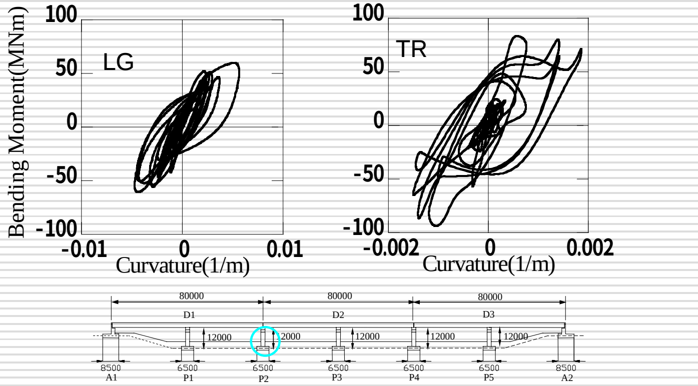


(7) Bridge supported by elastomeric bearings



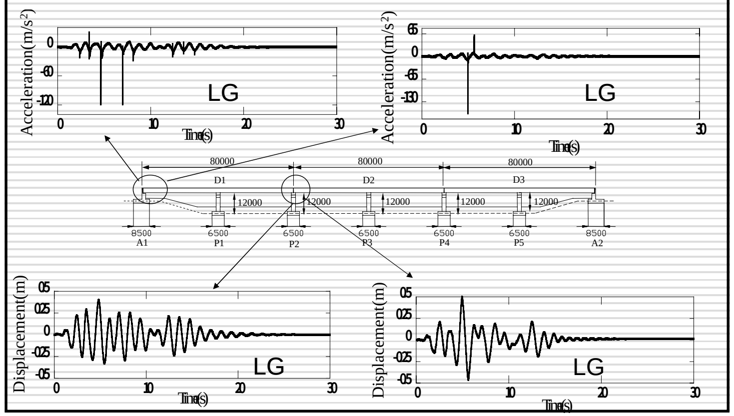
(7) Bridge supported by elastomeric bearings (2)

Moment vs. curvature hysteresis of column



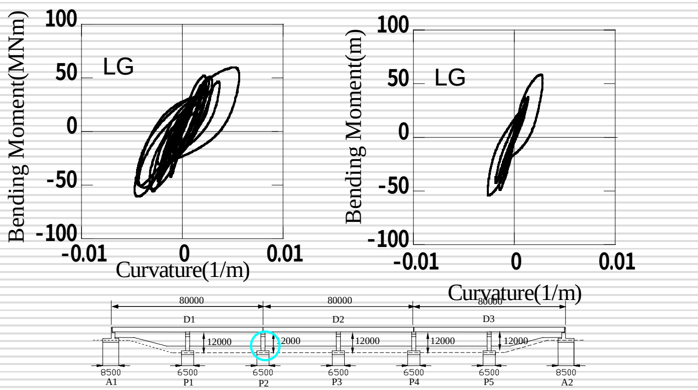
(8) Bridge supported by HDB

Elastomeric bearing HDR



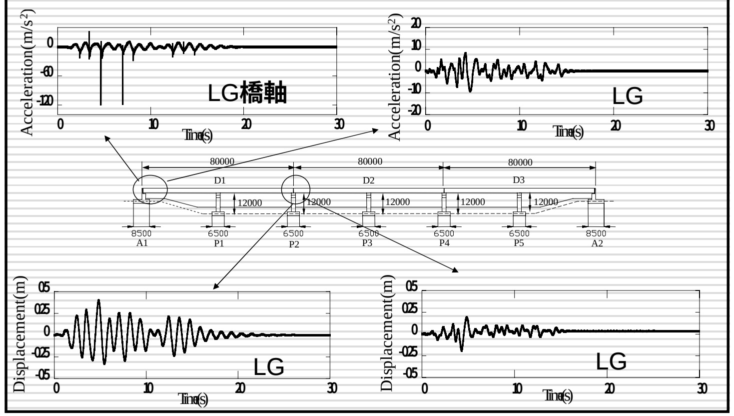
(8) Bridge supported by HDB(2)

Elastomeric Bearing HDR

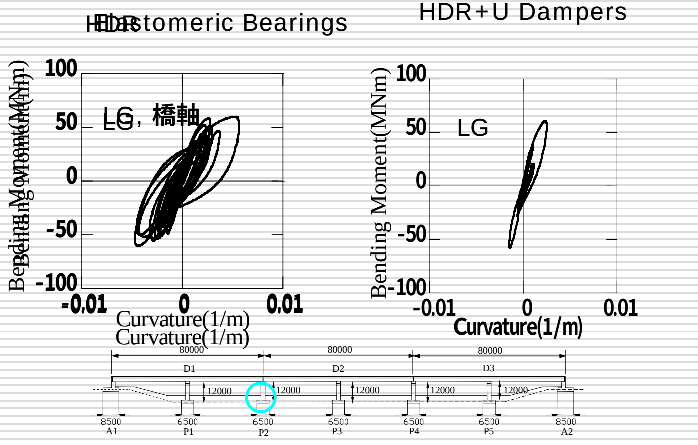


(9) Bridge supported by HDR & U Dampers

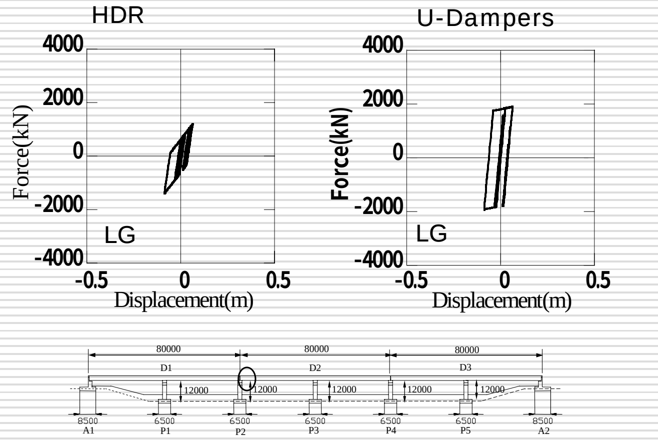
Elastoimeric bearing HDR+U Dampers



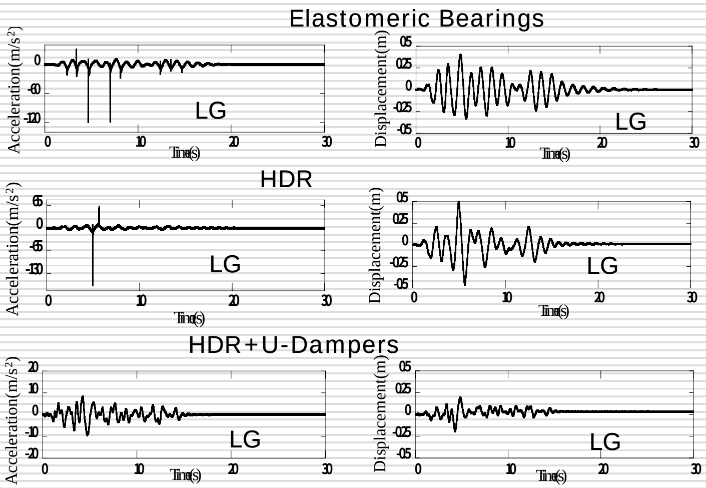
(9) Bridge supported by HDR & U Dampers(2)



(9) Bridge supported by HDR & U Dampers(3)



(10) Are U Dampers Effective?



(10) Are U Dampers Effective?(2)

Moment vs. curvature hysteresis at the plastic hinge in the longitudinal direction