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

第6章　その他の形式のディバース
Chapter 6 Other Types of Devices

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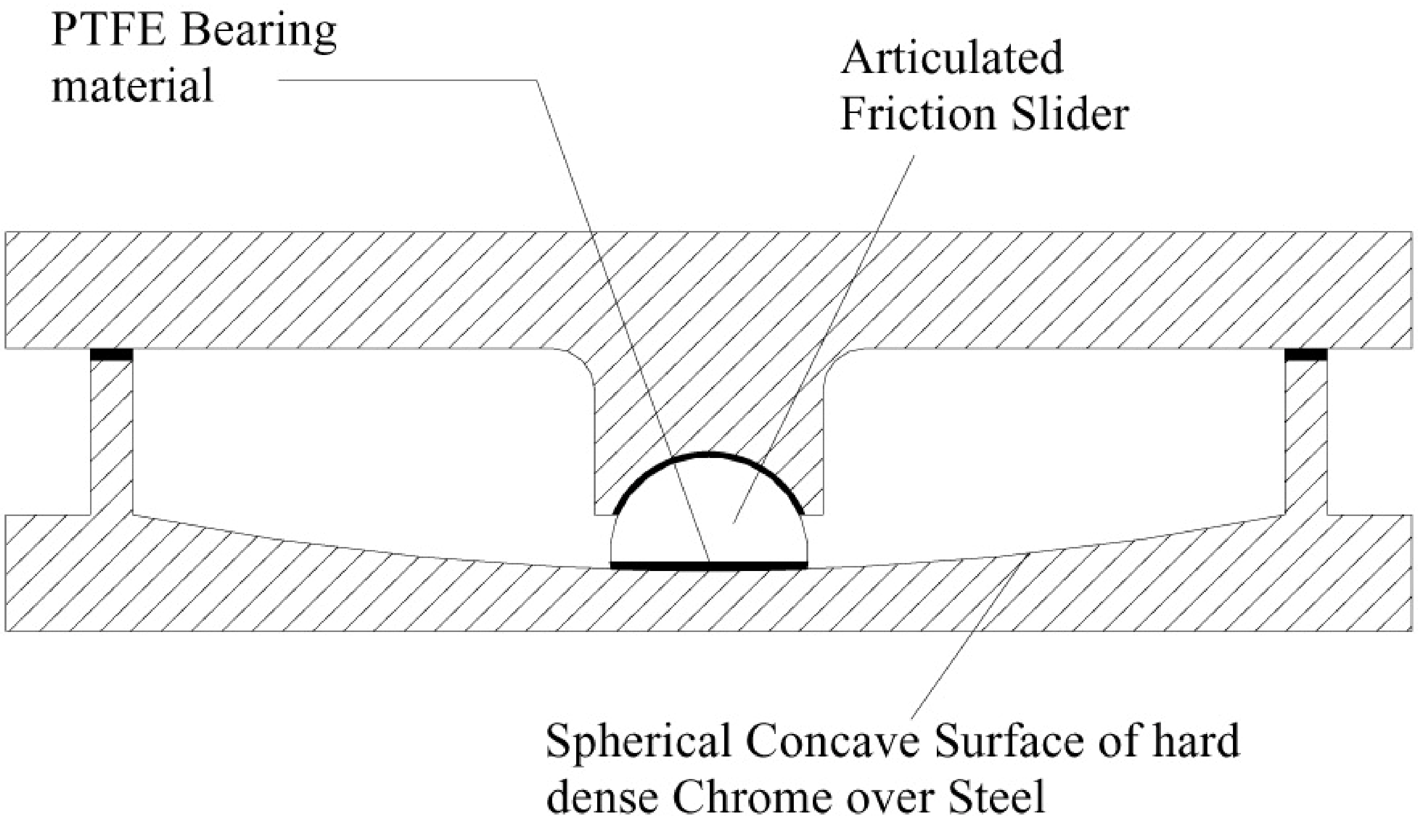
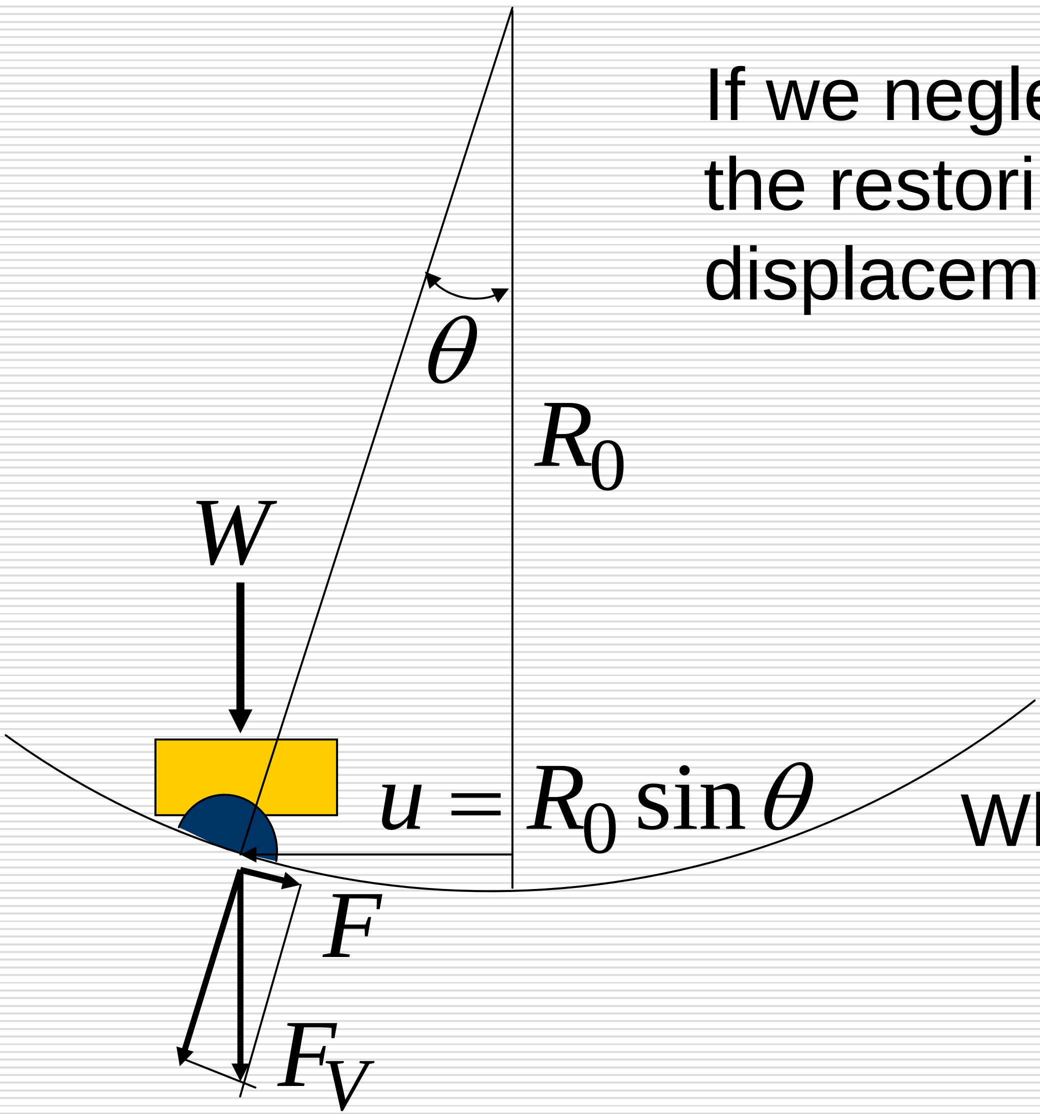
6.1 Friction Pendulum System (FPS)

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

$$F = F_V \sin\theta$$

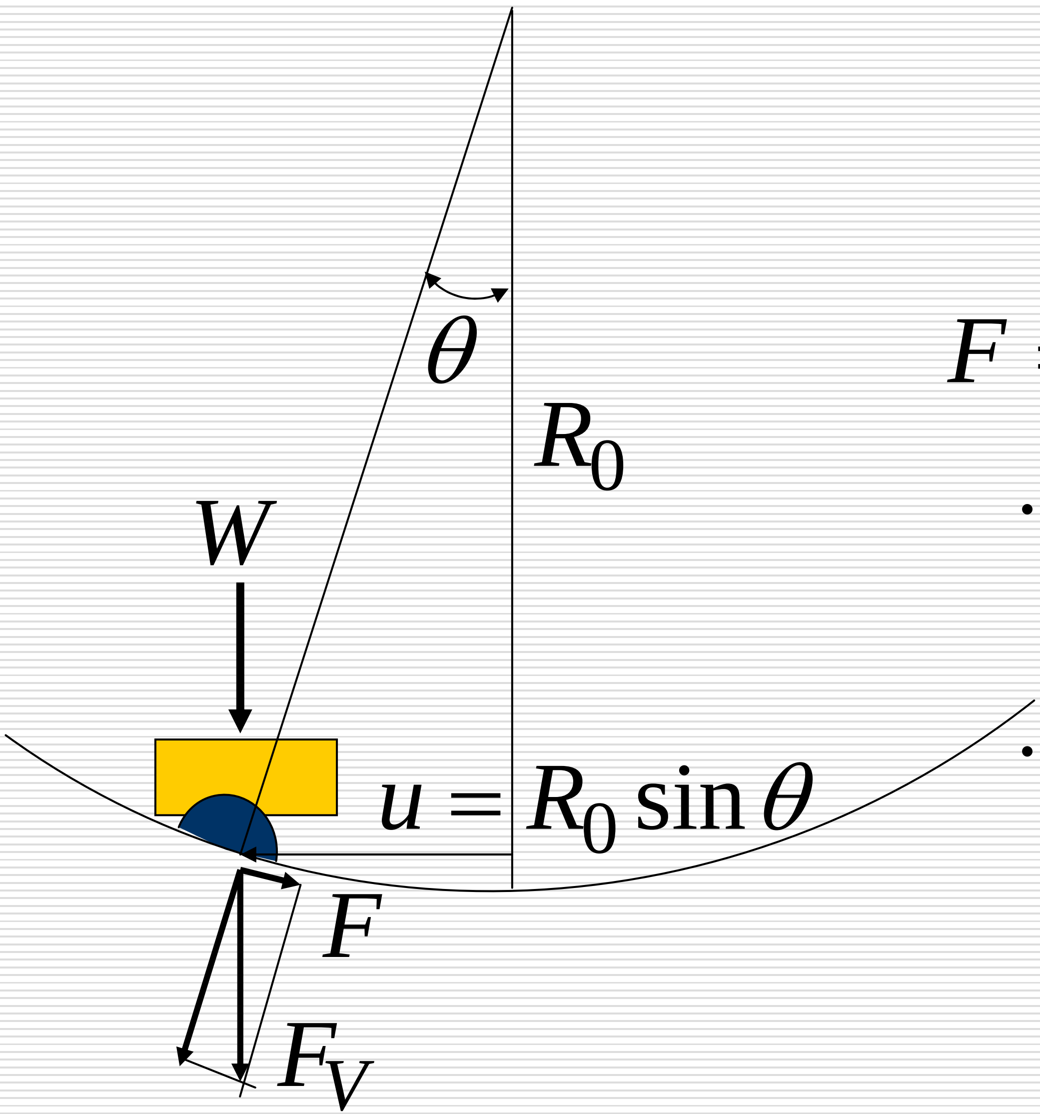
$$u = R_0 \sin\theta$$

When θ is small,

$$F \approx F_V \theta$$

$$u \approx R_0 \theta$$

3) Stiffness K



$$F \approx F_V \theta$$

$$u \approx R_0 \theta$$

$$F = Ku$$

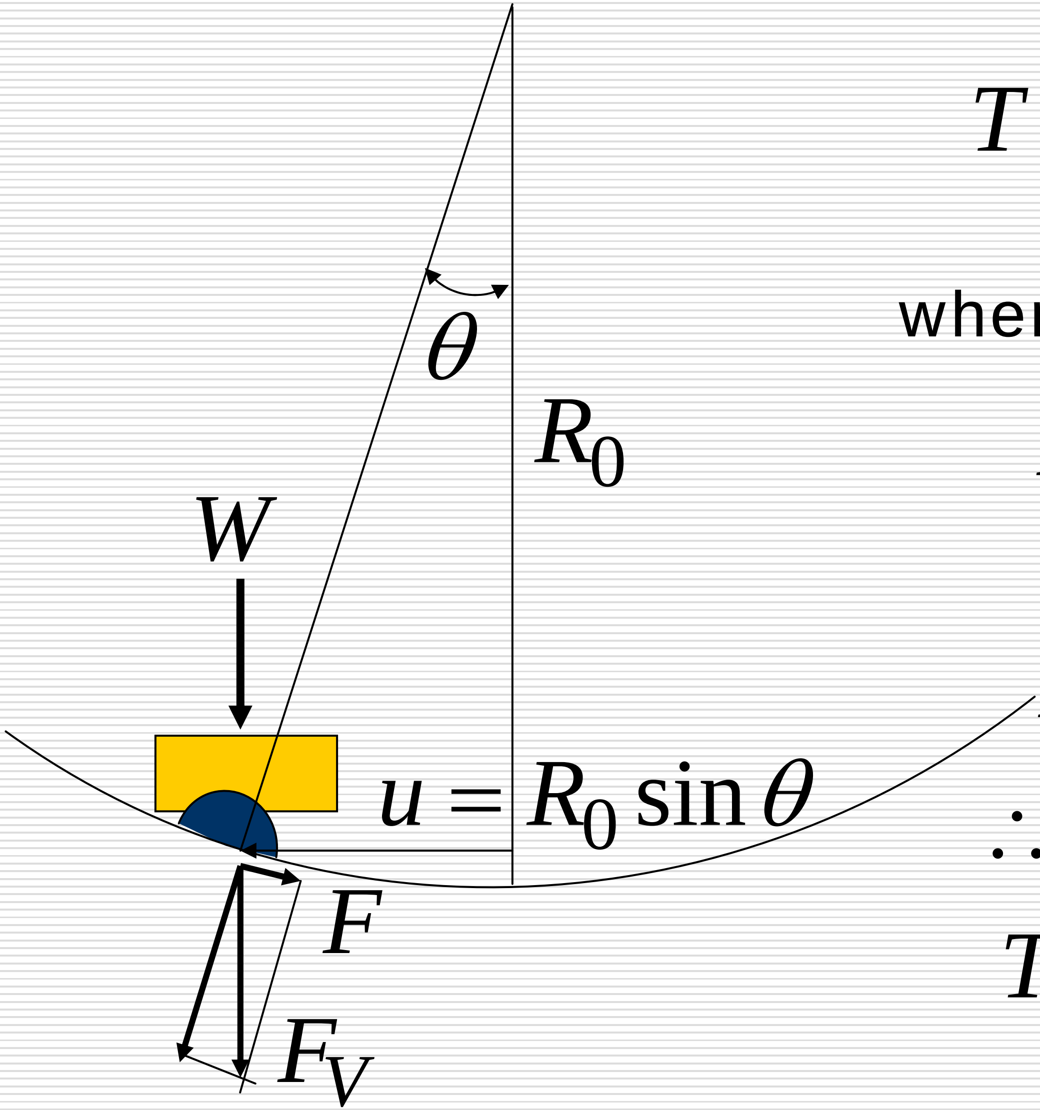
$$\therefore$$

$$F_V \theta = K R_0 \theta$$

$$\therefore$$

$$K = \frac{F_V}{R_0}$$

4) Natural Period of a Structure Supported by FPS



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

where

$$M = \frac{W}{g} = \frac{F_V}{g}$$

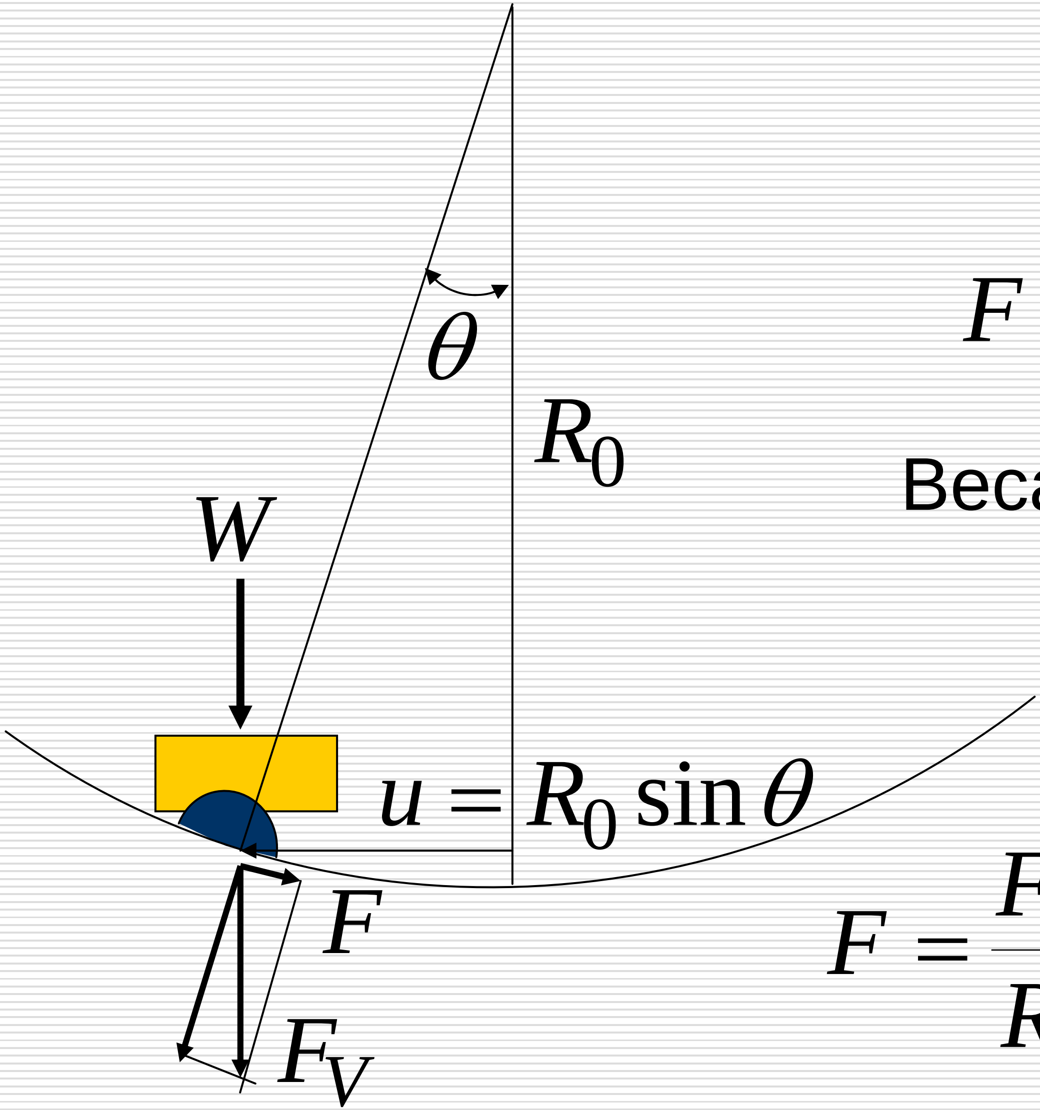
$$K = \frac{F_V}{R_0}$$

$$\therefore$$

$$T = 2\pi\sqrt{\frac{R_0}{g}}$$

Natural period is independent of mass M

5) Lateral Force vs. Lateral Displacement Hysteresis



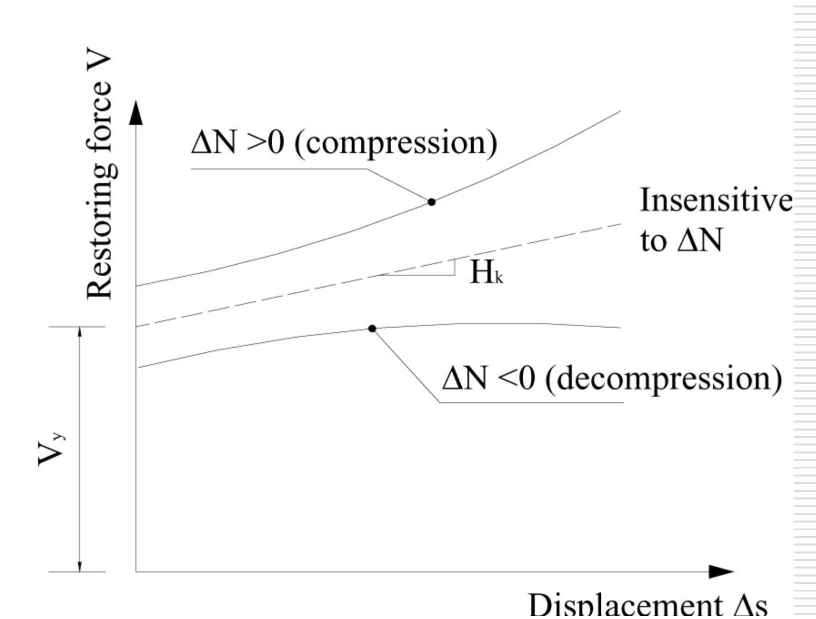
$$F = F_V \sin\theta$$

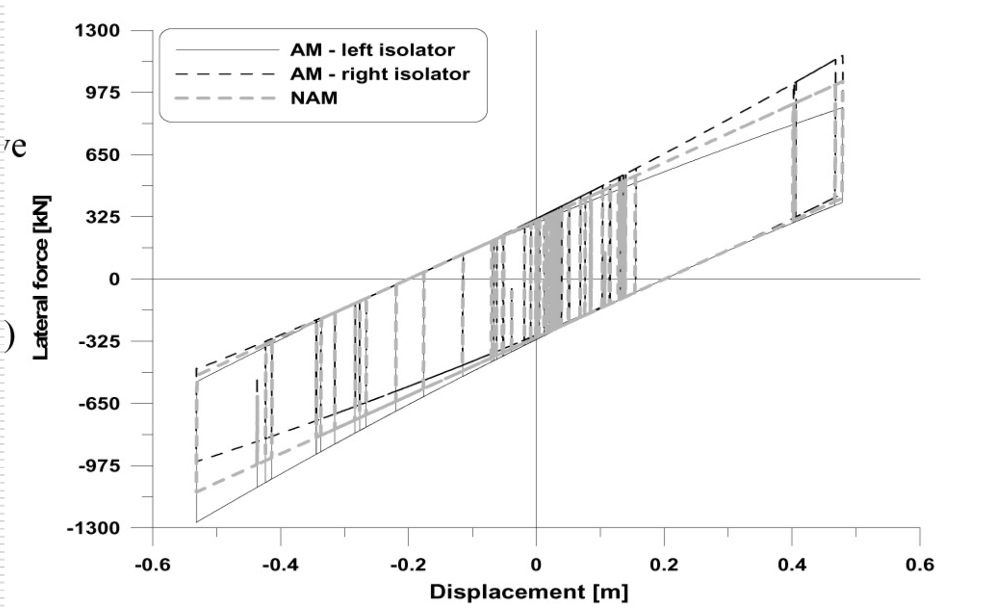
Because,

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

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

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





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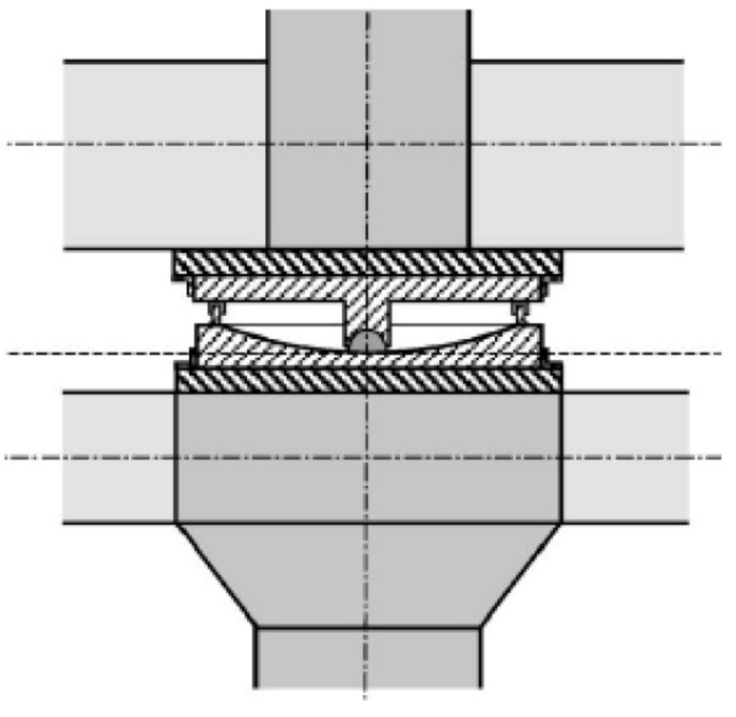
6) Summary of Characteristics of FPS

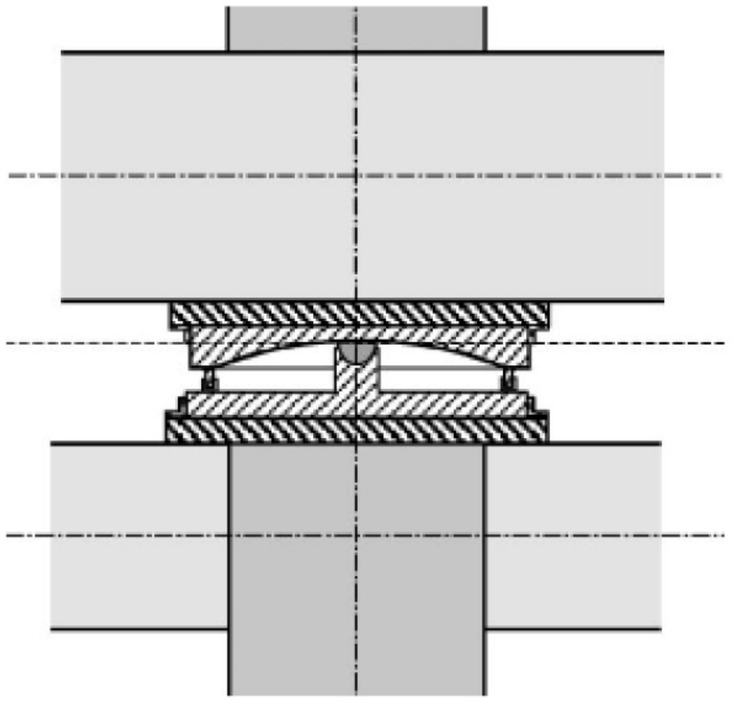
- FPS is governed by 2 parameters
  - ✓Radius of the spherical surface
  - ✓Friction coefficient at the sliding interface
- Neglecting variation of the friction coefficient with velocity and pressure that slightly effect the peak response of the system, the only one parameter is the radius of the spherical 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



After Professor M. Calvi

8) Example of FPS

Courtesy of Prof. Steven Mahin, UCB

Friction Pendulum System

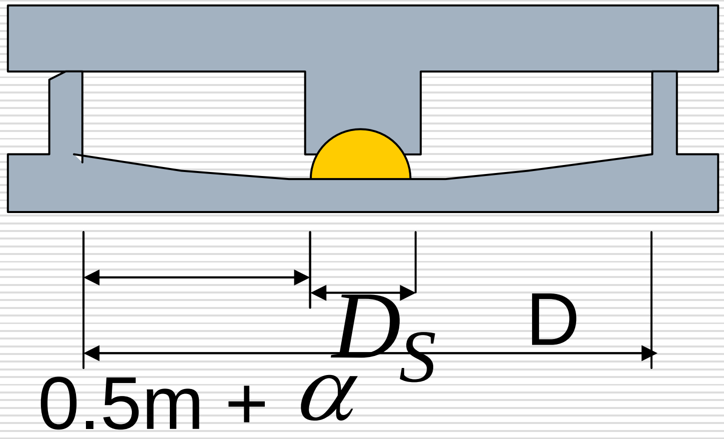
Courtesy of Dr. Victor Zayas, Engineering Protection System


E/W

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

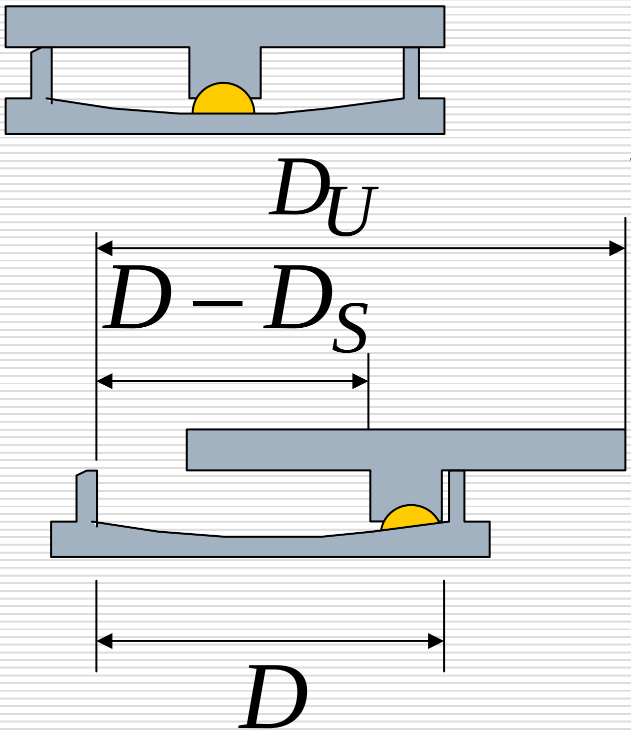


If we consider $\alpha = 0.15m$ and $D_S = 0.2m$

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

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

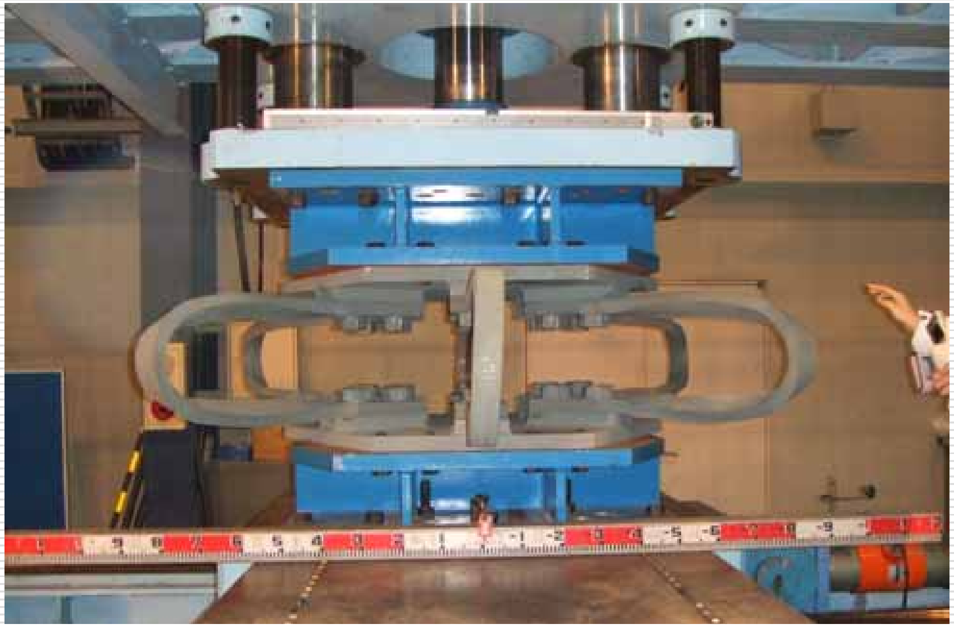
$$D_U = 2(D - D_S) + D_S$$
$$= 2D - D_S$$

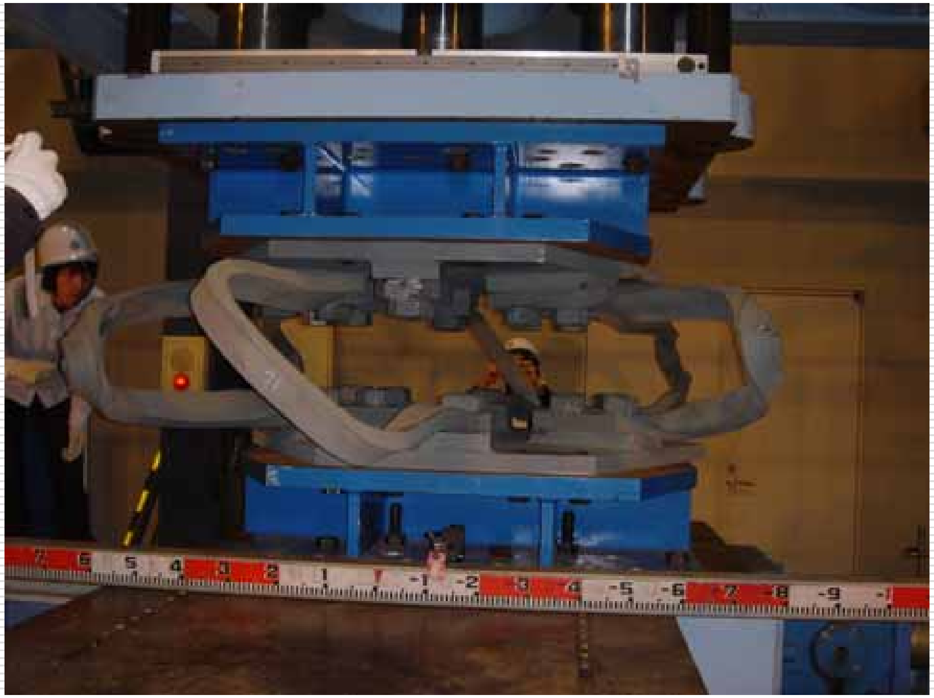
If D=1.5m, D_U becomes 2.8m

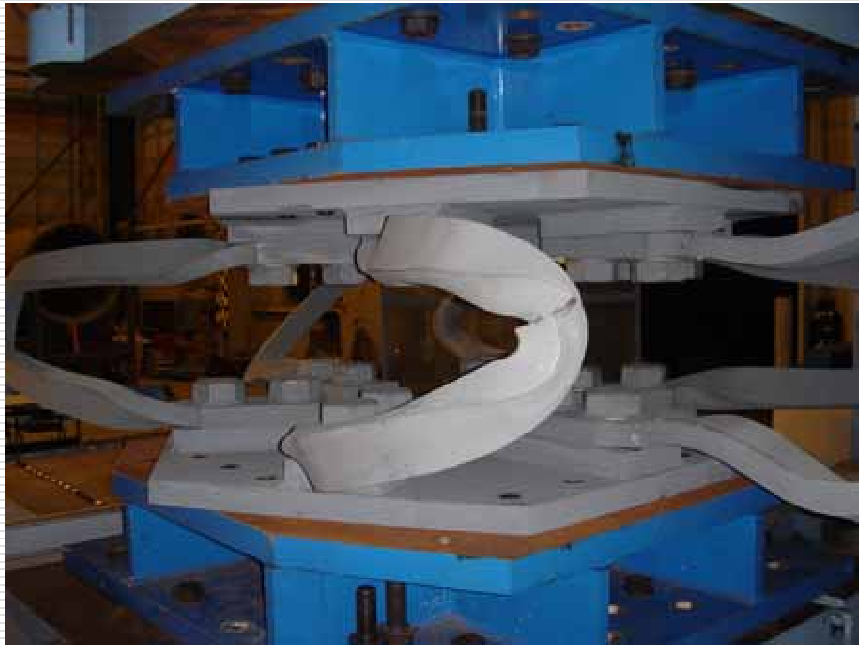
New types of FPS are being developed for coping with this problem.

6.3 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

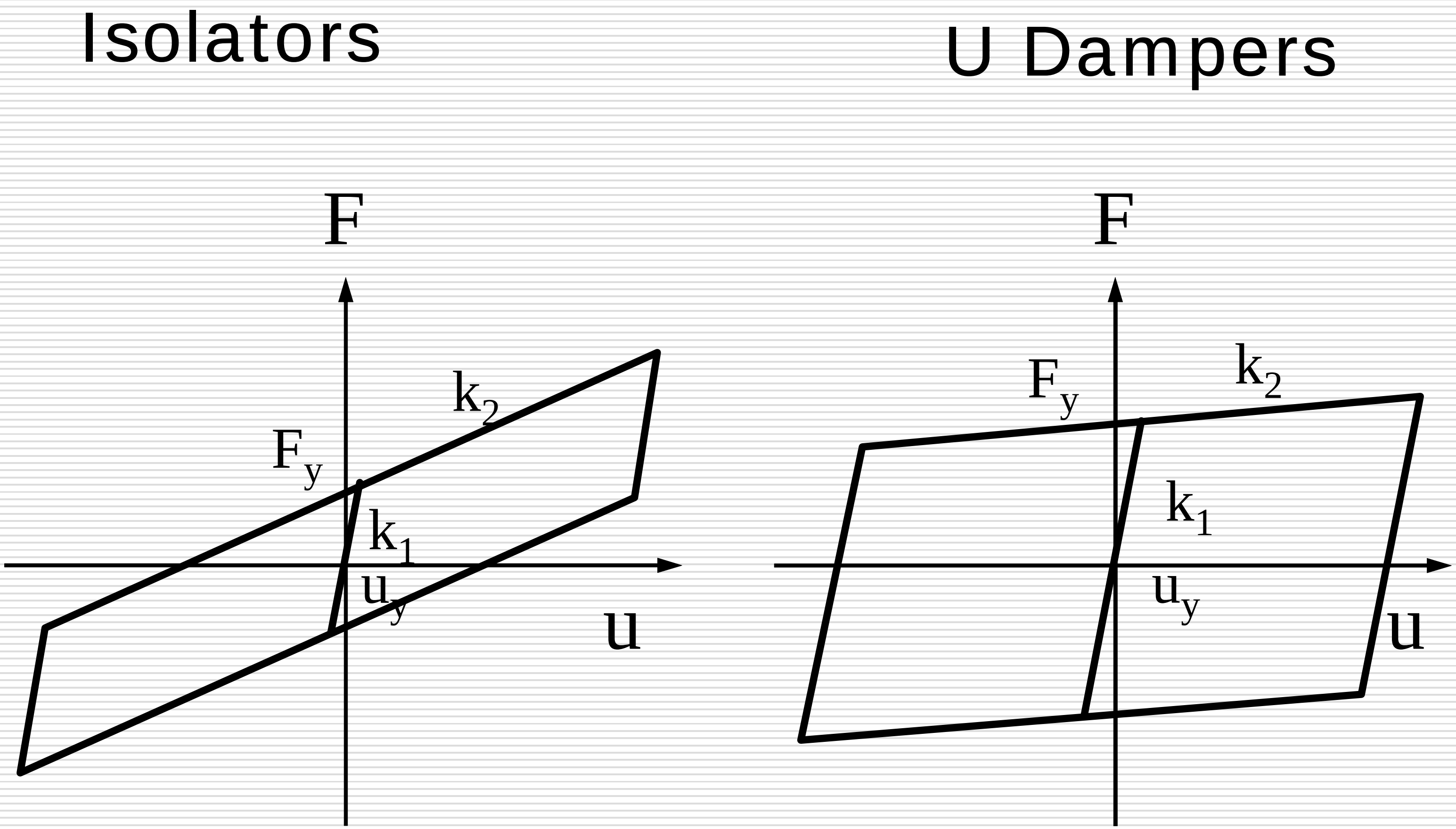
- 低降伏点鋼を使用
- ほぼバイリニア型の履歴ループ

●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.

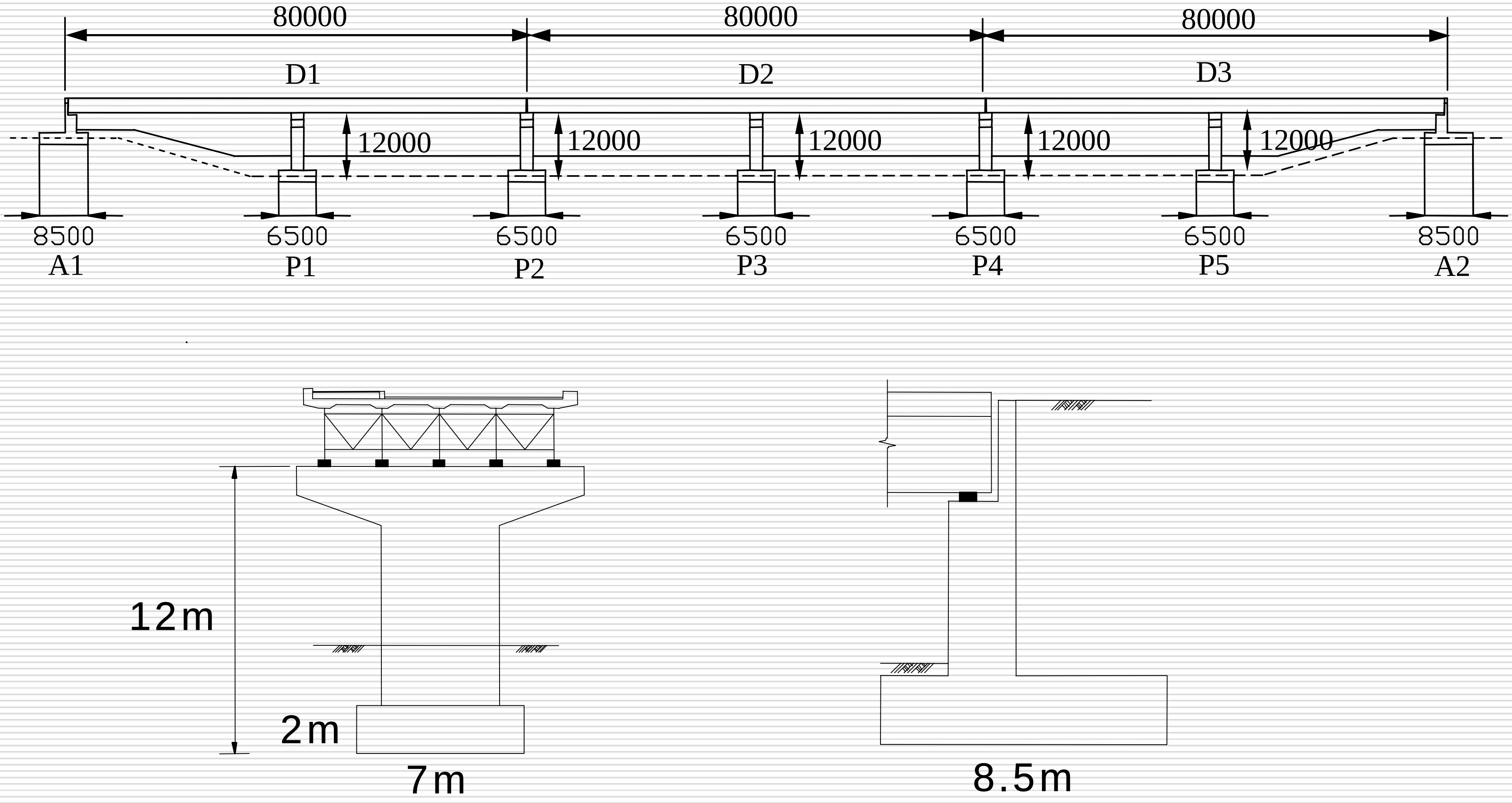
- They can be implemented for not only new bridges but also existing bridges. Because they can be so set that they cover bearings, they are appropriate for implementation to bridges where space around bearings is limited
- Amount of energy dissipation and stiffness can be varied by appropriately choosing 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

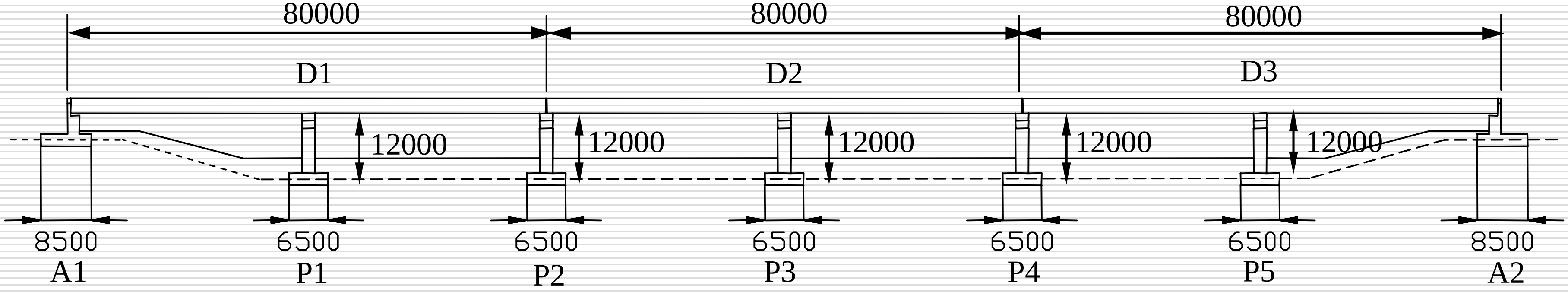
(1) Target bridge



室谷、川島、土木学会地震工学研究論文集、No. 29、2007

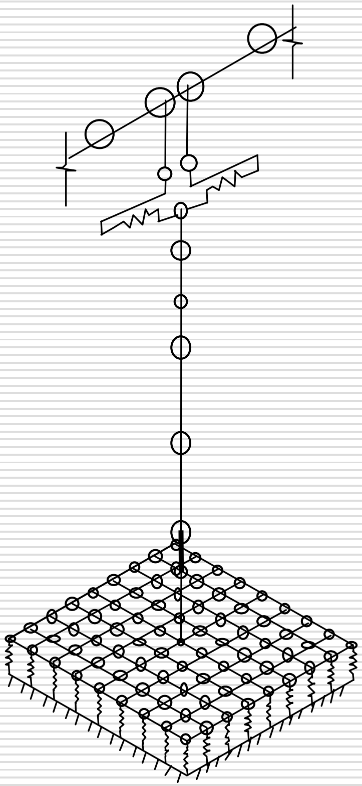
(2) Combinations of Isolators & Dampers

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

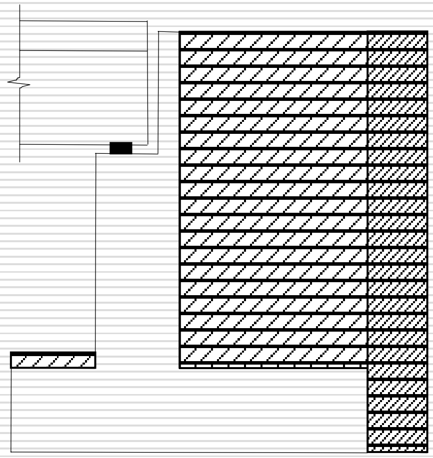


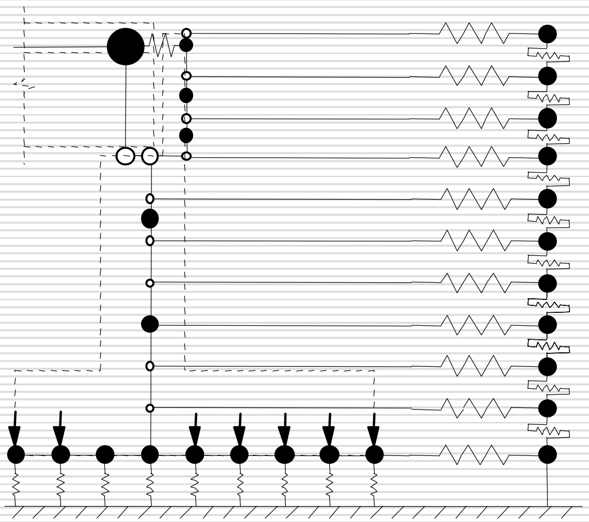
(3) Analytical Model

Columns



Abutments





(4) U-Dampers used in Analysis

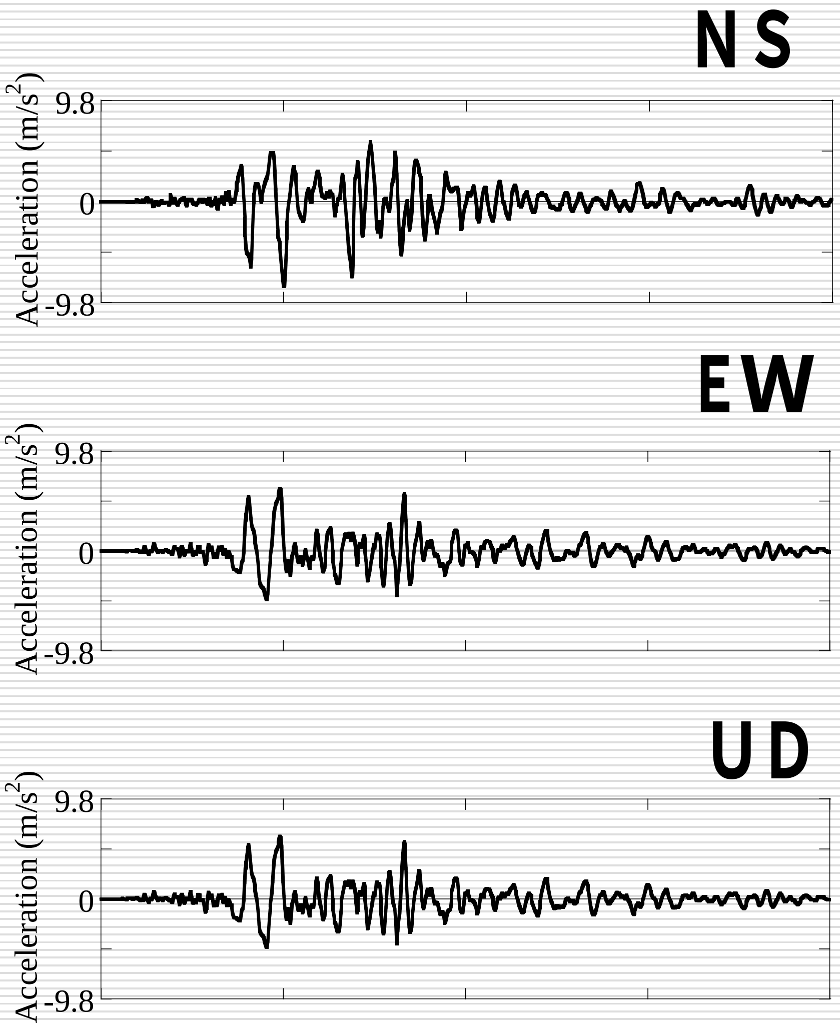
- Yield strength、Yield Displacement ＝24．2 mm
- Design Displacement (Displacement under which U Dampers are stable for at least 20 times loading) ＝450mm
- Ultimate Displacement (Displacement under which U Dampers may rupture under 20 times loadings) ＝650mm
- NSUD45(Shin Nippon Steel Engineering) ×8

(5) Basic Parameters of the Target Bridge

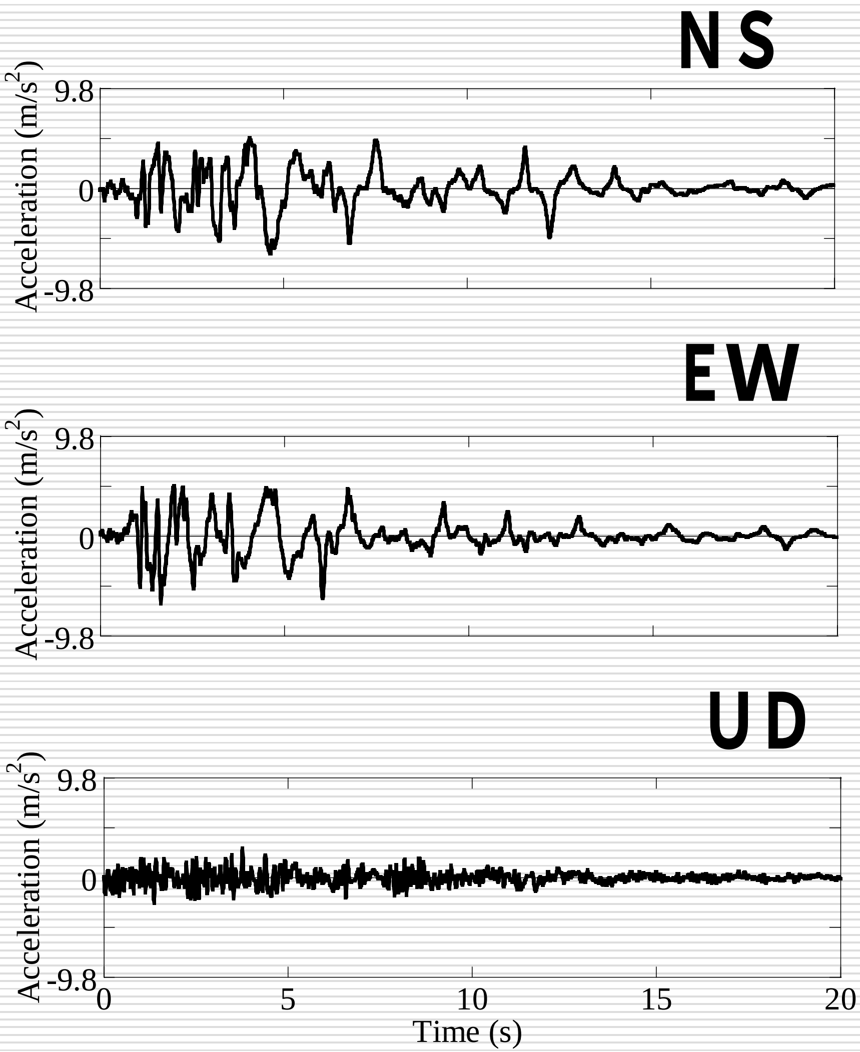
- Fundamental natural period in the longitudinal direction
  - ✓Elastomeric bearings：1.09s
  - ✓HDB：0.85s
  - ✓HDR+U Dampers：0.72s
- Element damping ratio Deck =2%、Column at the plastic hinge ＝**2%**、Column at other than plastic hinge ＝**5%**、abutment 、footing ＝5%、ground ＝10%

(6) Ground Motions

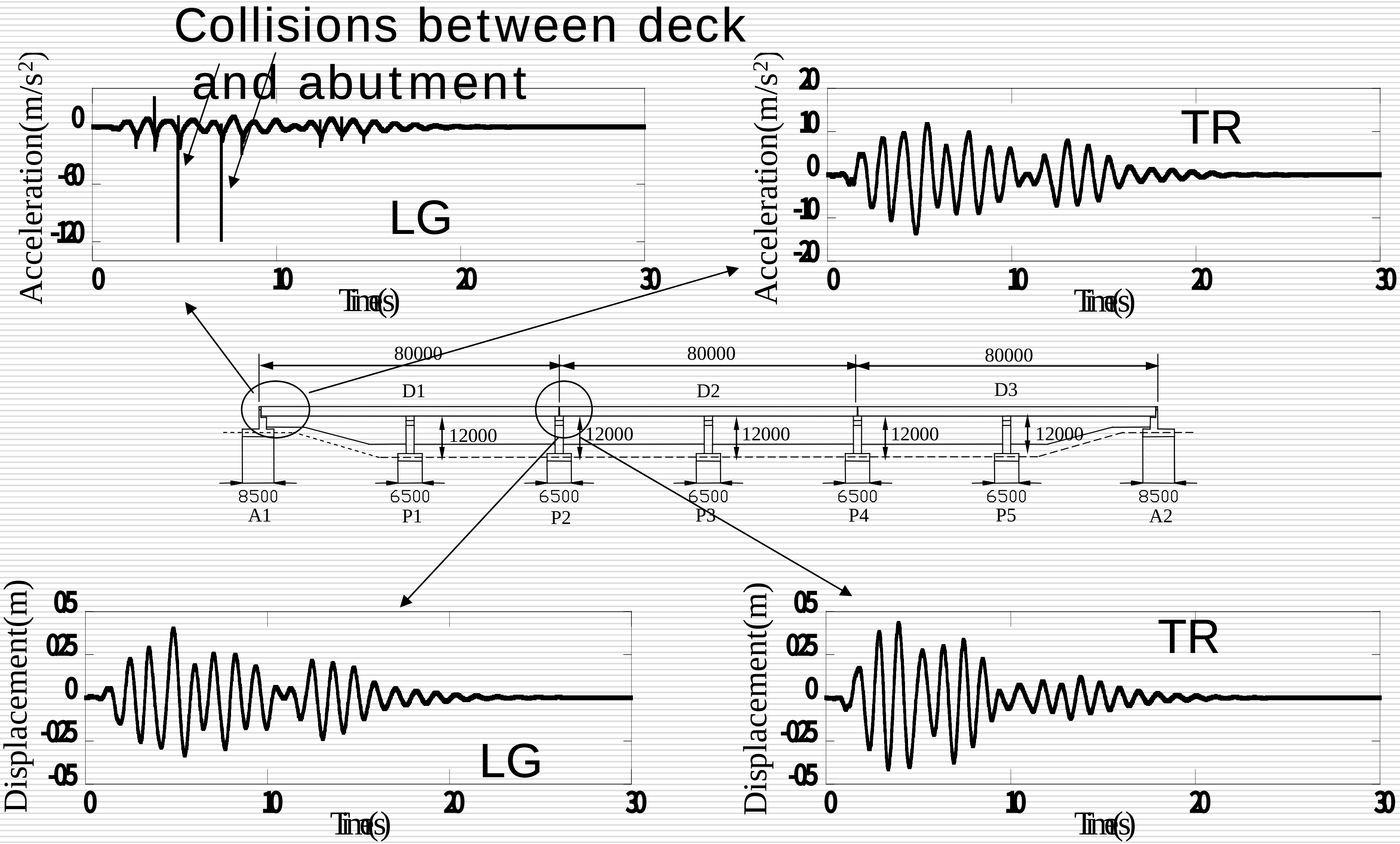
JMA Kobe Observatory



JR Takatori Station

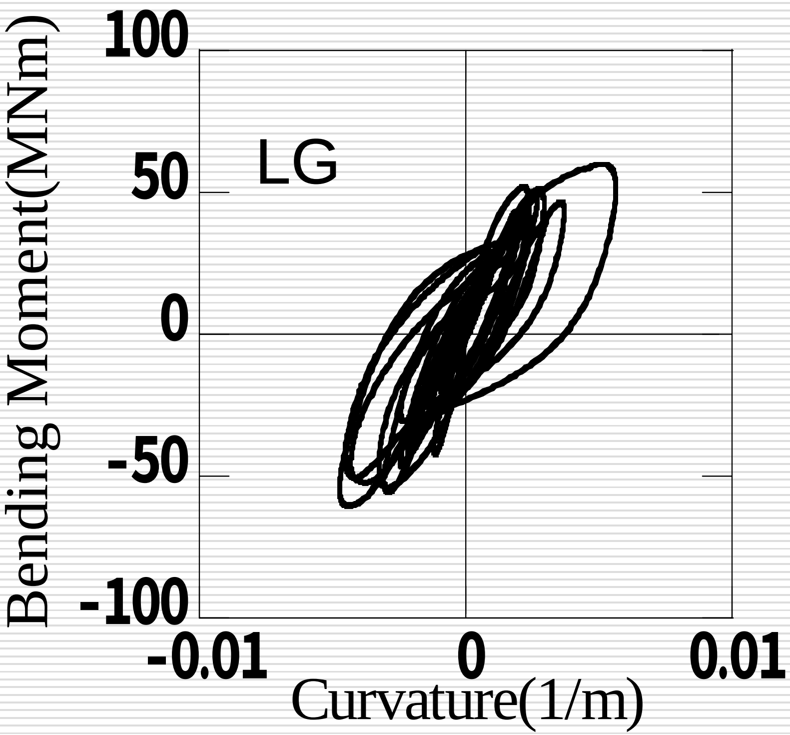


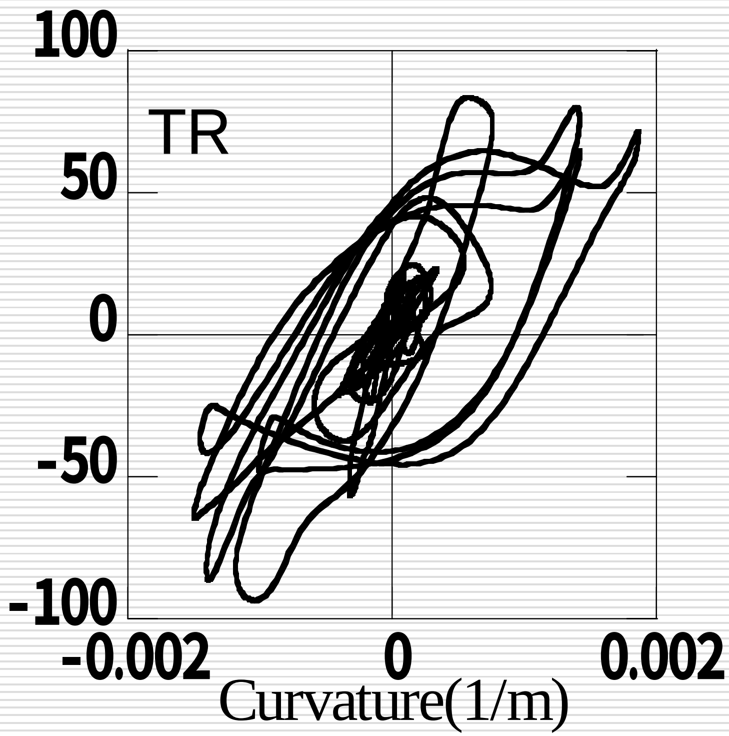
(7) Bridge supported by elastomeric bearings

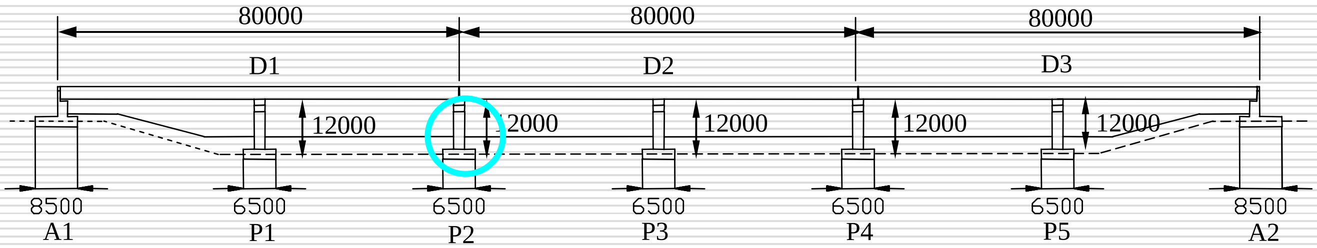


(7) Bridge supported by elastomeric bearings (2)

Moment vs. curvature hysteresis of column

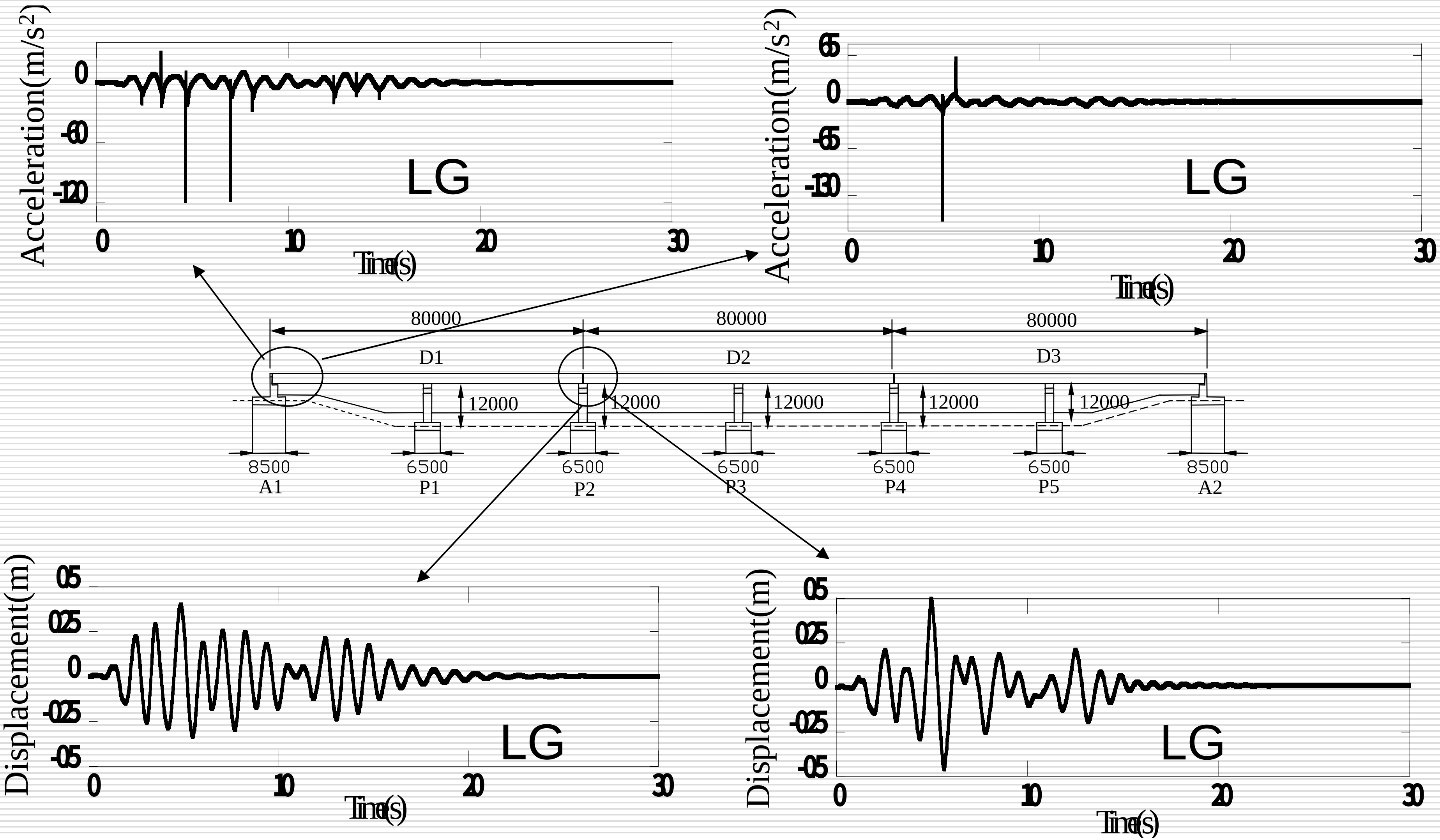






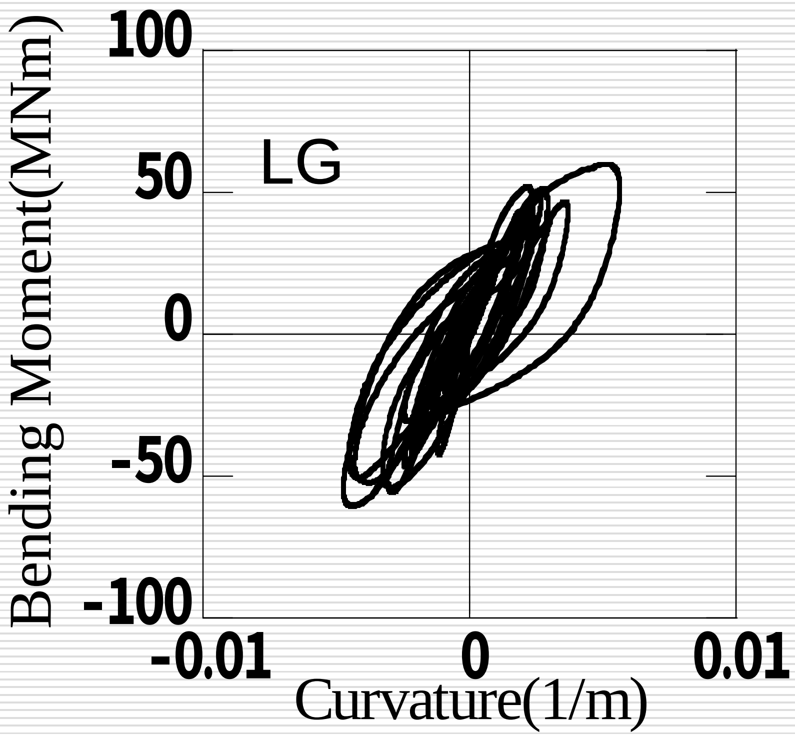
(8) Bridge supported by HDB

Elastomeric bearing　　　　HDR

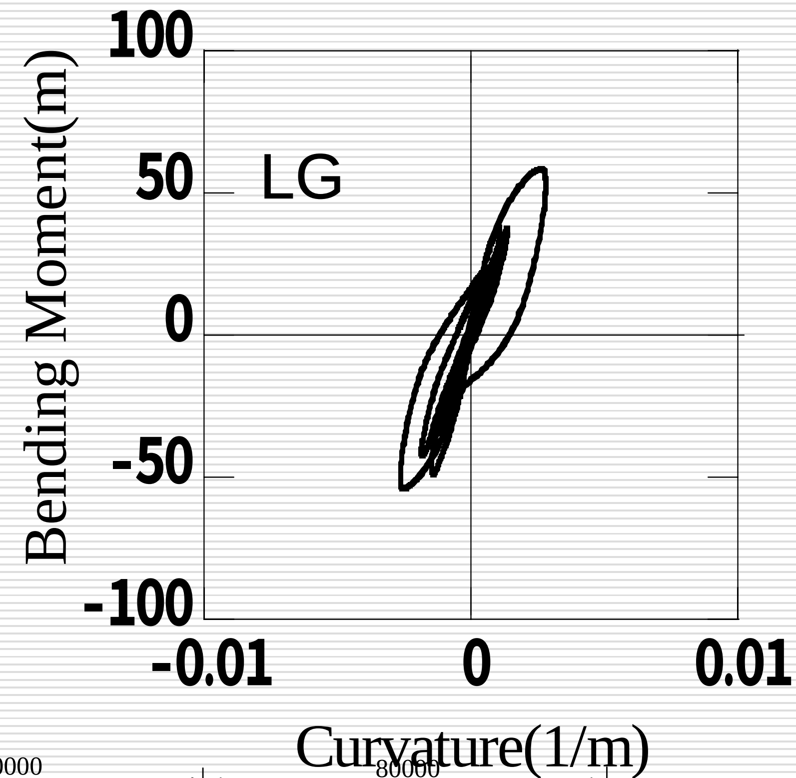


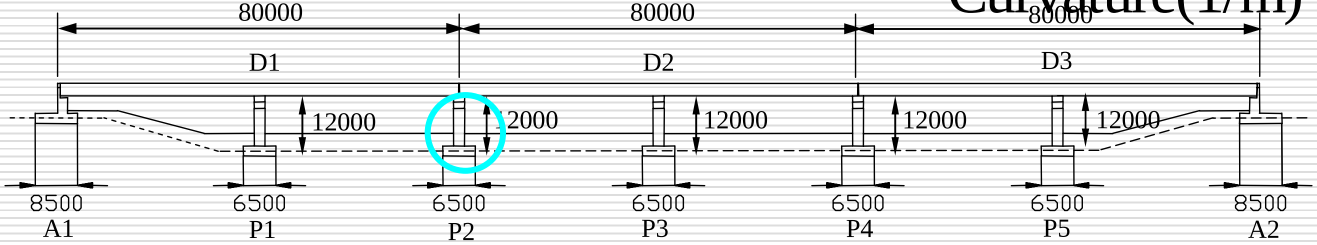
(8) Bridge supported by HDB(2)

Elastomeric Bearing



HDR

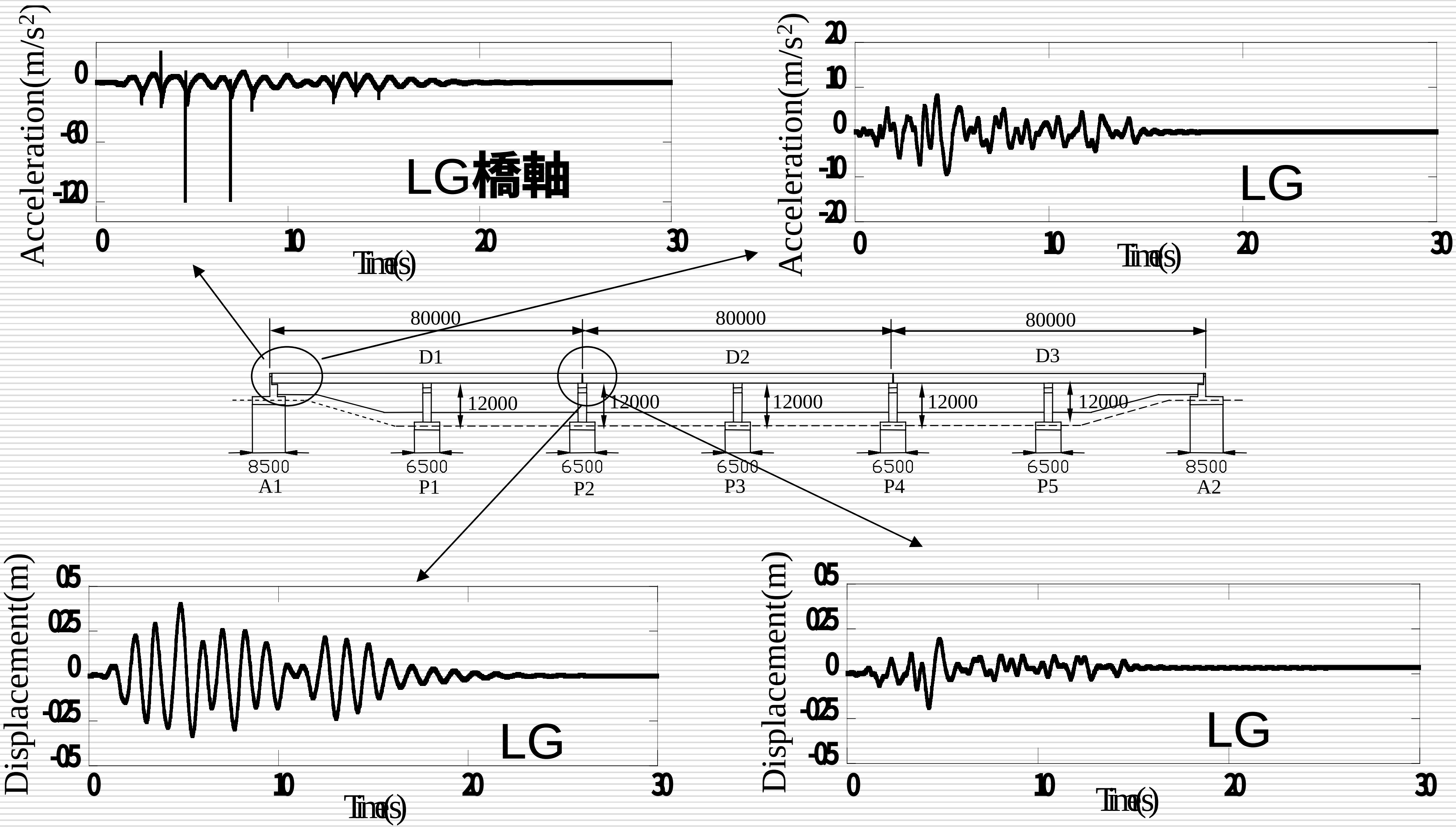




(9) Bridge supported by HDR & U Dampers

Elastoimeric bearing

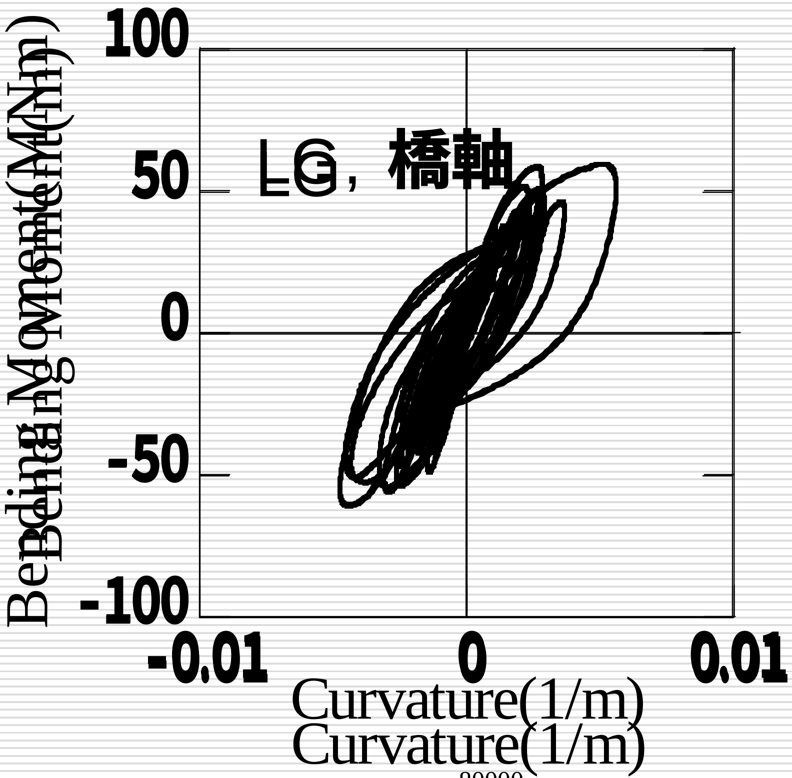
HDR+U Dampers



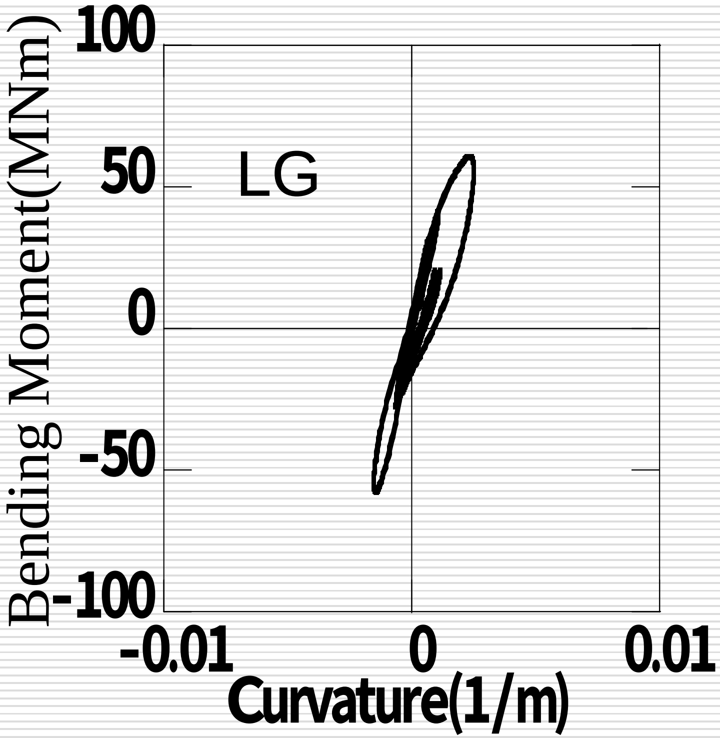
(9) Bridge supported by HDR & U Dampers(2)

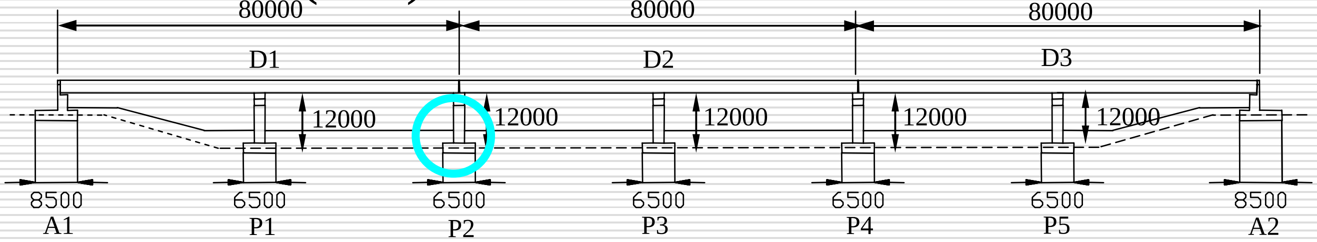
HDR

Elastomeric Bearings

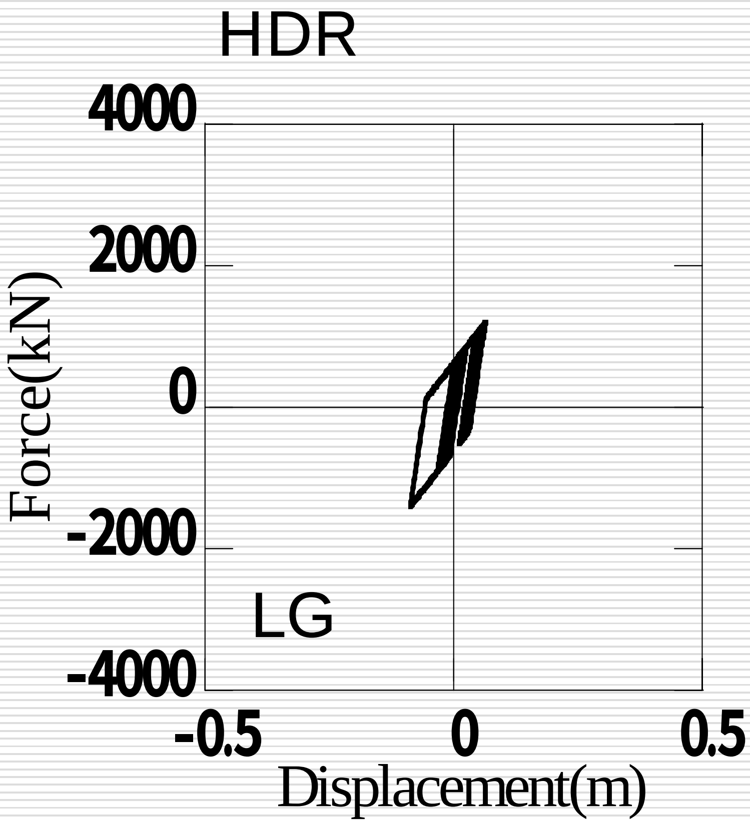


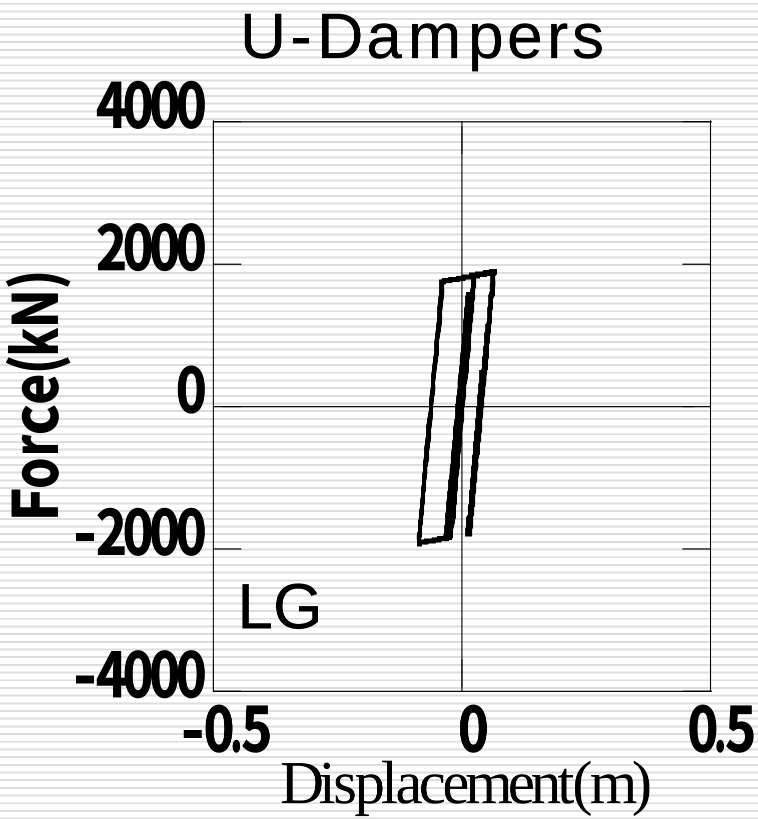
HDR+U Dampers

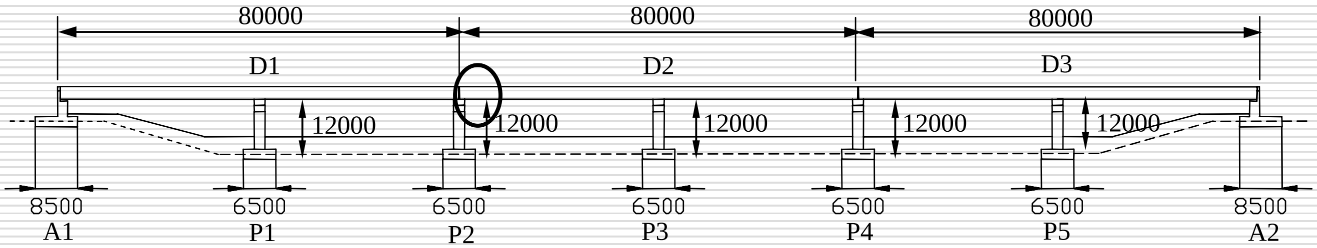




(9) Bridge supported by HDR & U Dampers(3)

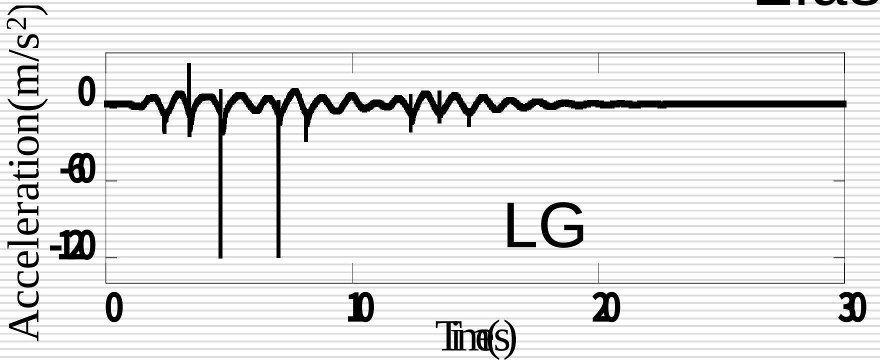


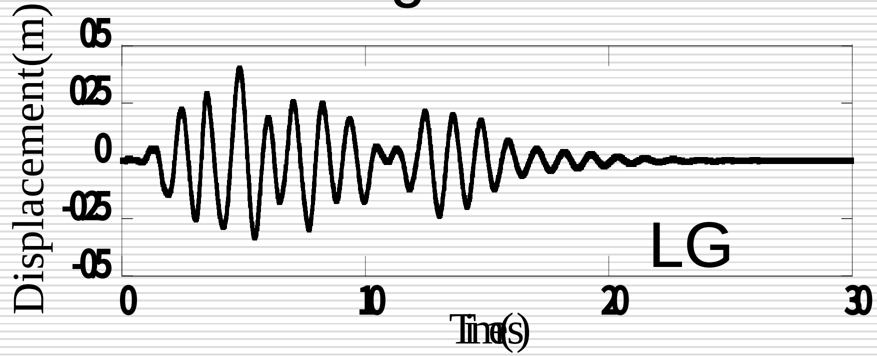




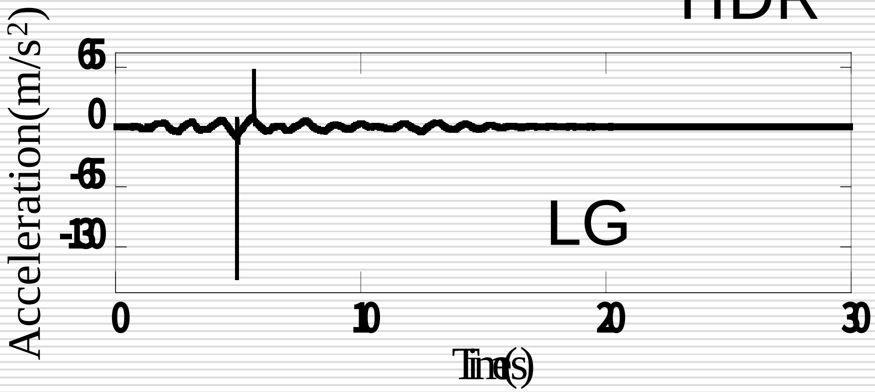
(10) Are U Dampers Effective?

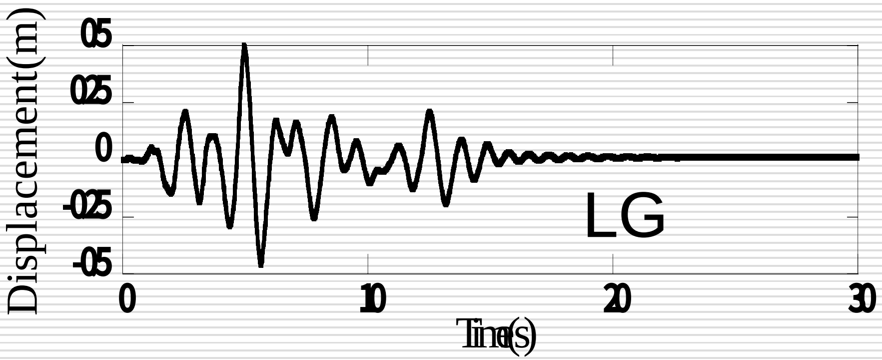
Elastomeric Bearings



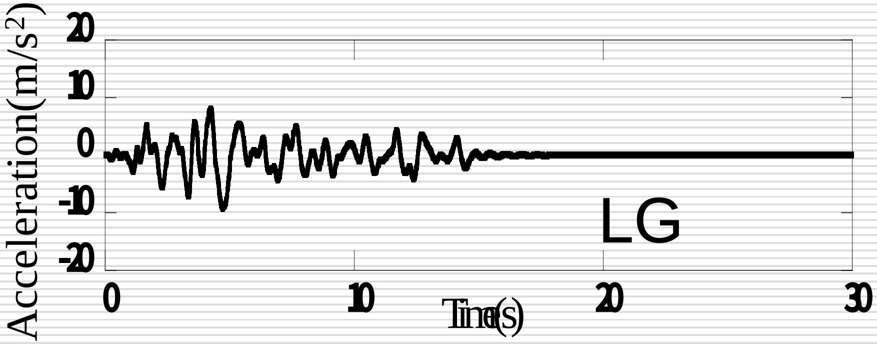


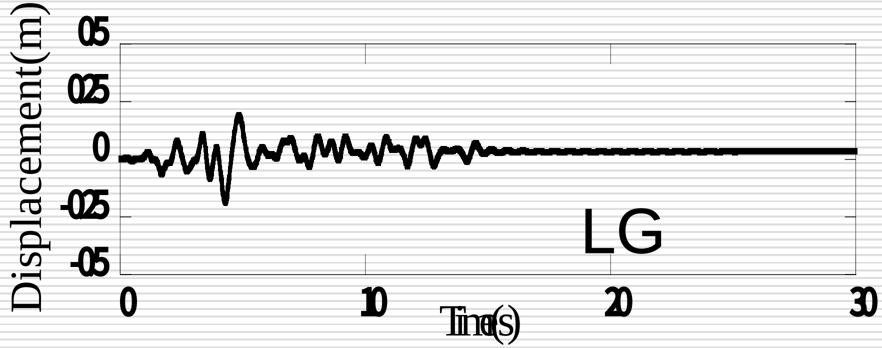
HDR





HDR+U-Dampers

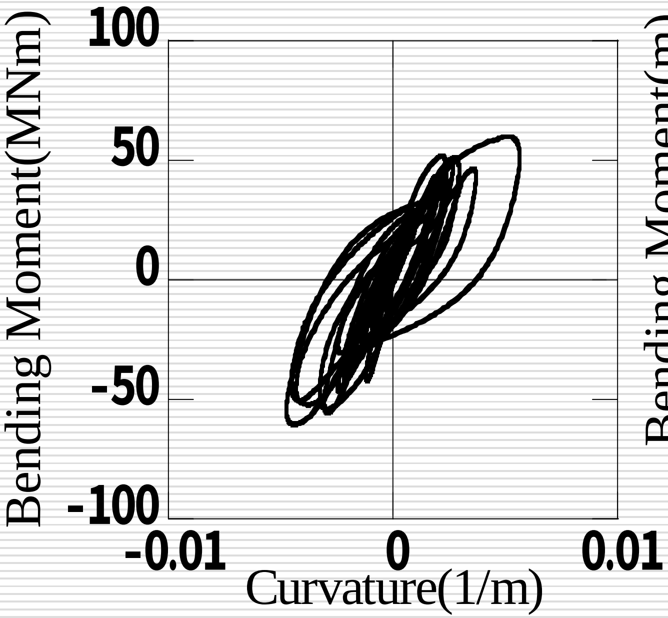




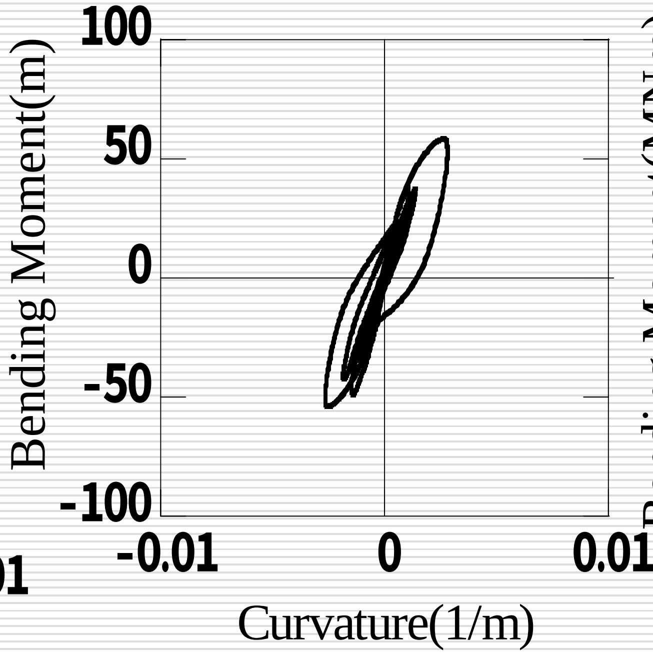
(10) Are U Dampers Effective?(2)

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

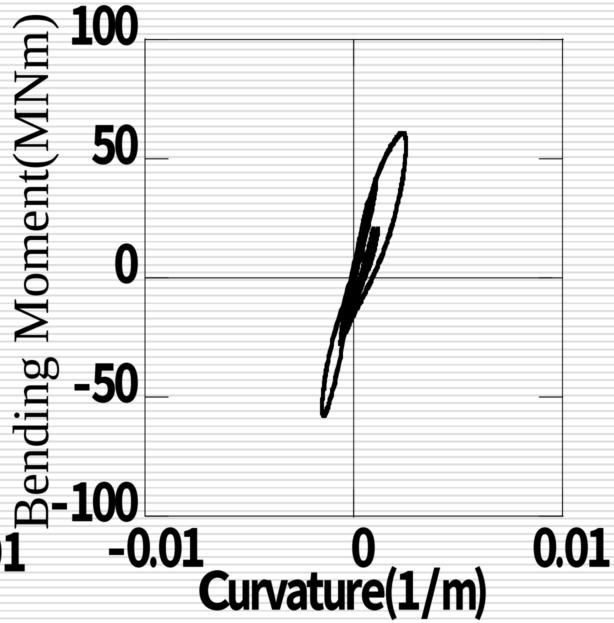
Elastomeric bearings



HDR



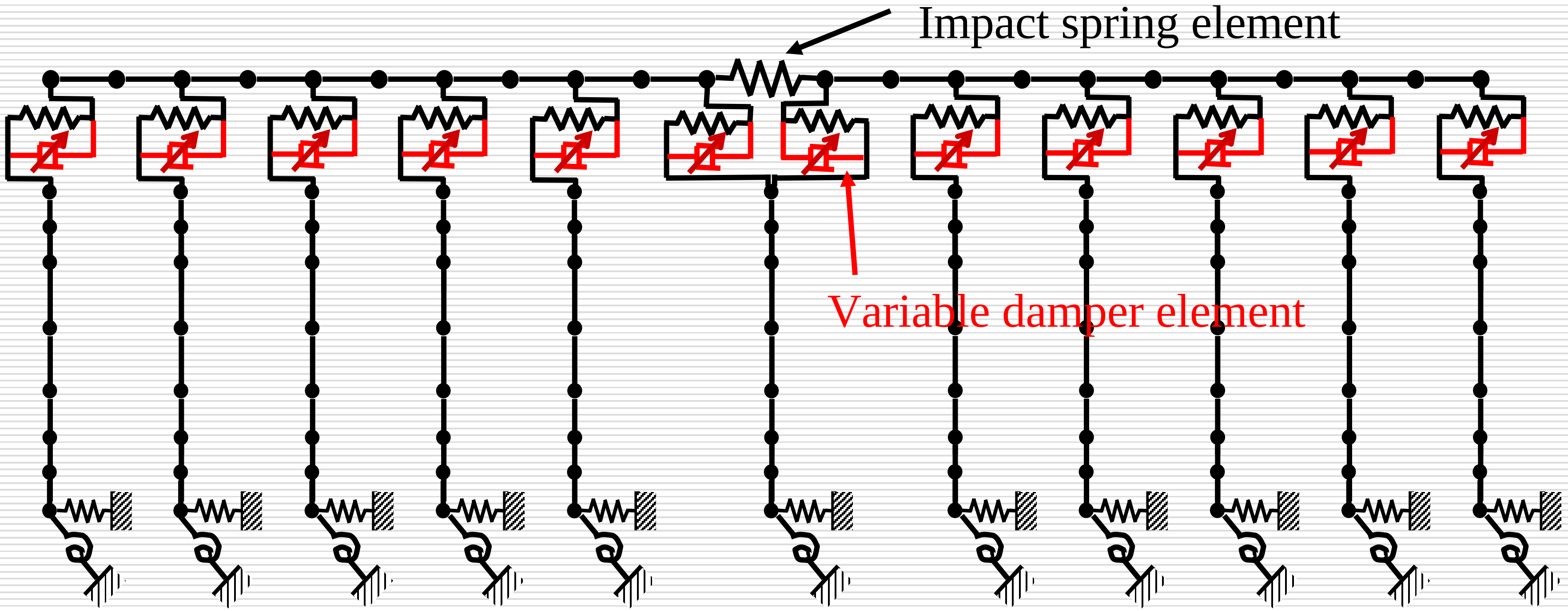
HDR+U-Dampers

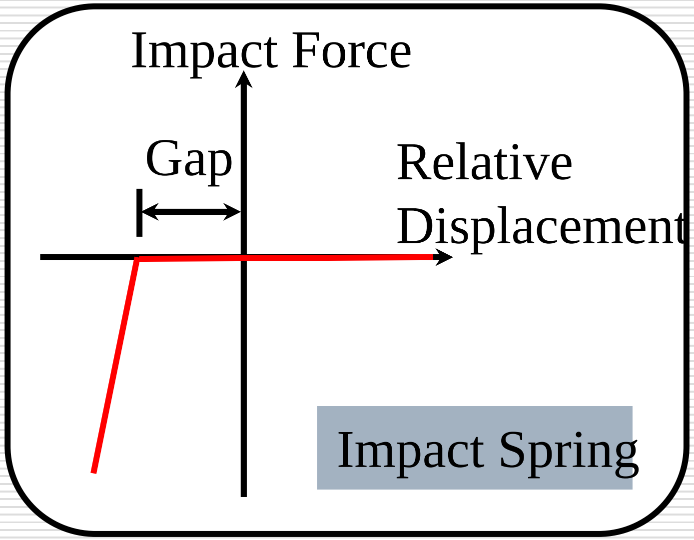


Variable dampers

Semi active

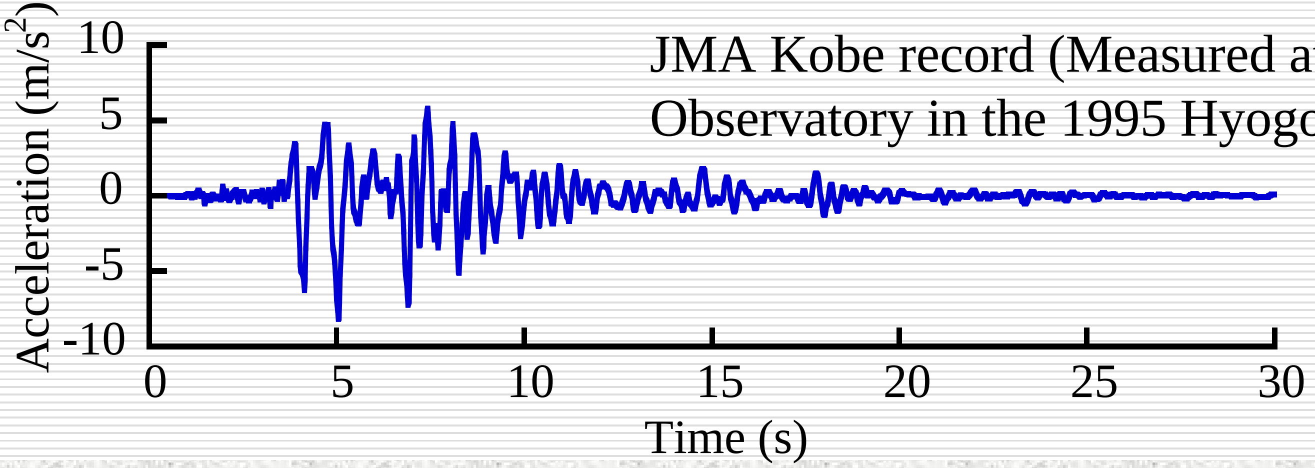
(1) Analytical Idealization

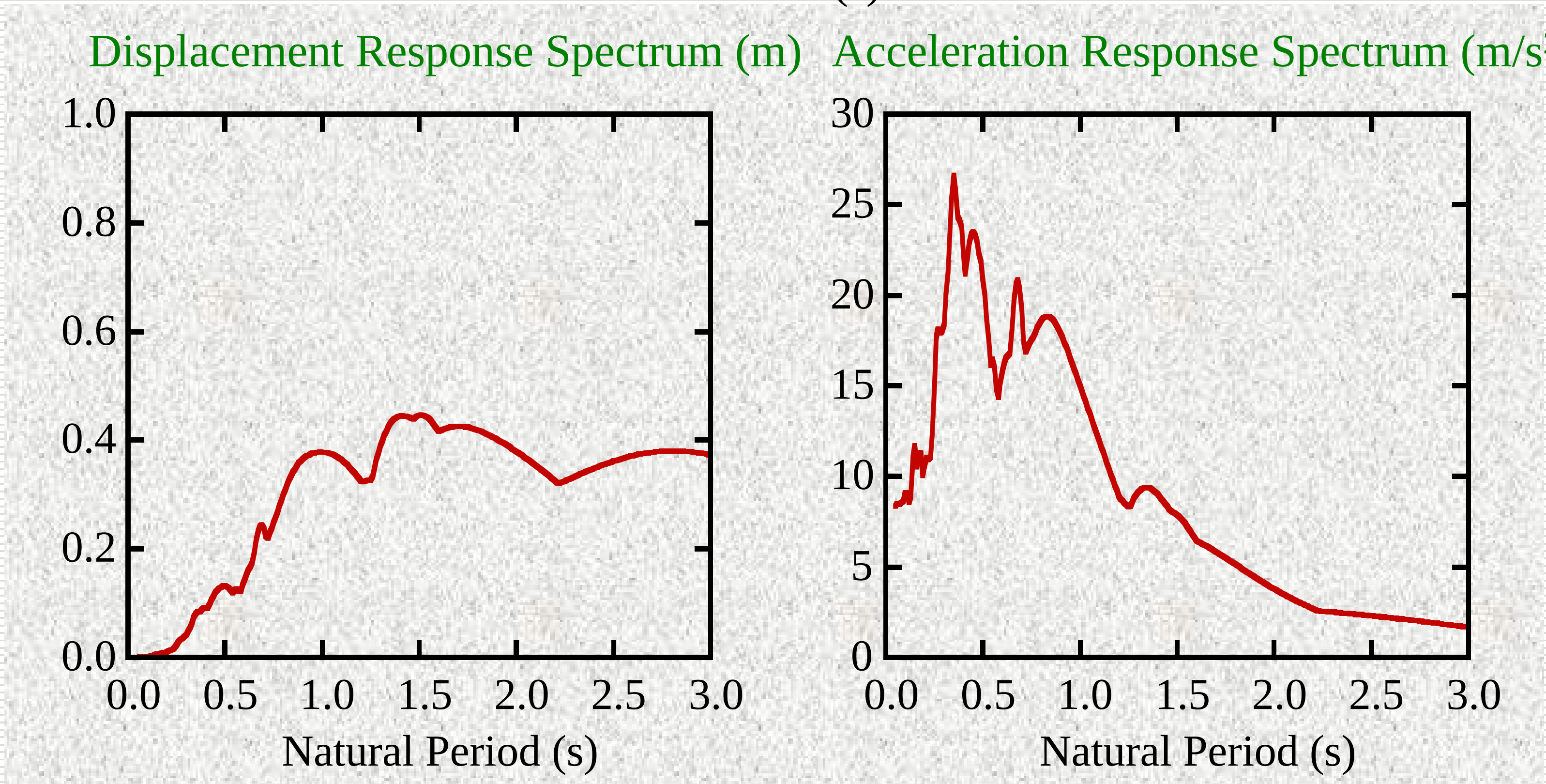




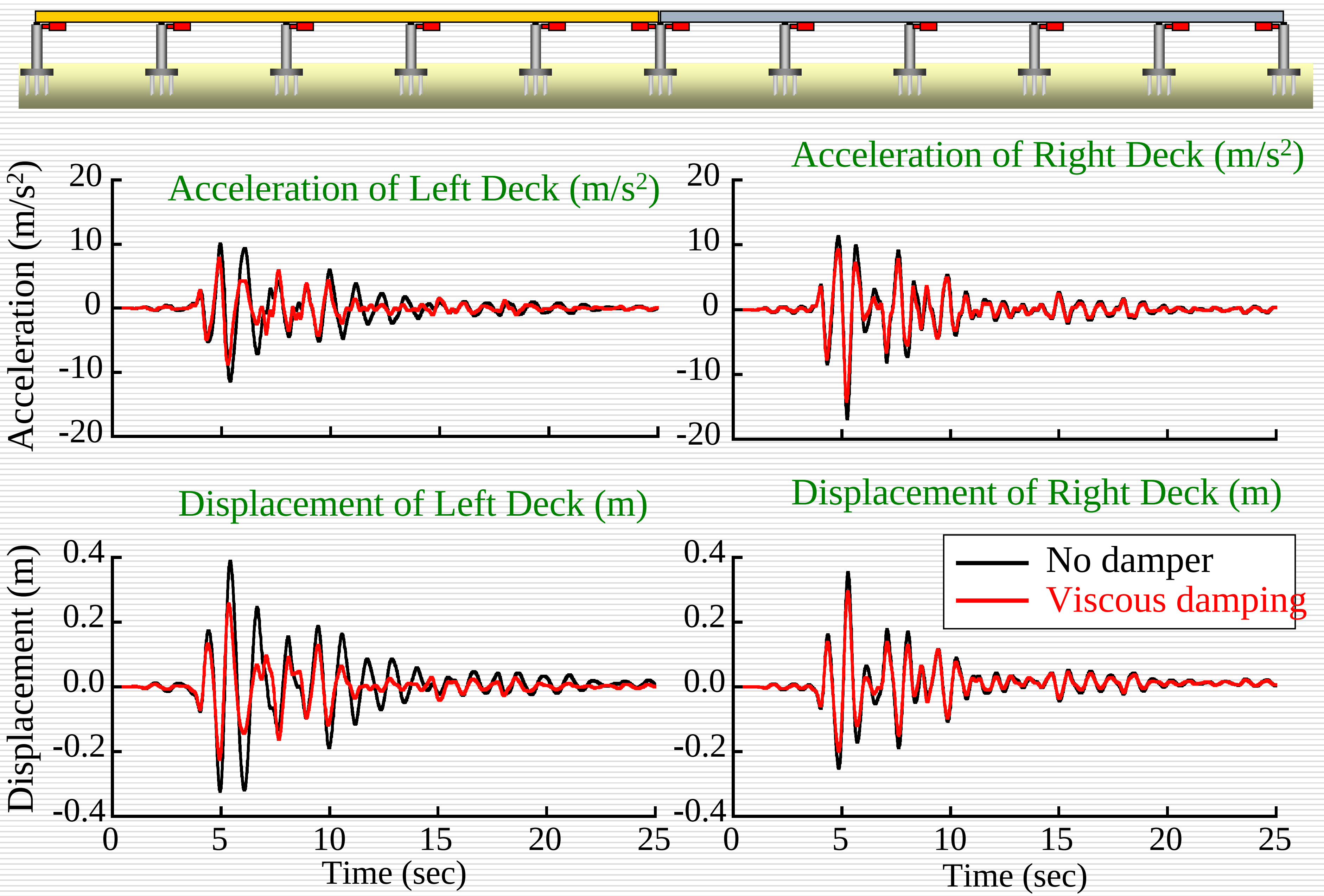
Natural period of the first mode is 1.19 s.
Natural period of the second mode is 0.94 s.

(2) Ground Motion which was Imposed to the Viaduct

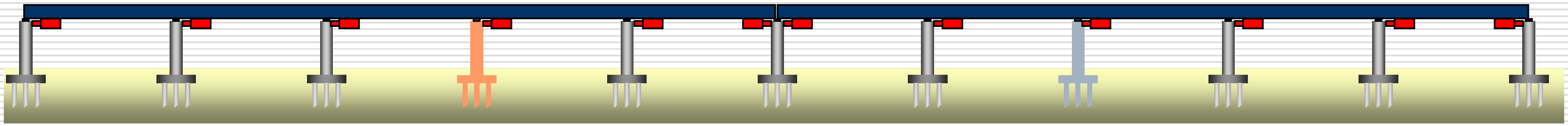




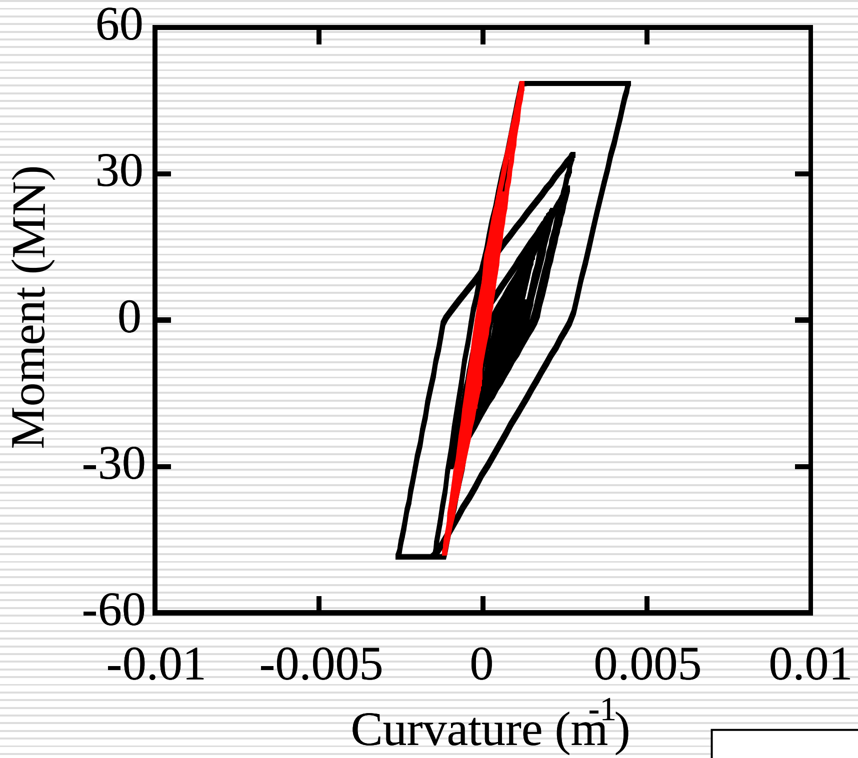
(3) Response of the Bridge with Viscous Dampers



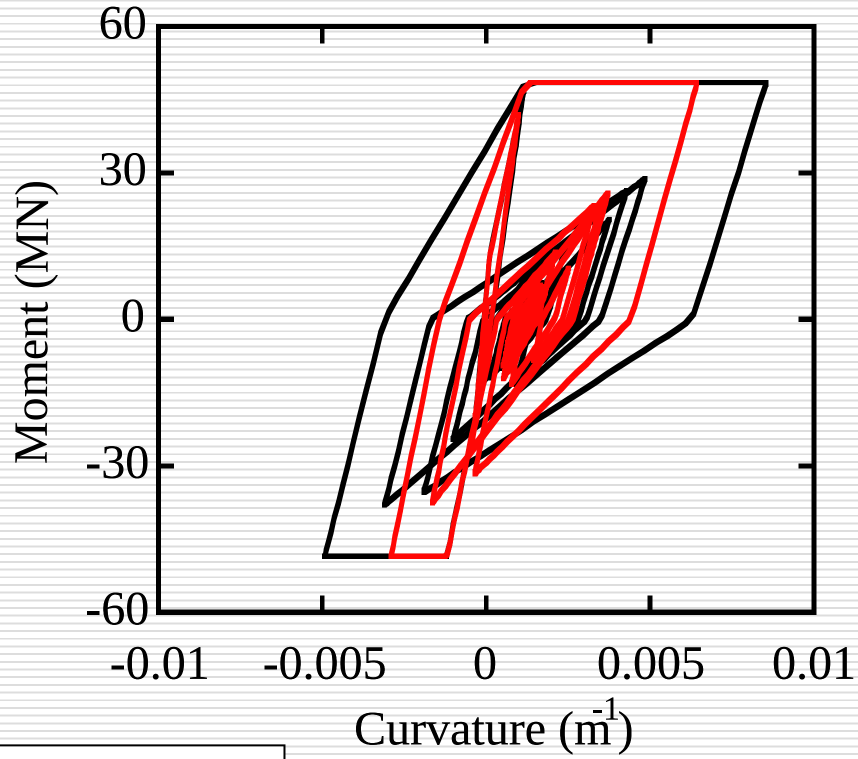
Response of the Bridge with Viscous Dampers



Moment vs. Curvature at
Plastic Hinge of Left Pier

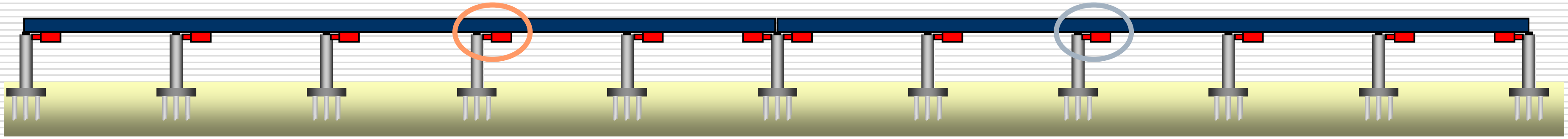


Moment vs. Curvature at
Plastic Hinge of Right Pier

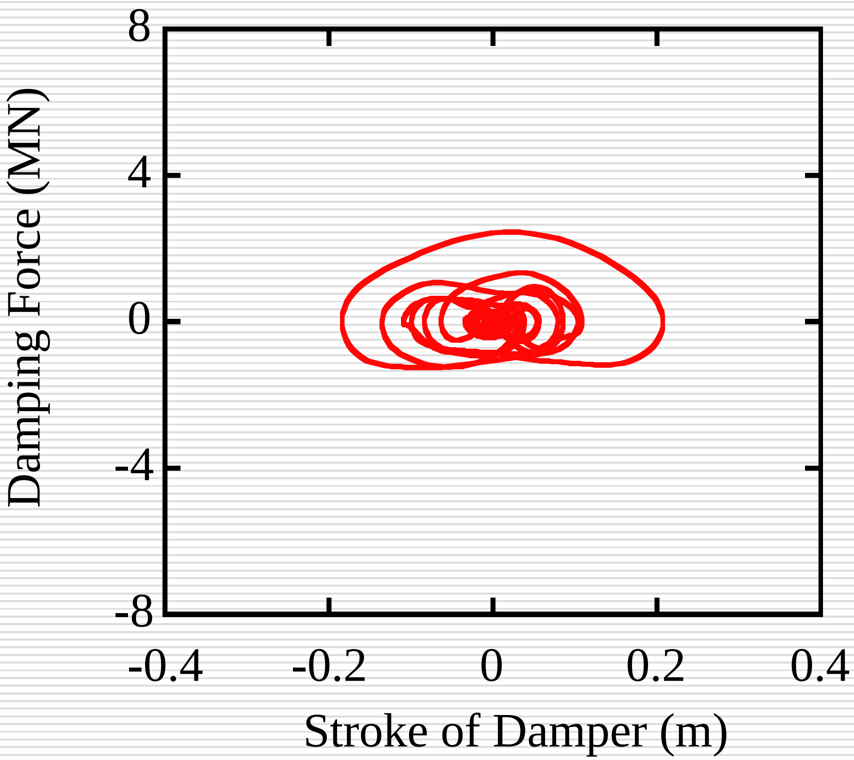


No damper
Viscous damping

Response of the Bridge with Viscous Dampers



Damping Force of Left Dampers (MN)



Damping Force of Right Dampers (MN)