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

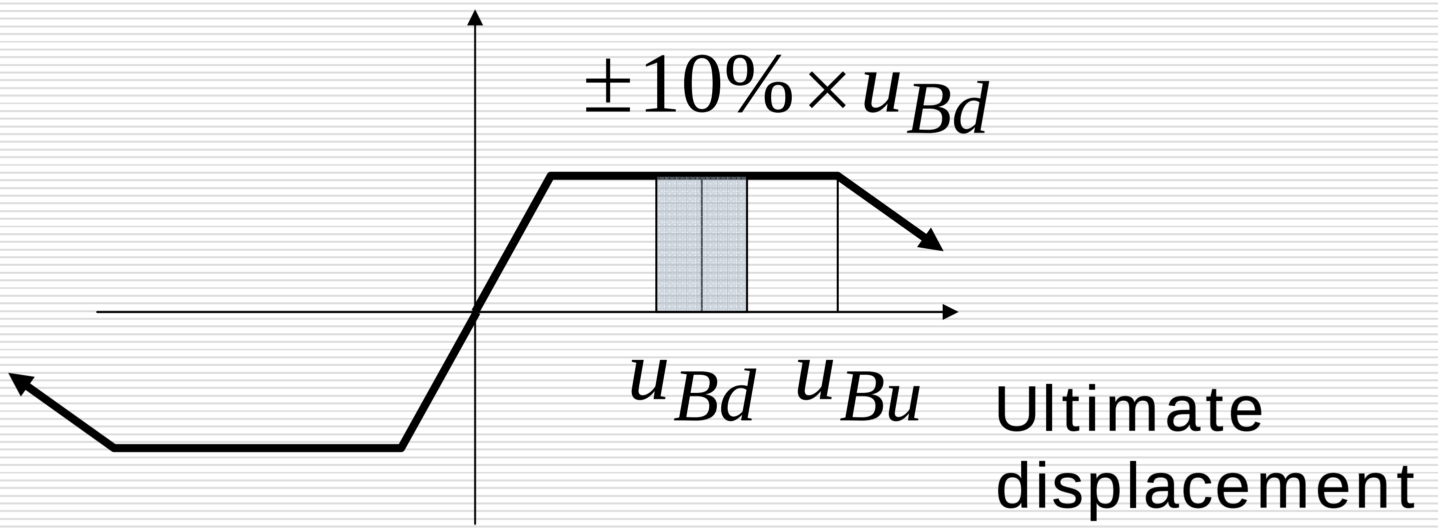
第5章　橋梁の免震設計(2)
Chapter 5 Design of Isolated Bridges (2)

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

(6) Design of Isolators and Dampers
(6) 免震装置の設計

Design Requirements for Devices

- Computed displacement of an isolator should be within +/-10% from the assumed design displacement u_{Bd}



(6) Design of Isolators and Dampers
(6) 免震装置の設計

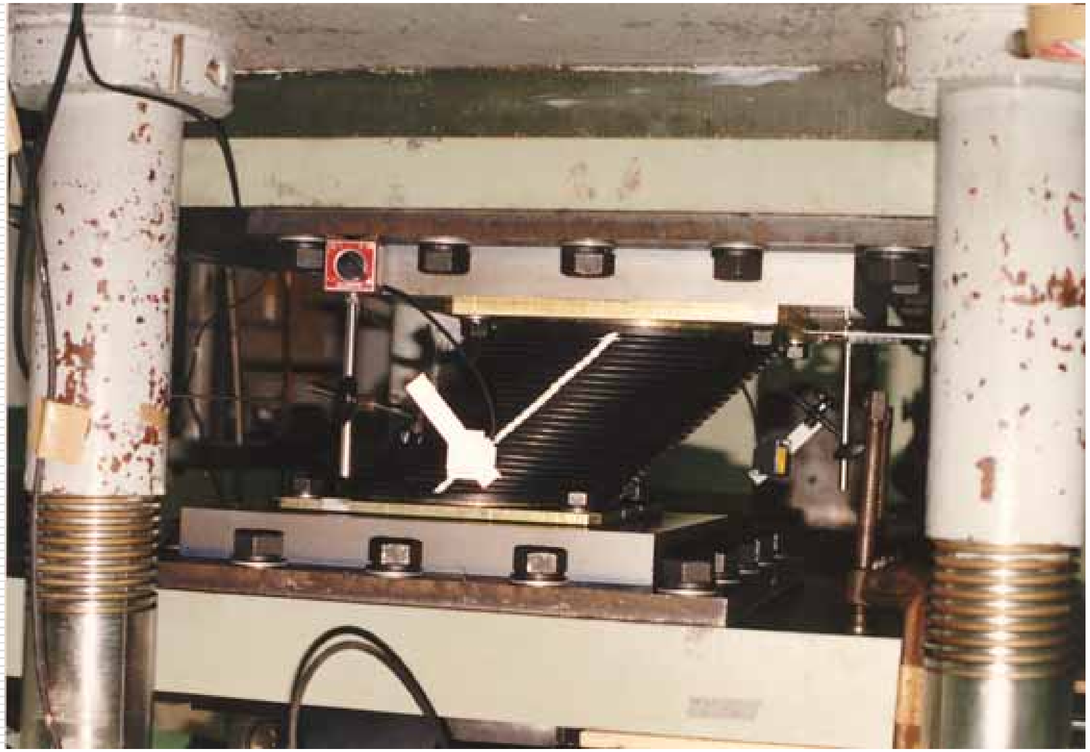
Design Requirements for Devices (2)

●Shear strain of the isolator (elastomeric type isolator such as LRB and HDR) subjected to design lateral force should be less than 250%.

●Local shear strain resulting from the seismic effect, dead weight, rotation and other effects should be less than rupture strain / 1.2.

●Lateral capacity > Lateral force demand

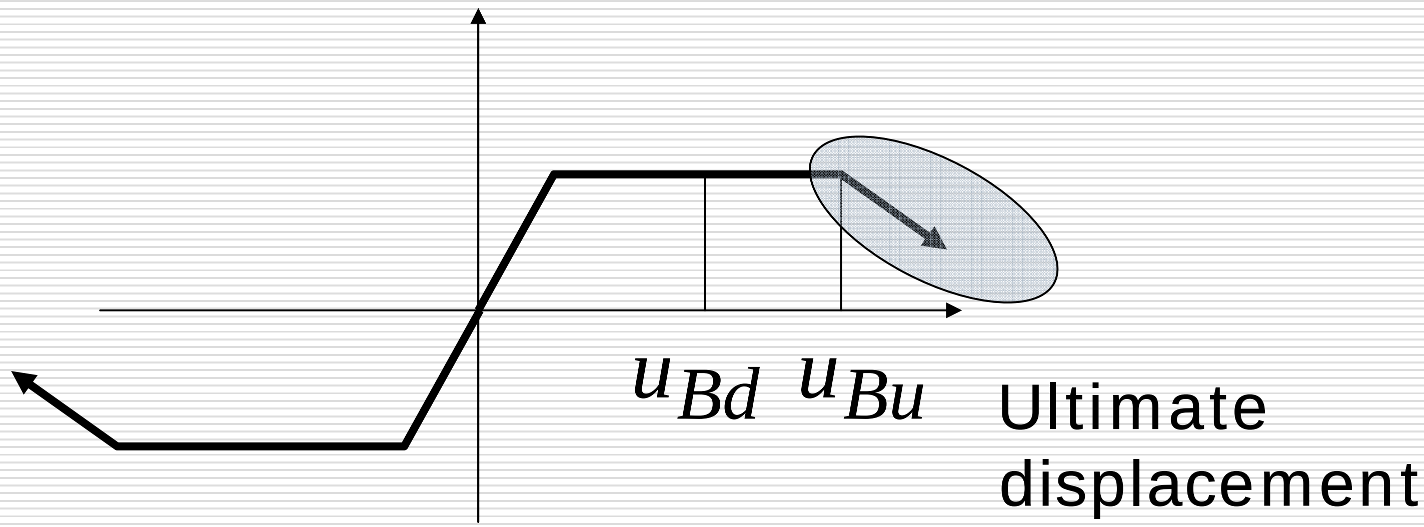
Deformation with 200% shear strain



(6) Design of Isolators and Dampers
(6) 免震装置の設計

Design Requirements for Devices (2)

●Devices having positive tangential stiffness at any displacement within the design displacement u_B should be used to prevent "shake down."



(6) Design of Isolators and Dampers
(6) 免震装置の設計

Design Requirements for Devices (3)

- Devices have to be designed & fabricated so that scatter of the stiffness & equivalent damping ratio are within 10% of the design values
- Devices have to be stable for at least 50 & 15 lateral load reversals with the design displacement u_B for Type I & Type II ground motions, respectively.

(6) Design of Isolators and Dampers
(6) 免震装置の設計

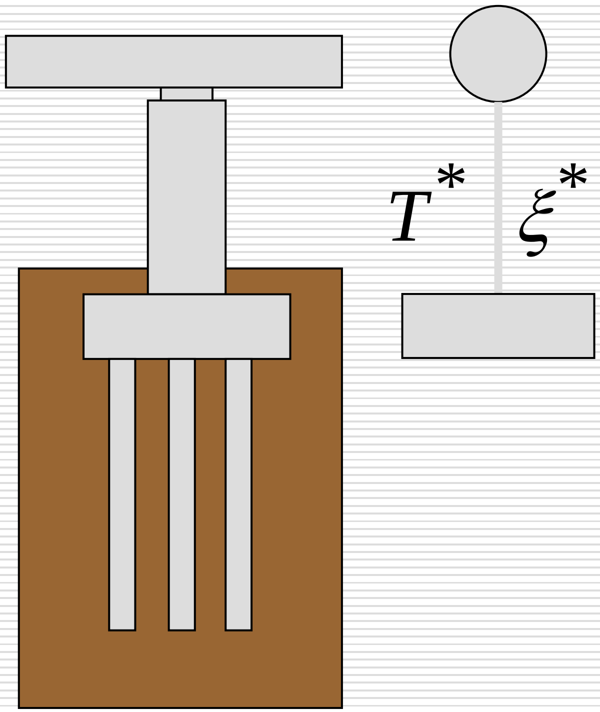
Design Requirements for Devices (4)

●A deck should return to the original rest position after it is subjected to a design ground motion. Residual displacement < 10% x design displacement.

●The stiffness and damping ratio of isolators and dampers should be stable for a change of load condition and natural environment

5.4 Column ductility factor vs. System ductility factor
5.4 ＬＲＢやＨＤＲを用いた免震設計の留意点橋脚の塑性変形の影響

1) How should we determine the "yield displacement" and "ultimate displacement" in a bridge in which both the isolator and the column undergo in the inelastic range?

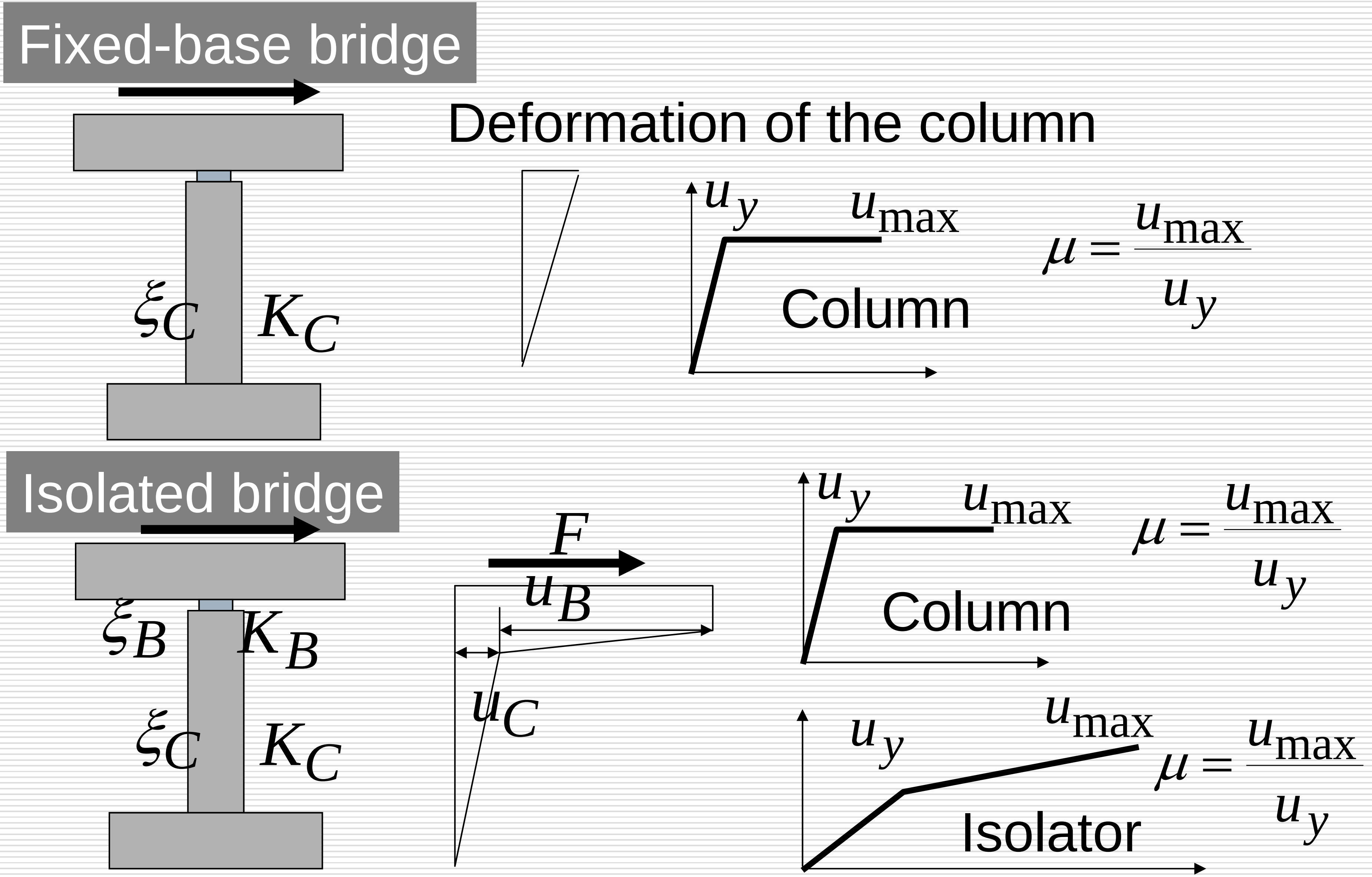


Response modification factor is determined based on the hysteretic behavior of a column, but does nonlinearity of the isolator affect the "yield displacement" and "ultimate displacement" of a bridge?

現在、荷重低減係数を定めるために必要な設計じん性率（降伏変位、終局変位）は橋脚の非線形性から定めると考えられてきたが、橋全体系としての降伏変位、終局変位は免震支承の影響を受けないのか?

$$R = \begin{cases} \sqrt{2\mu_r - 1} \\ \mu_r \\ \text{.........Empirical values} \end{cases}$$

2) Column Ductility Factor vs. System Ductility Factor 橋脚単独のじん性率と橋全体系のじん性率



3) Effect of Isolator Deformation on the System Ductility Factor
構造系じん性率と橋脚系じん性率の関係

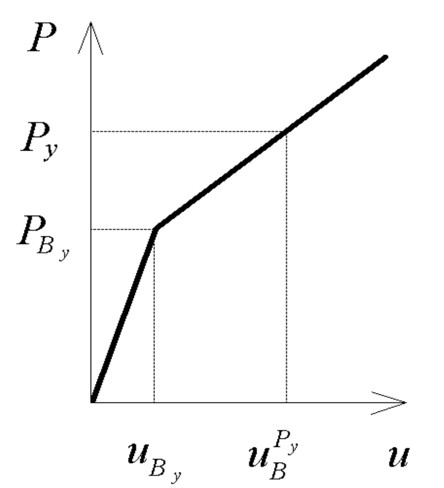
$$\mu_P = \frac{u_P^{\max}}{u_P^{P_y}} = \frac{u_P^{P_y} + u_{Pp}}{u_P^{P_y}} = 1 + \frac{u_{Pp}}{u_P^{P_y}}$$

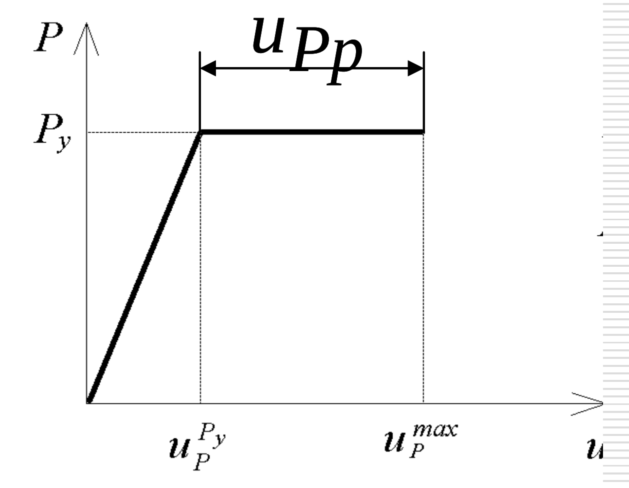
$$\therefore \quad u_{Pp} = u_P^{P_y}(\mu_P - 1)$$

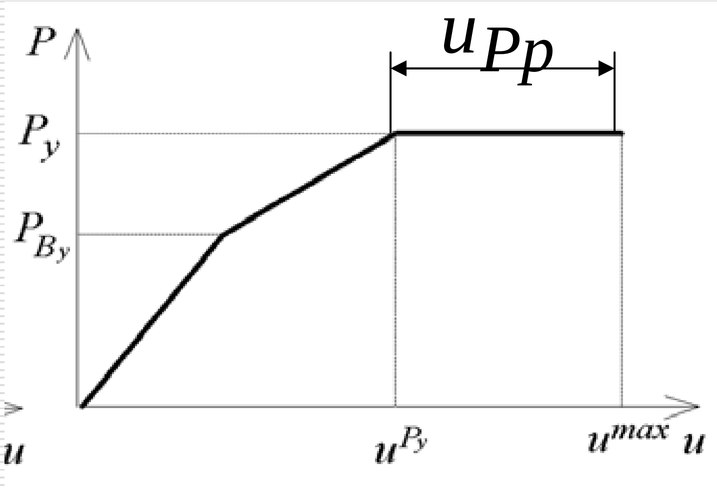
$$u^{\max} = u^{P_y} + u_{Pp}$$

$$u^{P_y} = u_P^{P_y} + u_B^{P_y}$$

Isolators Column System







Effect of Isolator Deformation on the System Ductility Factor

$$u^{\max} = u^{P_y} + u_{Pp}$$

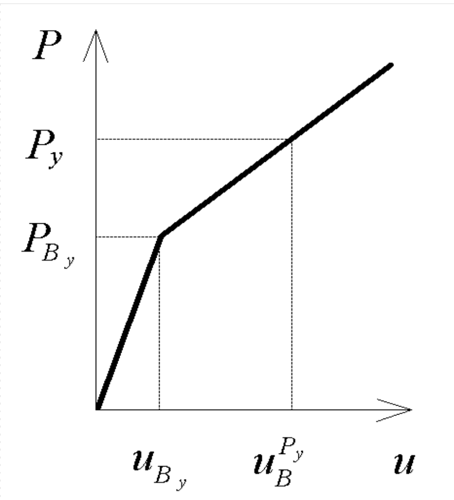
$$u^{P_y} = u_P^{P_y} + u_B^{P_y}$$

$$u_{Pp} = u_P^{P_y}(\mu_P - 1)$$

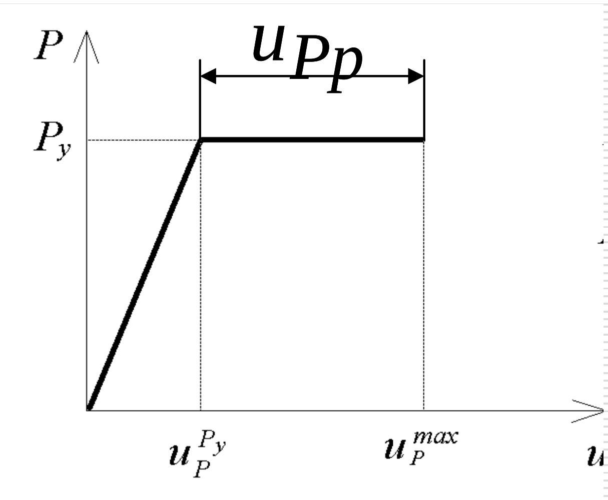
$$\therefore \quad \mu_S = \frac{u^{\max}}{u^{P_y}} = \frac{u^{Py} + u_{Pp}}{u^{Py}}$$

$$= 1 + \frac{u_{Pp}}{u^{P_y}} = 1 + \frac{u_P^{P_y}(\mu_P - 1)}{u_P^{P_y} + u_B^{P_y}}$$

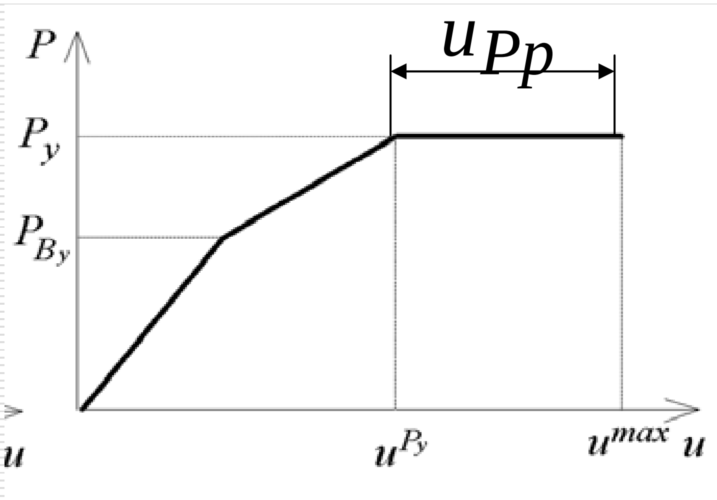
Isolators



Column



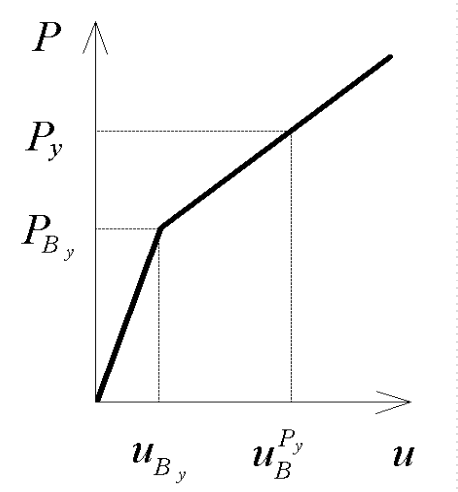
System



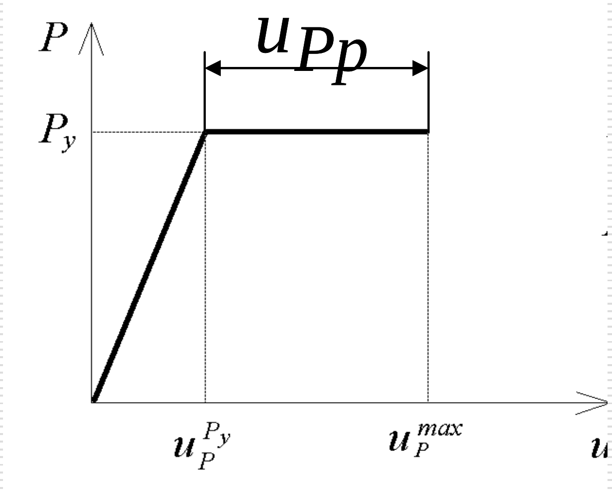
$$\mu_S = \frac{u^{\max}}{u^{P_y}} = 1 + \frac{u_P^{P_y}(\mu_P - 1)}{u_P^{P_y} + u_B^{P_y}}$$

$$c_f = \frac{u_B^{P_y}}{u_P^{P_y}} \qquad \mu_S = 1 + \frac{\mu_P - 1}{1 + c_f}$$

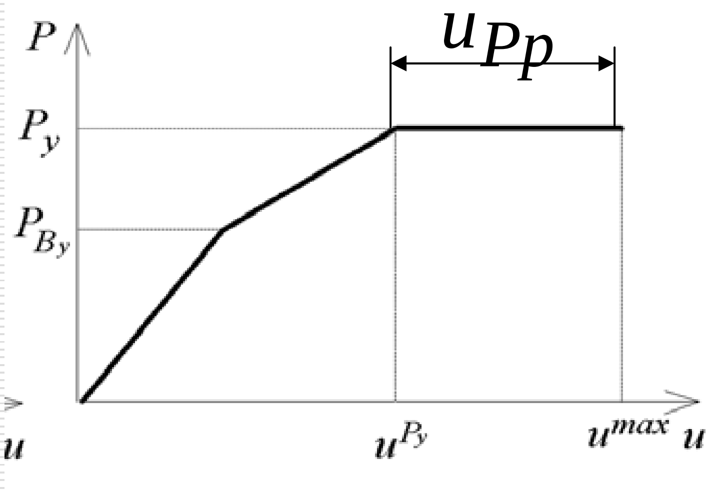
Isolators



Column



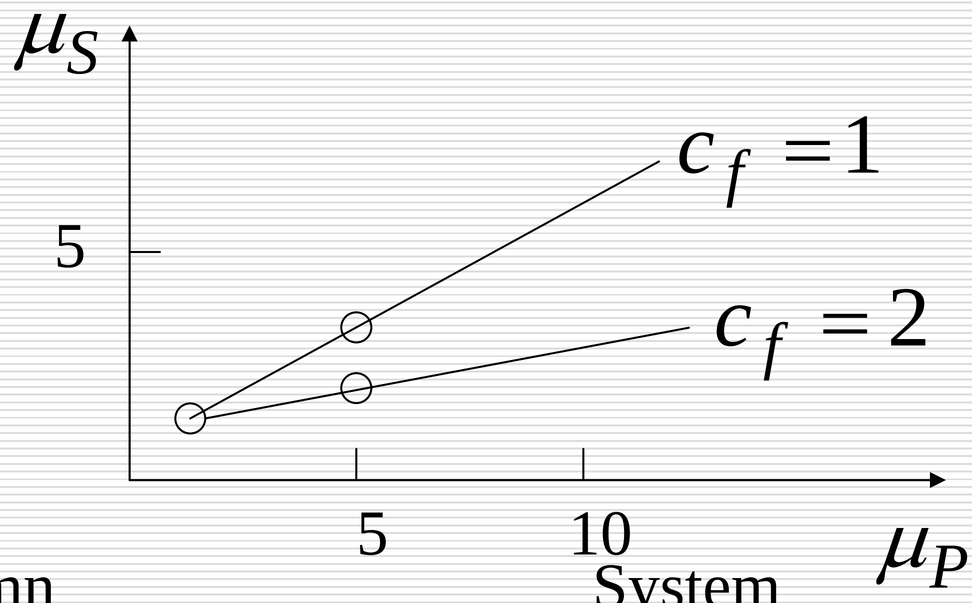
System



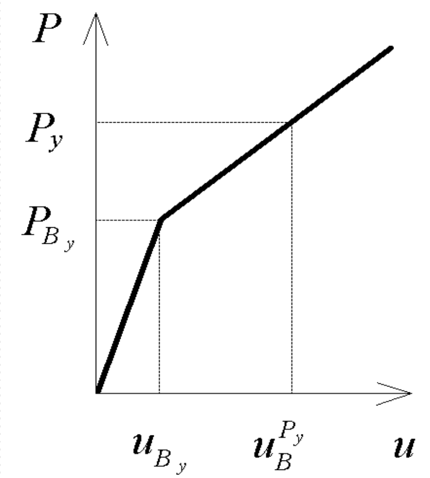
4) System Ductility Factor vs. Column Ductility

$$\mu_S = 1 + \frac{\mu_P - 1}{1 + c_f}$$

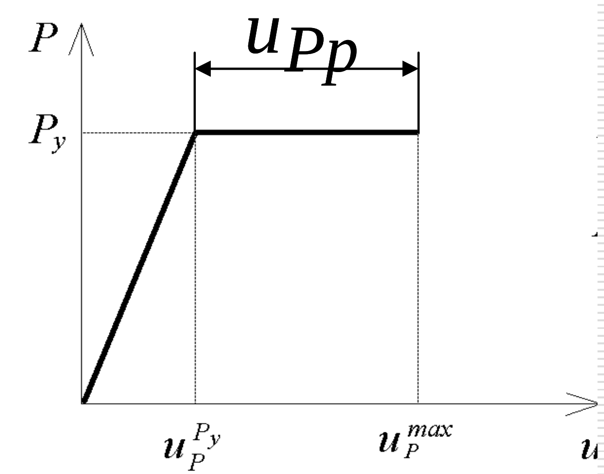
$$c_f = \frac{\dfrac{P_y}{u_B}}{\dfrac{P_y}{u_P}}$$



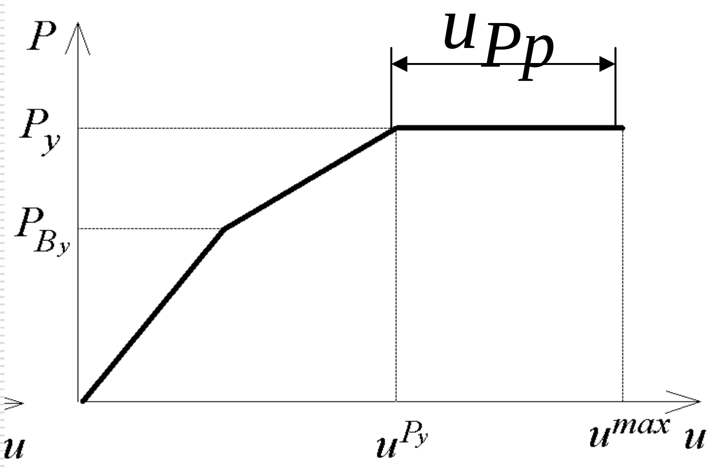
Isolators



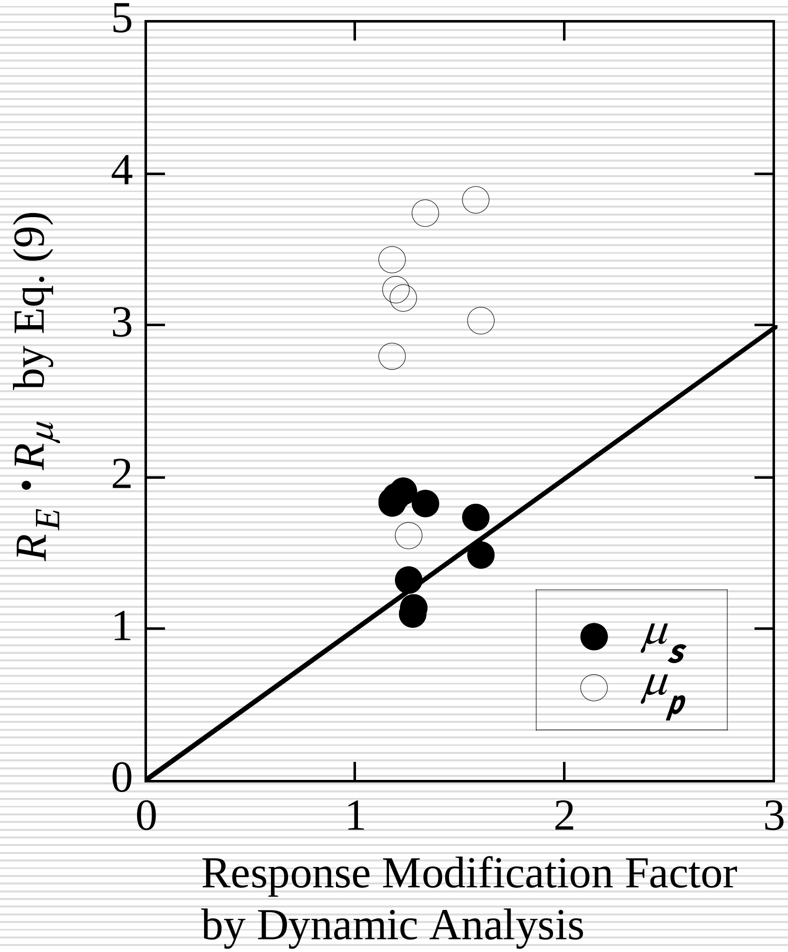
Column



System



5) Response Modification Factor should be Evaluated Based on not Column Ductility Factor but System Ductility Factor
荷重低減係数は構造系じん性率に基づいて評価しなければならない



5.5 Seismic Isolation with Limited Increase of Natural Period (= Menshin Design)

6.5 長周期化抑制型免震設計

1) Menshin Design　1)免震設計

Seismic Isolation
(European concept)
免震設計

Menshin Design
(Implementation of seismic isolation in Japan)
長周期化抑制型免震設計

Seismic Isolation	Menshin Design
Period shift	Limited period shift
Increase of the energy dissipation	Increase of the energy dissipation
	Distribute lateral force to as many substructures as possible

2) Favorable Implementations of Menshin Design

- Super multi-span continuous bridges
- Damage control of bearings and piers
- Seismic retrofit of existing bridges
- Deck connection to make simply supported decks to multi-span decks

3) Design Codes for Menshin Design

- 1989 Guideline for Menshin Design of Highway Bridges 道路橋の免震設計法ガイドライン(案)
- 1992: Manual of Menshin Design of Highway Bridges 道路橋の免震設計法マニュアル(案)
- 1995: Guide Specifications for Repair of Highway Bridges that suffered Damage in the 1995 Kobe Earthquake 1995年兵庫県南部地震んで被災した橋梁の復旧に使用する指針(建設省)
- 1996: Part V Seismic Design, Design Specifications of Highway Bridges 道路橋示方書 V耐震設計編
  - ✓First stipulations in the mandate code
- 2002: Part V Seismic Design, Design Specifications of Highway Bridges
- 2012: Manual of Menshin & Control Design of Highway Bridges 道路橋の免震・制震設計法マニュアル(案)

4) Design Specifications of Highway Bridges
4) 道路橋示方書

Japan Roads Association, 1996

Highway bridges with span length less than 200m

About 2000-3000 new bridges per year

- ●Part I Common Part
- ●Part II Steel Bridges
- ●Part III Concrete Bridges
- ●Part IV Foundations
- ●Part V Seismic Design

5) Part V Seismic Design 道路橋示方書 V耐震設計編 Design Specifications of Highway Bridges

Chapter 8 Menshin Design 第8章 免震設計

- 8.1 General
- 8.2 Menshin Design
- 8.3 Design Lateral Force
- 8.4 Design of Isolator and Energy Dissipator
  - 8.4.1 Basic Principle
  - 8.4.2 Evaluation of Safety of Isolator
  - 8.4.3 Design Displacement of Isolator
  - 8.4.4 Equivalent Stiffness & Damping Ratio
  - 8.4.5 Dynamic Performance of Bearings
- 8.5 Evaluation of Natural Period
- 8.6 Evaluation of Damping Ratio of Bridge System
- 8.7 Design Details
  - 8.7.1 Distance between Decks
  - 8.7.2 Expansion Joints

5.6 Merit of Seismic Isolation
5.6 免震設計のメリット

- Enhance the seismic performance **耐震性の向上**
- Decrease construction cost **建設コストの低減**

LRB & HDR are frequently implemented as one of elastomeric bearings without taking benefit of energy dissipation into design
免震設計をしないで、通常の耐震設計に基づき、ＬＲＢ、ＨＤＲを使用した橋梁も多い。

LRB & HDR are widely used for distributing the seismic lateral force to as many substructures as possible
地震時反力分散構造でＬＲＢやＨＤＲを使用