Kyrgyz-Japan Workshop
organized by the Japan Society of Seismic Isolation (JSSI)
Feb. 8 - 9, 2021

Basic Design of Vibration Controlled Structure and Full-Scale Experiments

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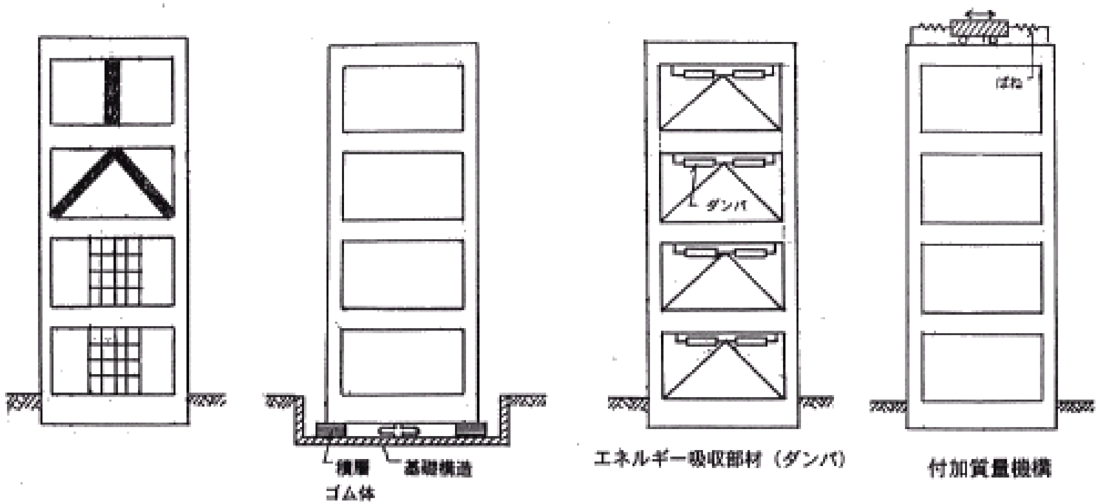
Tokyo Institute of Technology (TIT)

Ordinary Structural System vs. Two Protective Systems



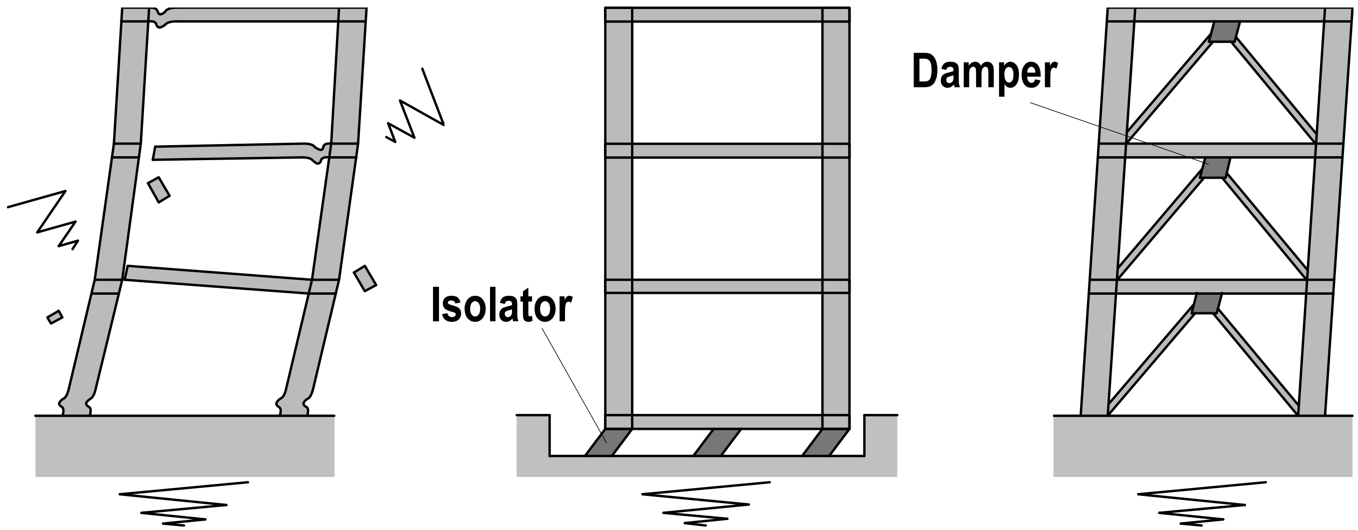
Conventional Structure | Seismic Isolation Structure | Vibration Controlled (VC) Structures

Conventional Structure : Dissipates seismic energy by **sacrificing members** (columns, beams, and walls).

Seismic Isolation Structure : **Isolates** building from ground shaking.

Vibration Controlled (VC) Structures: Mitigates damage and vibration using **dampers** installed at building floors or top.

Ordinary Structure vs. Two Protective Systems



Ordinary Structure:
Damage Caused by Seismic Energy

Seismic Isolation Structure:
Structure Isolated from Ground Motion

Vibration Controlled Structure:
Dampers Absorb and Dissipate Seismic Energy

CURRENT STATUS OF JAPANESE VIBRATION CONTROL TECHNOLOGY

After the 1995 Kobe Earthquake, **Most Major Buildings** are Either **Passively-Controlled** or **Base-Isolated** in Japan.

Various **Damper Types** and **Frame Types** Exist, and **Much More Variations** Expected.

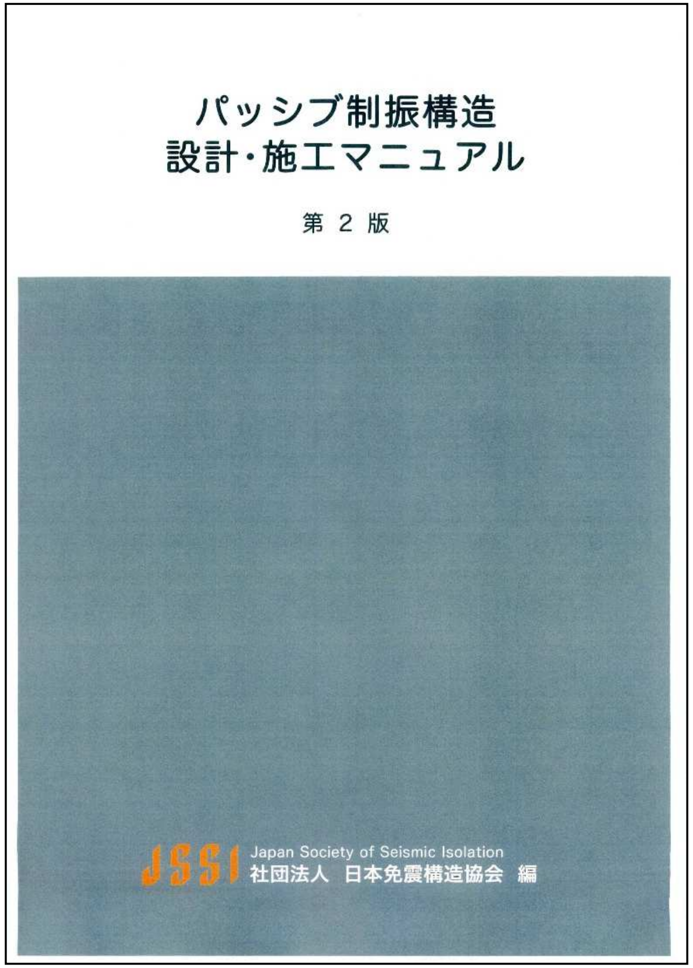
⇒ Needs for Further Research and Design Specifications

1. Individual Research Efforts.
2. Publication of “Passive Control Manual”:
   Response Control Committee, Japan Society of Seismic Isolation **(JSSI)**

JSSI Specifications for Passively Controlled Buildings

1st Edition, 405 pages, 2003

2nd Edition, 515 pages, 2005, 2007
3rd Edition, 561 pages, 2013



(Chinese Translation Completed, and will be Published This Fall)

被动减震结构设计·施工手册

（第2版）

JSSI（Japan Society of Seismic Isolation）

社团法人 日本隔震结构协会编写

翻译 蒋　通
校对 冯德民
中国建筑工业出版社

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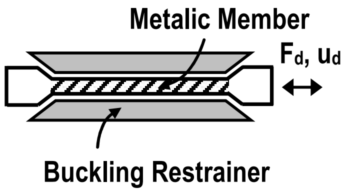
Deformation-Dependant Damper

<table>
<tr><th>Buckling – Restrained Brace (BRB)</th><th>Stiffened Shear Panel</th><th>Friction Damper</th><th>Friction Damper (Cylinder Type)</th></tr>
<tr>
<td>
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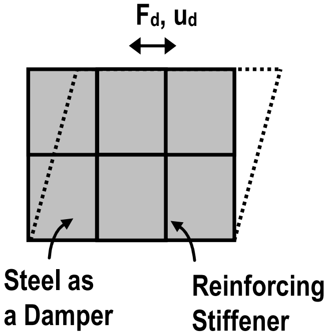
<td>
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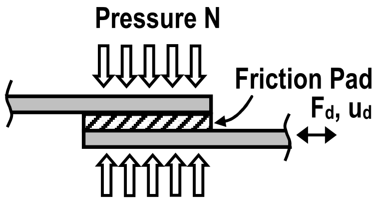
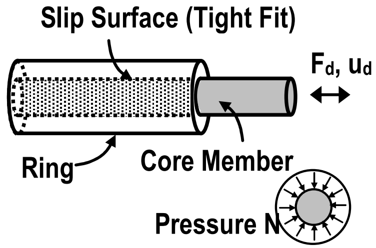
<td>

Friction Coefficient μ= 0.2～0.3</td>
<td>

Friction Coefficient μ= 0.1～0.2</td>
</tr>
<tr>
<td>$F_d = K_d \cdot f(u_d)$
Steel
Slip Resistance of Microstructure</td>
<td>$F_d = K_d \cdot f(u_d)$
Steel
Slip Resistance of Microstructure</td>
<td>$F_d = \mu \cdot N$
Friction (Brake) Pad
Slip Resistance at Pad-Metal Interface</td>
<td>$F_d = \mu \cdot N$
Metallic Surface
Slip Resistance at Metal Interface</td>
</tr>
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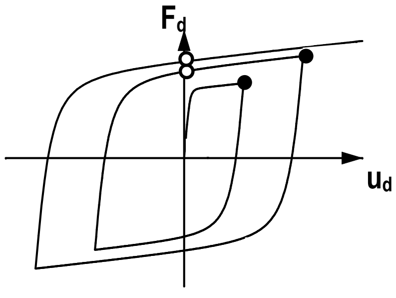
<td colspan="2">
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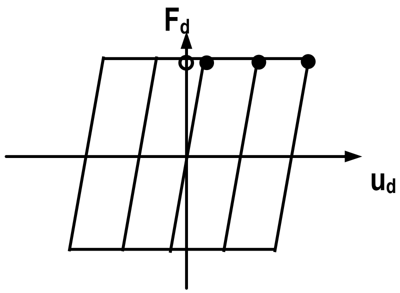
<td colspan="2">
</td>
</tr>
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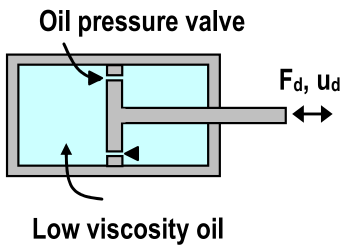
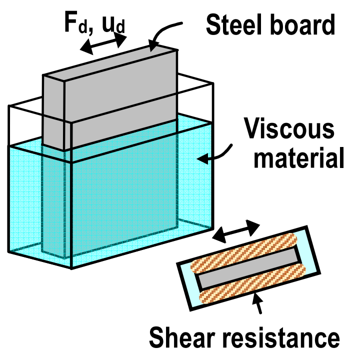
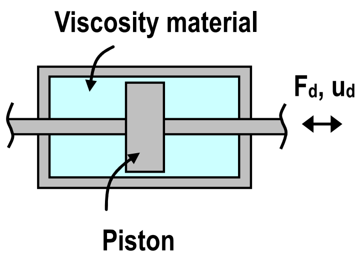
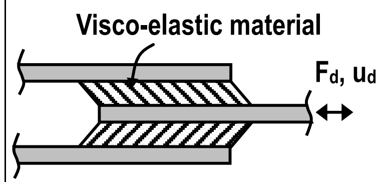
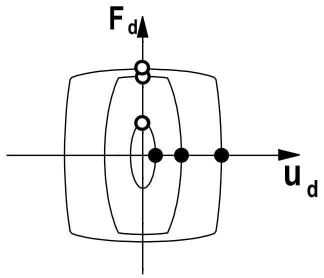
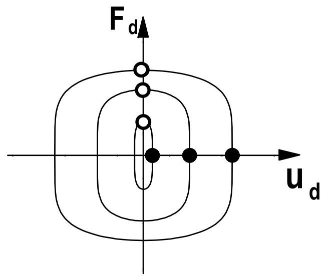
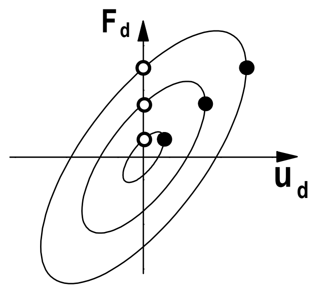
F_d = Damper Force
K_d = Damper Elastic Stiffness
u_d = Damper Deformation
$f(u_d)$ = Deformation-Dependent Function
○ = Zero Deformation
● = Maximum Deformation

Velocity-Dependant Damper

Oil damper	Viscous damper (wall type)	Viscous damper (cylinder type)	Visco-elastic damper
			
$F_d = C_d \cdot \dot{u}_d$ Oil Flow Resistance Relief Mechanism to Vary C_d	$F_d = C_d \cdot \dot{u}_d^{\ \alpha}$ High Polymer Compound Shear Resistance Temperature-Dependent	$F_d = C_d \cdot \dot{u}_d^{\ \alpha}$ High Polymer Compound Flow Resistance Temperature-Dependent	$F_d = K_d(\omega) \cdot u_d + C_d(\omega) \cdot \dot{u}_d$ Acrylic & Diene Compound Shear Resistance Temp.- & Freq.-Dependent
			

F_d = Damper Force u_d = Damper Deformation $\dot{u}_d$ = Damper Velocity

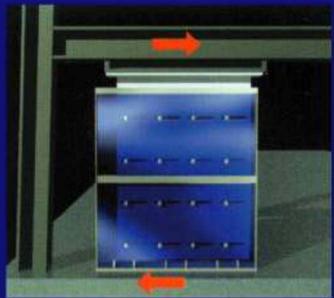
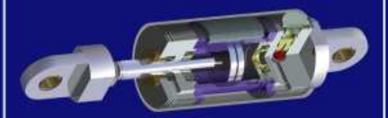
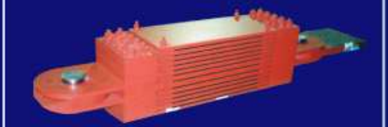
C_d = Damper Coefficient ω = Circular Frequency

○ = Zero Deformation

● = Maximum Deformation

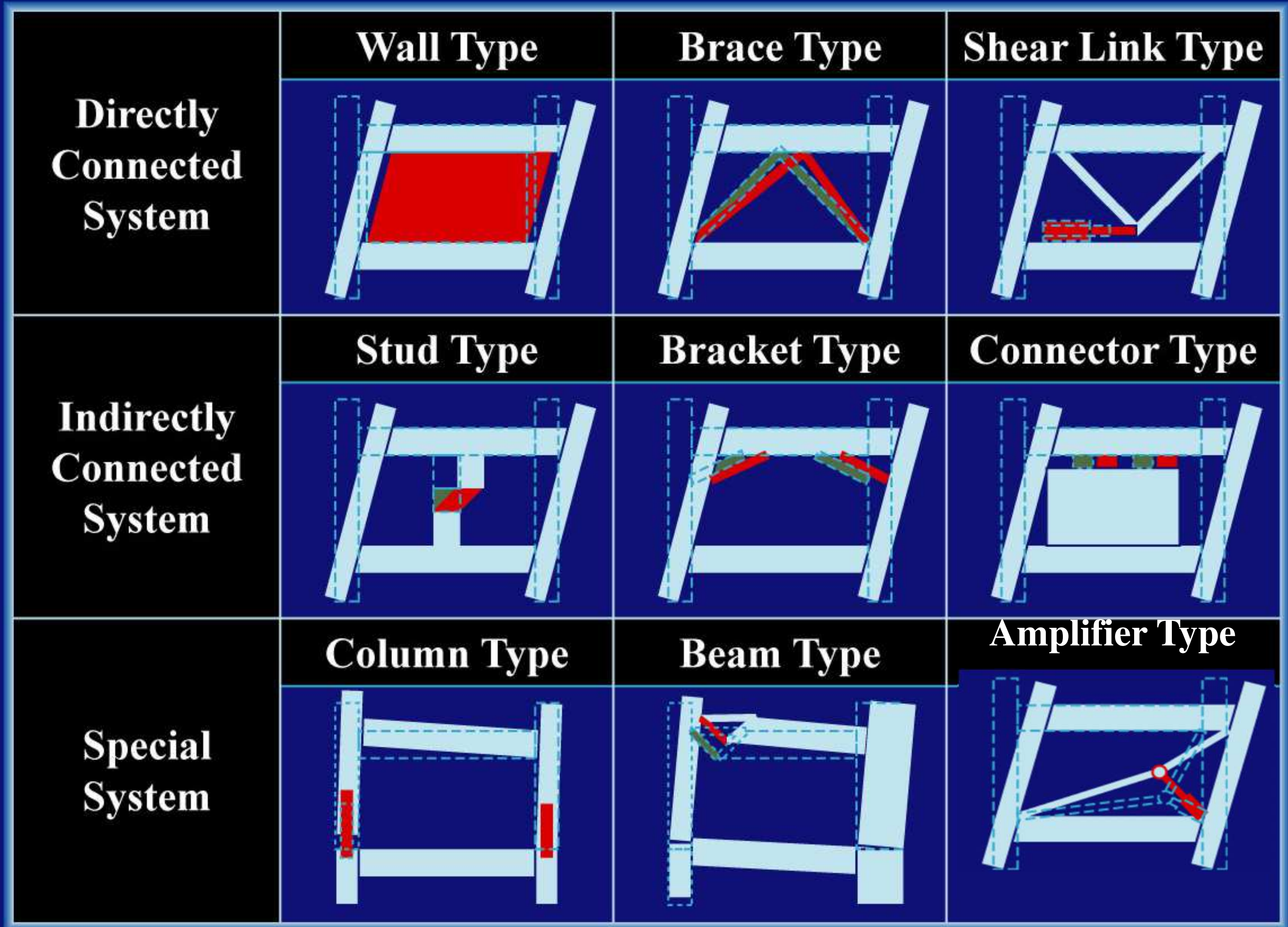
Manual Outline: Applicability

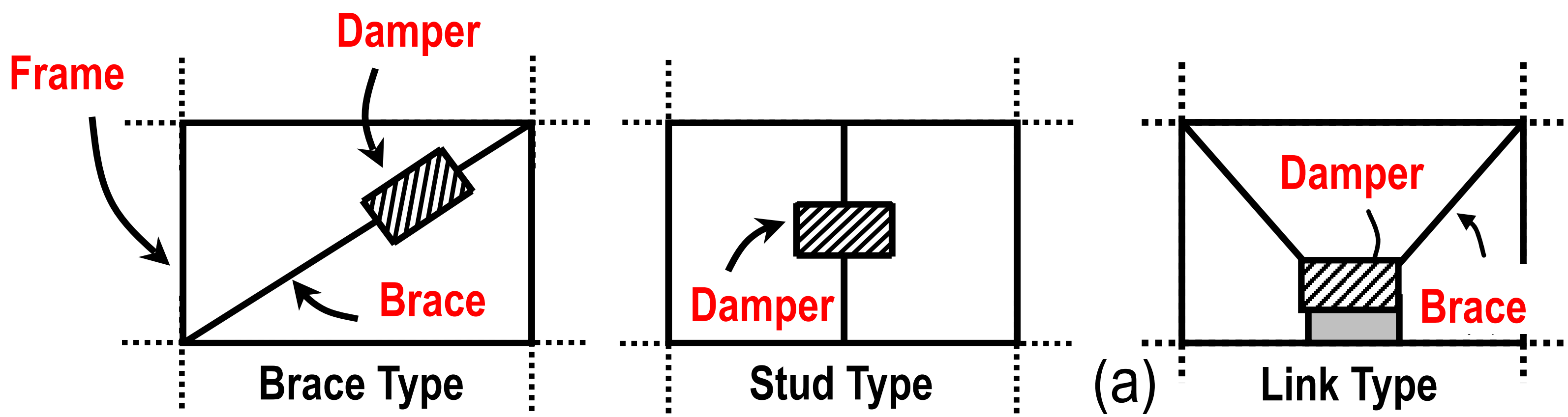
Devices of Passive Control Systems

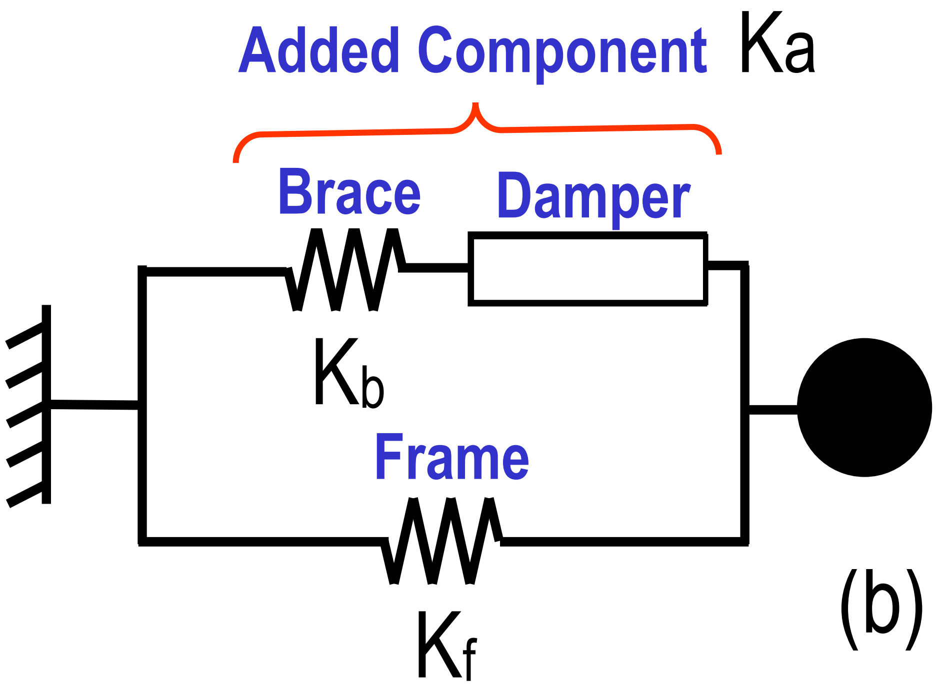
Viscous Damper	**Oil** Damper	**Viscoelastic** Damper	**Steel** Damper
			
$F = C\,\dot{u}^{\alpha}$	$F = C\,\dot{u}$	$F = K\,(\omega)\cdot u + C\,(\omega)\cdot\dot{u}$	$F = K\cdot f(u)$
Combined Ellipse and Rectangle Hysteresis	Ellipse Hysteresis	Inclined Ellipse Hysteresis	Bilinear Hysteresis
Silicon Fluid etc.	Oil	Acryl, Butadiene etc.	Steel, Lead, Friction Pad, etc.
Shear Resistance, Flow Resistance	Orifice Flow Resistance	Shear Resistance	Yielding Resistance Slipping Resistance
Plane, Box, and Tube Shapes	Tube Configuration	Tube and Plane Shapes	Tube and Plane Shapes

Manual Outline: Applicability

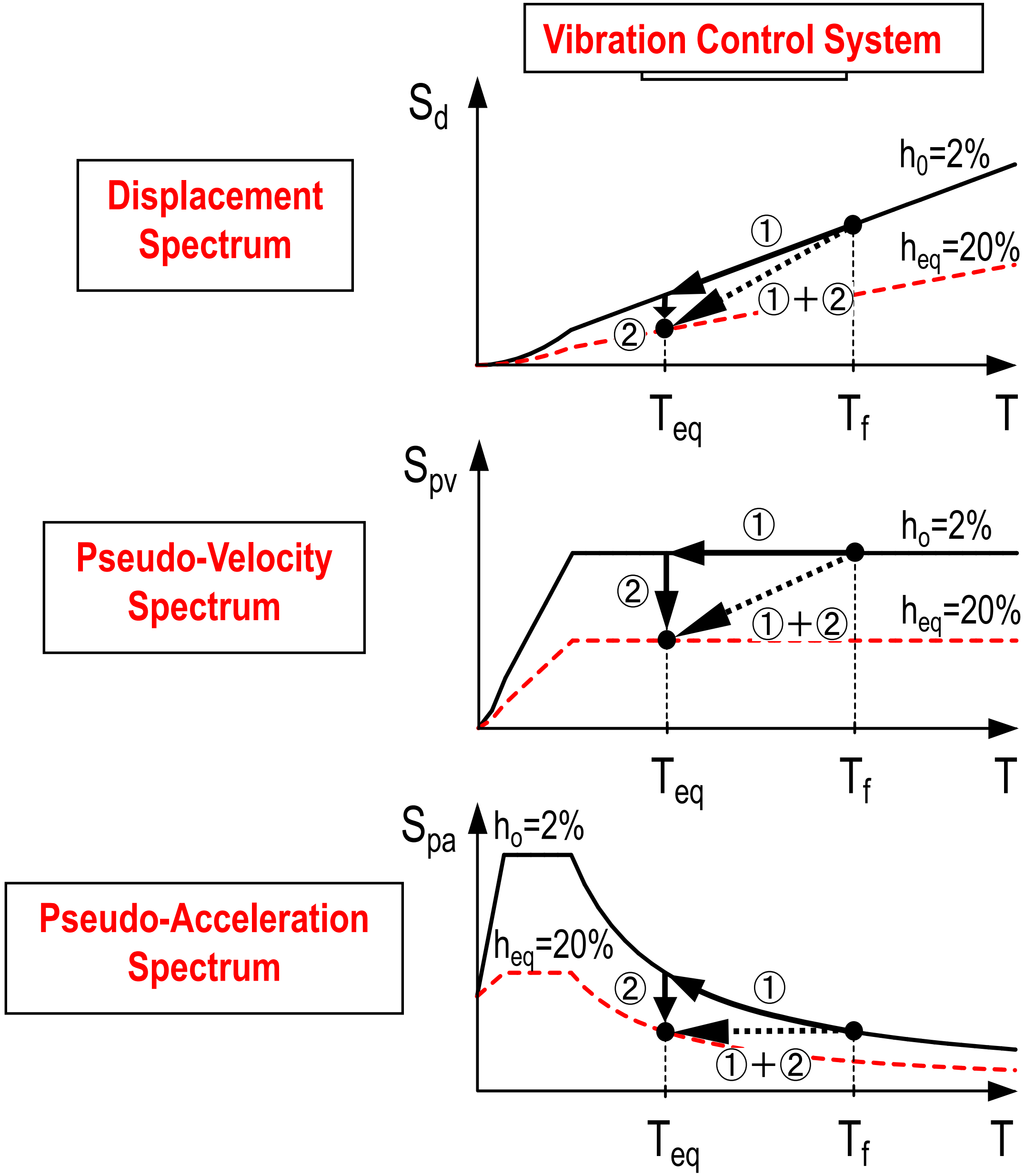
Framing Types of Passive Control Systems







Unified Model to Evaluate Various Frame Types



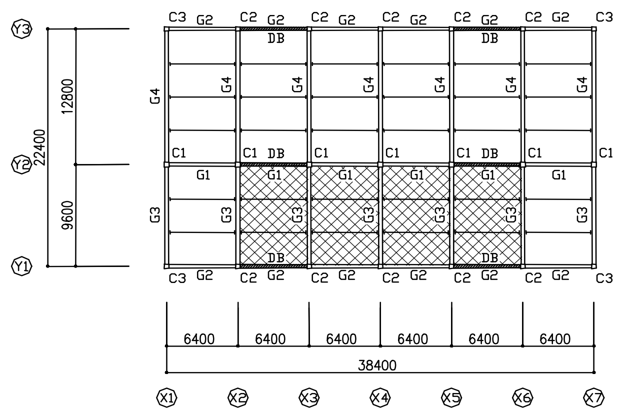
Effects of Adding Dampers:

① Shorten the period ⇒

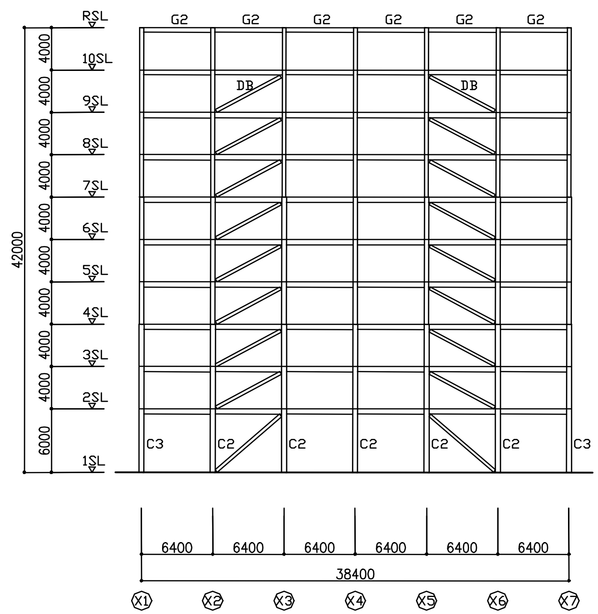
Reduce displ.

② Increase the damping ⇒

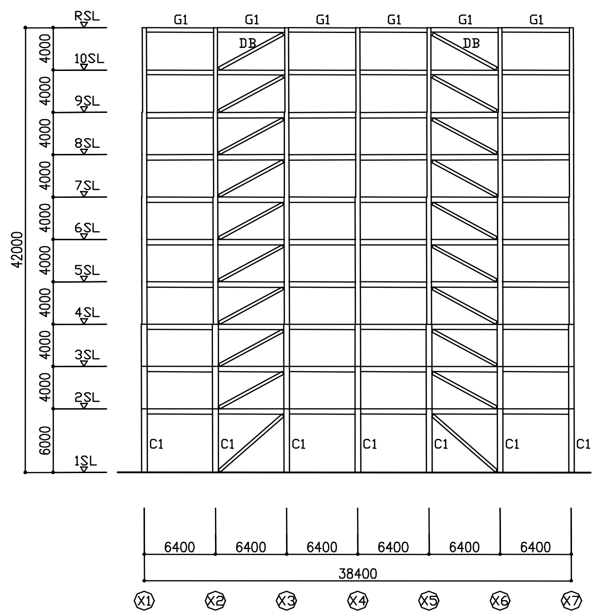
Reduce displ. and acc.



伏図

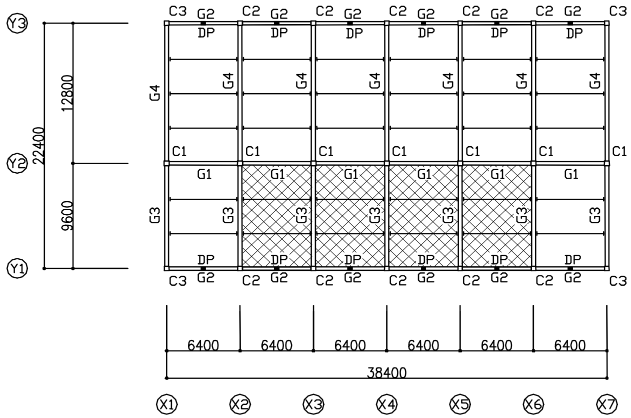


Y1、Y3通り軸組図

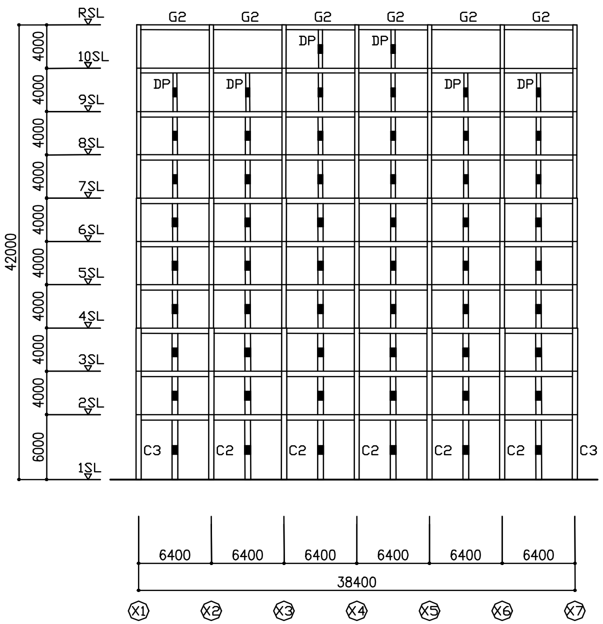


Y2通り軸組図

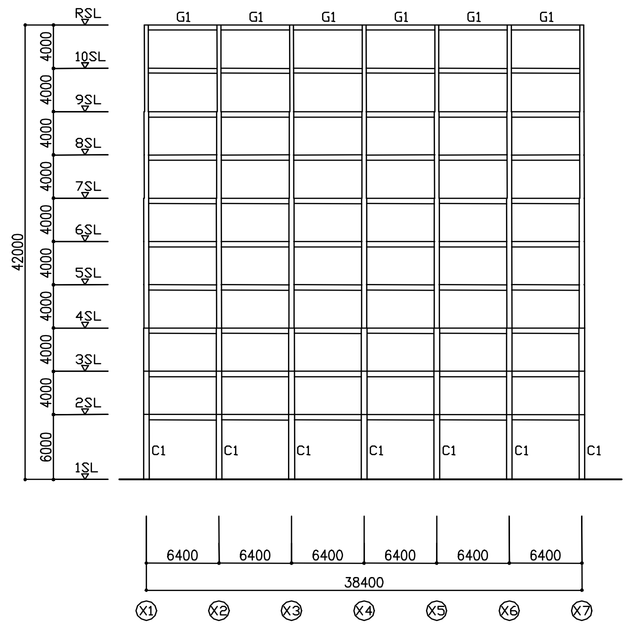
10-Story JSSI Theme Structure with Brace Type Dampers



伏図



Y1、Y3通り軸組図



Y2通り軸組図

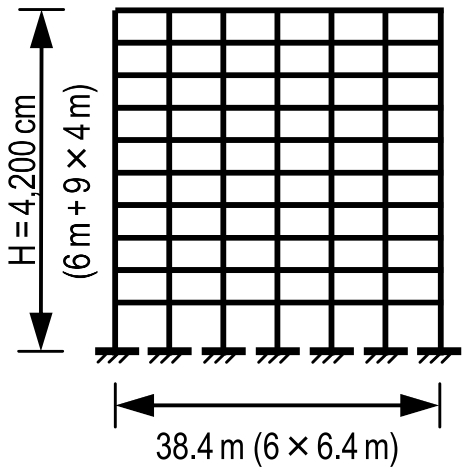
10-Story JSSI Theme Structure with Stud Type Dampers

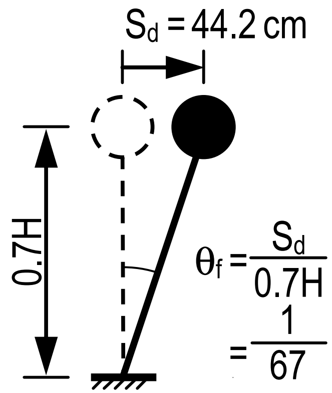
Outline of Design Process

Single-Degree-of-Freedom Modeling

$$H_{eff} = \sum_{i=1}^{N}\left(W_i H_i^2\right) \Big/ \sum_{i=1}^{N}\left(W_i H_i\right) \approx 0.7H$$

$$= 0.7 \times 4200 = 2960\text{cm}$$



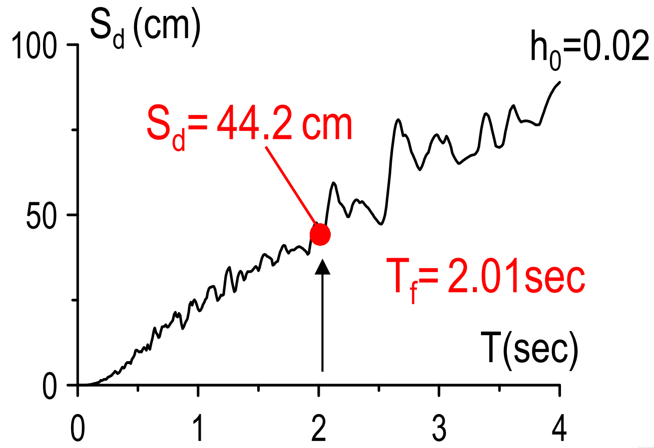


Get Story Drift Angle (Undamped)

$$\theta_f = S_d / 0.7H = 44.2/2960 = 1/67 \text{ rad}$$

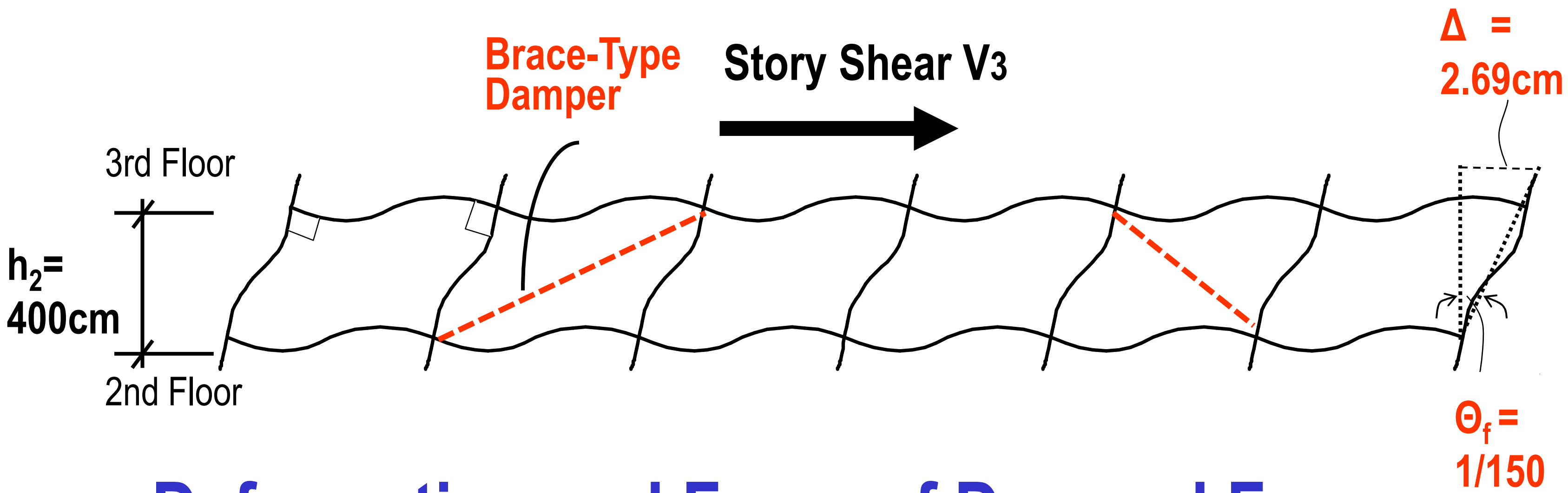
Get Required Disp. Reduction Factor for the Target Story Drift Angle (Damped)

$$R_d = \theta_{max} / \theta_f = (1/150)/(1/67) = 0.45$$



Undamped: $\Delta_f = h_2\theta_f = 400\text{cm} \times 1/67 = \mathbf{5.97cm}$

Damped: $\Delta = (h_2\theta_f)\cdot R_d = \mathbf{5.97cm} \times 0.45 = \mathbf{2.69cm}$

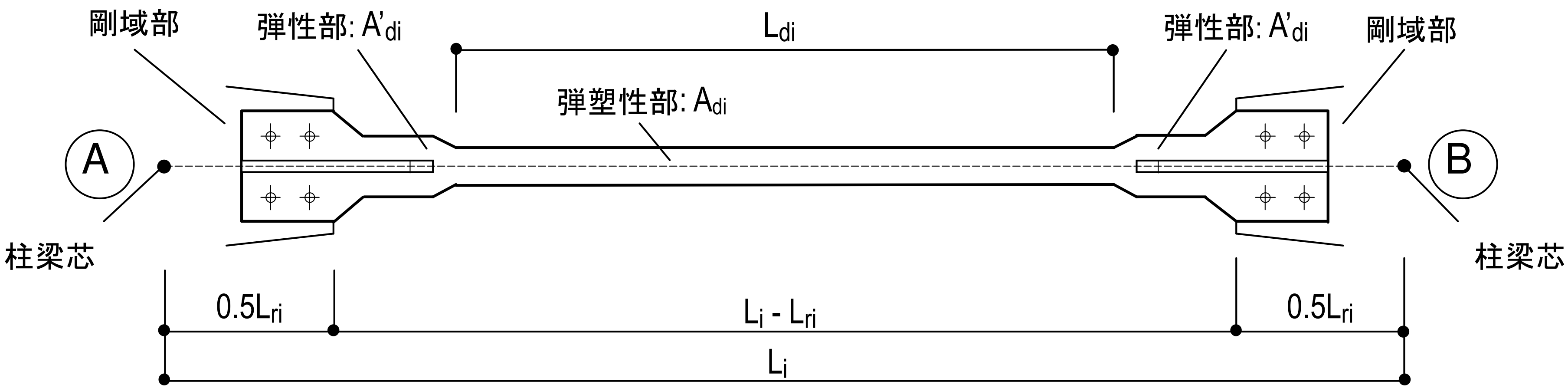


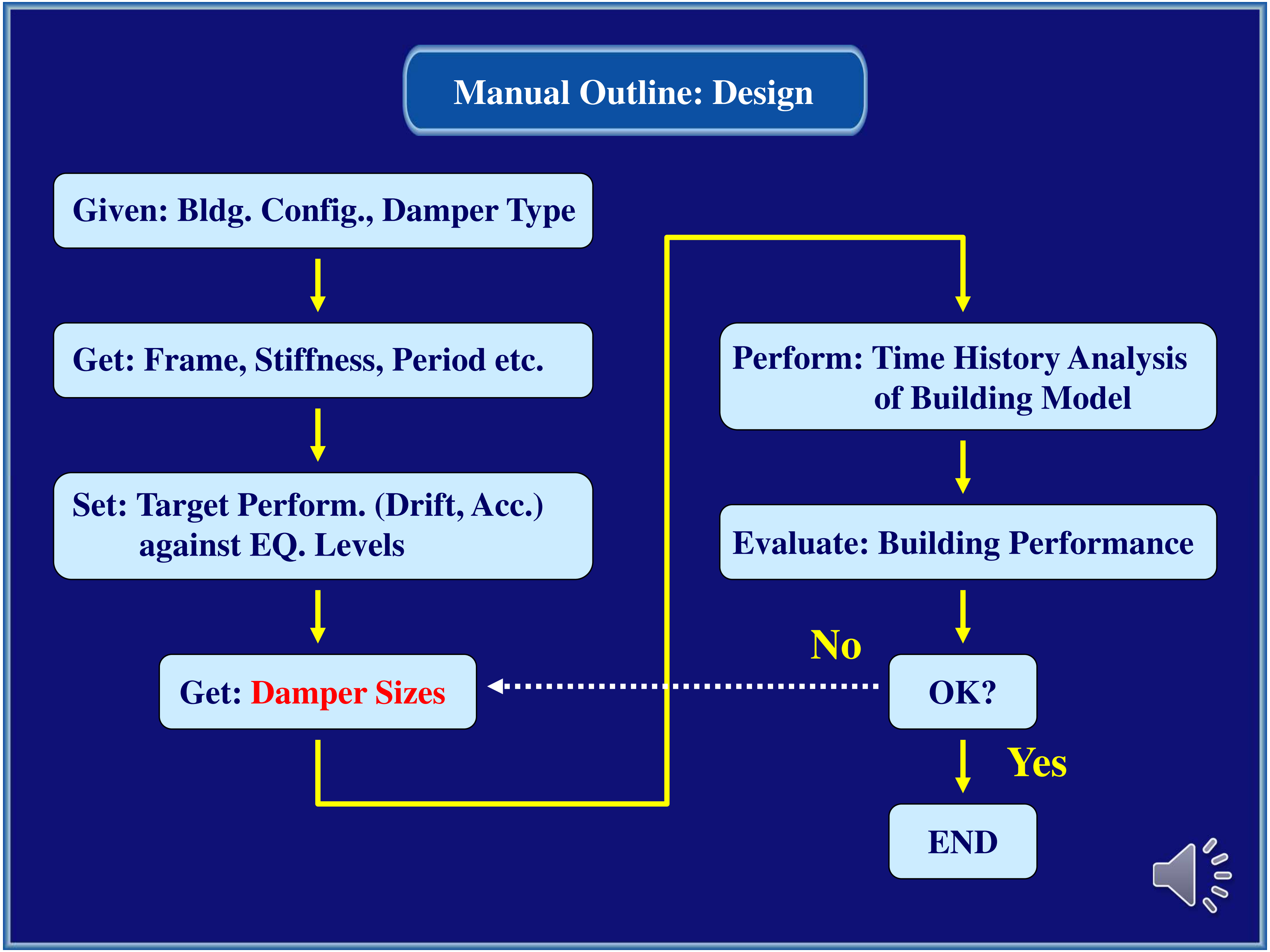
Deformation and Force of Damped Frame

After Estimating the Required Force and Ductility Demand (e.g. Steel Damper), Size the Proportion:

Rigid End Zone Length = **Lri**
Elastic Area & Plastic Area = **A'di** , **Adi**
Plastic Portion Length = **Ldi**

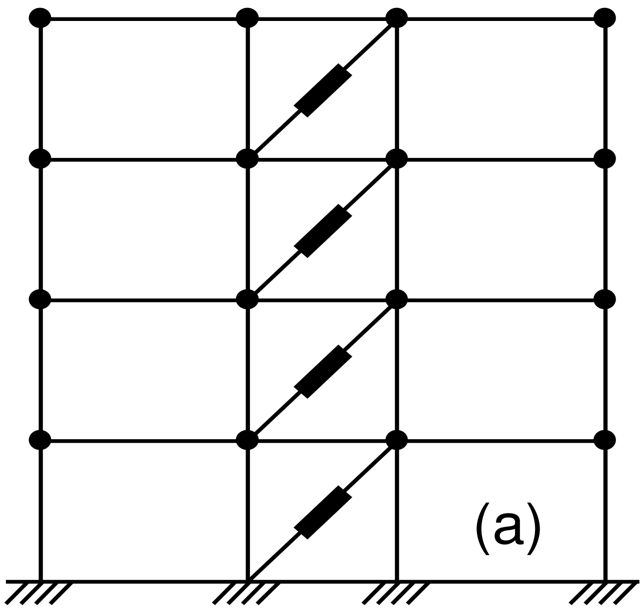
(LY225 Material or Others)

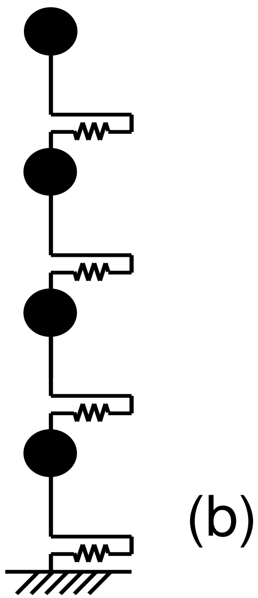



Manual Outline: Design
Given: Bldg. Config., Damper Type
Get: Frame, Stiffness, Period etc.
Set: Target Perform. (Drift, Acc.) against EQ. Levels
Get: Damper Sizes
Perform: Time History Analysis of Building Model
Evaluate: Building Performance
No
OK?
Yes
END

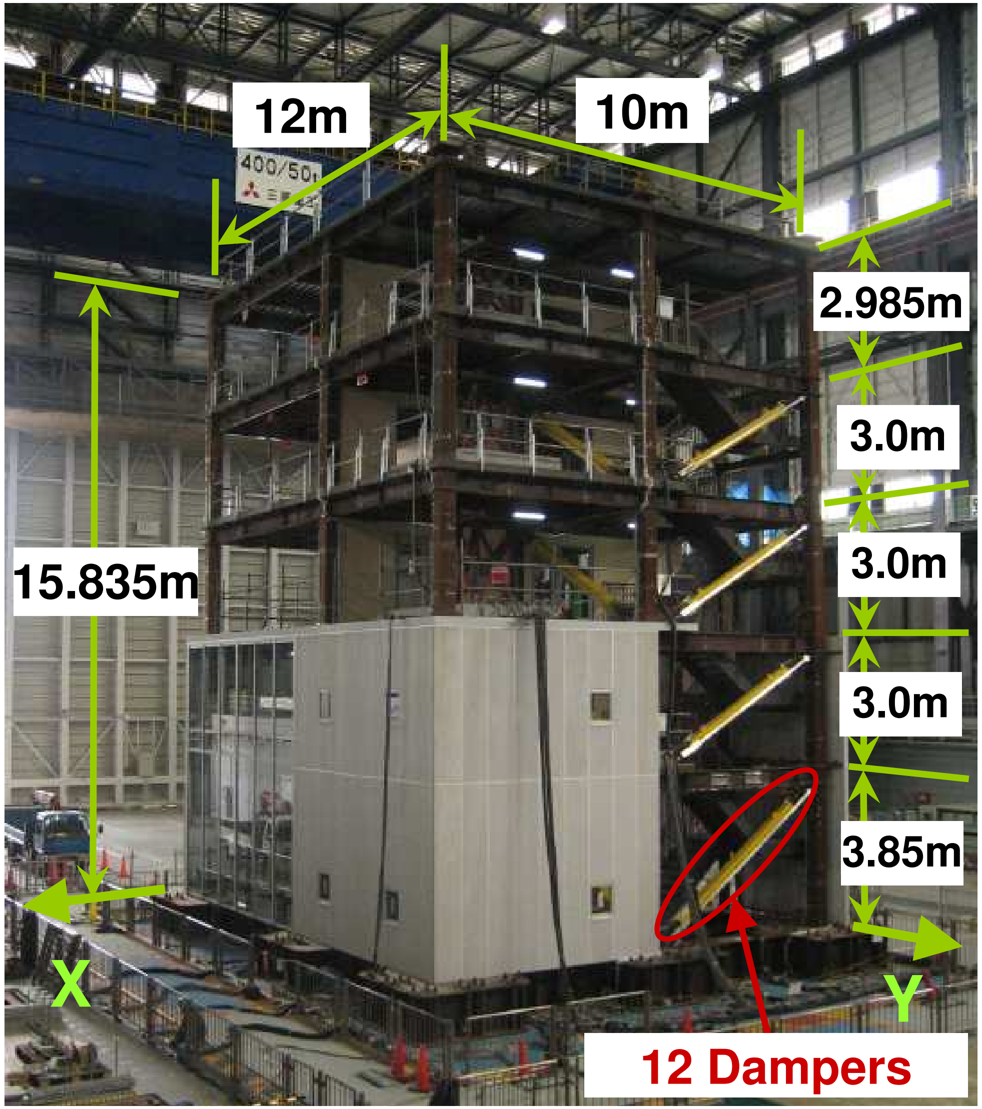
Dynamic Time History Analysis Methods (Detailed Analysis vs. Approx. Analysis)

(a) Member-to-Member Model (b) Stick Model





Full-Scale 5-Story Specimen



Square Section Col.：BCR295 □-350 1F:19,22(FA), 2～3F: 16,19(FA), 4～5F:12(FB)

Damper：**Steel, Viscous, Oil, Visco-Elastic**

Beam：SN490B

Undamped Bay（Beam End）

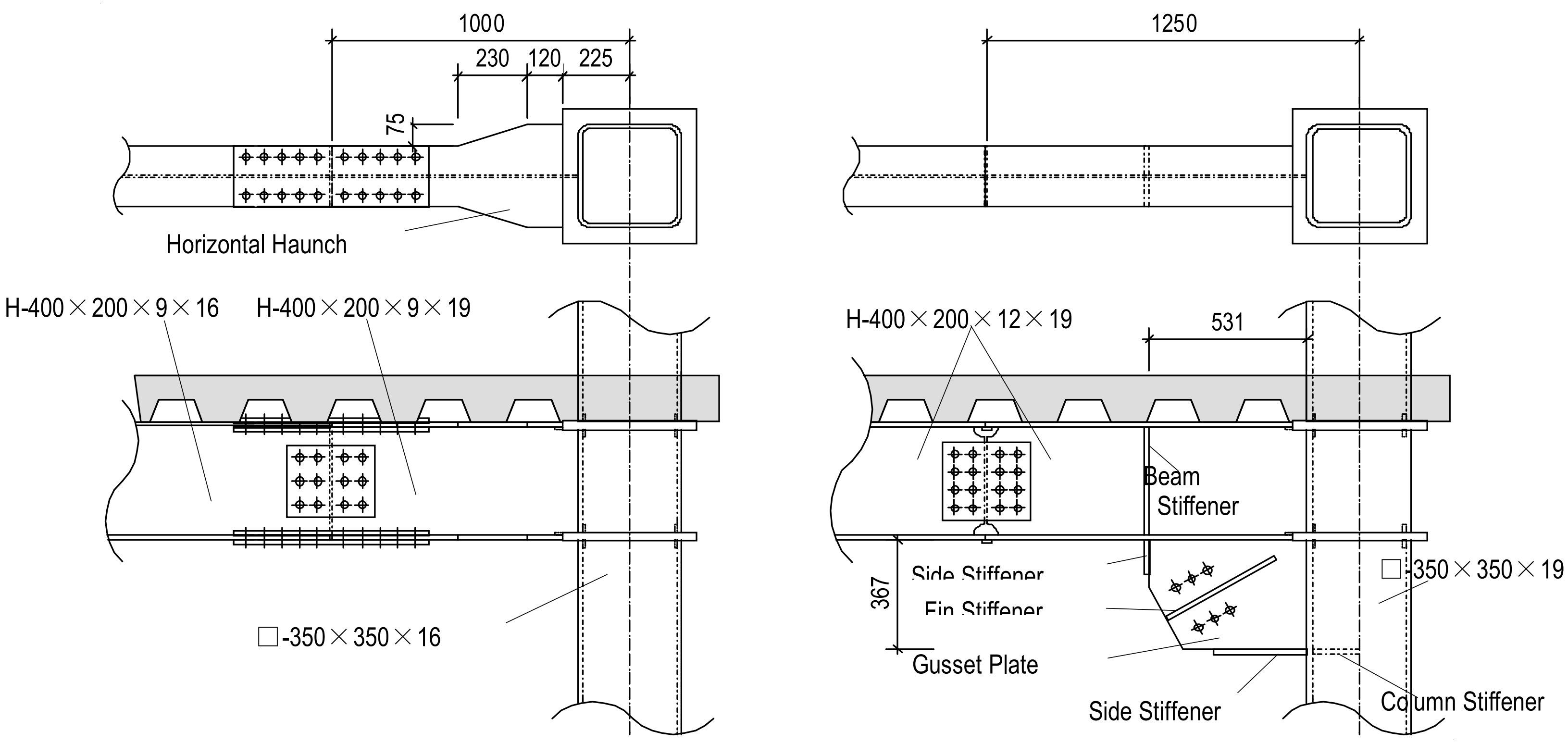
RF	H-400x200x9x12	(FB)
5F	H-400x200x9x16	(FA)
2～4F	H-400x200x9x19	(FA)

Damped Bay（Beam End）

RF	H-400x200x9x12	(FB)
5F	H-400x200x12x16	(FA)
4F	H-400x200x12x16,19	(FA)
3F	H-400x200x12x19,22	(FA)
2F	H-400x200x12x22	(FA)

Total Weight:580t（Including Foundation Beam）

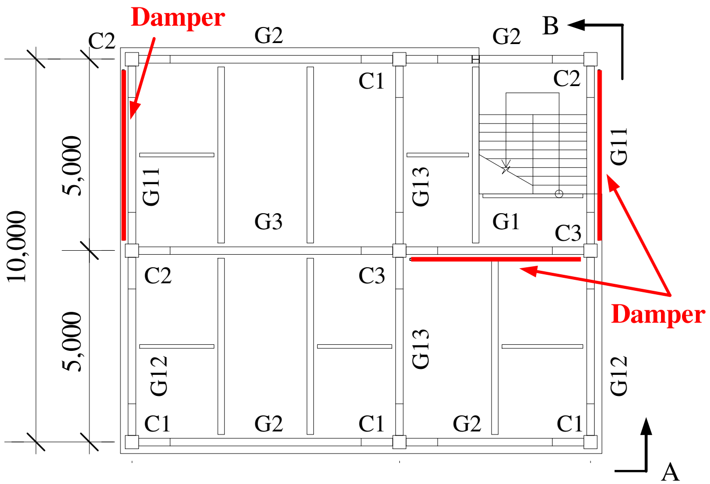
Beam-Column Joints (w.o. & w. Damper)



(A) BEAM-COLUMN-GUSSET CONNECTIONS (B) BEAM-COLUMN CONNECTIONS

Sample for Deformation Measurement (Oil Damper Case)

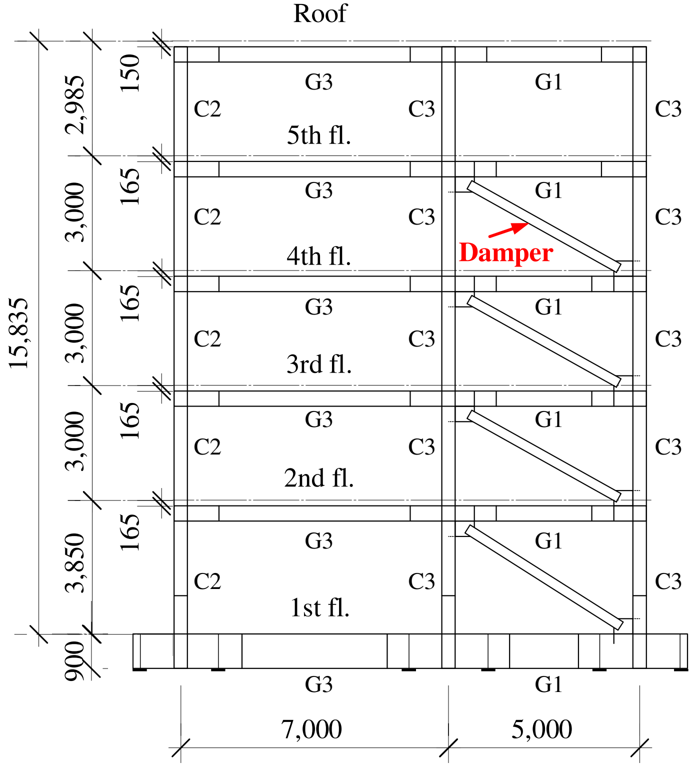
Full-Scale 5-Story Building with Dampers

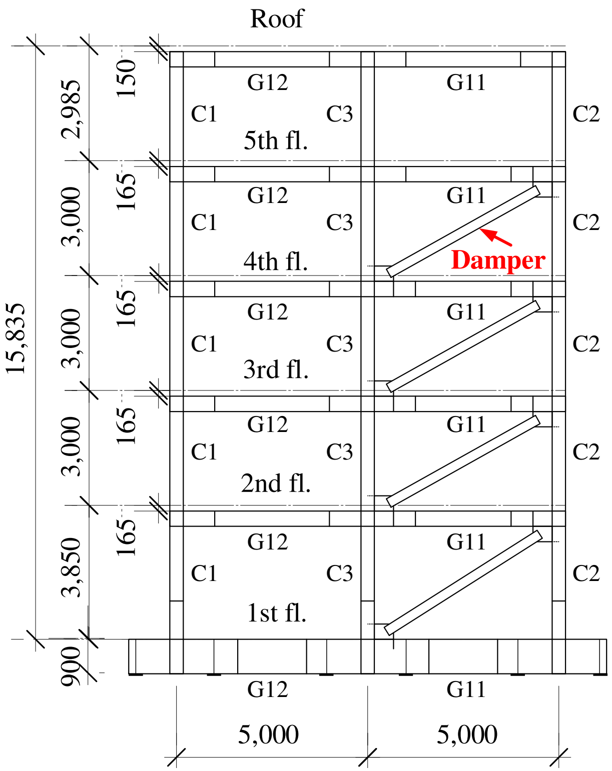


Seismically Active Wt .: 4,734 kN

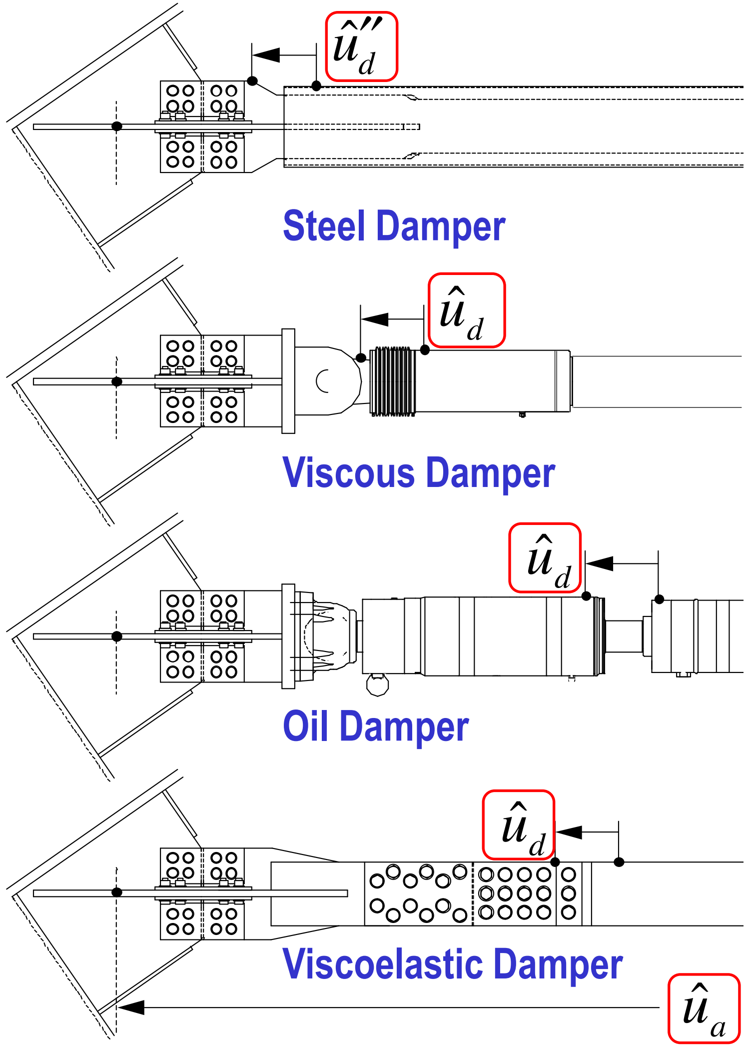
Frame Period: 0.74s (x), 0.79s(y)

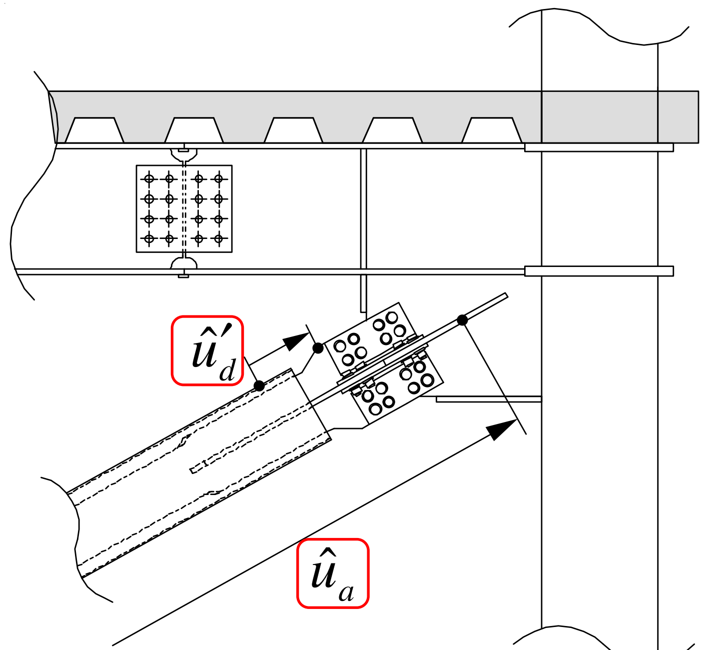
With Elast. Steel Damper: 0.53s (x), 0.56s(y)





Deformations of Dampers vs. Added Components





$\hat{u}_d = \hat{u}'_d + \hat{u}''_d$ (Summation of disp. of both ends, steel damper only)

$\hat{u}_a = \hat{u}_d$ + deformation of supporting members and connections

Major Damper Types Used in Japan

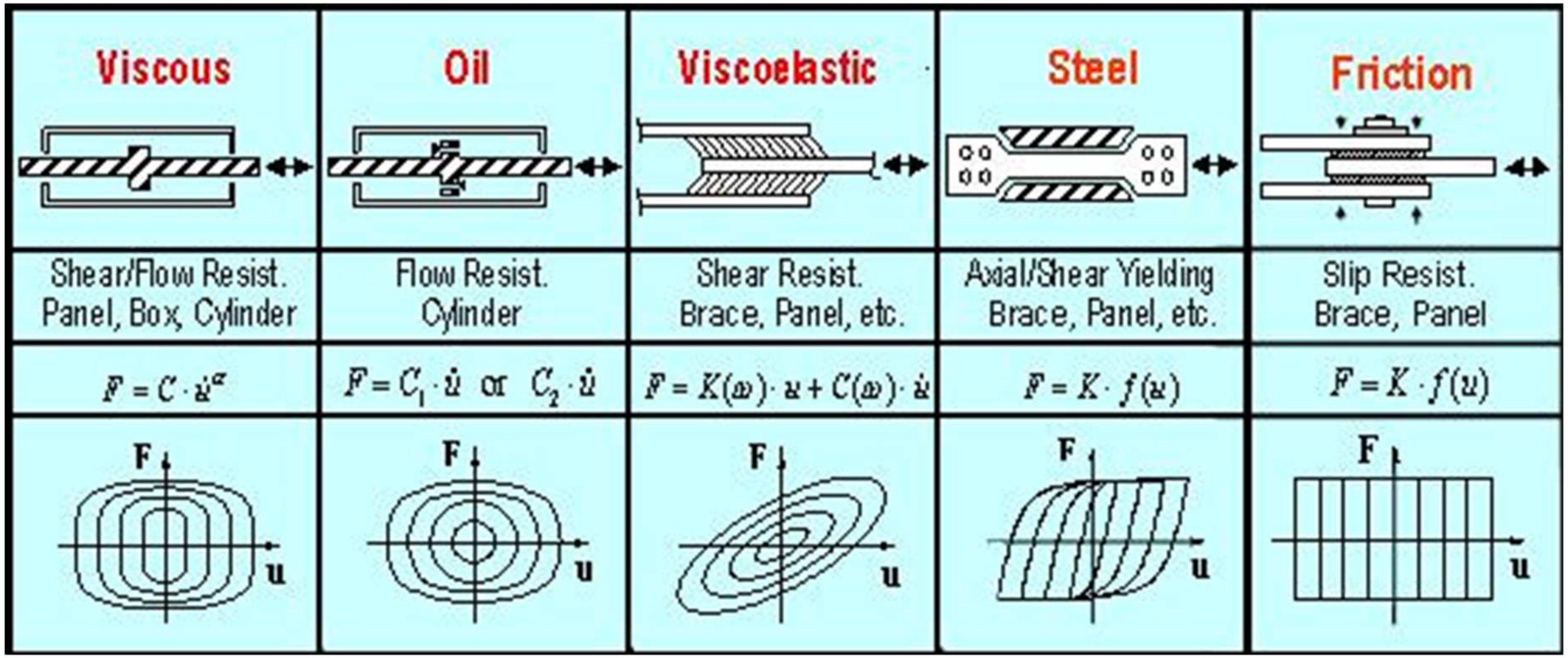
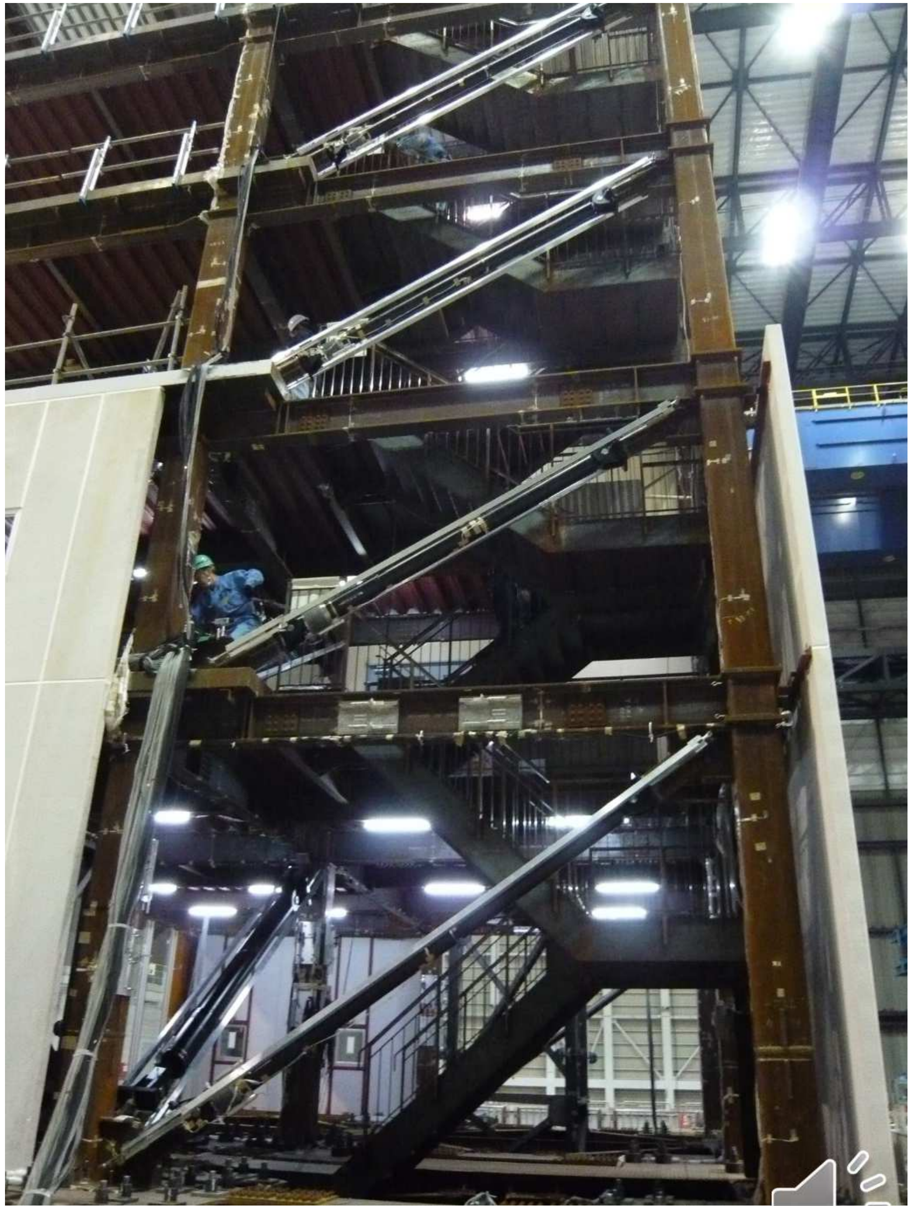


Fig. 4 Five Types of Dampers Considered by JSSI Manual

Five Major Damper Types Considered by JSSI Manual,
Japan Society for Seismic Isolation,
1st Edition and 2nd Editions, 2002, 2005, and 2007

Steel Dampers

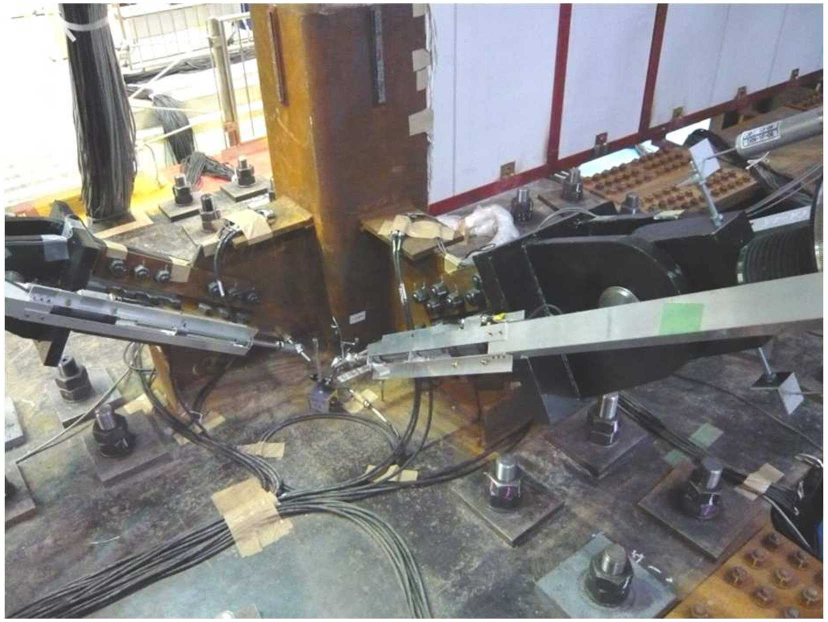


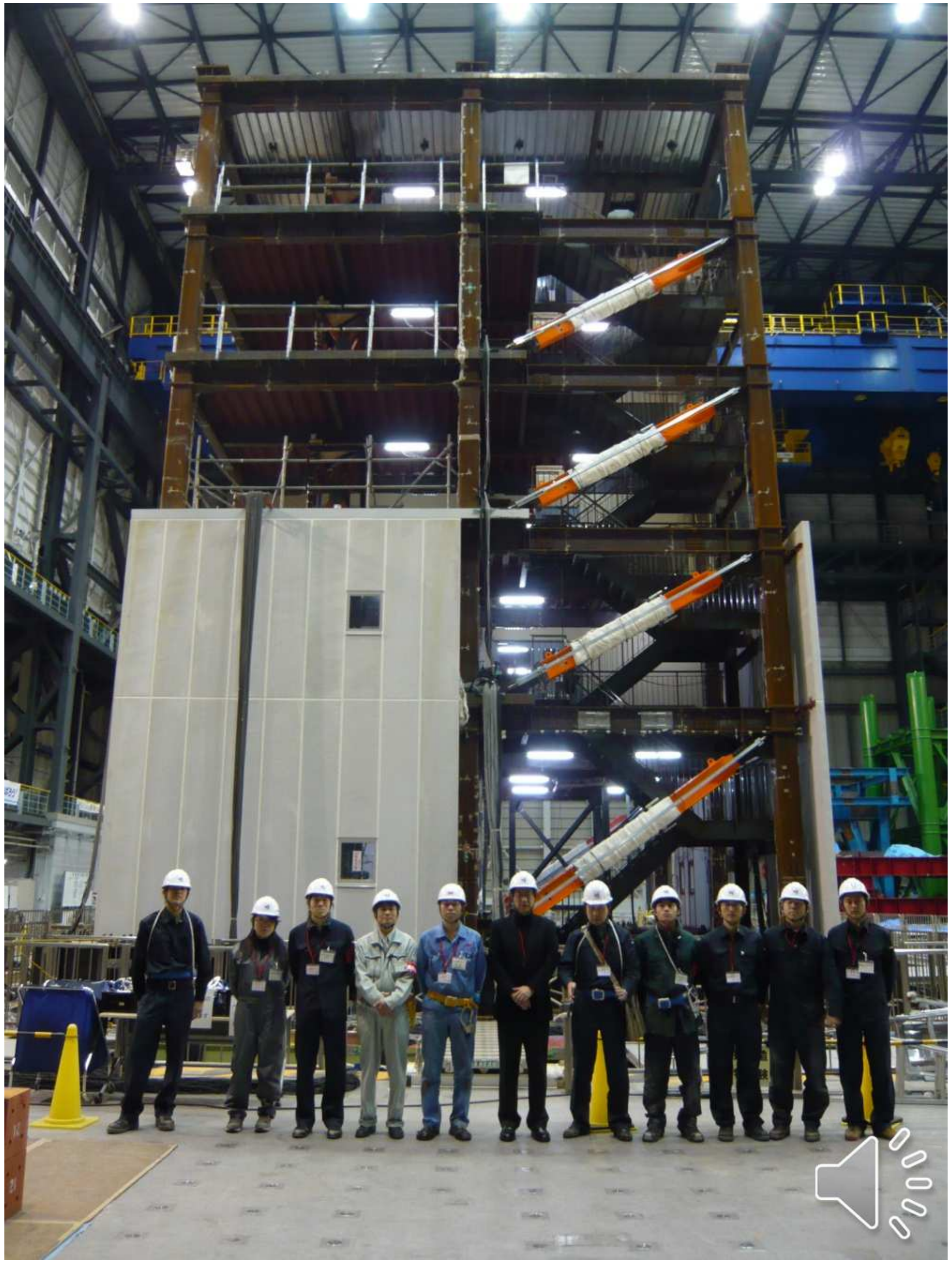
Viscous Dampers

Oil Dampers

Viscoelastic Dampers



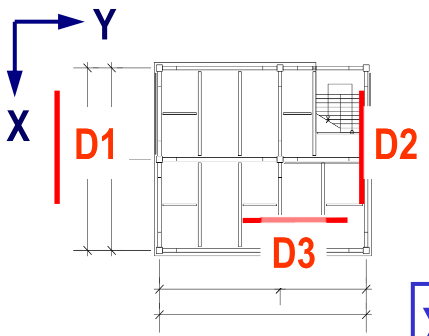
X1


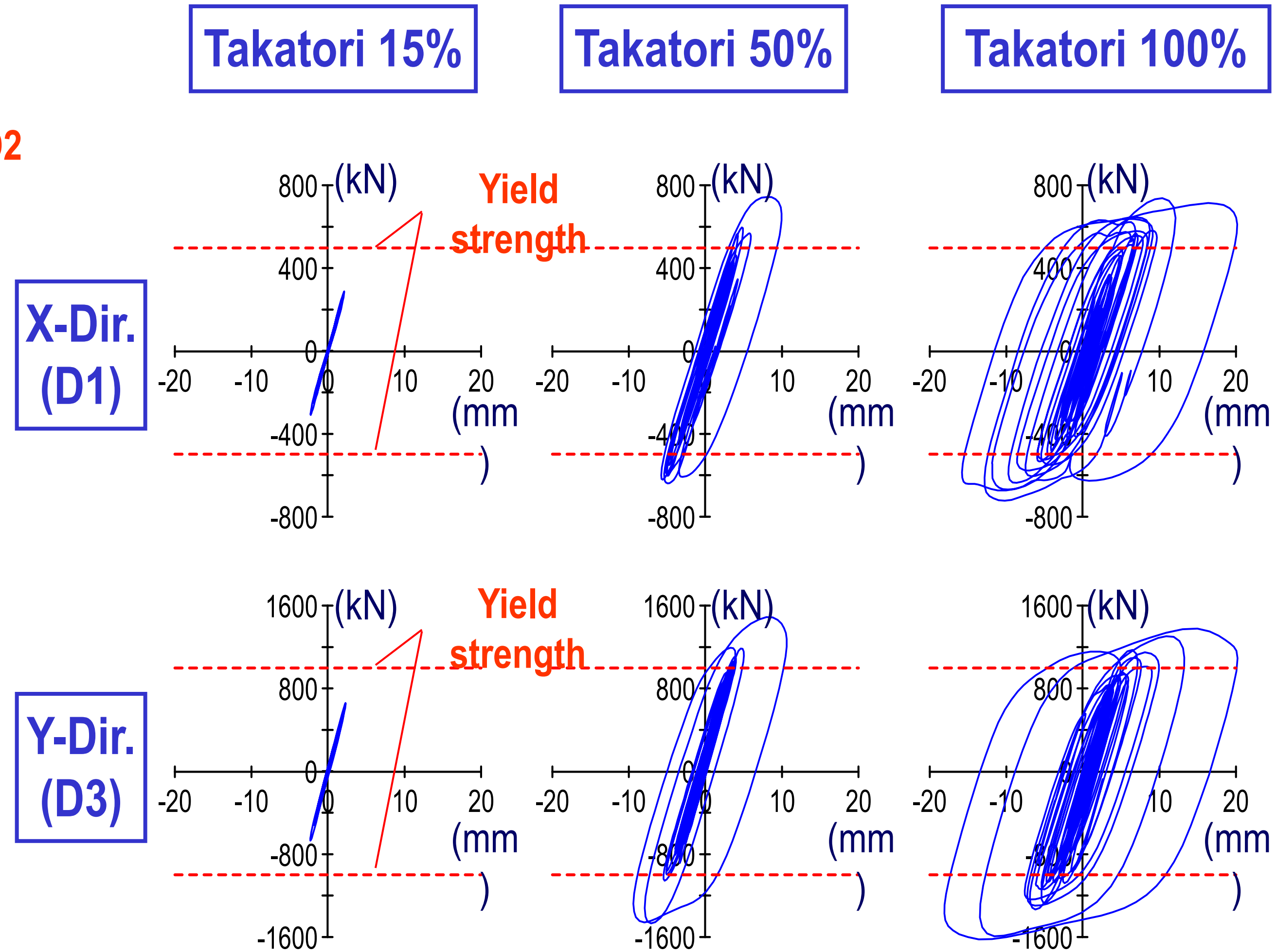




TCR 15:29.36.23


実大5層制振建物実験
Full-Scale 5-Story
Passively-Cotrolled Building Test
at E-Defense
(February.28～April.7,2009)

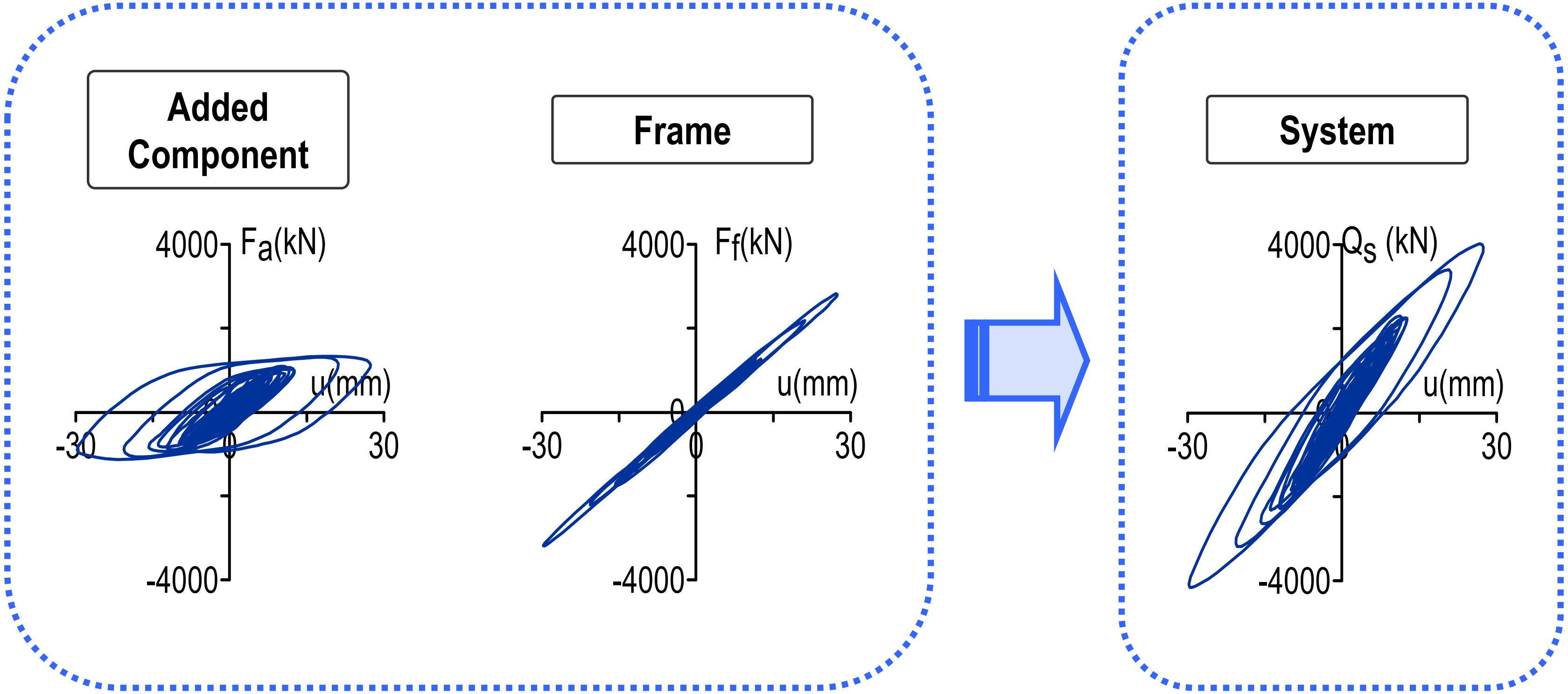
Hysteresis Curves of Dampers (Seel Dampers, 1st Story)



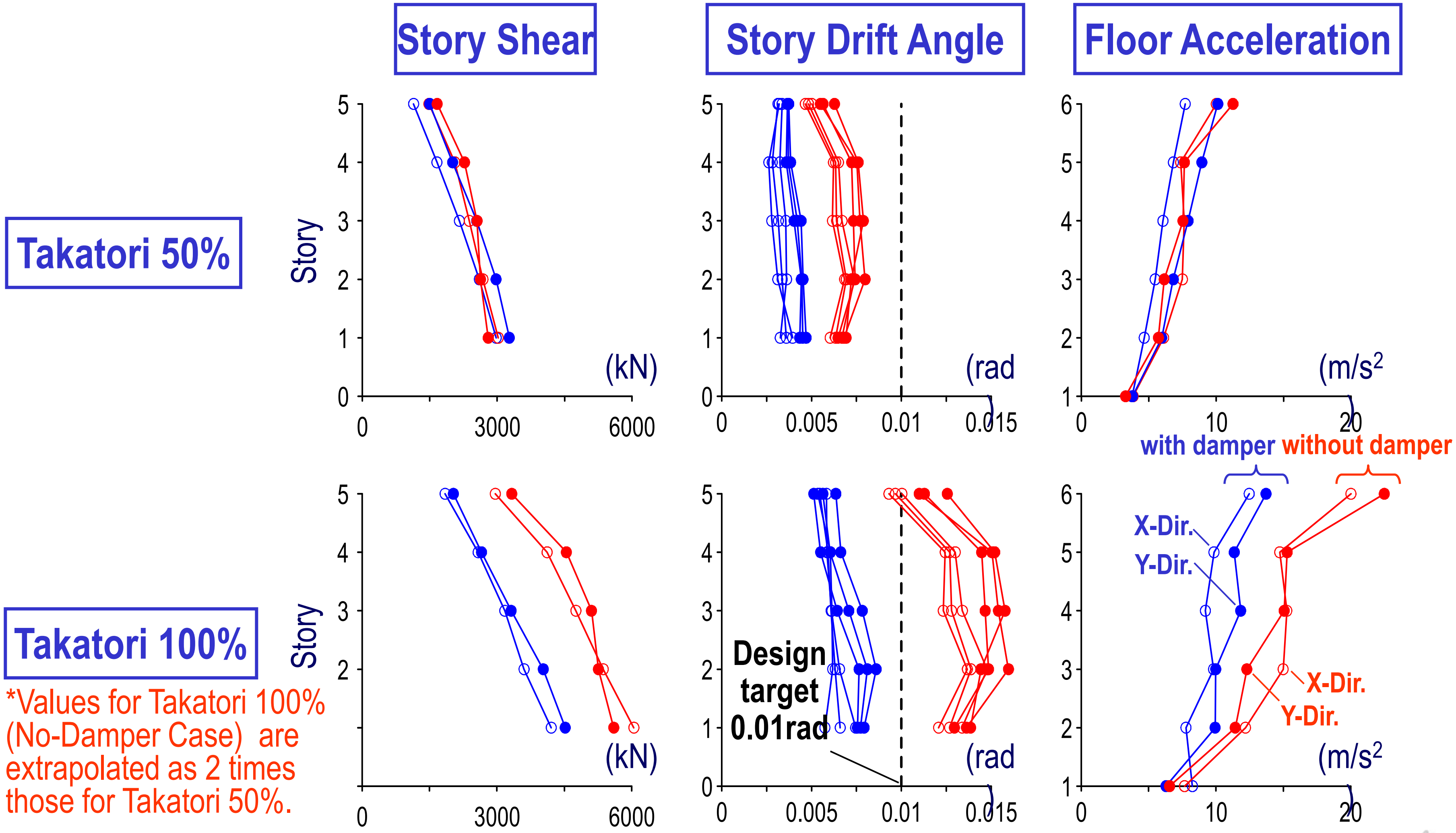


Measured Forces and Deformation (100% Takatori Ground Motion)

Added Component vs. Frame, and Total System (Y, 1st Story)



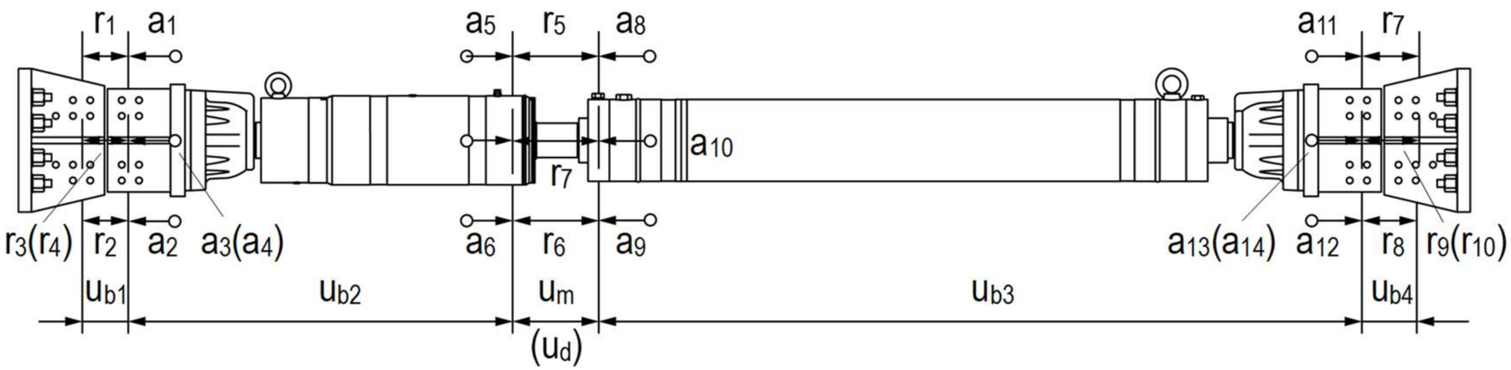
Maximum Reponses (Steel Damper Case vs. No-Damper Case)



*Values for Takatori 100% (No-Damper Case) are extrapolated as 2 times those for Takatori 50%.

Re-Testing of Dampers Used for 5-Story Bldg. (Steel Damper, Tokyo Tech.)

Full-Scale Damper Tests



$u_{b1} = (r_1+r_2+r_3+r_4)/4$

$u_{b2} = (a_1+a_2+a_3+a_4)/4+(a_5+a_6+a_7)/3$

$u_{b3} = (a_8+a_9+a_{10})/3+(a_{11}+a_{12}+a_{13}+a_{14})/4$

$u_{b4} = (r_7+r_8+r_9+r_{10})/4$

$u_m\ (u_d) = (r_5+r_6+r_7)/3$

Sample for Deformation Measurement (Oil Damper Case)

Conclusions

Seismic isolation systems and vibration control (VC) systems have become the standard technology to protect human lives, building functionality, and assets against major earthquakes.

VC systems are discussed, with emphasis on added damping and stiffness.

Full-scale tests results using the world's largest shake table (E-Defense) indicate significant benefit from using dampers.