Vibration Control Buildings in Japan

May 2017

Building Research Institute, Japan

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2. Basic concept of vibration control
3. Vibration control devices
4. Vibration control design
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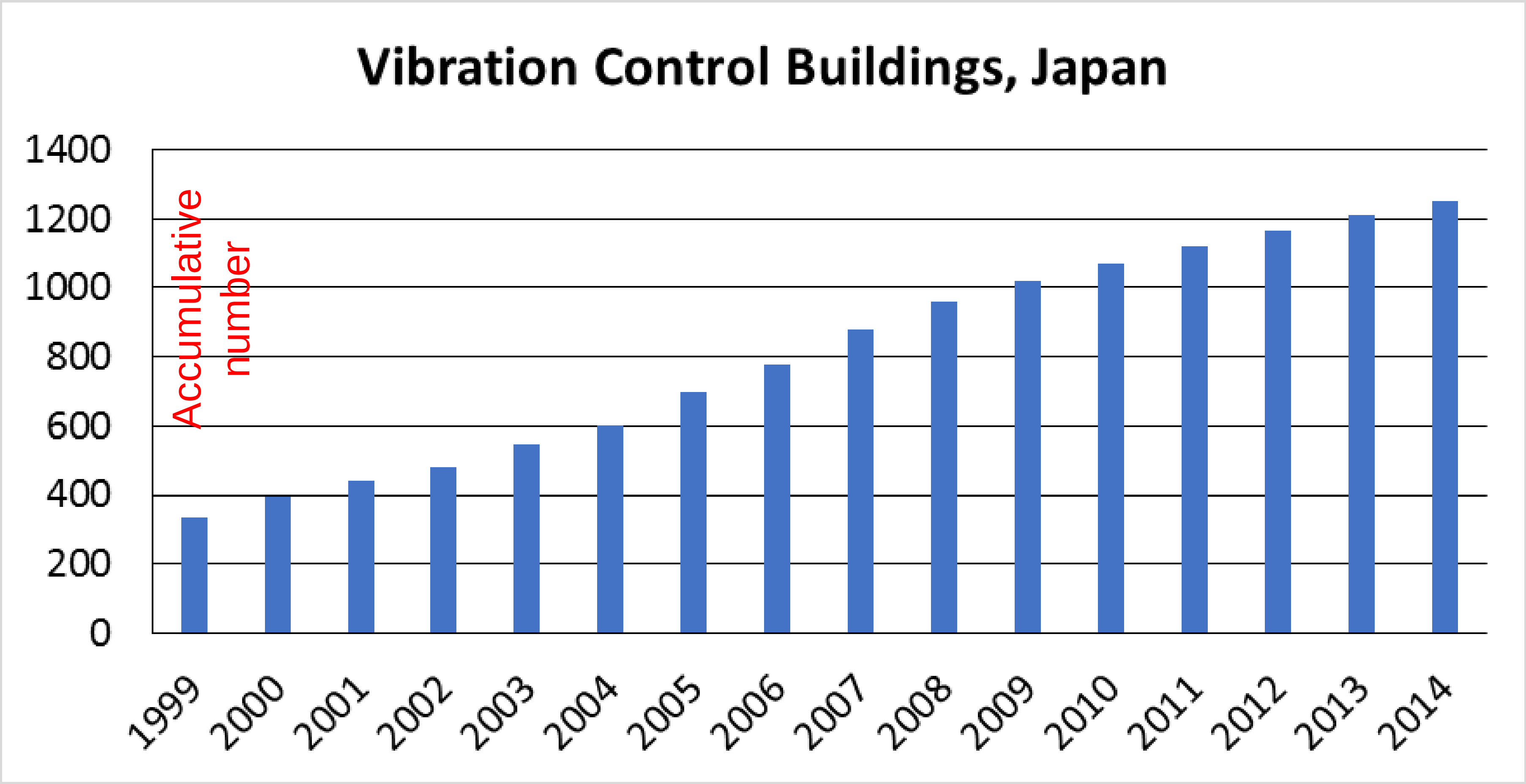
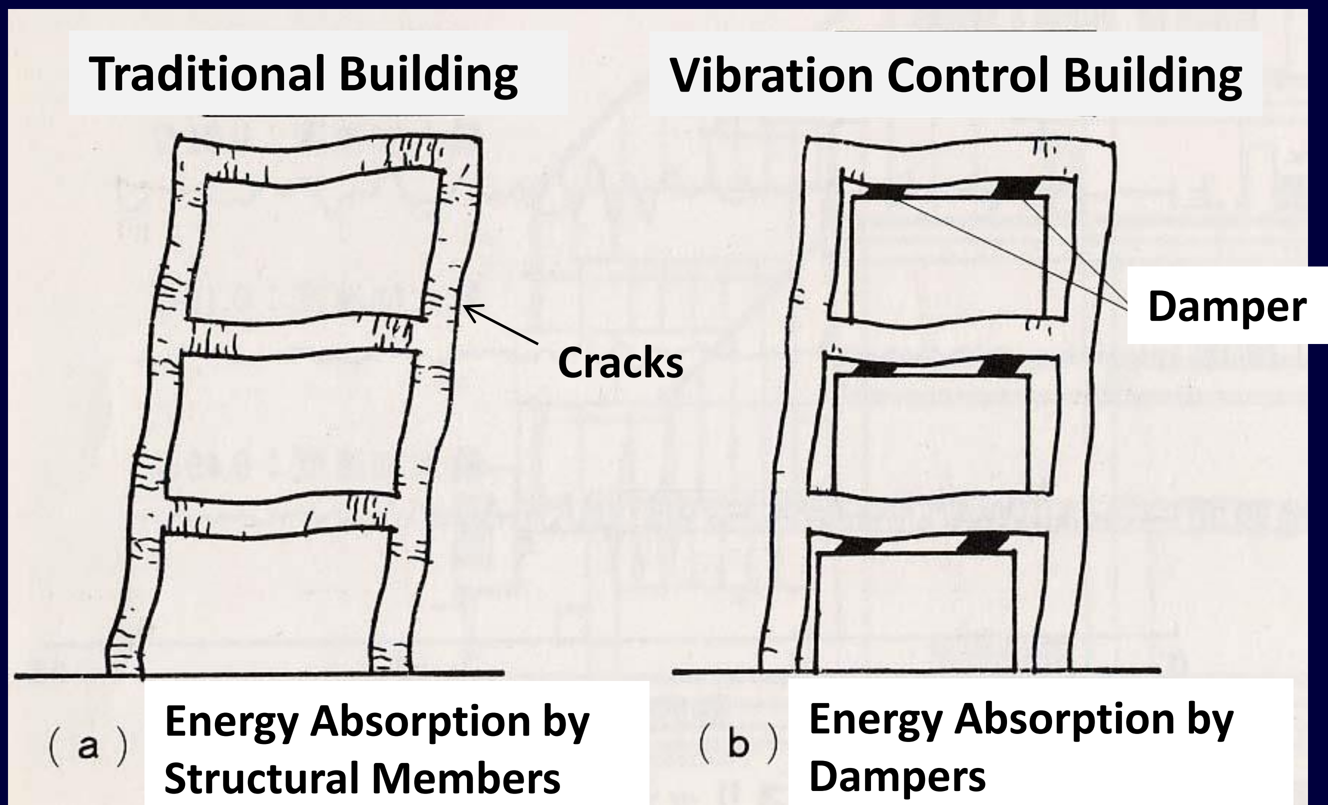
Vibration Control buildings in Japan



Seismic Isolation and Vibration Control

Principle of Vibration Control

Reduction of Response by dampers which absorb input energy



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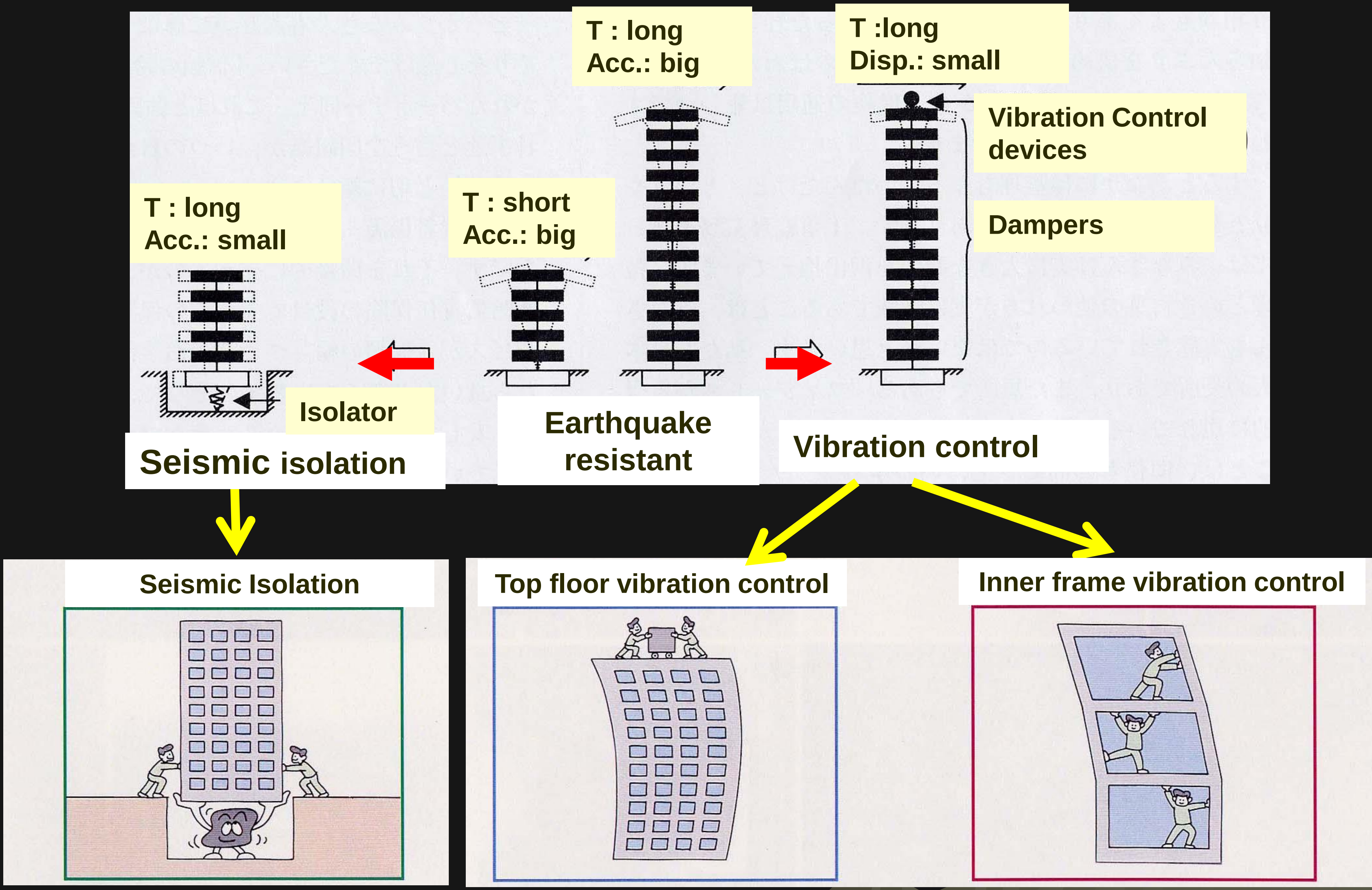
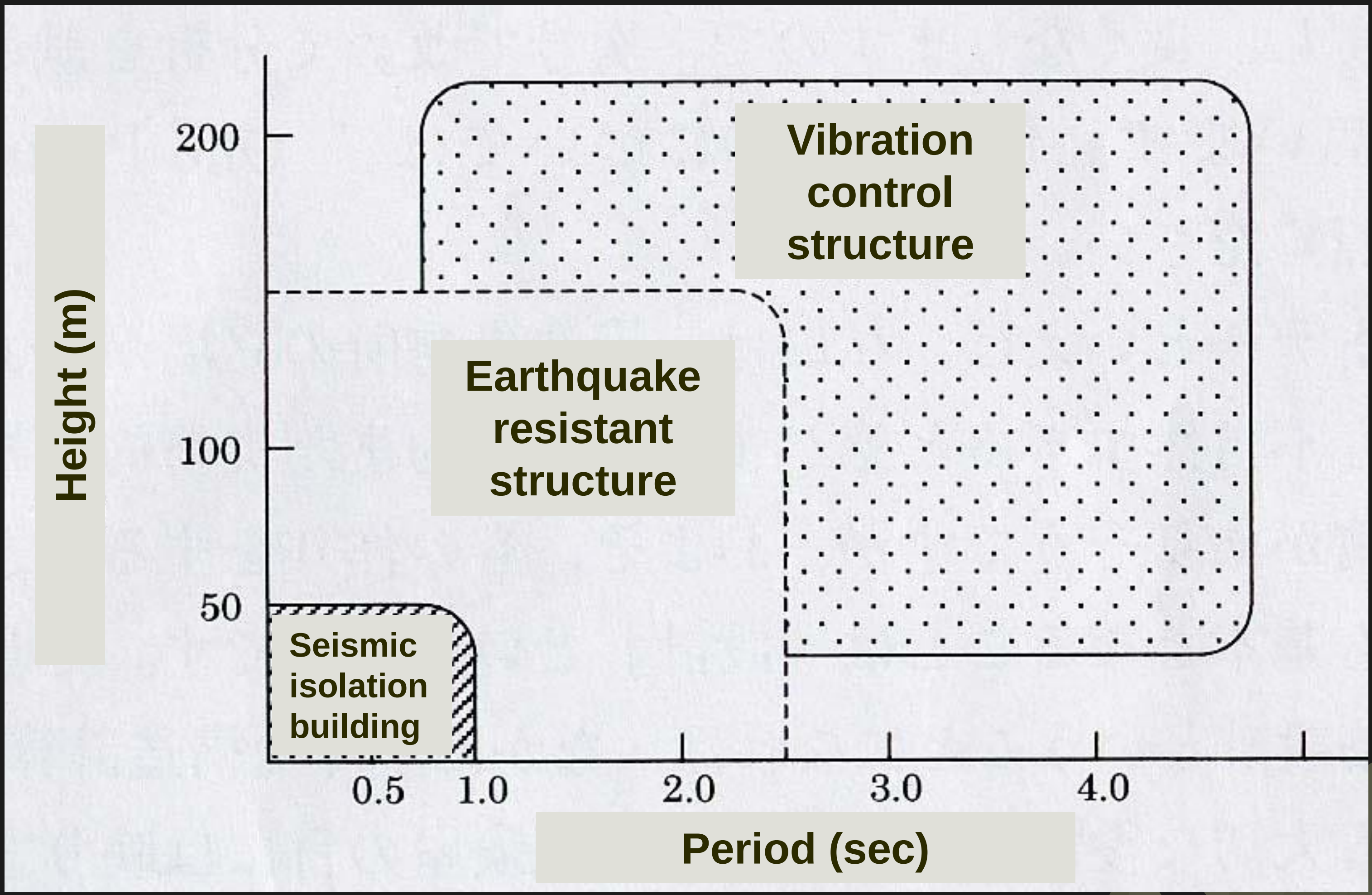
Basic Concept of Vibration Control



Basic Concept of Vibration Control

Recommended height and period of buildings



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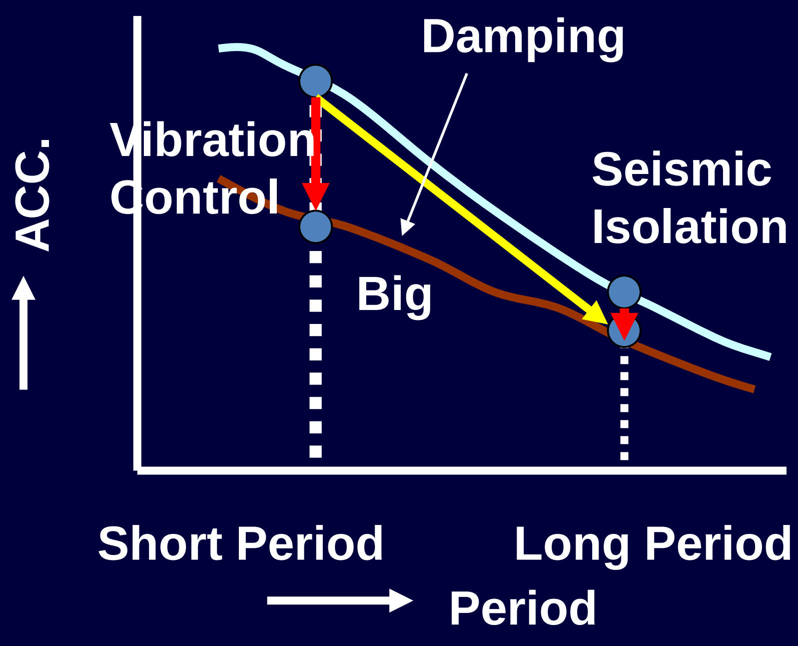
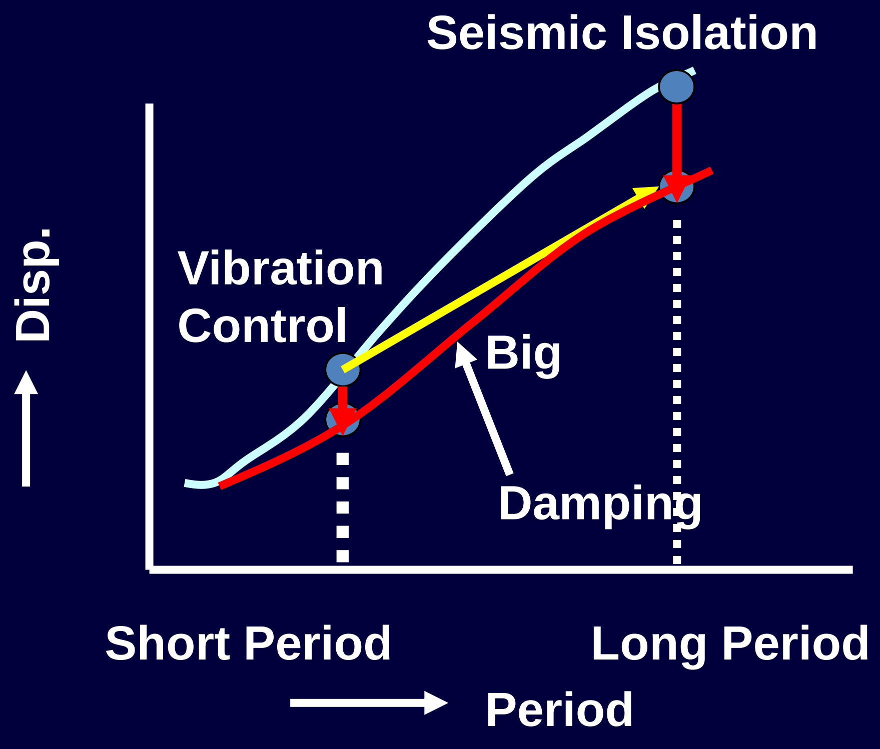
Principle of Seismic Isolation and Vibration Control





Response Acceleration **Response Displacement**

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Vibration Control Devices

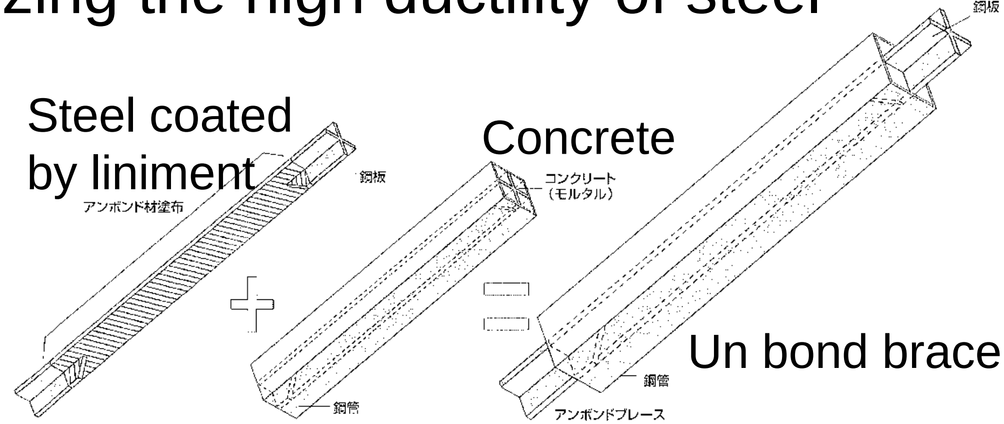
AIJ ,2007

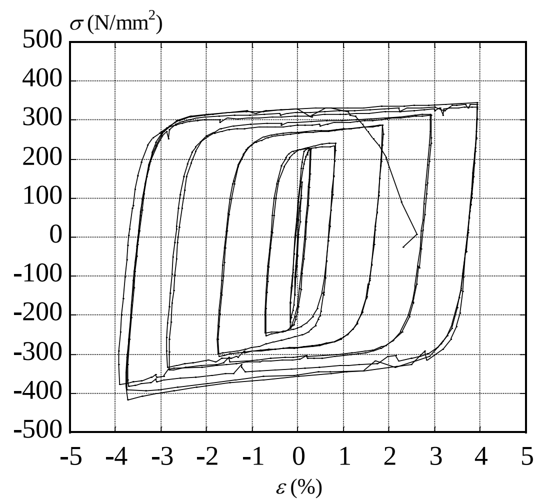
Mechanical Property	Devices
Displacement depended damping (Hysteresis) damping type	① Steel
	② Lead
	③ Friction
Velocity depended damping (Viscous damping type)	④ Oil
	⑤ Viscous
	⑥ Visco-elastic

■ Displacement depended damper

①Steel Damper

Utilizing the high ductility of steel



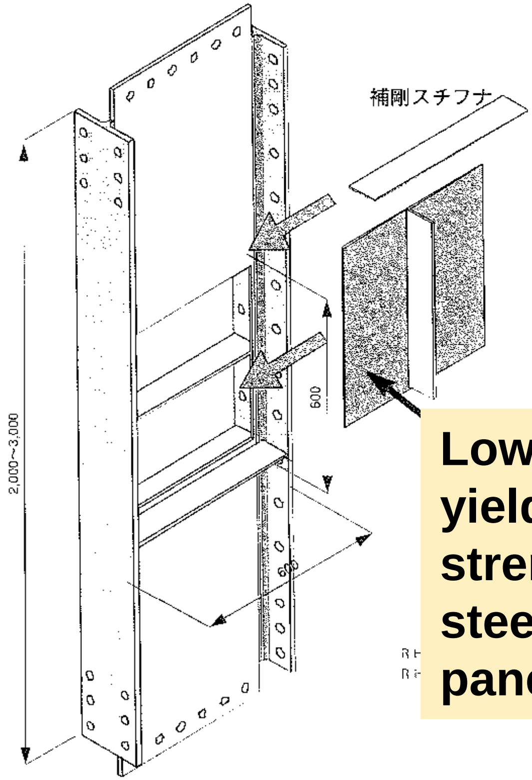


Buckling restrain brace

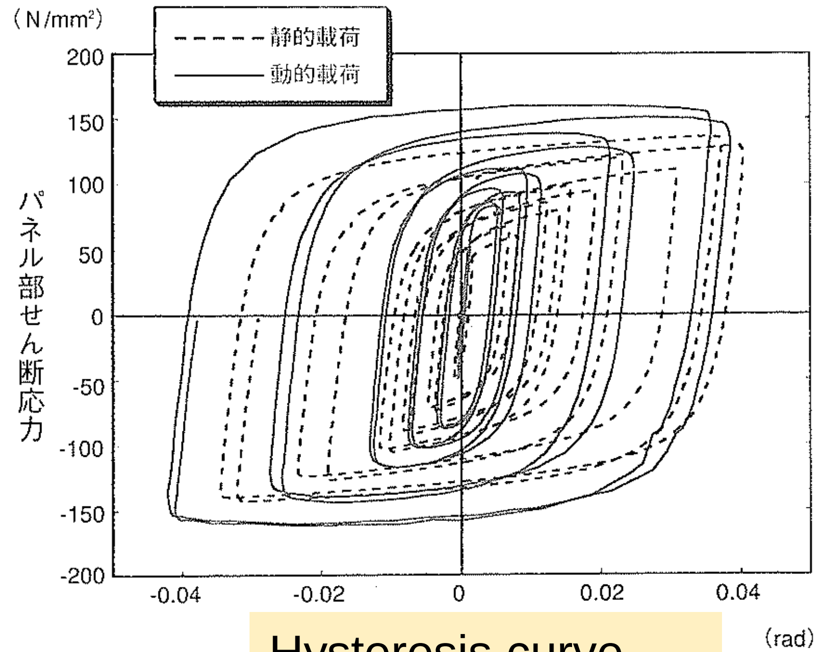
Hysteresis curve

■ Displacement depended damper

① Steel Damper



Low yielding strength steel panel



Hysteresis curve

Column type shear panel

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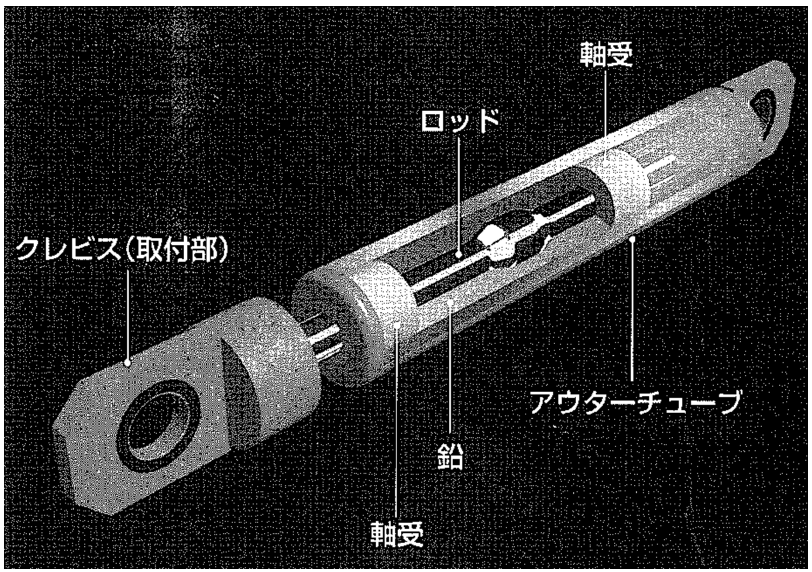
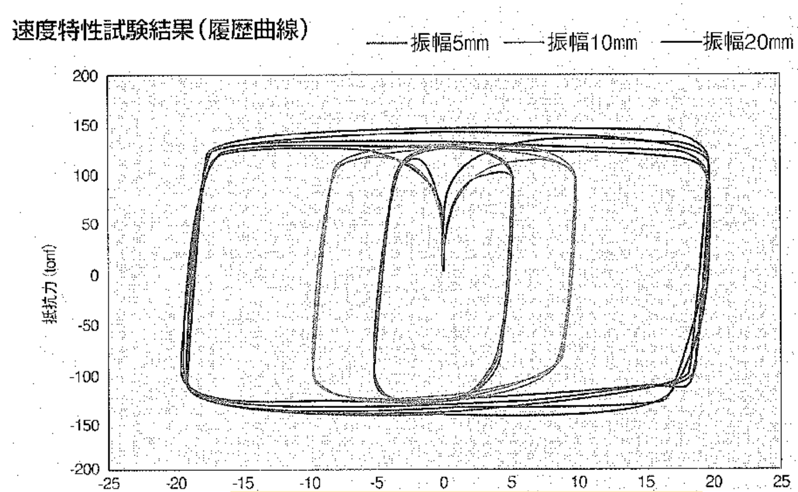
■ Displacement depended damper

②鉛ダンパー

Utilizing the high ductility of lead
Utilizing the plastic fluid resistant of lead



Lead Damper (Cylinder type)



Hysteresis curve

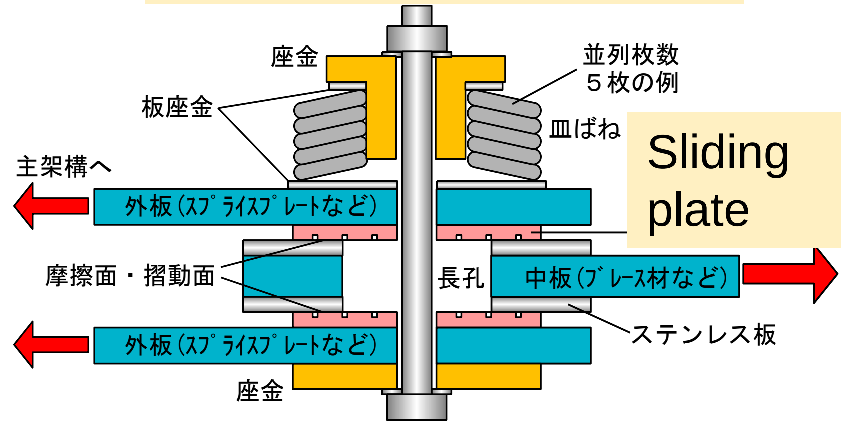
■ Displacement depended damper

③Friction damper

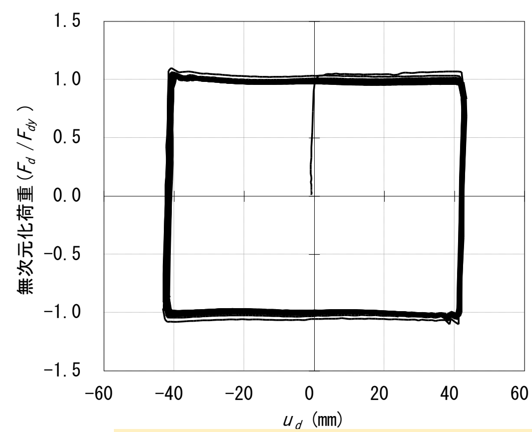
Transforming vibration energy into thermal energy

Friction damper (Bolt system）

Plate spring +bolt system



Sliding plate

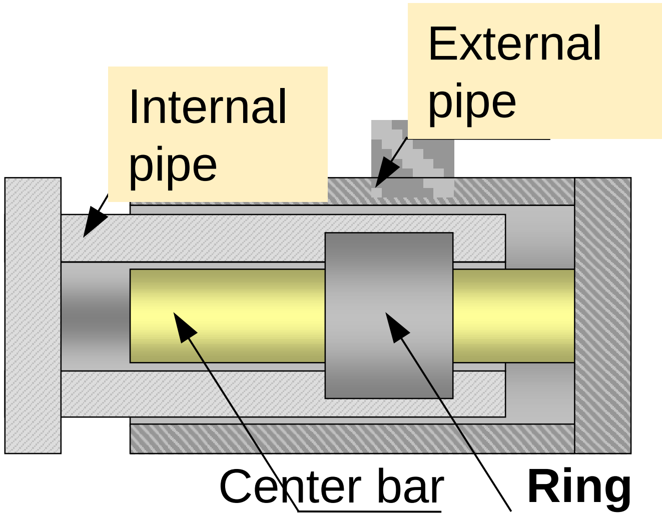


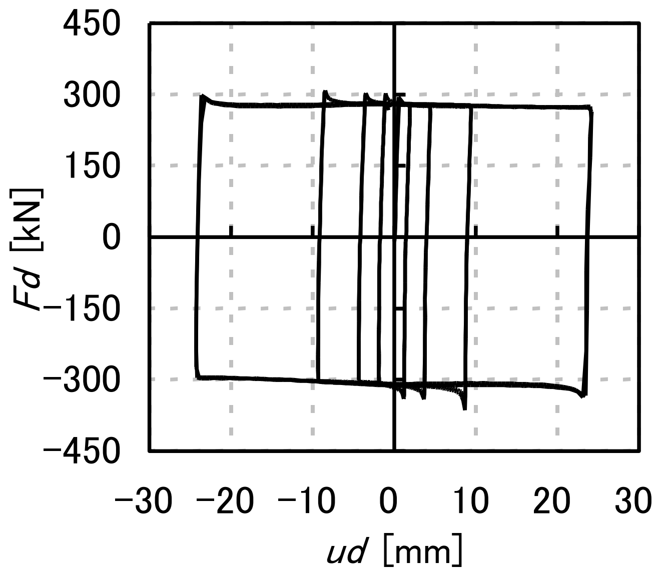
Hysteresis curve

■ Displacement depended damper

③Friction Damper

Transforming vibration energy into thermal energy





Friction Damper (Ring system)

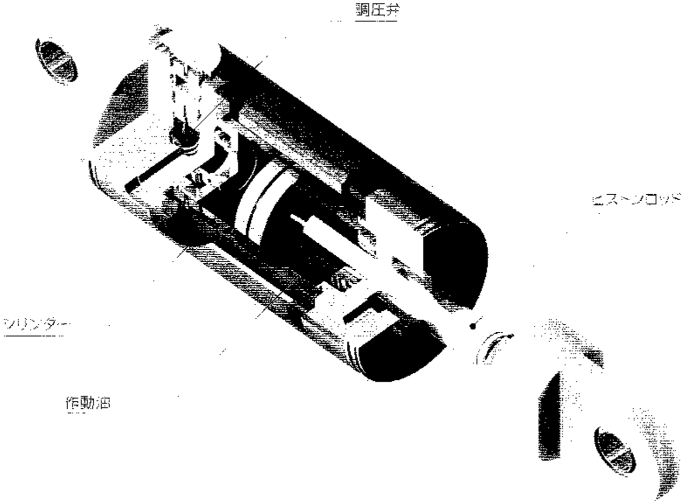
Hysteresis curve

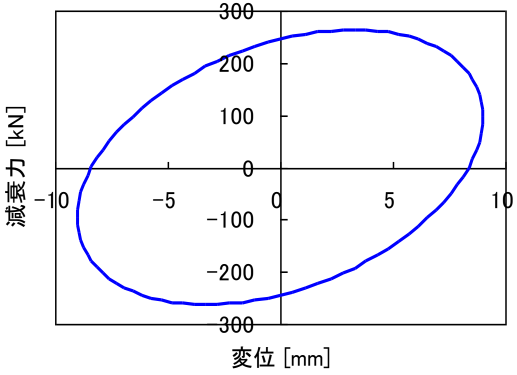
■ Velocity depended damper

① Oil Damper

Utilizing the fluid resistance of oil

Oil Damper



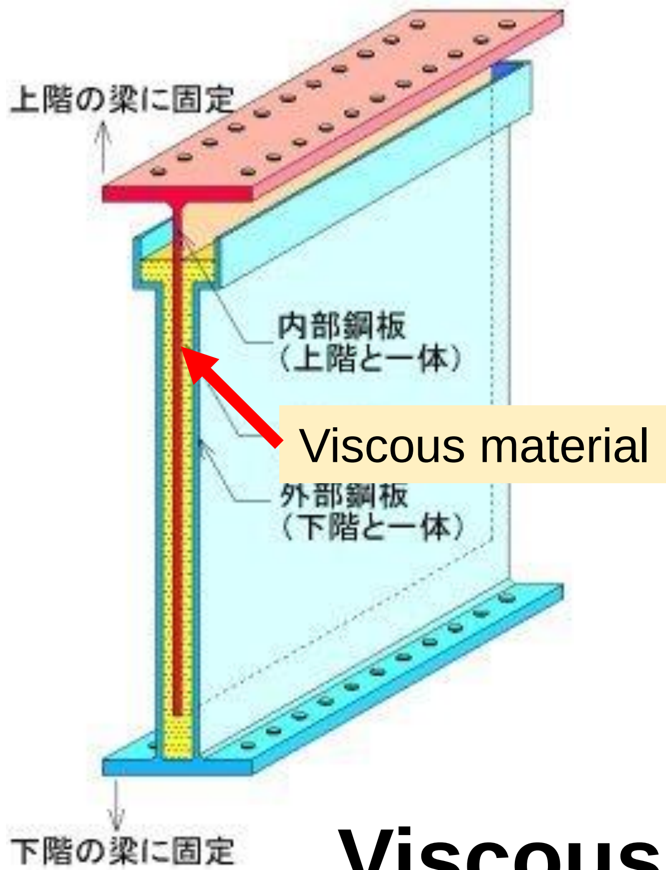


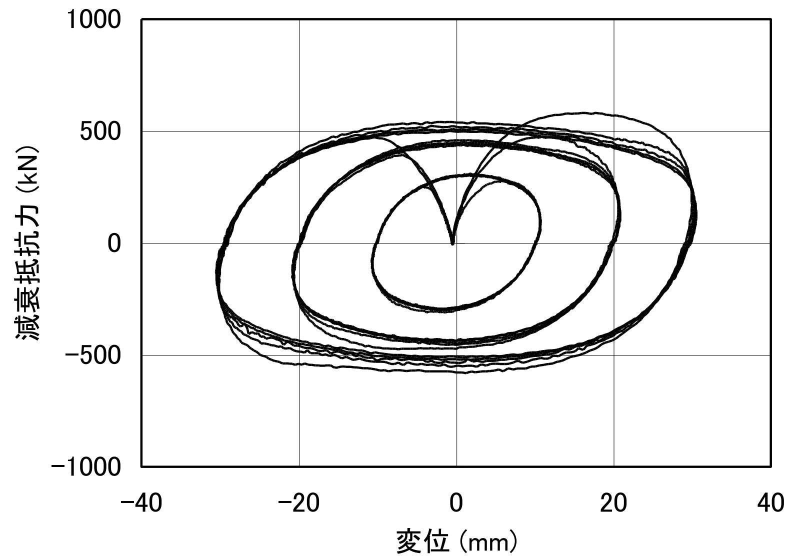
Hysteresis curve

■ Velocity depended damper

② Viscous Damper

Utilizing the shear resistance of polymer material



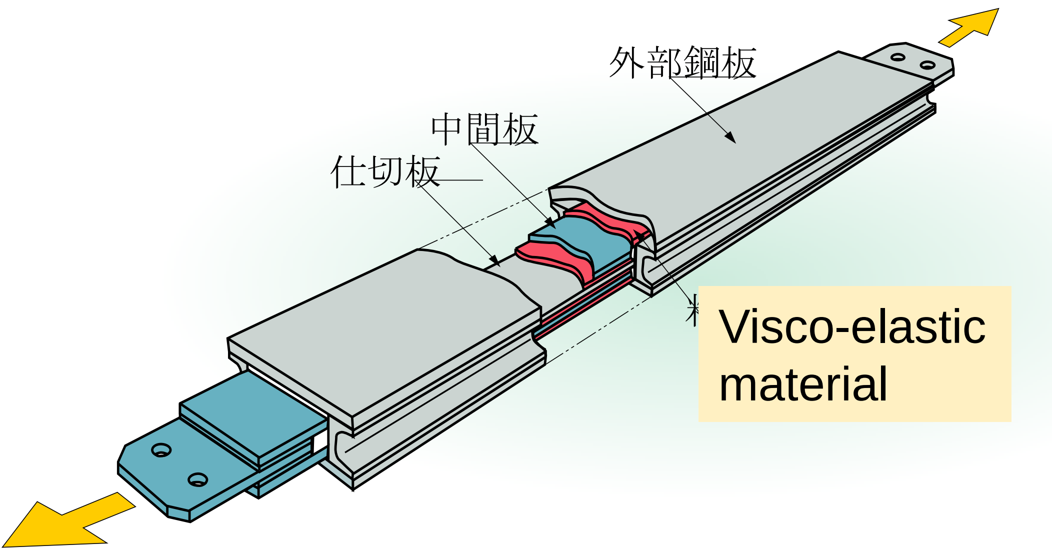


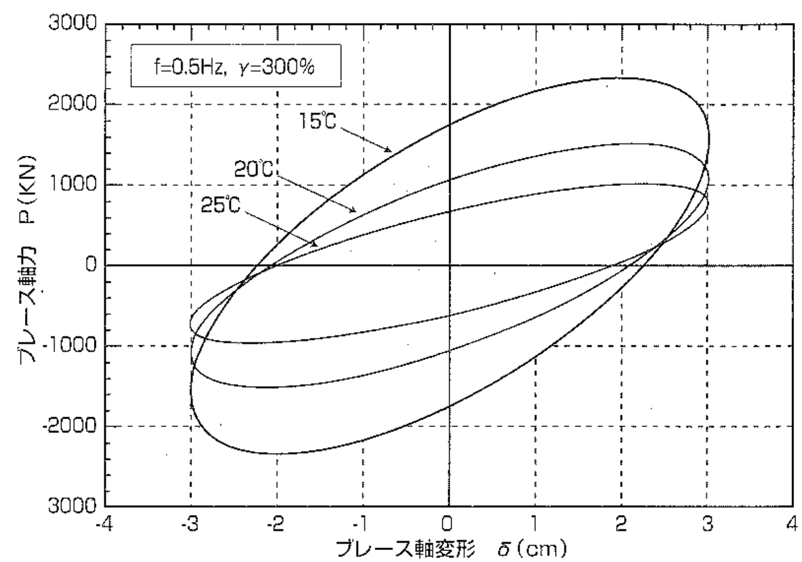
Viscous Damper（wall type）

■ Velocity depended damper

③ Visco-Elastic damper

Utilizing the shear resistance of visco−elastic material



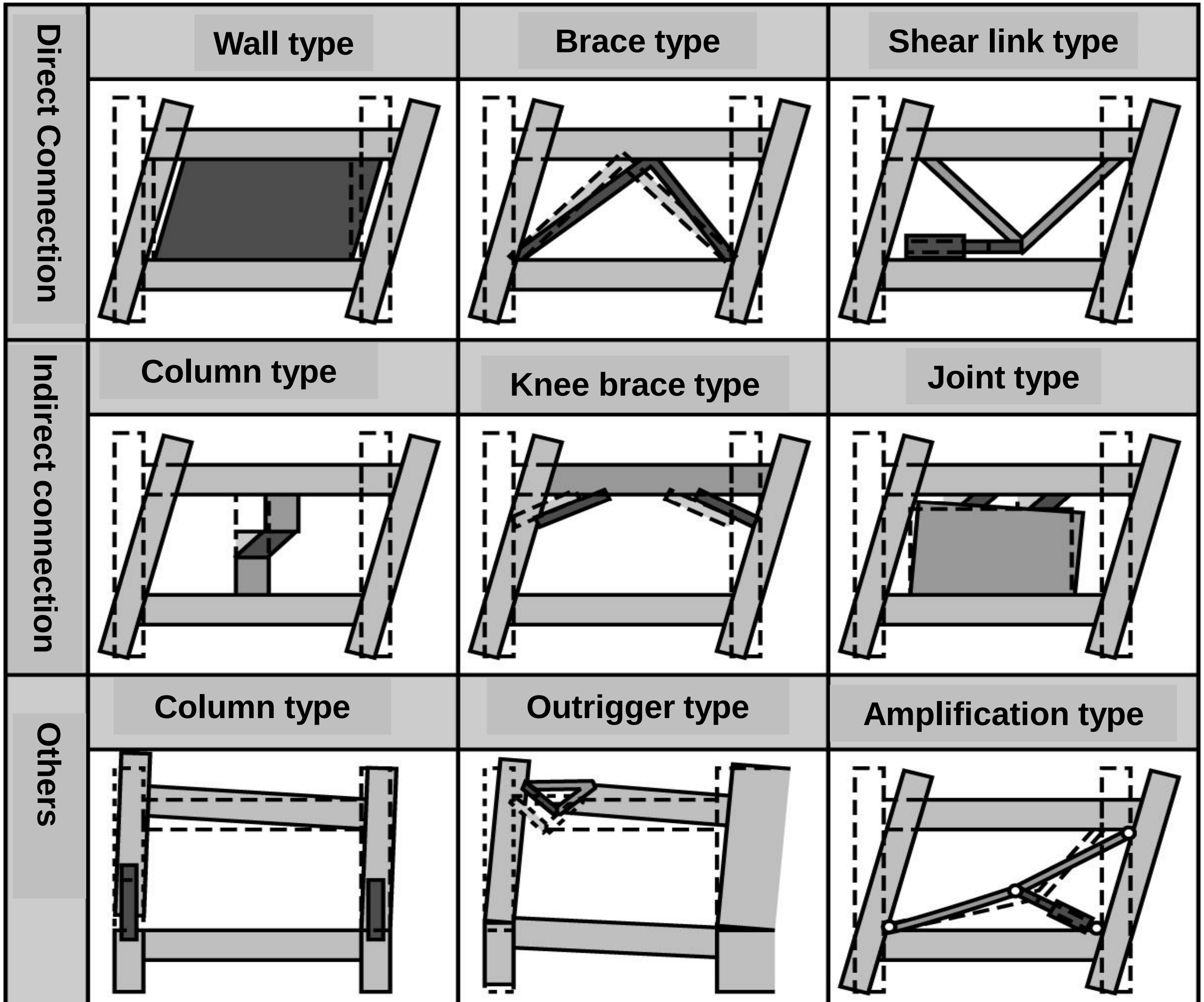


Hysteresis curve

Visco-elastic damper

日本建築学会関東支部:免震･制振構造の設計2007年、4章

Installation of Devices



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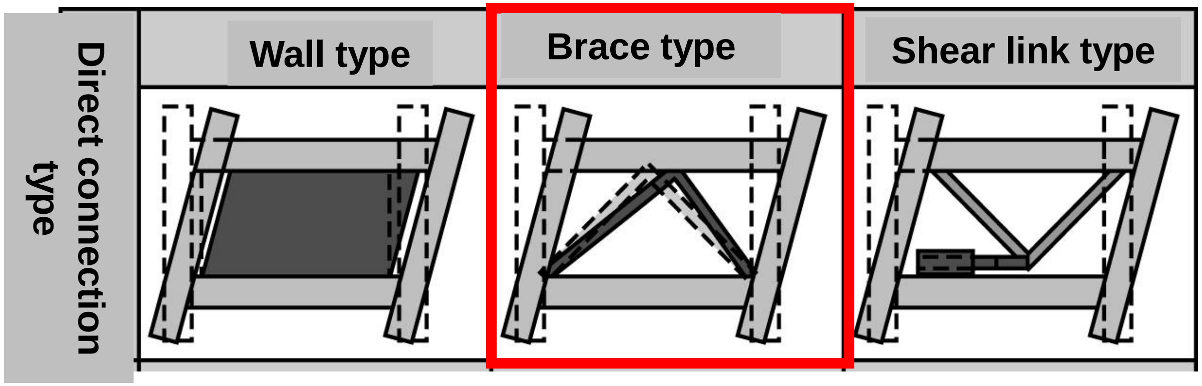
Installation of Devices



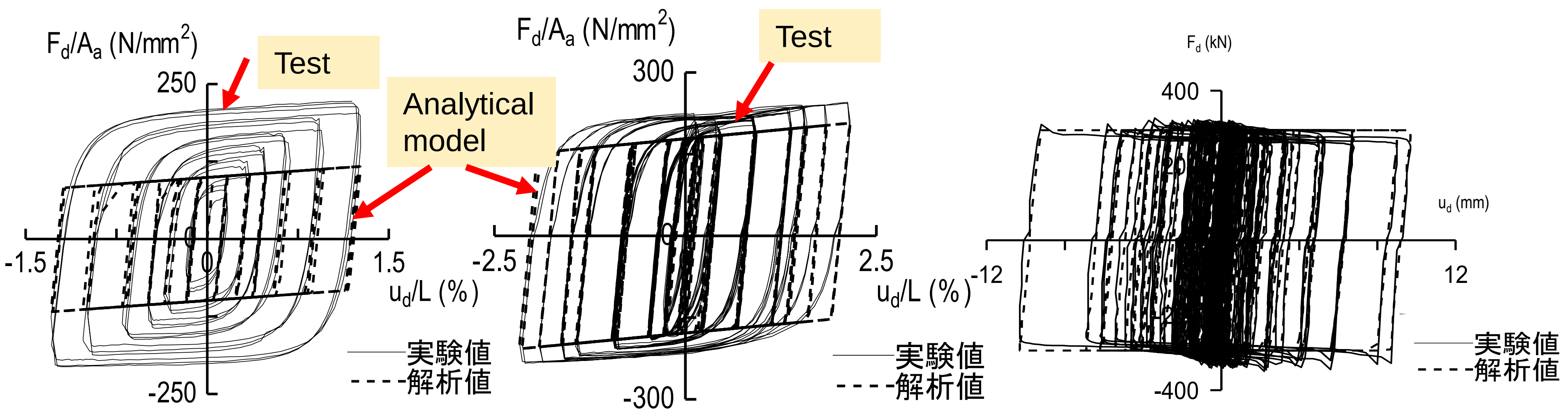
Buckling restrain brace

Friction damper brace

Oil damper brace

Analytical modeling of devices

(1)Displacement depended damper



(a) Buckling restrain brace (LY100)

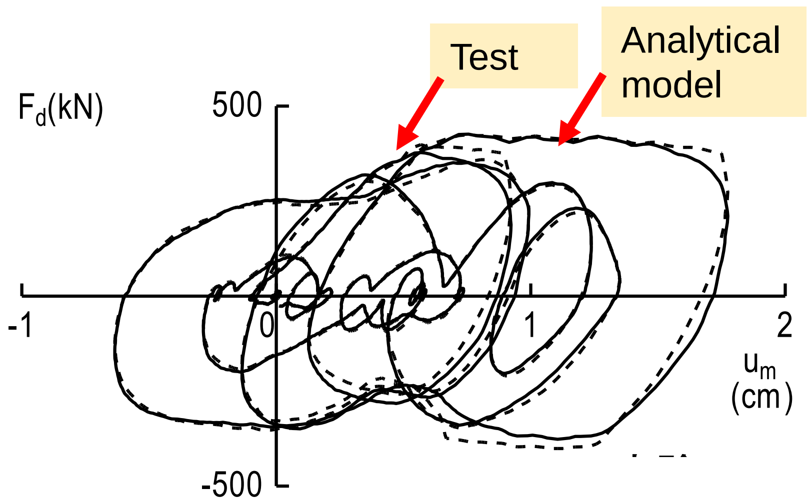
(b)Buckling restrain brace (LY225)

(c)Friction damper

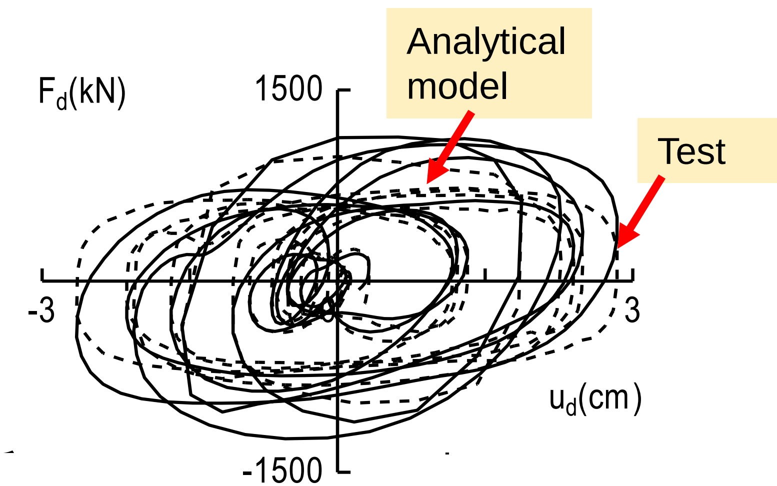
Comparison of analytical model and test result (steel damper and Friction damper)

Analytical modeling of devices

(2) Velocity depended damper



(a)Oil damper (with relief valve)



(b) Viscous damper (wall type)

Comparison of analytical model and test result
(Oil damper and Viscous damper)

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Structural Design of Vibration Control Buildings in Japan

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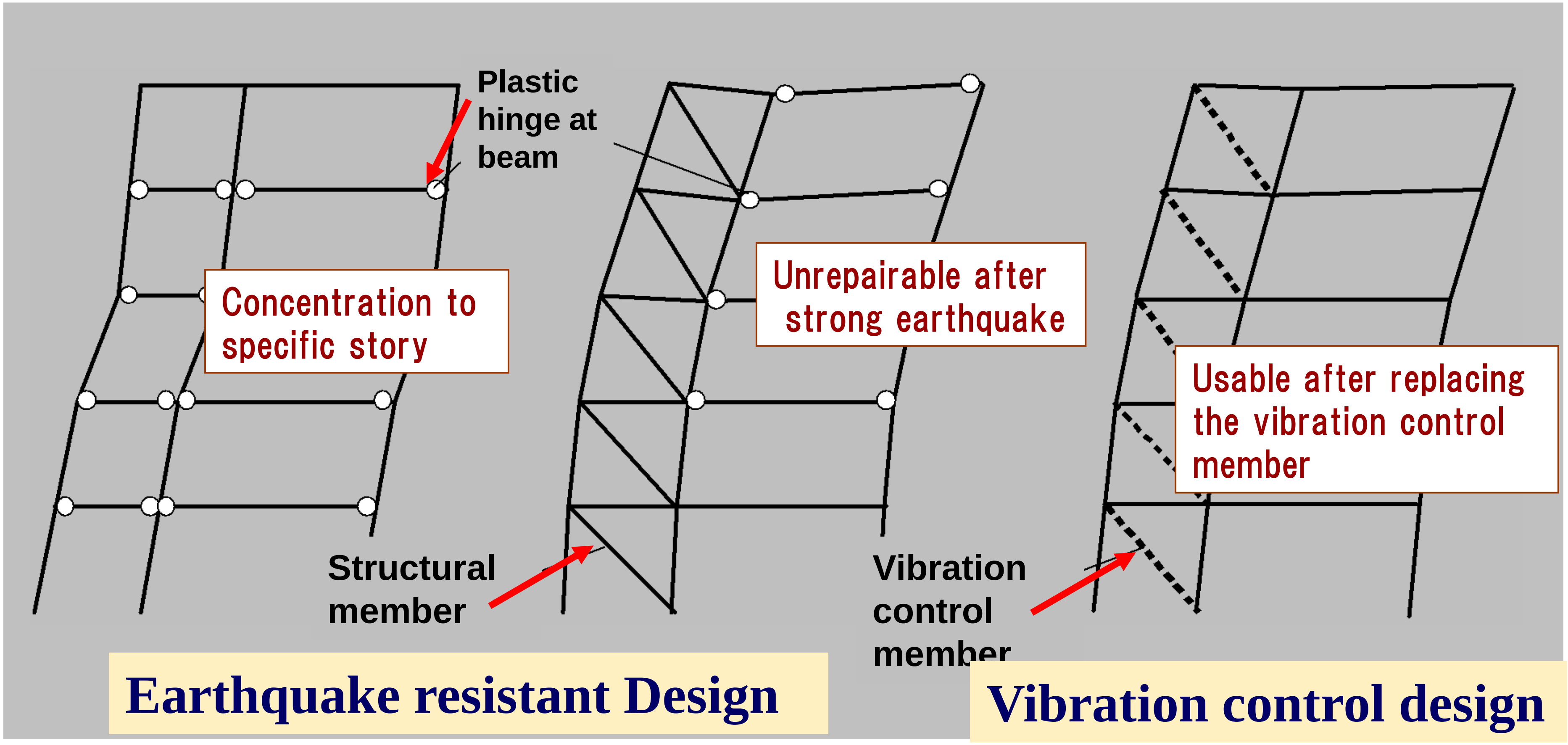
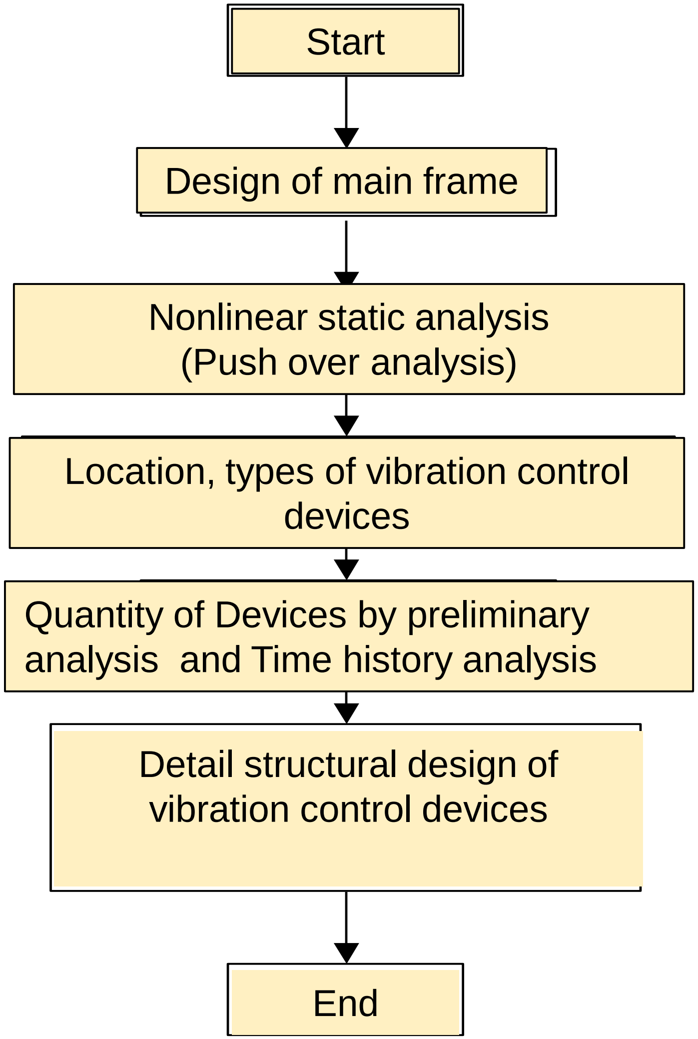
Comparison of Earthquake resistant design and vibration control design

Takeuch T. , Titec



Design of vibration control



Flow diagram of vibration control design

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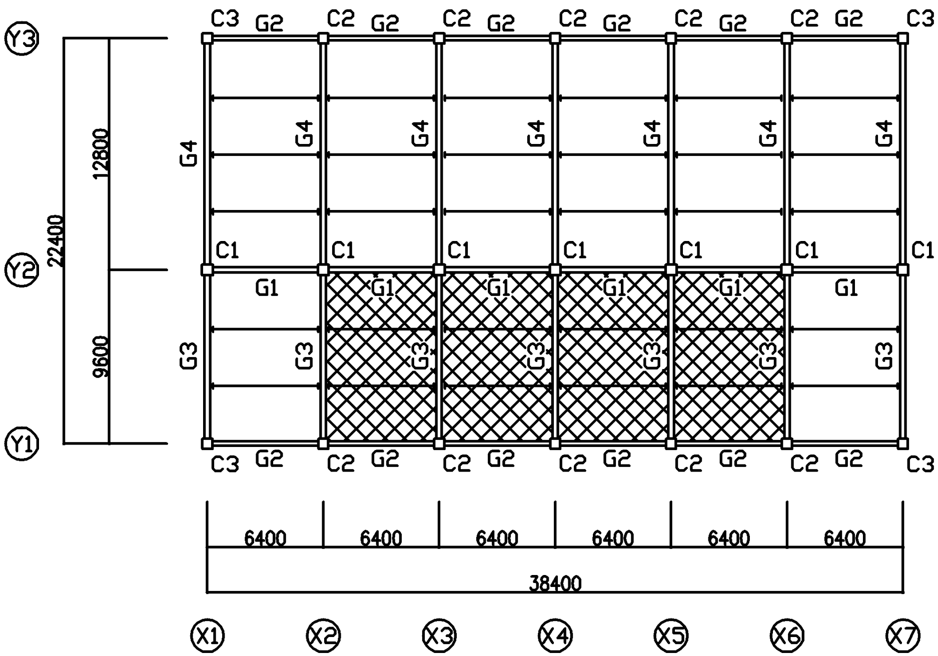
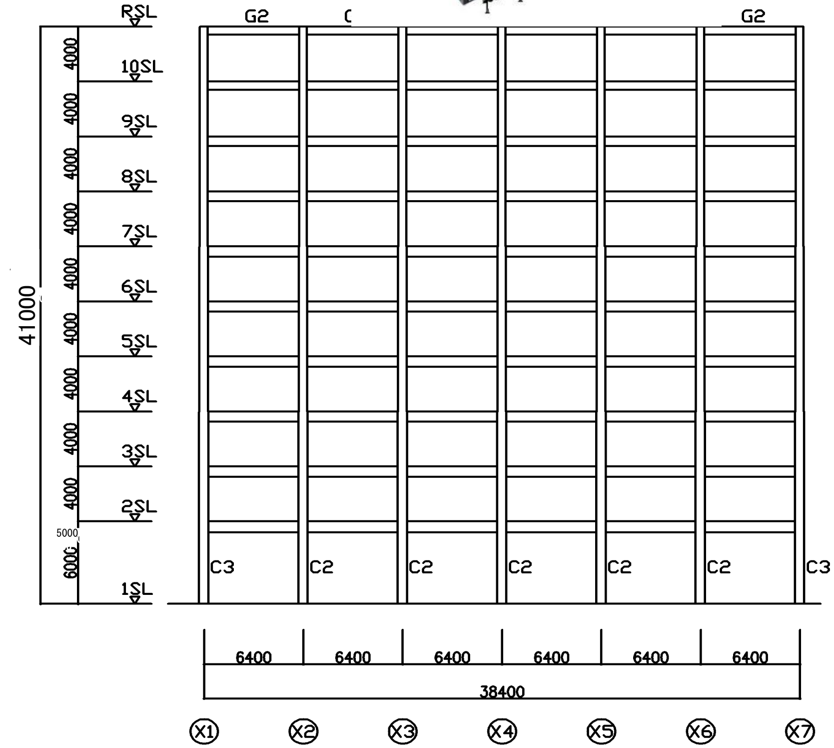
Outline of the analyzed building

- Steel Structure, 10F, Office building
- Moment resisting frame
- Height of building: 41m
- Analyzed direction: X direction



(a) Plan



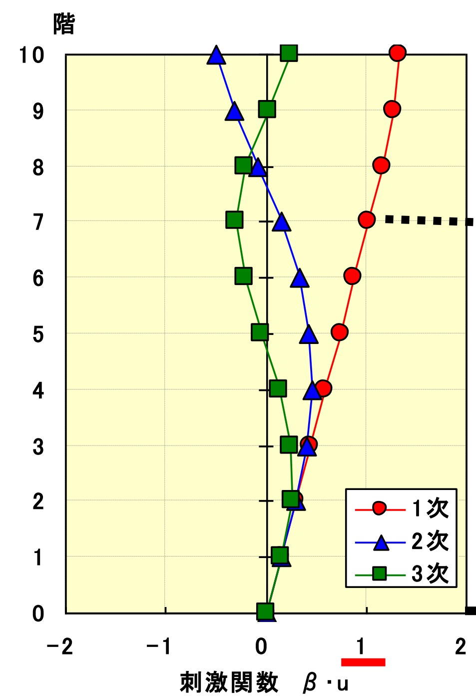
(b) Elevation (Y1,Y3)

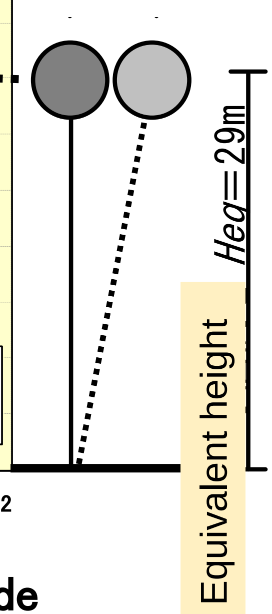
Property of the main frame

AIJ 2007

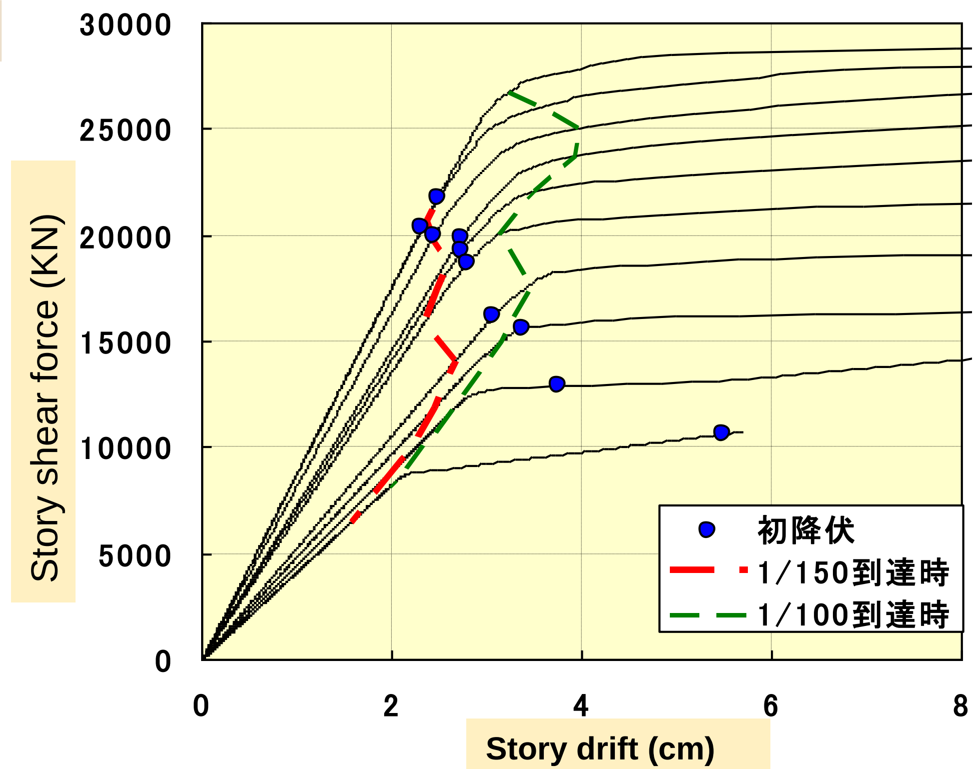
Natural period; T(s) and Participation factor (β)

Mode	T (sec)	β
1 st	1.33	1.33
2nd	0.48	-0.49
3rd	0.27	-0.29





Vibration mode



Story shear force vs Story drift

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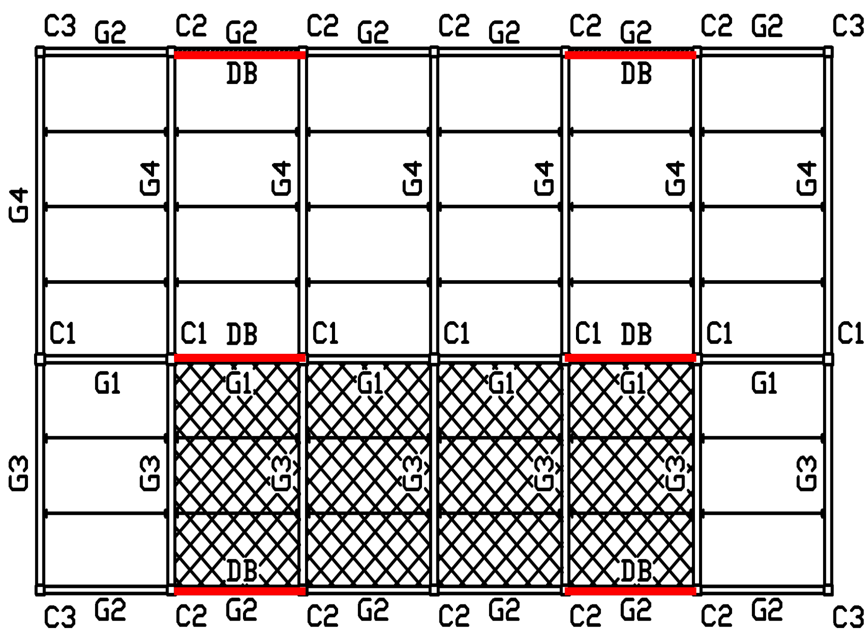
(1) Location of Dampers

Type of damper : **Steel damper (Buckling retrain brace type)**

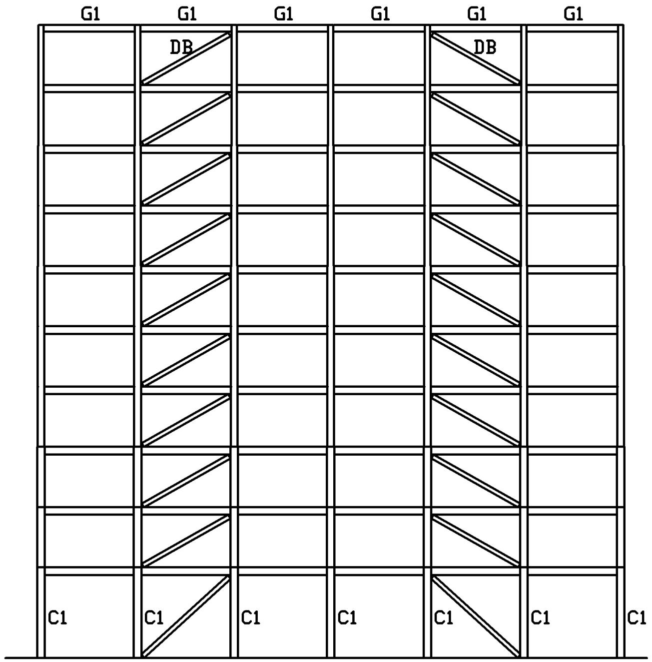
Type of installation : **Brace type**

Location for plan : **Symmetry**

Location for elevation : **Continuous from ground to top floor**



(a) Plan



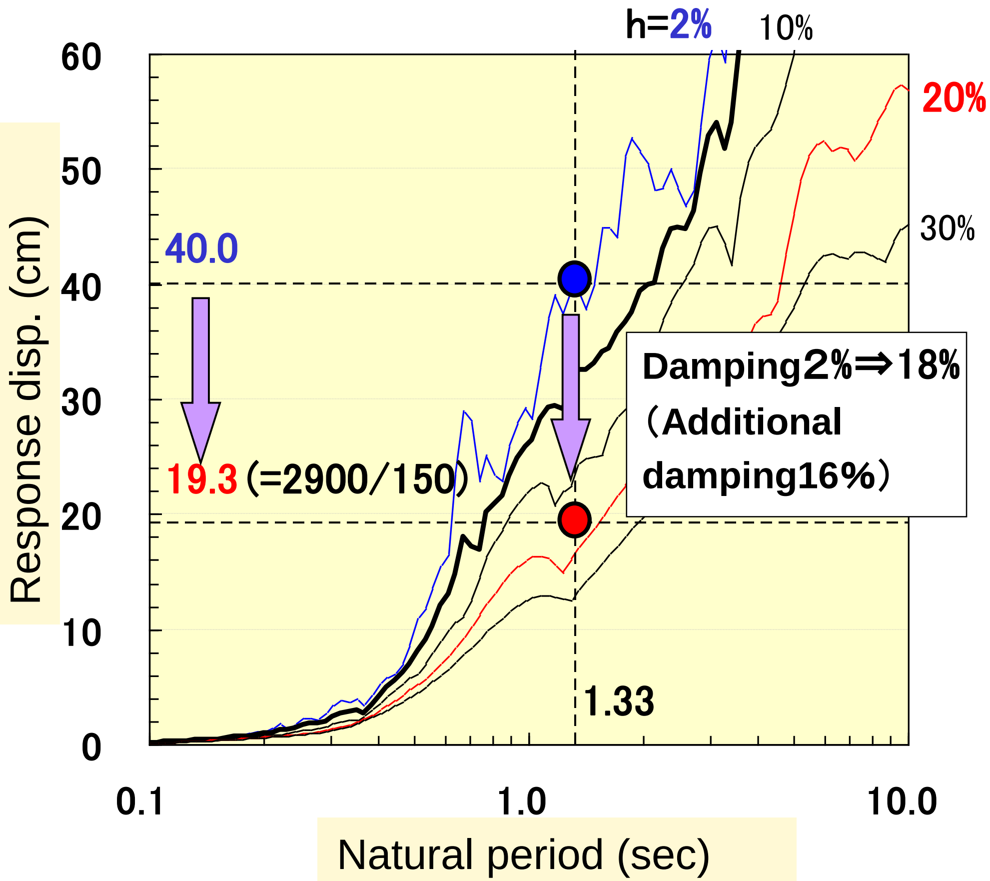
(b) Y2 Elevation

(2) Calculation of quantity of damper

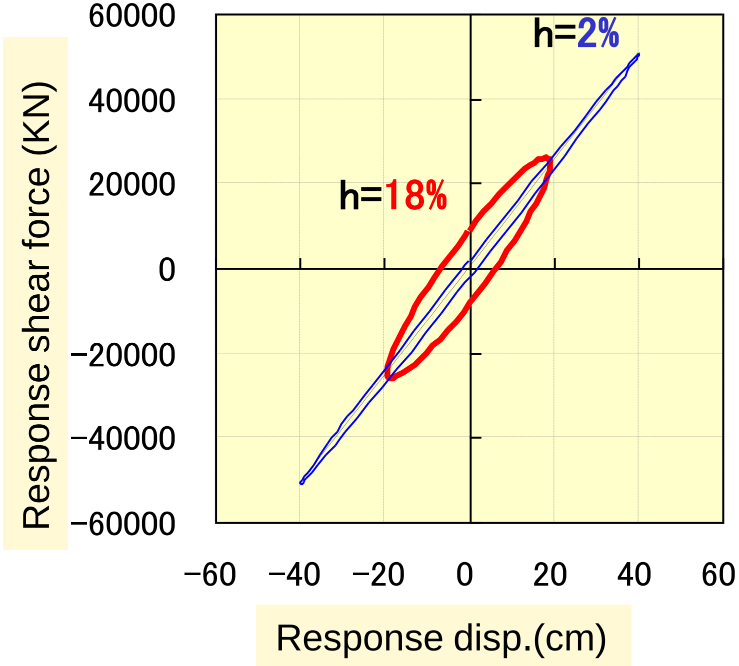
Target Capacity:

Input Ground motions: three kinds of code based strong artificial motions.

Maximum response story drift: 1/150rad



Maximum response spectrum for design ground motions



Hysteresis curve

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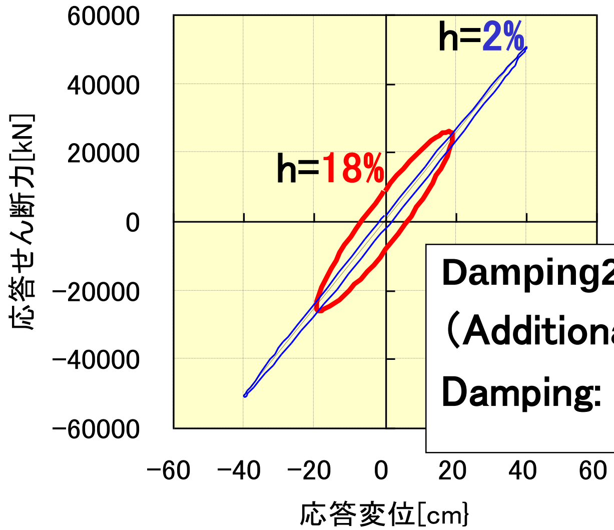
(2) Calculation of quantity of damper

Damper strength to get the required additional damping



Damping2%⇒18%
(Additional
Damping: 16%)

Hysteresis curve

$$h_{eq} = 0.8 \times \frac{1}{4\pi}\frac{\Delta W_d}{W_f} = 0.8 \times \frac{2}{\pi}\left(1 - \frac{1}{\mu_d}\right) \times \frac{Q_{dy}}{Q_f} \qquad (1.3.6)$$

より、

Required additional damping 16(%)

$$Q_{dy} = \frac{h_{eq}}{0.8 \times \frac{2}{\pi}\left(1 - \frac{1}{\mu_d}\right)} \times Q_f \qquad (1.3.7)$$

Ground floor shear force ＝29,303 (kN)

Ductility factor of damper＝5.0

・Strength of dampers at ground floor

$$Q_{dy} = \frac{h_{eq}}{0.8 \times \frac{2}{\pi}\left(1 - \frac{1}{\mu_d}\right)} \times Q_f = \frac{0.16}{0.8 \times \frac{2}{\pi}\left(1 - \frac{1}{5.0}\right)} \times 29{,}303 = 11{,}507\,(\mathrm{kN})$$

(2) Calculation of quantity of damper

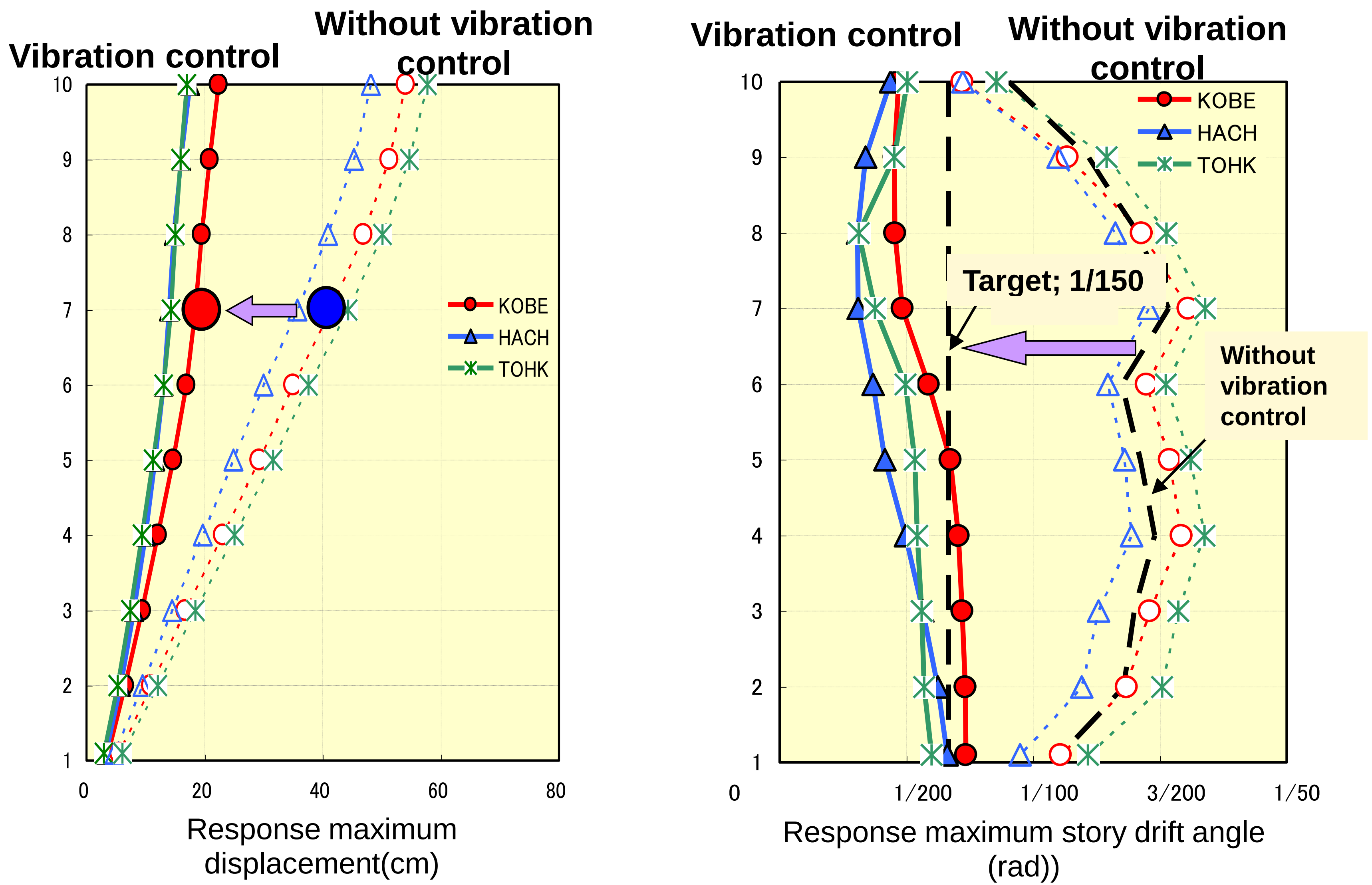
Quantity of dampers at each story

- Ductility factor of dampers are assumed as constant; μ_{di}=5.0
- Distribution of story shear coefficient is Ai which is defined by Japanese seismic code

Property of Damper (strength and stiffness at each story)

F	目標*ui* (mm)	*Kfi* (kN/mm)	*Qfi* (kN)	*Qdyi* (kN)	*Ci* / *Ai*	*Kdi* (kN/mm)	*μ di*
10	26.7	413	11,023	1,456	0.578	273	5.0
9	26.7	447	11,907	6,240	0.578	1,170	5.0
8	26.7	486	12,953	9,990	0.578	1,873	5.0
7	26.7	529	14,093	12,960	0.578	2,430	5.0
6	26.7	679	18,112	12,512	0.578	2,346	5.0
5	26.7	708	18,881	14,777	0.578	2,771	5.0
4	26.7	733	19,540	16,649	0.578	3,122	5.0
3	26.7	819	21,837	16,378	0.578	3,071	5.0
2	26.7	878	23,412	16,336	0.578	3,063	5.0
1	33.3	879	29,303	11,507	0.578	1,726	5.0

Reconfirmation of designed result by time history analysis）



Result of time history analysis

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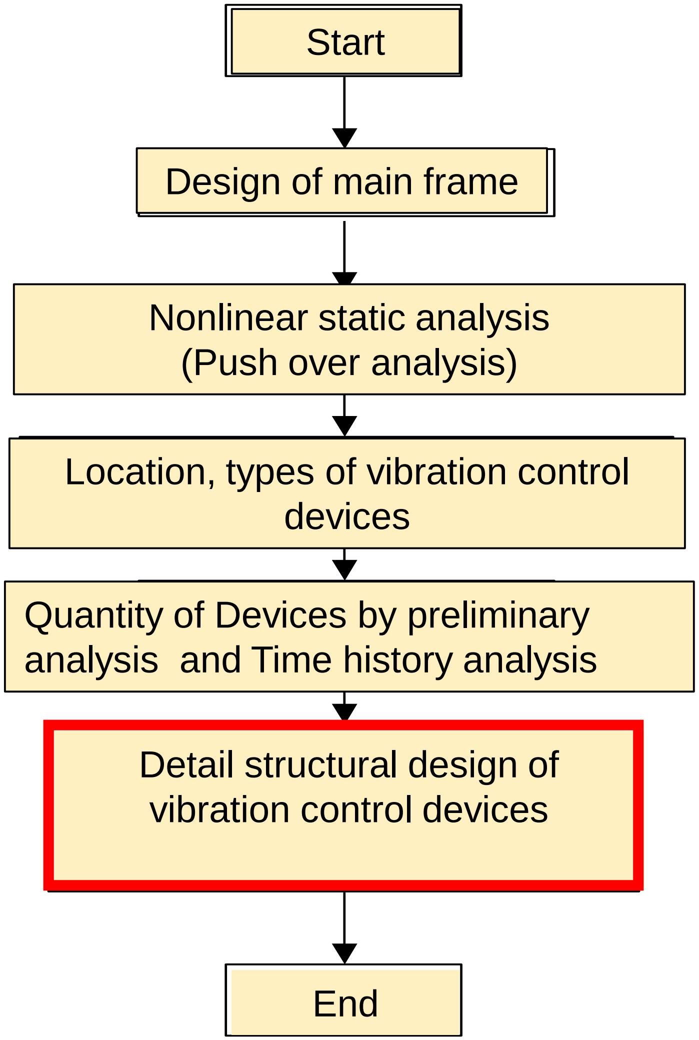
Detail structural design of devices



Flow of vibration control design

Strength and stiffness of each story total dampers

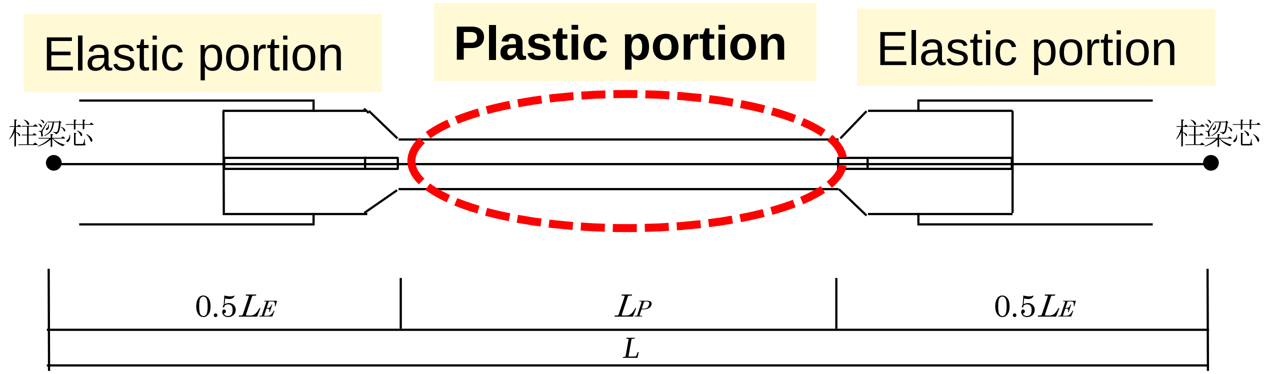
- ・Angle of installation
- ・Number of dampers at each story

Strength and stiffness of one piece of damper

Property of damper at each story
（Strength and axial stiffness of one damper）

階	階高 hi (m)	ｽﾊﾟﾝ S (m)	$\cos\phi$	設置本数 n	$Qdyi$ (kN)	Nd' (kN)	kdi (kN/mm)	kd' (kN/mm)
10	4.0	6.4	0.848	2	1,456	859	273	190
9	4.0	6.4	0.848	4	6,240	1,840	1,170	407
8	4.0	6.4	0.848	6	9,990	1,963	1,873	434
7	4.0	6.4	0.848	8	12,960	1,910	2,430	422
6	4.0	6.4	0.848	8	12,512	1,844	2,346	408
5	4.0	6.4	0.848	10	14,777	1,743	2,771	385
4	4.0	6.4	0.848	10	16,649	1,963	3,122	434
3	4.0	6.4	0.848	10	16,378	1,931	3,071	427
2	4.0	6.4	0.848	10	16,336	1,926	3,063	426
1	5.0	6.4	0.788	8	11,507	1,825	1,726	347

(a) Buckling retrain brace



Construction of Brace

- **Length of plastic length**

$$L_P = (a - a')/(1 - a) \times L$$

a : Area ratio of plastic and elastic zone(＝0.4)

a': Area ration of plastic and equivalent section

L : Length of brace

- **Ductility factor of plastic zone**

$$\mu_P = (\mu_d - 1) \times (K_P / K_d'') + 1$$

μ_d : Ductility factor of damper

K_P : Axial stiffness at plastic zone

K_d'' : Axial stiffness of brace

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(a) Buckling retrain brace

Property of brace at each story

階	Nd' (kN)	Kd' (kN/mm)	δdy (mm)	採用ブレース		L (mm)	A_d (mm^2)	L_P (mm)	L_P/L	K_P (kN/mm)	μ_P	Nd'' (kN)	Kd'' (kN/mm)	$\mu d''$
				降伏軸力タイプ	A_P (mm2)									
10	859	190	4.5	1,000	4,532	7,547	8,268	1,863	0.25	501	9.9	1,020	225	5.0
9	1,840	407	4.5	2,000	8,896	7,547	16,230	1,863	0.25	983	9.9	2,002	443	5.0
8	1,963	434	4.5	2,000	8,896	7,547	16,230	1,863	0.25	983	9.9	2,002	443	5.0
7	1,910	422	4.5	2,000	8,896	7,547	16,230	1,863	0.25	983	9.9	2,002	443	5.0
6	1,844	408	4.5	2,000	8,896	7,547	16,230	1,863	0.25	983	9.9	2,002	443	5.0
5	1,743	385	4.5	2,000	8,896	7,547	16,230	1,863	0.25	983	9.9	2,002	443	5.0
4	1,963	434	4.5	2,000	8,896	7,547	16,230	1,863	0.25	983	9.9	2,002	443	5.0
3	1,931	427	4.5	2,000	8,896	7,547	16,230	1,863	0.25	983	9.9	2,002	443	5.0
2	1,926	426	4.5	2,000	8,896	7,547	16,230	1,863	0.25	983	9.9	2,002	443	5.0
1	1,825	347	5.3	2,000	8,896	8,122	15,036	2,594	0.32	706	8.4	2,002	381	5.0

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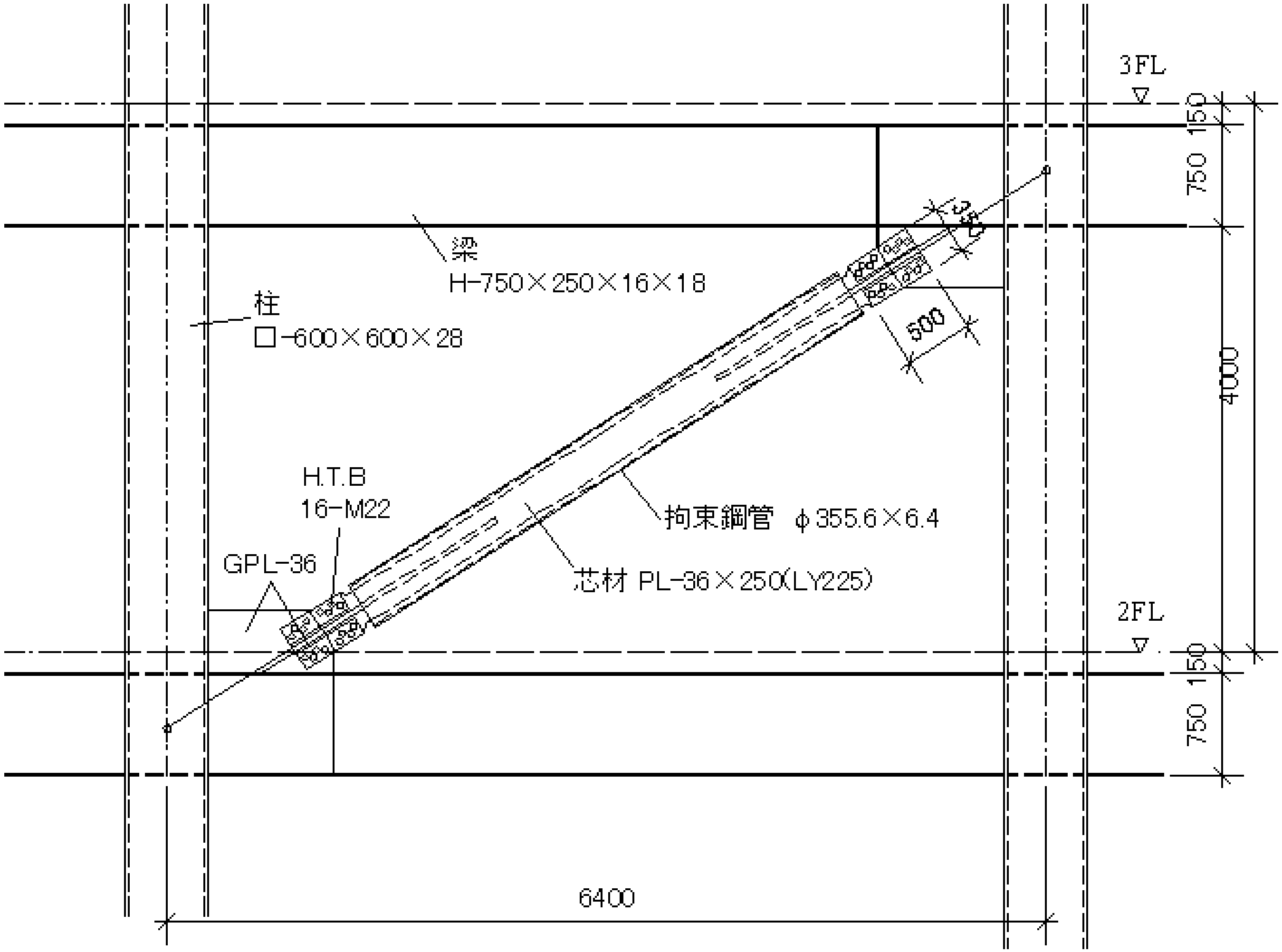
(a) Buckling retrain brace



Detail structural drawing of the brace

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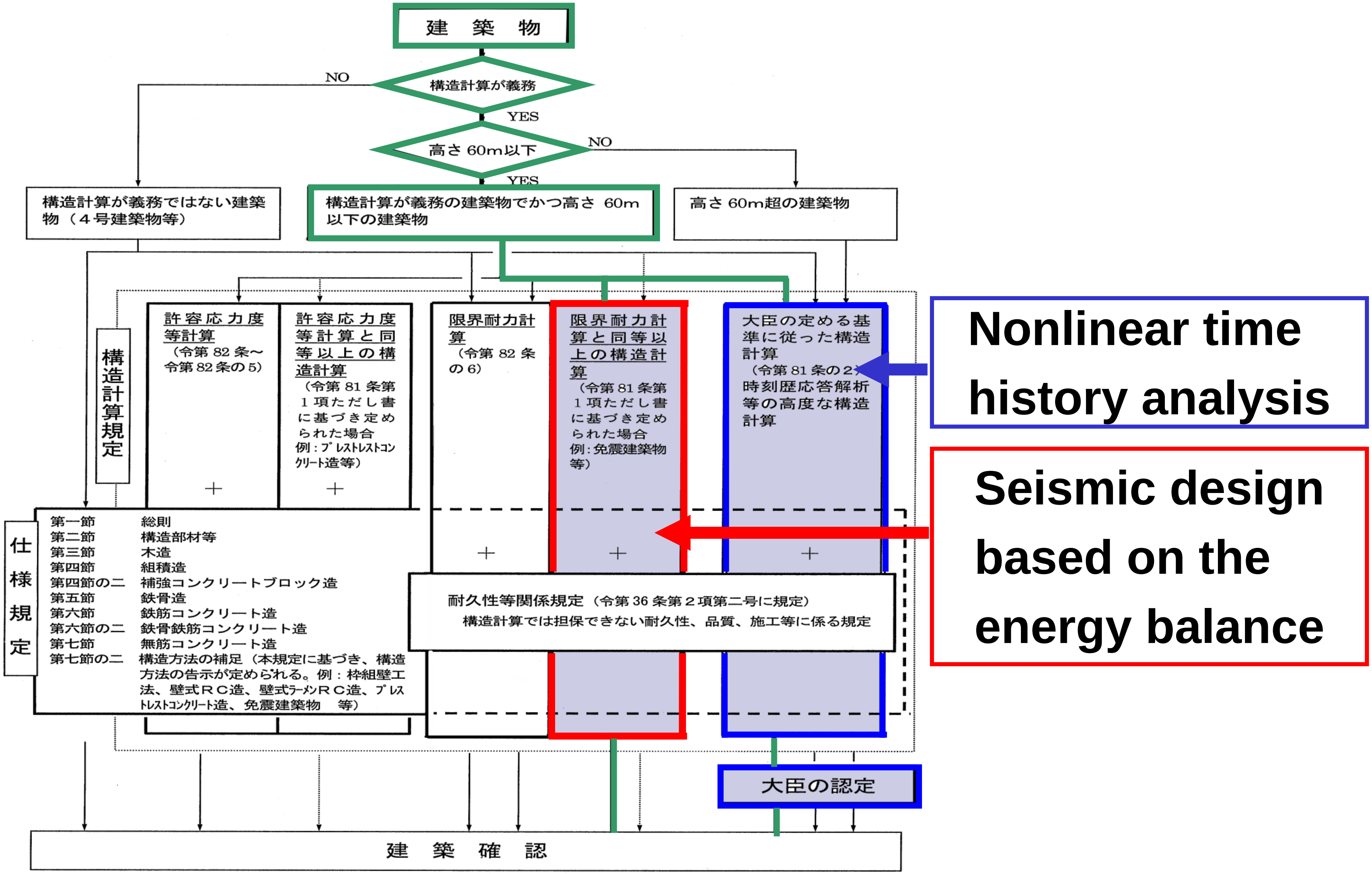
Approval system of Vibration control building in Japan



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Consideration on vibration control design

Takeuchi, T. ,Titec

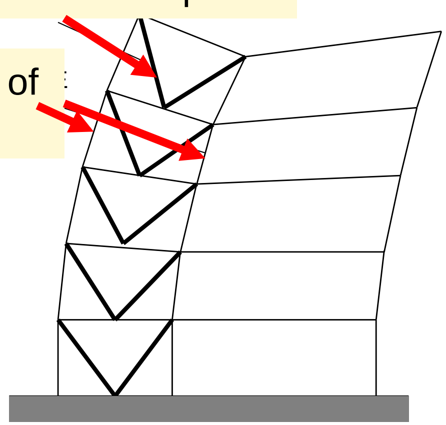
Design : Nonlinear time history analysis

Investigation on effective conditions on the response by the main frame and damper.

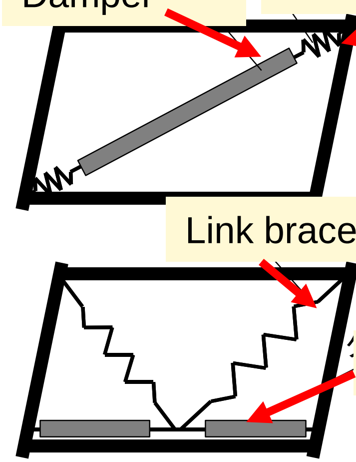
Modeling of main frame and damper are most important issues for analysis.

Appropriate modeling

（Stiffness of main frame,／effect of flexural behavior／Stiffness of joint portion and surrounding frame



Flexural deformation of main frame



Deformation at joint portion

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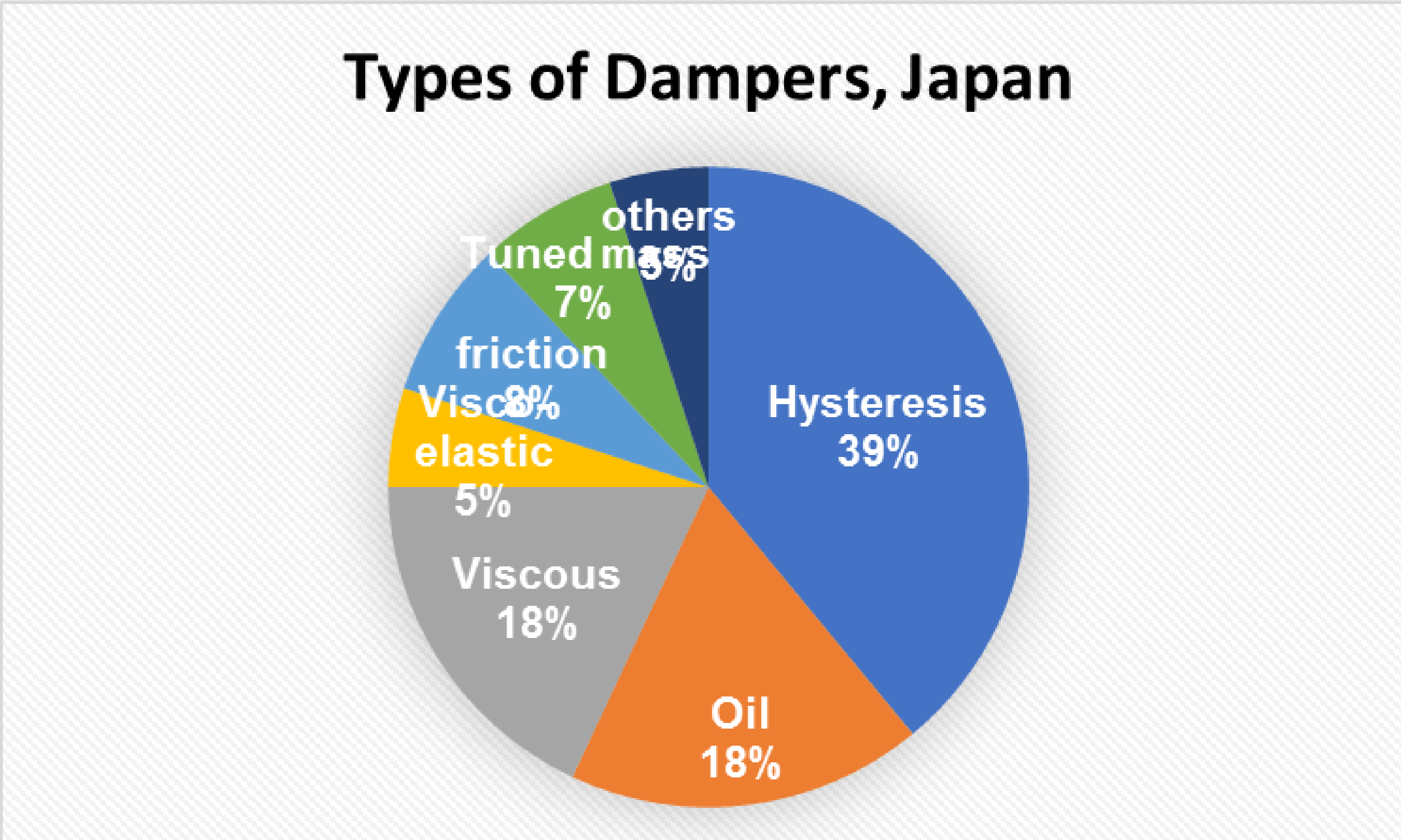
Examples of Vibration Control Buildings in Japan

Vibration Control Building



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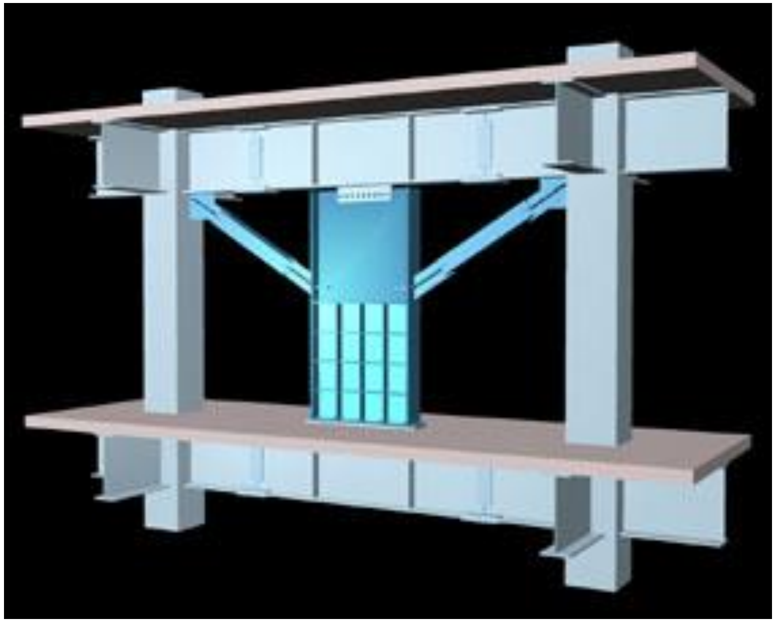
Vibration Control Building

High Rise office Building (Steel St.)

Takeuchi (Tokyo Institute of Tech.)



Low Yielding Strength Steel Damper

Vibration Control Building

Medium Rise office Building(Steel. St)

Takeuchi (Tokyo Institute of Tech.)

Outside View

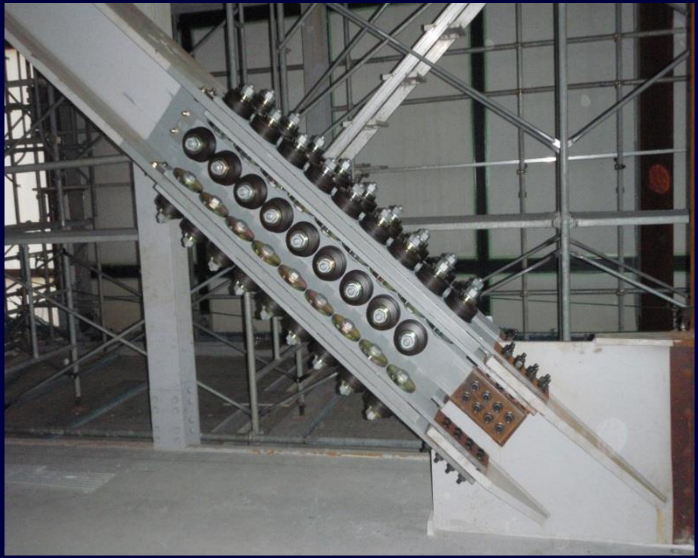
Installation of Oil Damper

Vibration Control Building

30F office Building（Steel St.）

31F　Office Building（steel St.）

Vibration Control Building



Friction Damper: Brace type

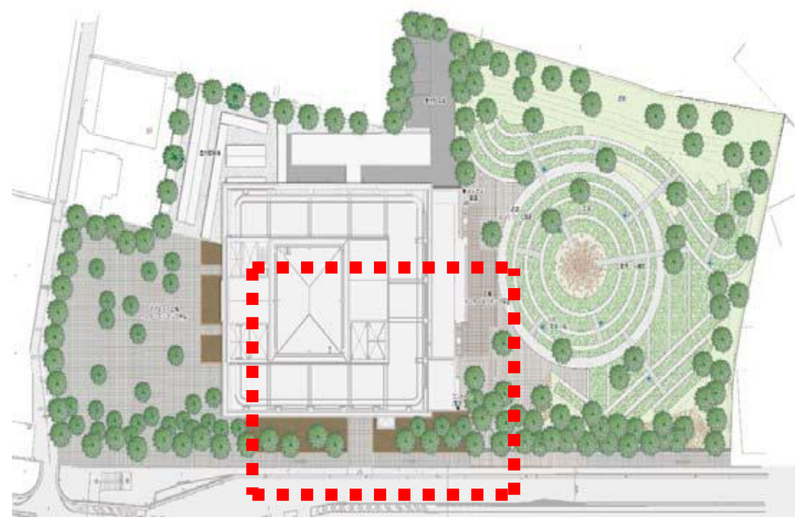
Vibration Control Building

Friction Damper: Column type

Vibration Control Building

High rise residential building

45F, B1F
H=155.5 m
Residential Building
Passive Control System



OBAYASHI

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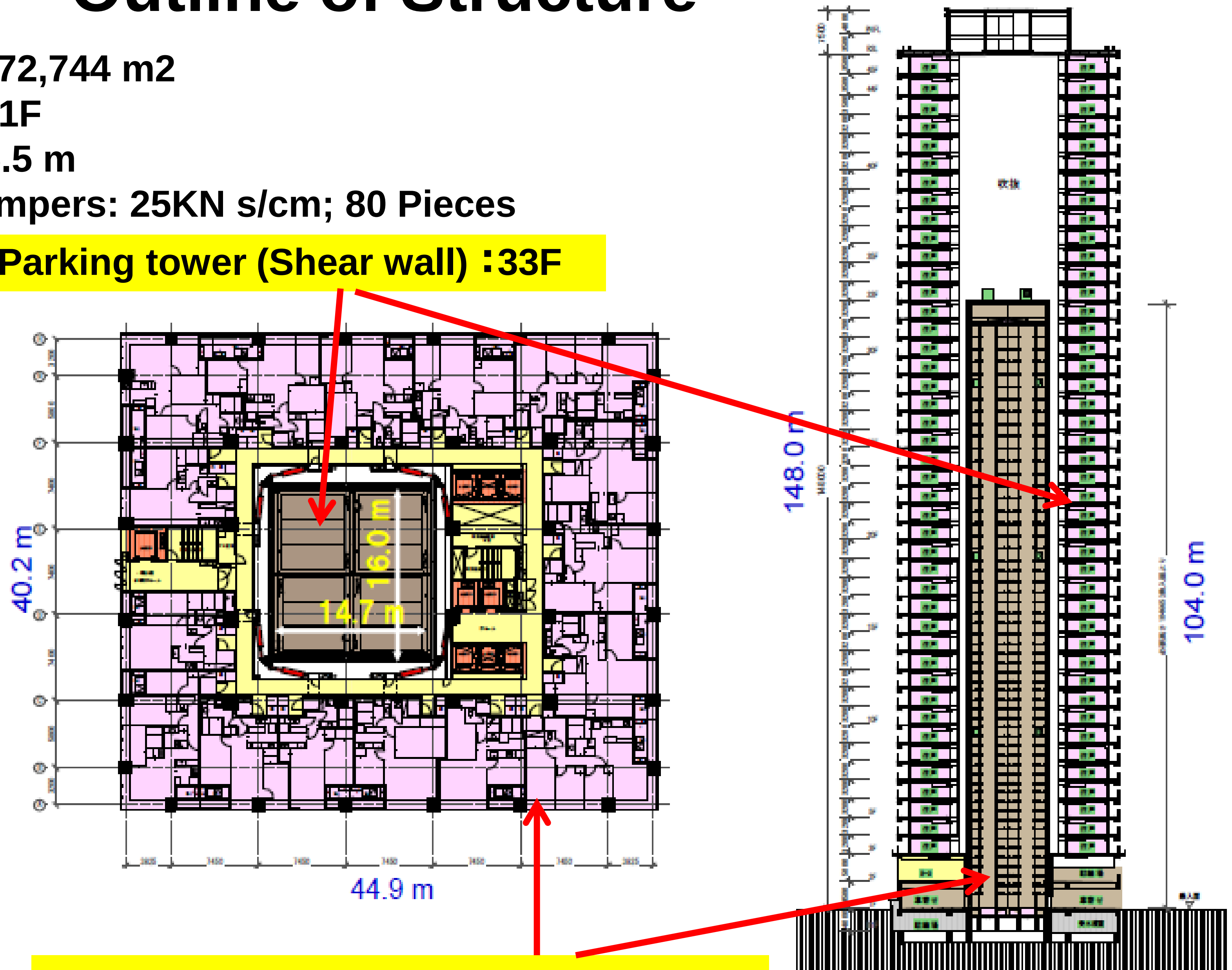
Outline of Structure

Area: 72,744 m2
45F, B1F
H=155.5 m
Oil dampers: 25KN s/cm; 80 Pieces

Parking tower (Shear wall) :33F



Residential Part (Frame Structure):45F

OBAYASHI

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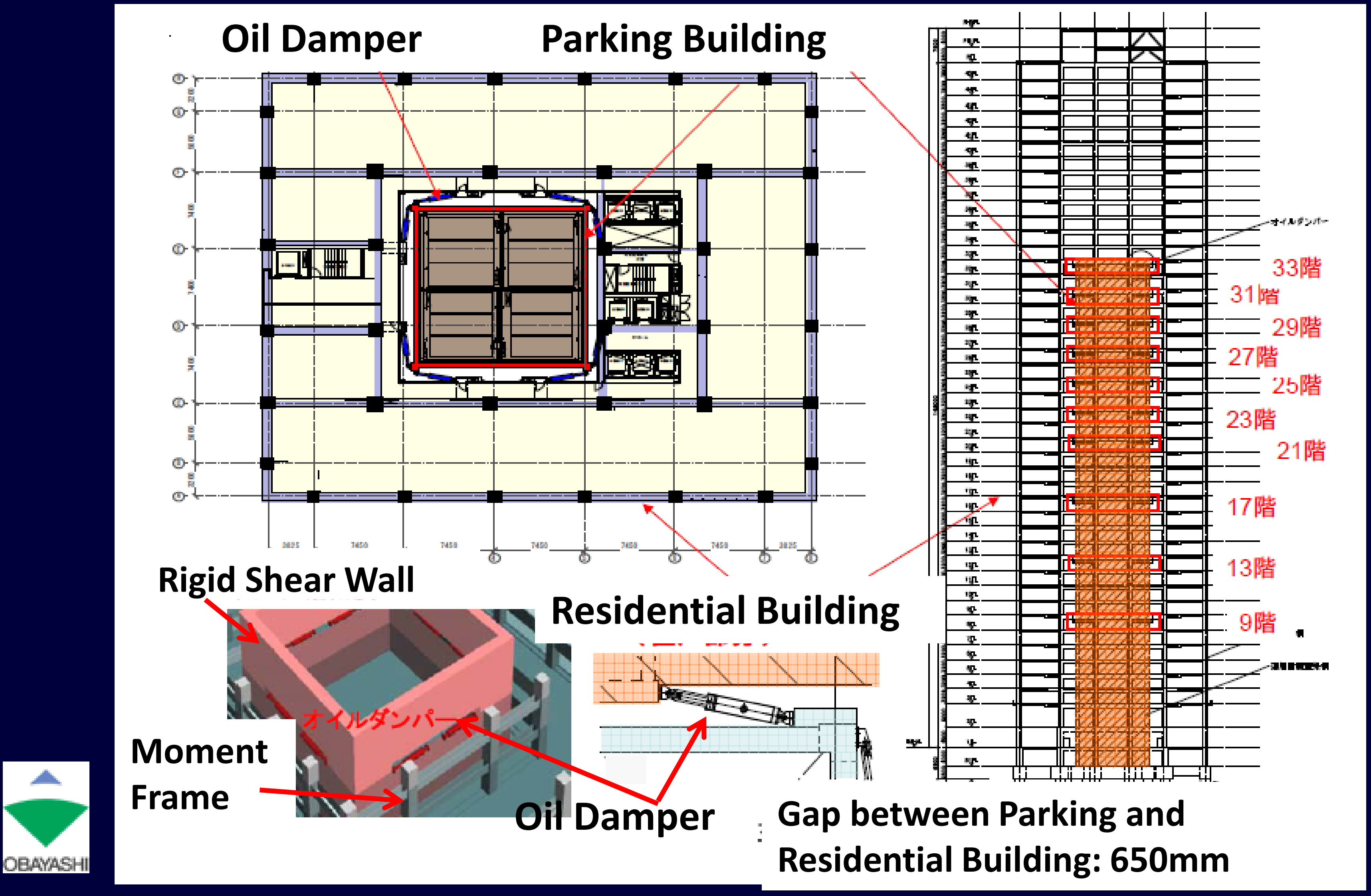
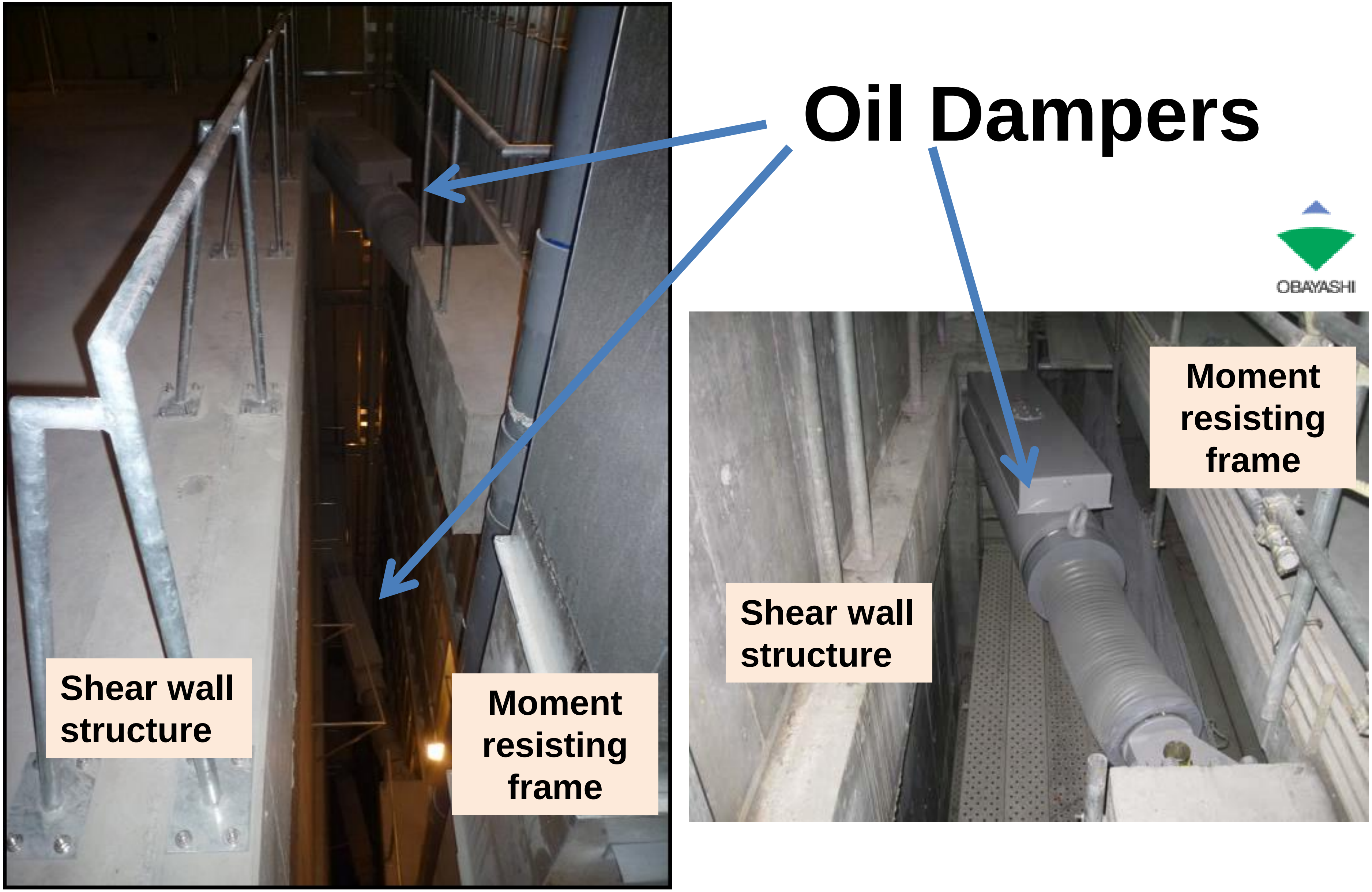
Double tube vibration control system



Oil Damper between moment resisting frame and shear wall structure



Vibration Control Building

By 2020, many Olympic facilities will be constructed in Tokyo Bay Area

http://image.search.yahoo.co.jp/search?rkf=2&ei=UTF-8&p

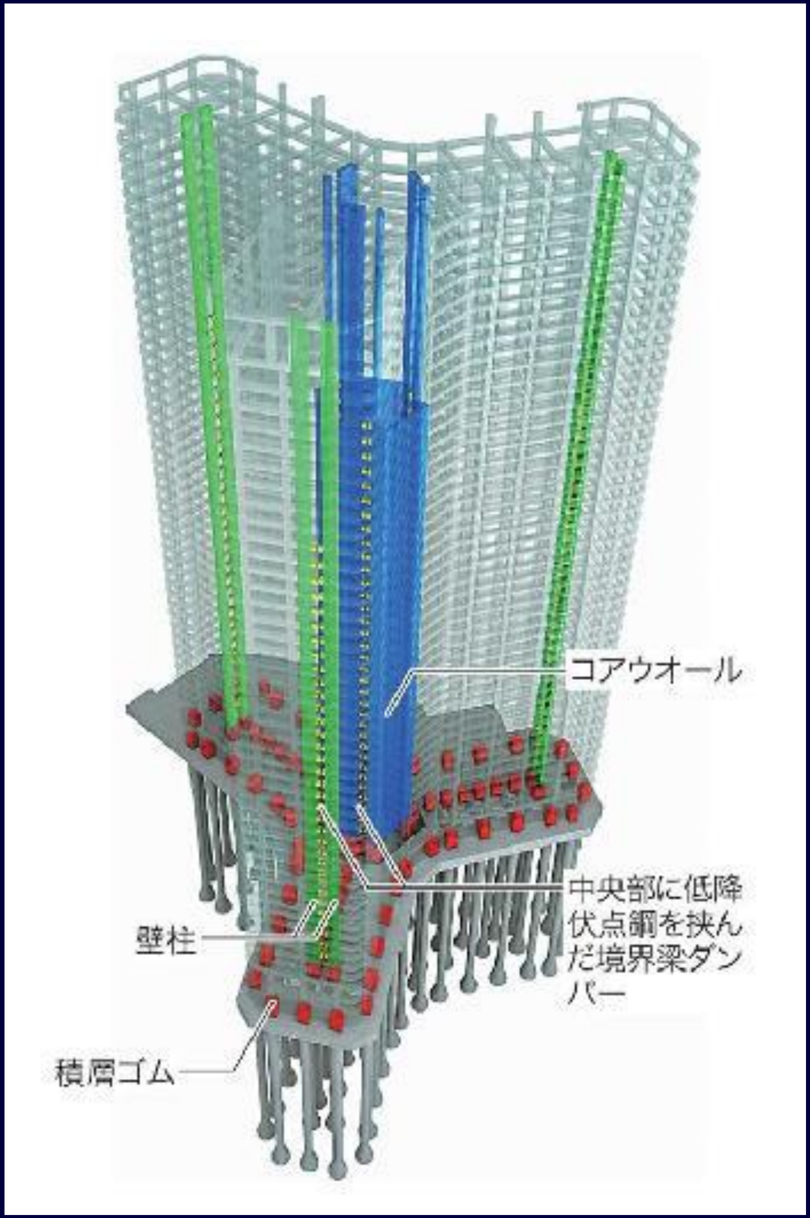
Vibration Control Building

Tokyo Bay Area

High Rise Residential Building (2014. August)

http://kenplatz.nikkeibp.co.jp/article/building/news/20130911/631735/?P=1

Vibration Control Building



B2F, 44F   H=250m

Isolators: 84

Natural Rubber Bearings: 21

Lead Plug Rubber Bearings: 63

Dampers: 204

Low strength Steel Damper (LY225)

Installed between Boundary Beams

Isolation Story: B2F

http://kenplatz.nikkeibp.co.jp/article/building/news/20130911/631735/?P=1

Vibration Control Building

Low Strength Steel Damper between Boundary Beams

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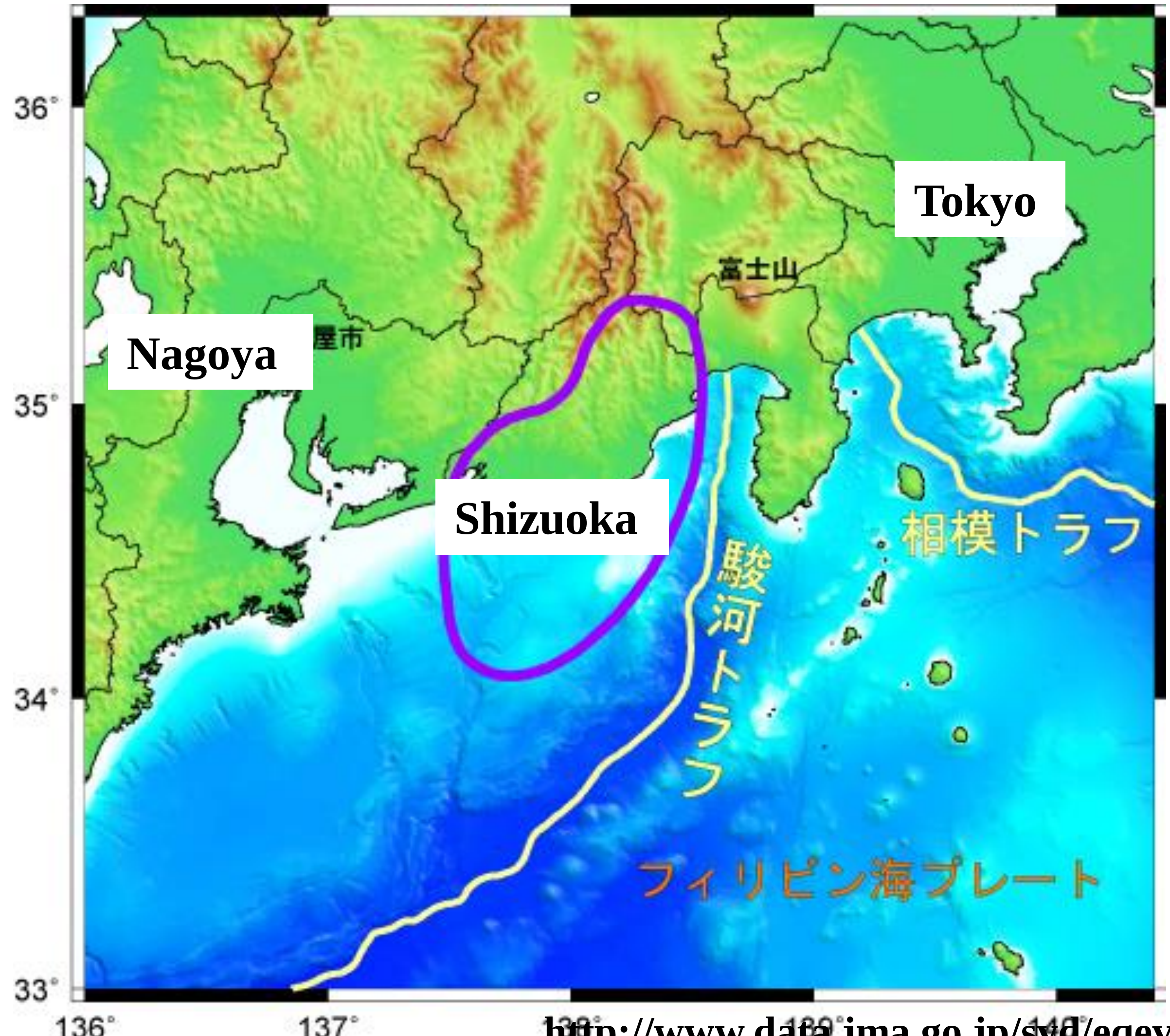
Retrofitting of residential building by friction damper in Japan

From JBDPA "Seismic retrofitting examples of existing reinforced buildings in Japan, 2009"

M8 Tokai Earthquake was predicted in 1976



http://www.data.jma.go.jp/svd/eqev/data/tokai/tokai_eq1.html

Outline of Building

Name : **A-Building**
Use : **Residential Building**
Story : **5 stories**
Total Area : **640 m^2**
Original Construction : **1968**
Retrofitting Construction: **2006**
Location : **Shizuoka City, Japan**

Retrofitting Project:
Design and construction work: Obayashi corporation
Structural test: Toyohashi University of Technology (TUT) and Obayashi corporation
Fund: Shizuoka prefecture

Before retrofitting **After retrofitting**

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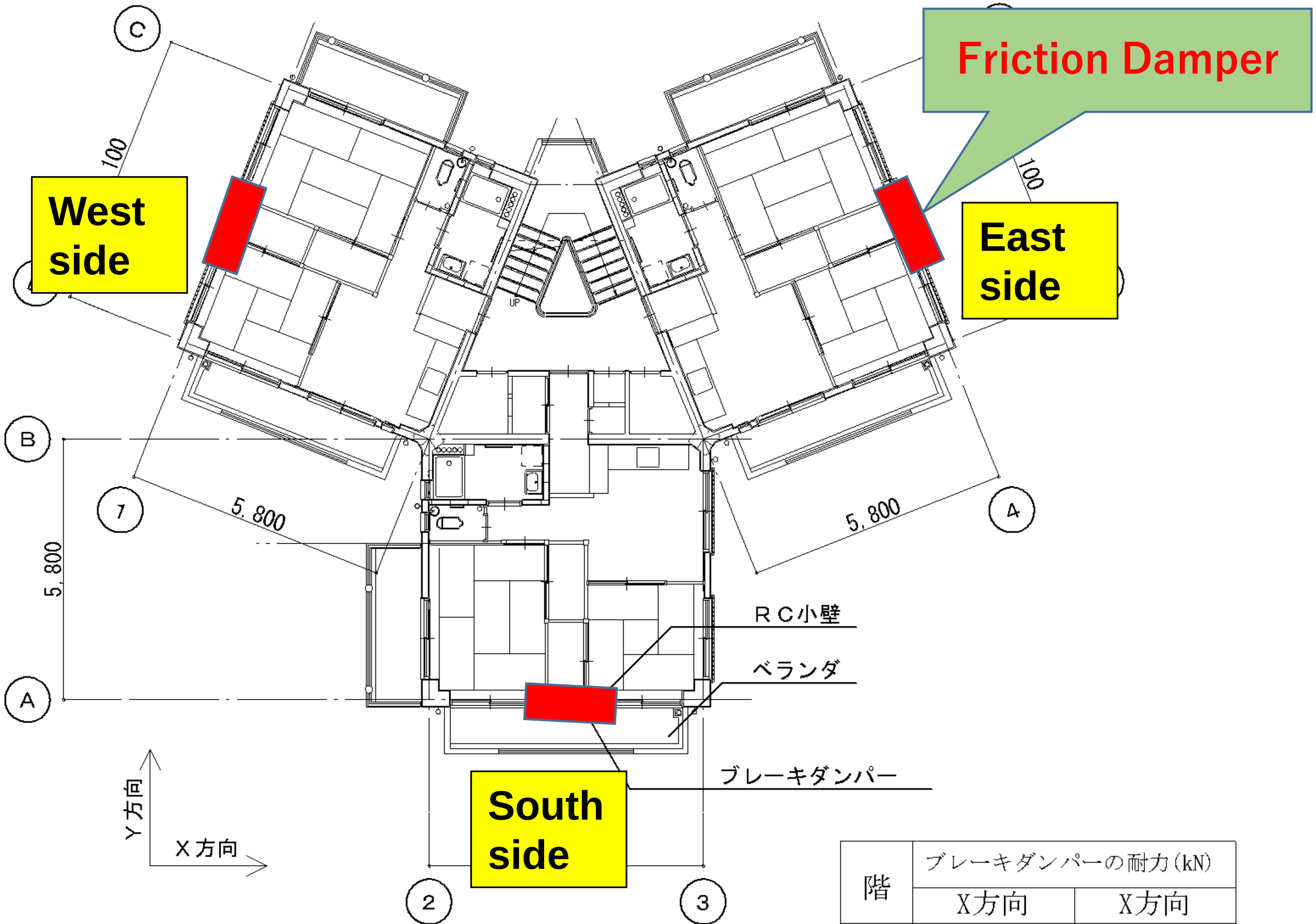

1～5階平面図

階	ブレーキダンパーの耐力(kN)	
	X方向	X方向
5	125.0	125.0
4	350.0	200.0
3	575.0	350.0
2	650.0	450.0
1	700.0	450.0

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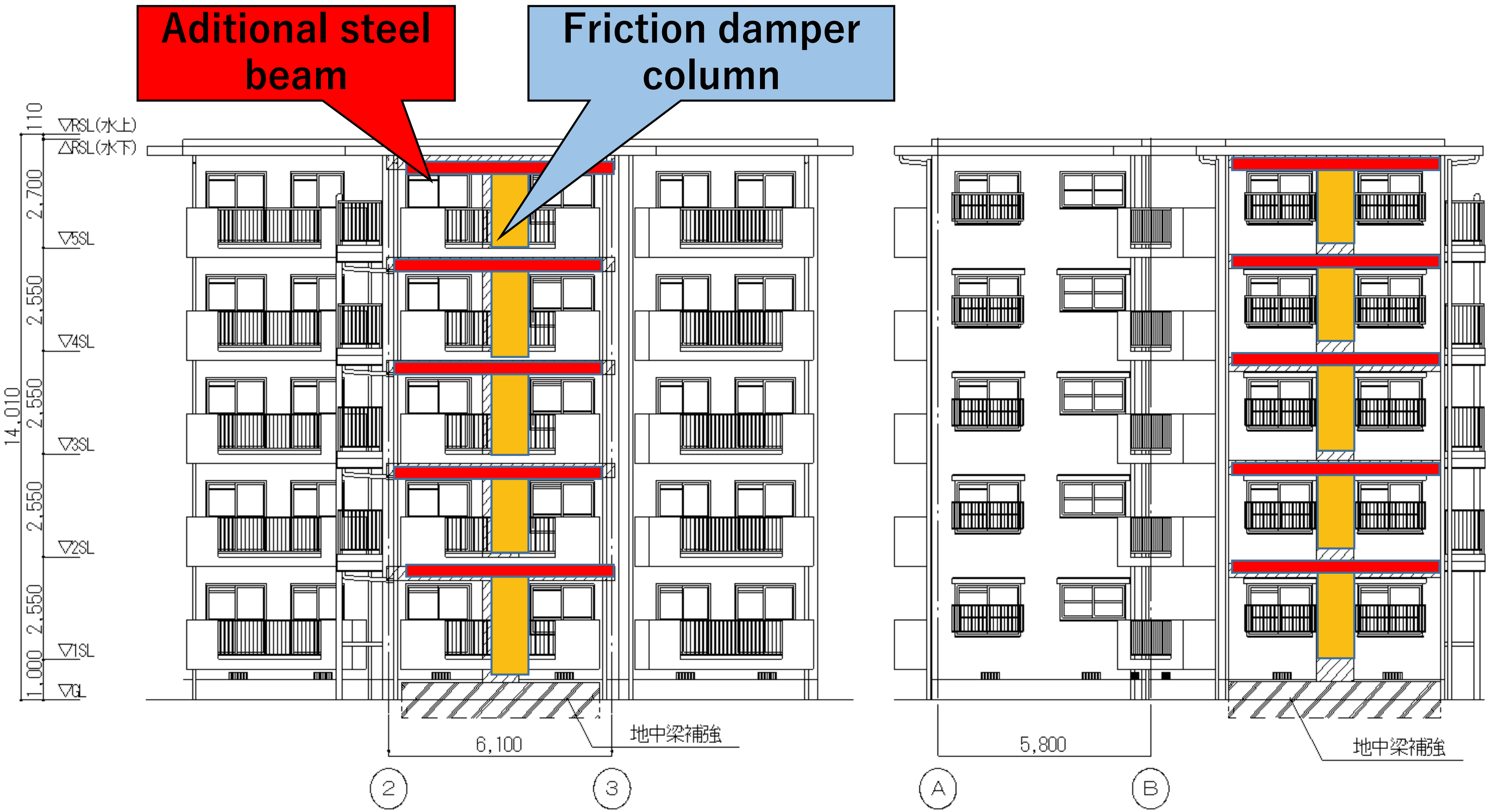

South elevation

East elevation

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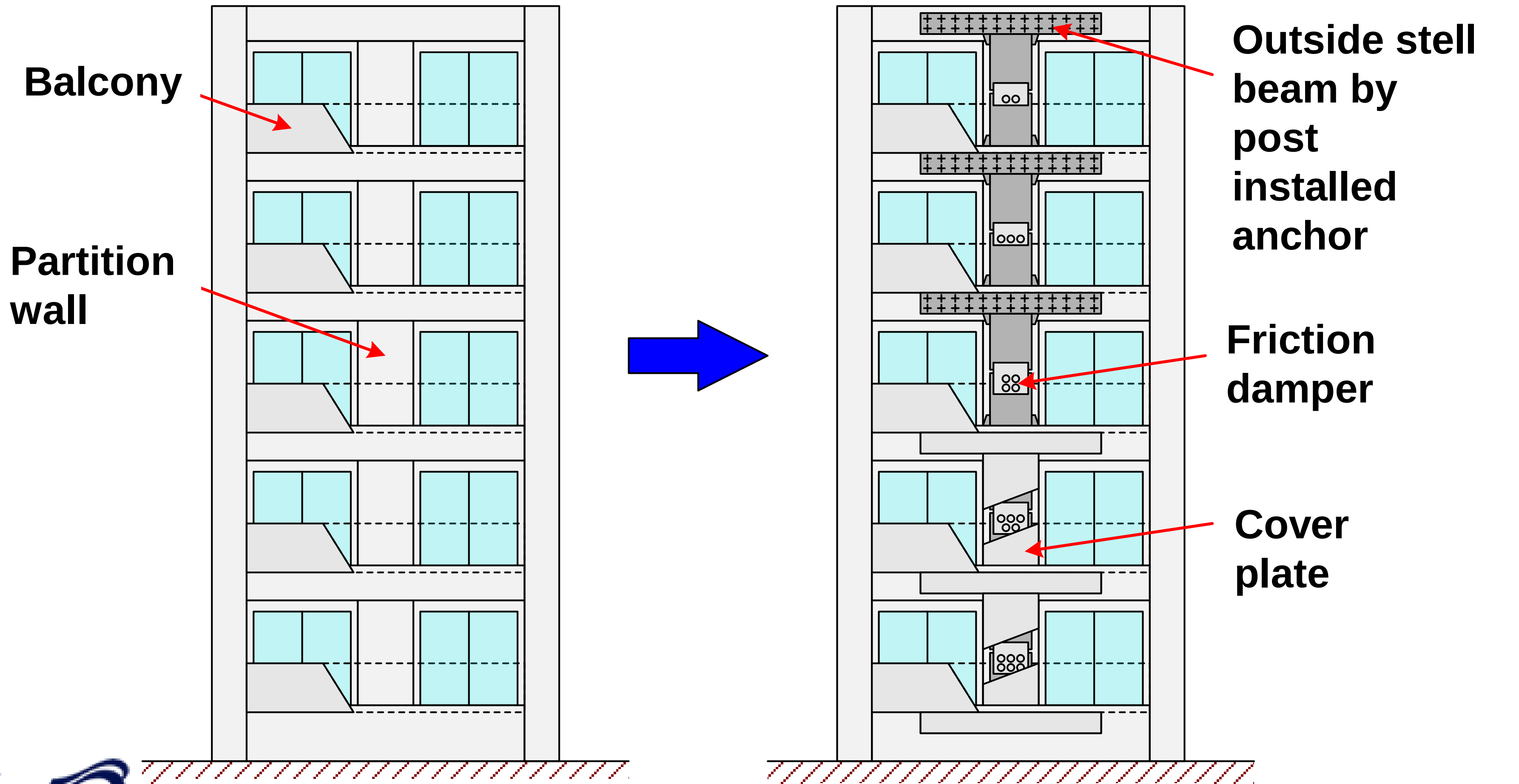
Characteristic of retrofitting

Benefit by friction damper :①Outside Retrofitting ②Small space③Low cost ④Maintenance free



Before retrofitting

After retrofitting

Is Index of Existing Building

E_T=0.90

Dirction	Story	Modelig	S_D	T	I_S	I_S/E_T	C_TS_D
X	5	ALL	1.00	0.96	1.57	1.75	1.64
		Zone A	1.00	0.96	1.10	1.22	1.14
	4	ALL	1.00	0.96	0.97	1.07	1.01
		Zone A	1.00	0.96	0.60	0.66	0.62
	3	ALL	1.00	0.96	0.79	0.87	0.82
		Zone A	1.00	0.96	0.51	0.57	0.53
	2	ALL	1.00	0.96	0.74	0.83	0.77
		Zone A	1.00	0.96	0.56	0.62	0.58
	1	ALL	1.00	0.96	0.79	0.88	0.82
		Zone A	1.00	0.96	0.57	0.63	0.59
Y	5	ALL	1.00	0.96	1.58	1.75	1.65
		Zone 1	1.00	0.96	1.30	1.44	1.35
	4	ALL	1.00	0.96	1.00	1.11	1.04
		Zone 1	1.00	0.96	0.81	0.90	0.84
	3	ALL	1.00	0.96	0.89	0.98	0.92
		Zone 1	1.00	0.96	0.70	0.78	0.73
	2	ALL	1.00	0.96	0.79	0.87	0.82
		Zone 1	1.00	0.96	0.70	0.78	0.73
	1	ALL	1.00	0.96	0.84	0.93	0.87
		Zone 1	1.00	0.96	0.72	0.79	0.75

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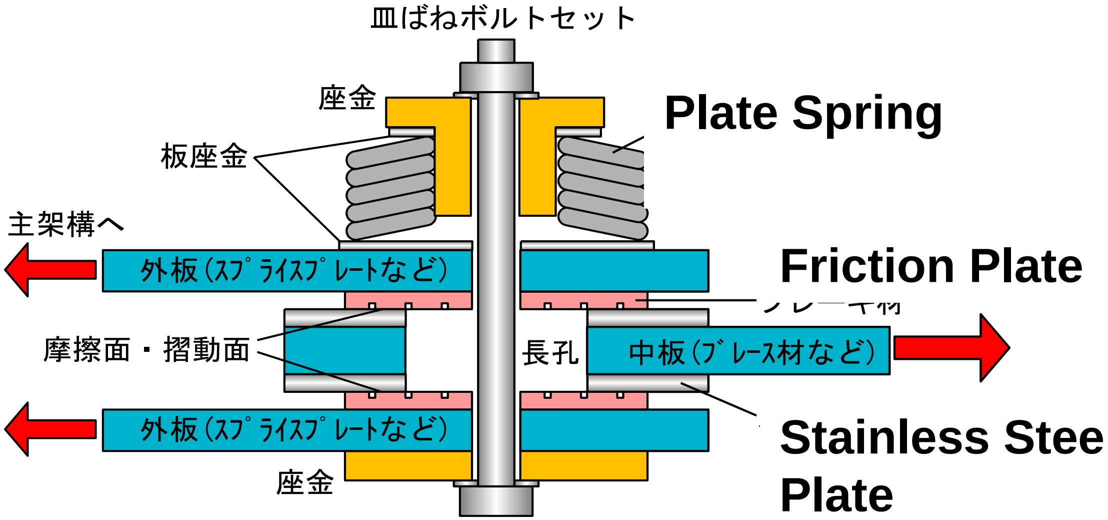
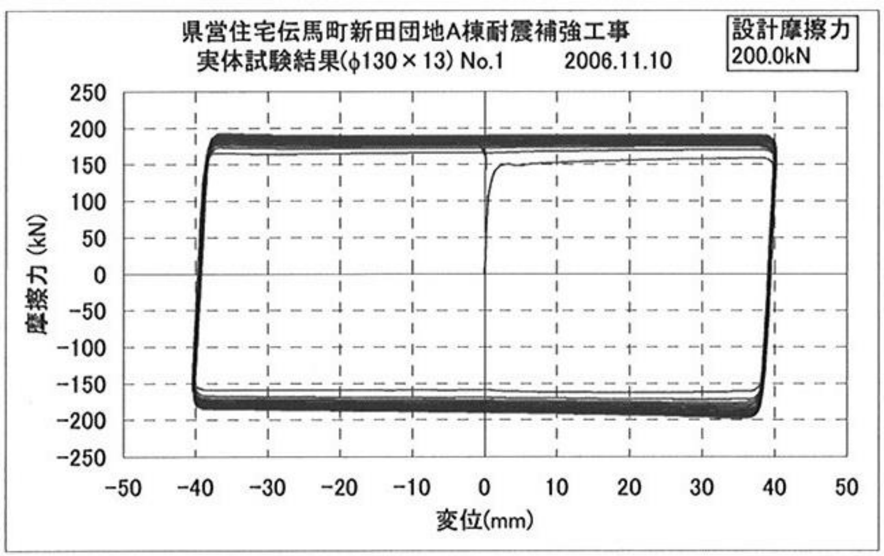
Preliminary Study on Retrofitting Methodology

Case	Methodology	Characteristic	Adoption
1	Wing wall	Lot of quantities	
2	Reaction frame	Surrounding land space is small	
3	Super frame	Big frame and lot of cost	
4	Friction Damper	Low cost, maintenance free, small space, outside installing	O



Structure of Friction Damper



Restoring Force Characteristics of Friction Damper

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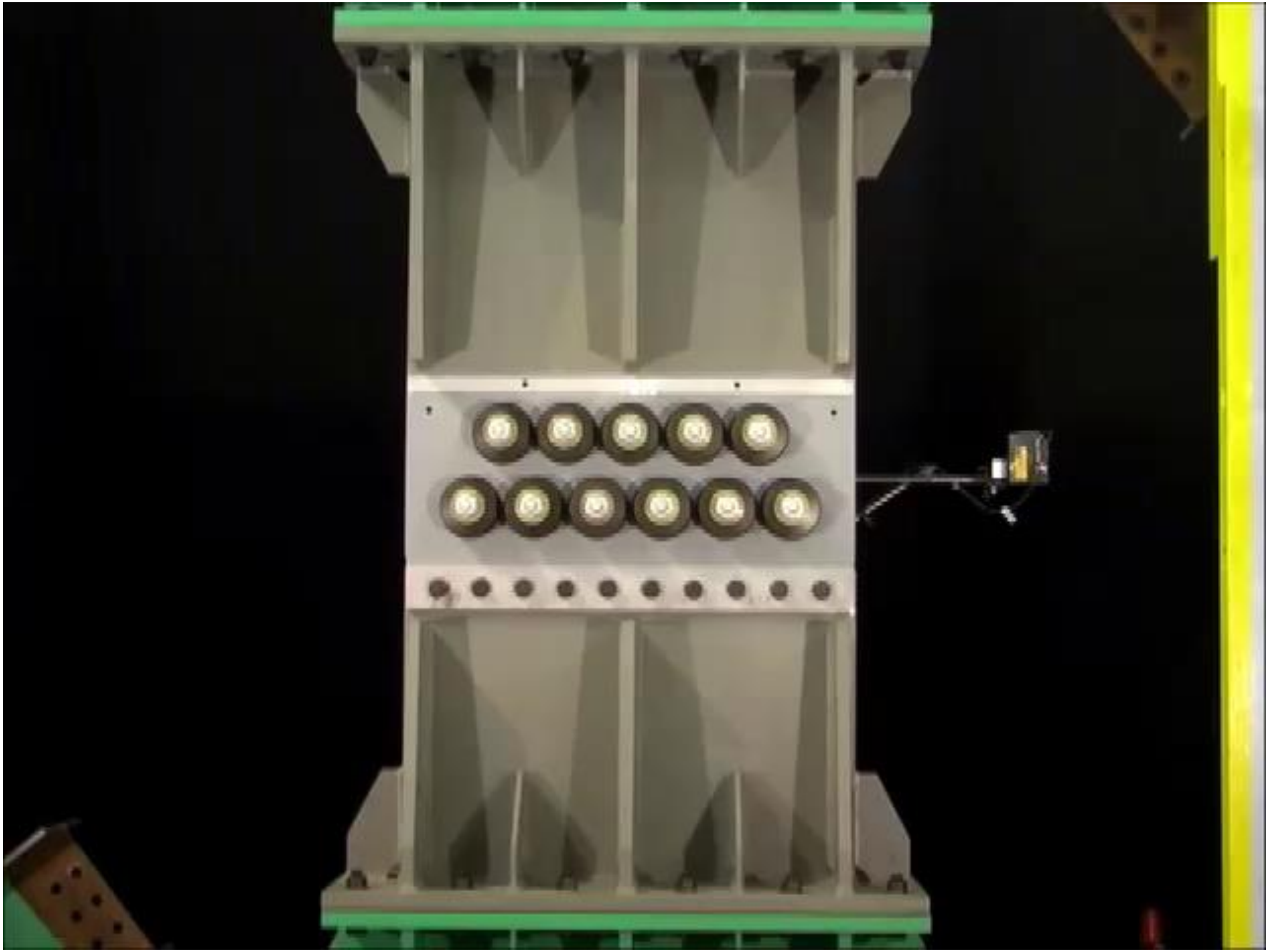
Structural test



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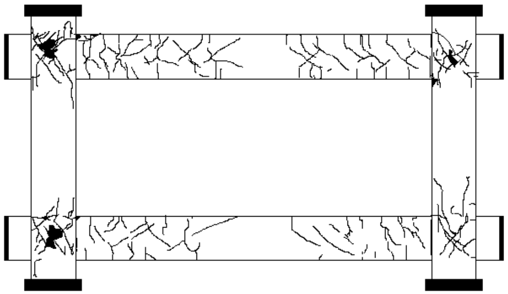
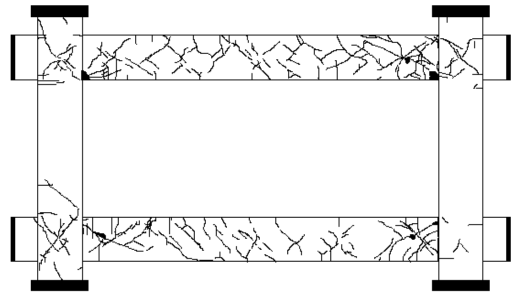
Structural Test

OBAYASHI TUT

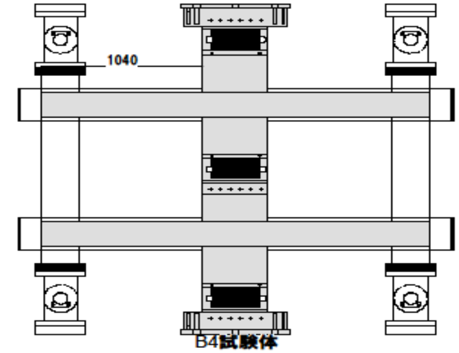
Crack of RC Frame and Restoring Force Characteristics

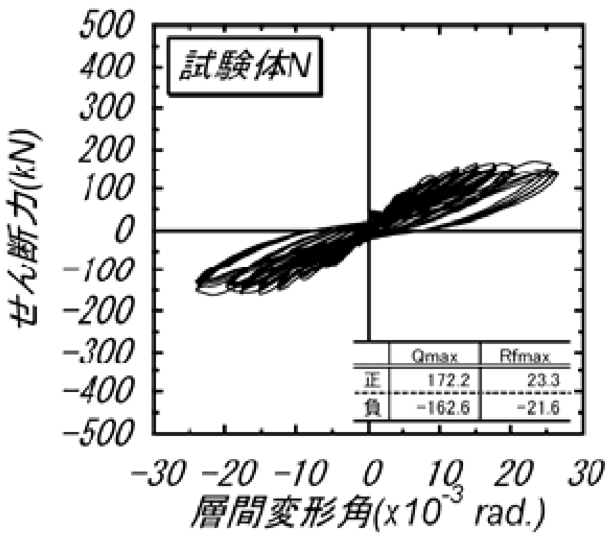


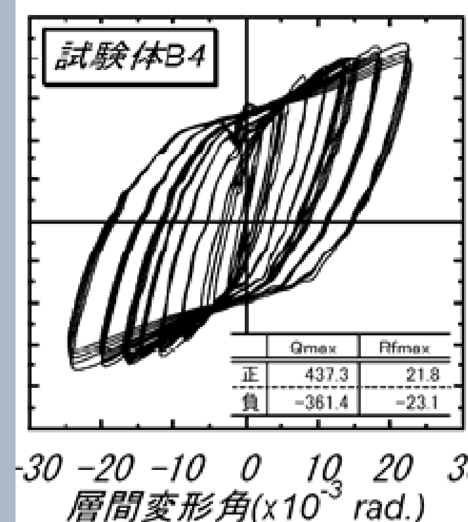
試験体N



試験体B4



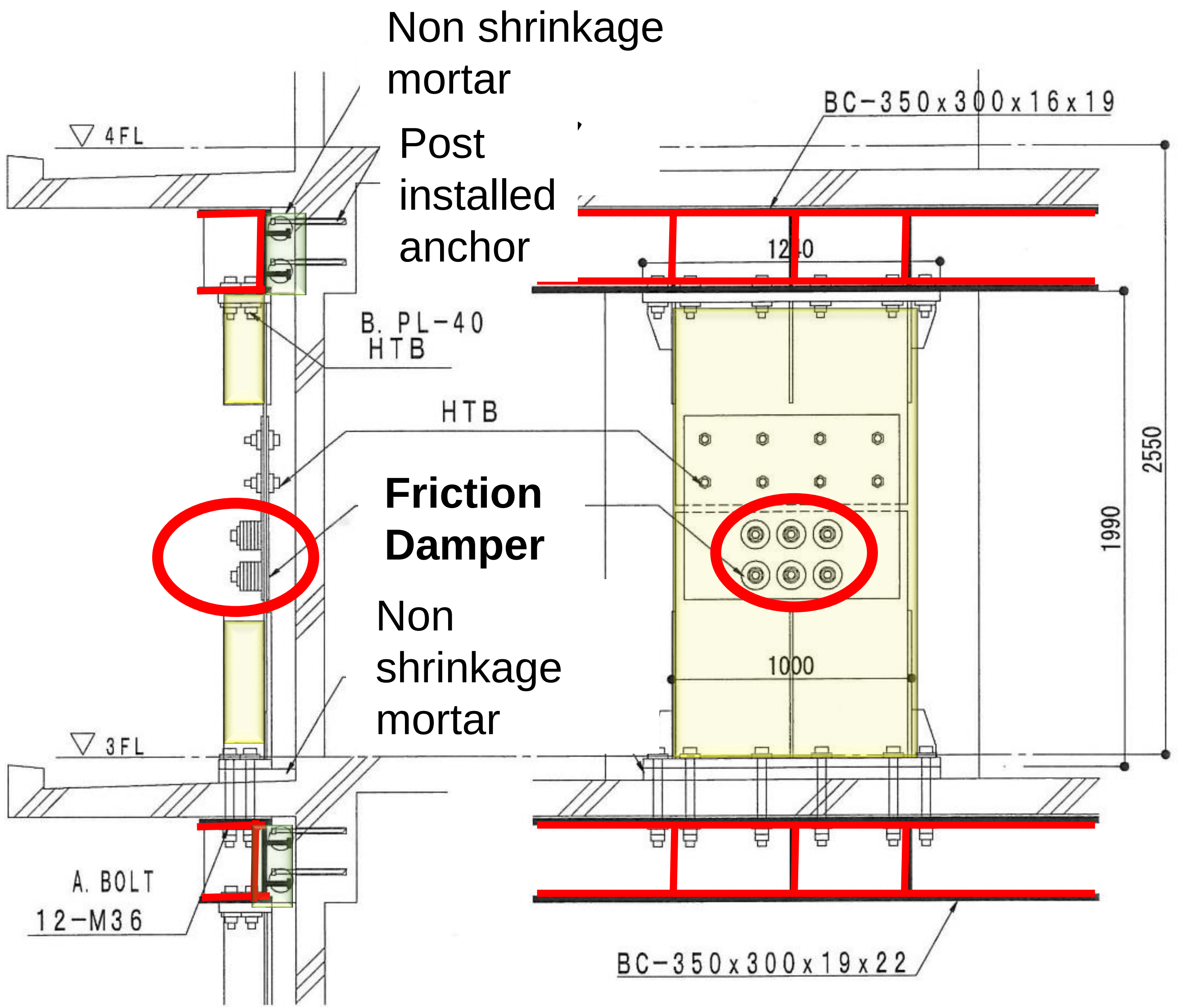




Before Retrofitting

After Retrofitting

OBAYASHI TUT



Detail Drawing of Retrofitting

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Is Index after Retrofitting

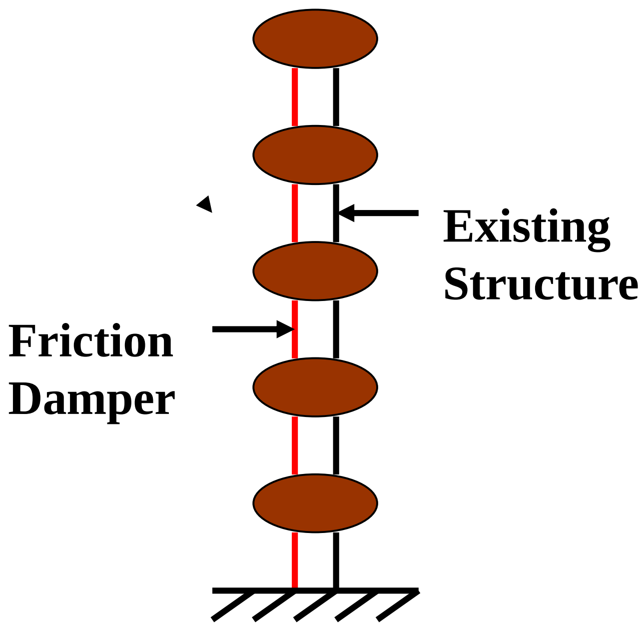
ET=0.90

Story	X Direction (Zone A)				Y Direction (Zone 1)			
	Before Retrofitting		After Retrofitting		Before Retrofitting		After Retrofitting	
	I_S	$C_T S_D$	I_S	$C_T S_D$	I_S	$C_T S_D$	I_S	$C_T S_D$
5	1.10	1.14	1.05	1.10	1.30	1.35	1.47	1.54
4	0.60	0.62	0.90	0.94	0.81	0.84	1.03	1.08
3	0.51	0.53	0.94	0.98	0.70	0.73	0.96	1.00
2	0.56	0.58	0.92	0.96	0.70	0.73	0.99	1.03
1	0.57	0.59	0.93	0.97	0.72	0.75	0.94	0.97

Nonlinear time history analysis

1) Analytical model

■**Structure：**
Five lamped mass shear model



■**Parallel coupling of existing structure and friction damper**

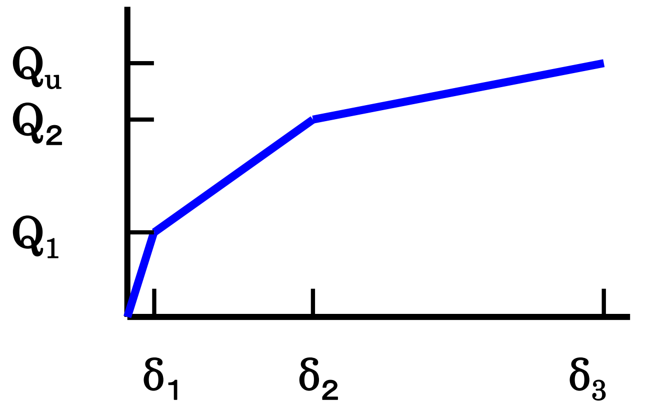
Analytical Model

■**Damping Factor：**
3% proportional to secant stiffness

2) Restoring force characteristics of existing building

■**Skelton curve is obtained by pushover analysis**

■**Hysteresis rule is after the TAKEDA Model.**



Skelton Curve of Structure

Shear force and disp. of each story

階	δ 1(cm)	Q1(kN)	δ 2(cm)	Q2(kN)	δ 3(cm)	Qu(kN)
5	0.430	135.2	2.200	406.7	4.400	406.7
4	0.385	130.3	2.080	392.0	4.160	392.0
3	0.439	153.9	2.060	460.6	4.120	460.6
2	0.514	200.9	2.060	603.7	4.120	603.7
1	0.457	227.4	2.606	683.1	5.212	683.1

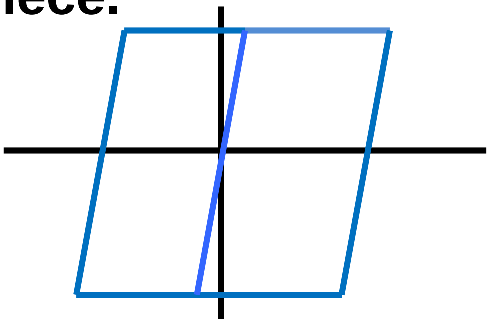
3) Restoring force characteristics of friction damper

■Model of Friction damper: Normal bi-linear

■Initial elastic stiffness of damper

1) Considering the stiffness of the steel panel connected to the damper.
2) And furthermore, considering the stiffness of the beams connected to the friction damper column. Then finally the adopted stiffness is 70% of above 1) stiffness.

■Yielding force of friction damper
200KN per one piece.



Normal bilinear force characteristics of friction damper

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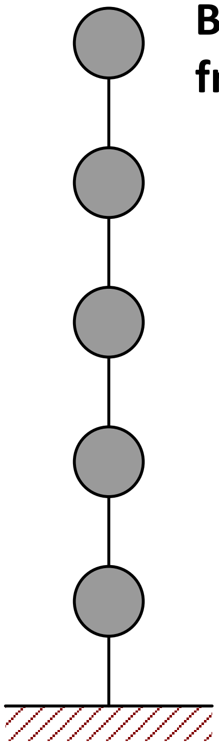
4) Input Ground motion

■**Peak acceleration was scaled up by 1.2 which is local zone factor in Shizuoka.**
■**Artificial ground motions were made based on MLIT notice.**

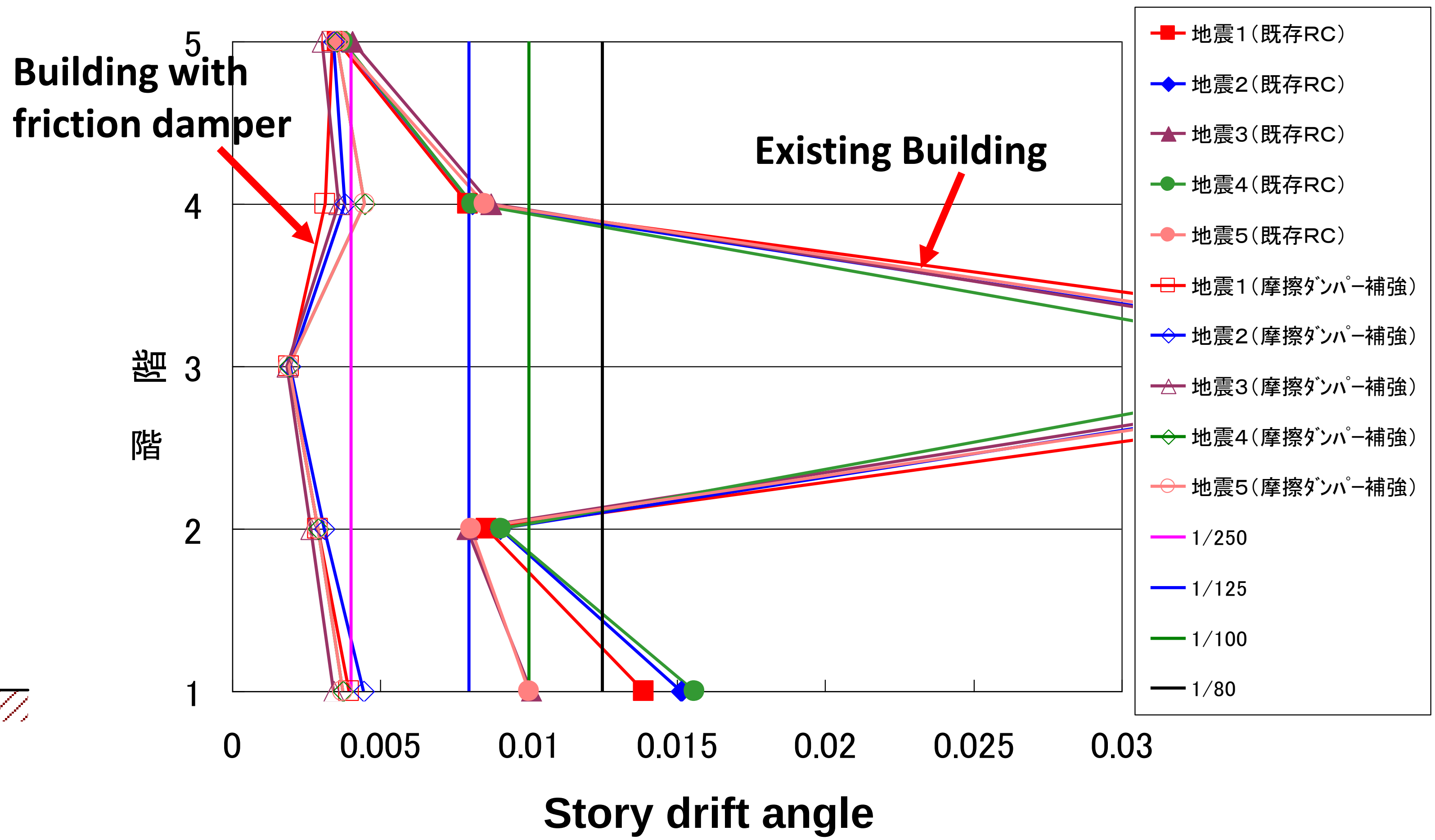
Peak ground motion of input ground motion

地震波名	TWR1	TWR2	TWR3	TWR4	TWR5	TWR6	TWR7	TWR8	TWR9	TWR10
時間間隔(sec)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
データの総数(個)	2540	2540	2540	2540	2540	2540	2540	2540	2540	2540
最大加速度絶対値(gal)	403.45	461.34	372.03	393.67	375.95	379.50	460.50	366.24	414.35	375.00
地域係数1.2を考慮した最大加速度絶対値(gal)	484.14	553.61	446.44	472.40	451.14	455.40	552.60	439.49	497.22	450.00

Result of nonlinear time history analysis

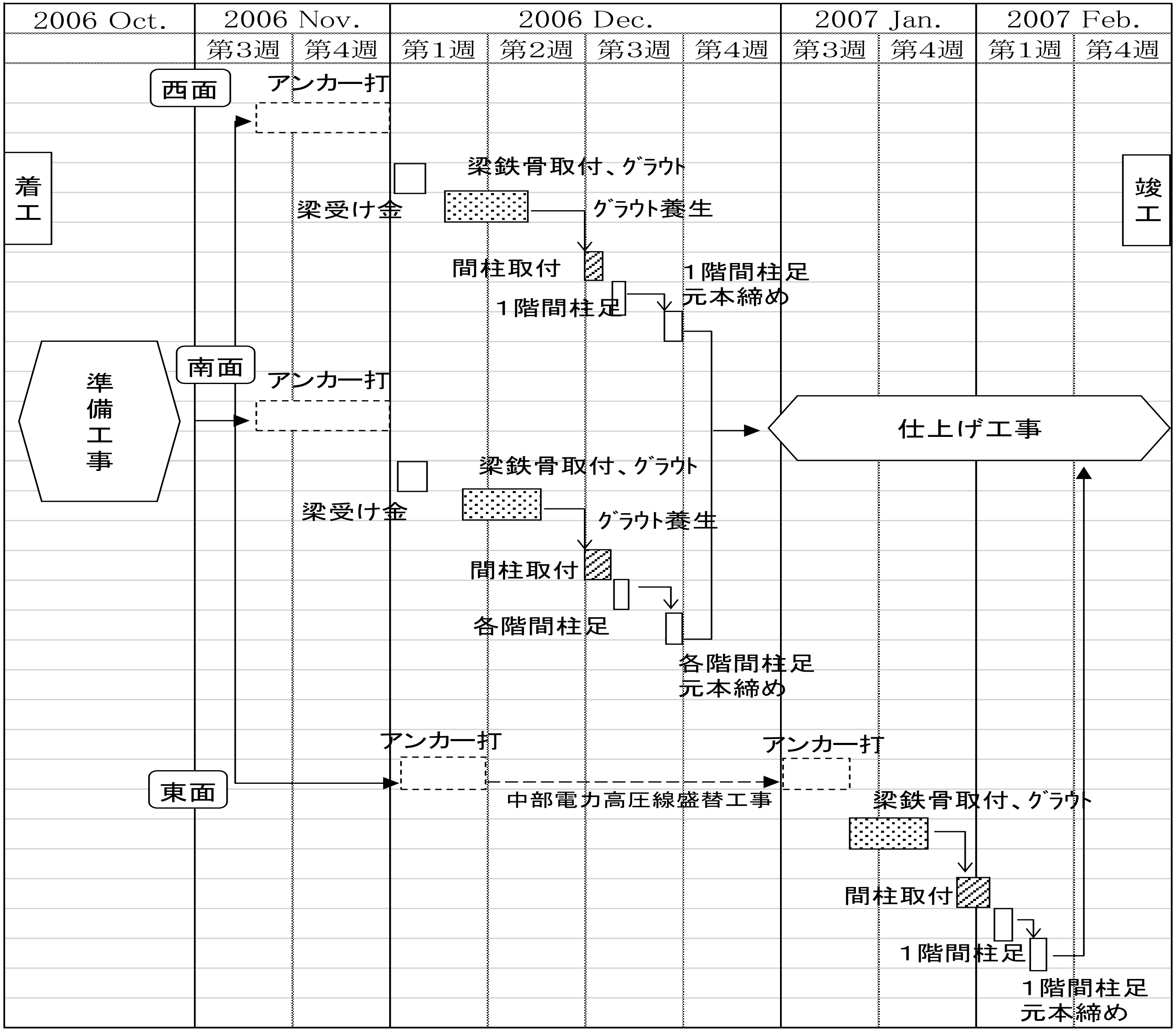


Model



Construction Schedule

（5 months）



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Construction Work

① Installing the anchor on the existing beam

② installed anchors on the beam
Shear force between newly installed steel beam and existing RC beam.

③ Newly installed steel beam is lifted.

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④ **Installing the new beam on the part of post installed anchor.**

⑤ **After installing the new steel beam**

⑥ Grouting the mortar behind the steel beam

⑦ Friction damper column

⑧ Lifting the friction damper column

⑨ Setting work to newly installed steel beam

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⑩ Completion of setting work of friction damper column

⑪ Completion of retrofitting work

⑬ Friction damper can be seen from outside as appealing and visual checking after earthquakes.

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High rise buildings retrofitted by the vibration control methodology

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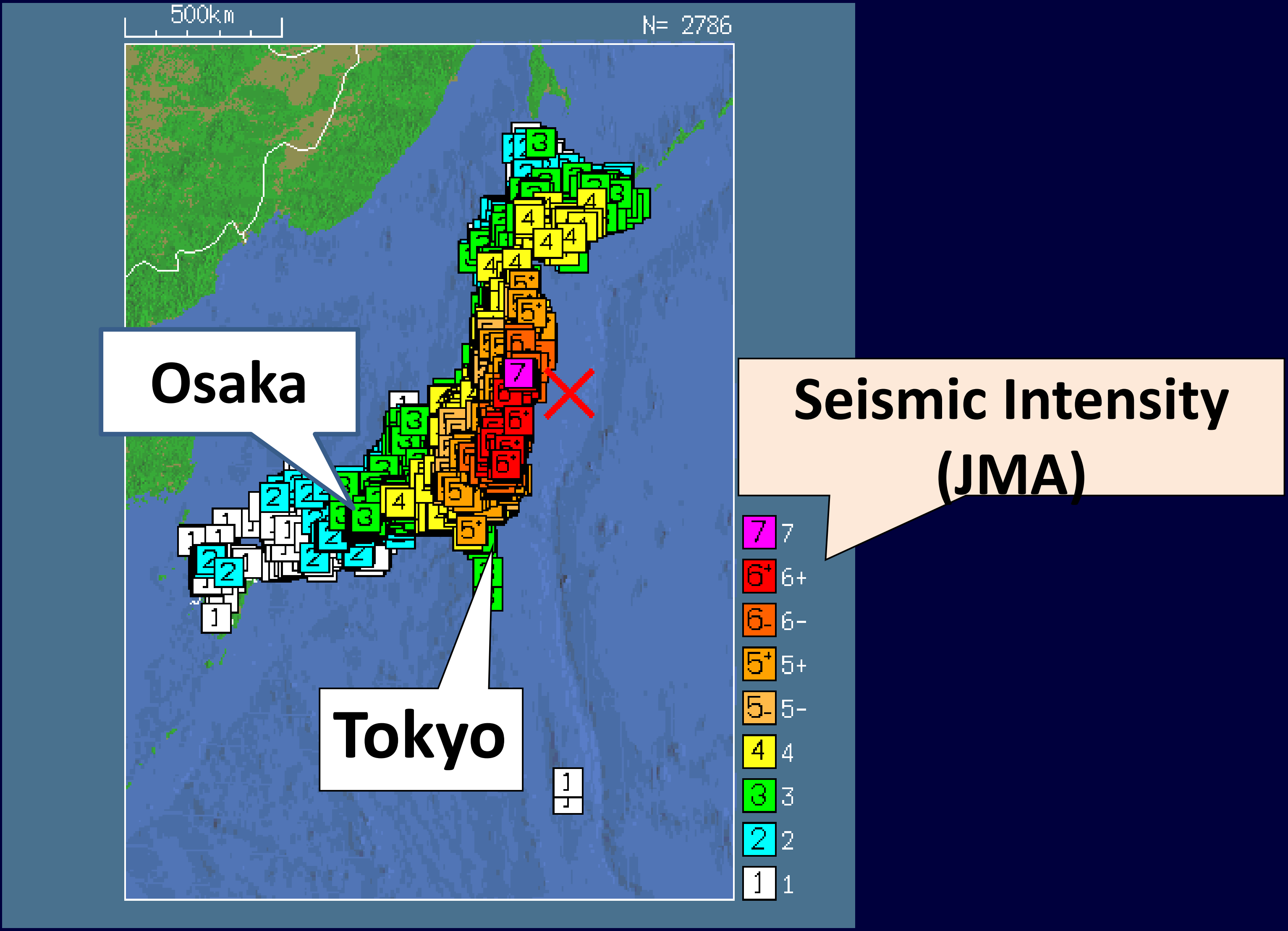
Seismic Intensity: Tohoku Earthquake, 11th, March, 2011



High rise building in Shinjuku, Japan

Original construction: 1979, 55F, H=223m,Steel structure

After Kimura Y., Taisei co.

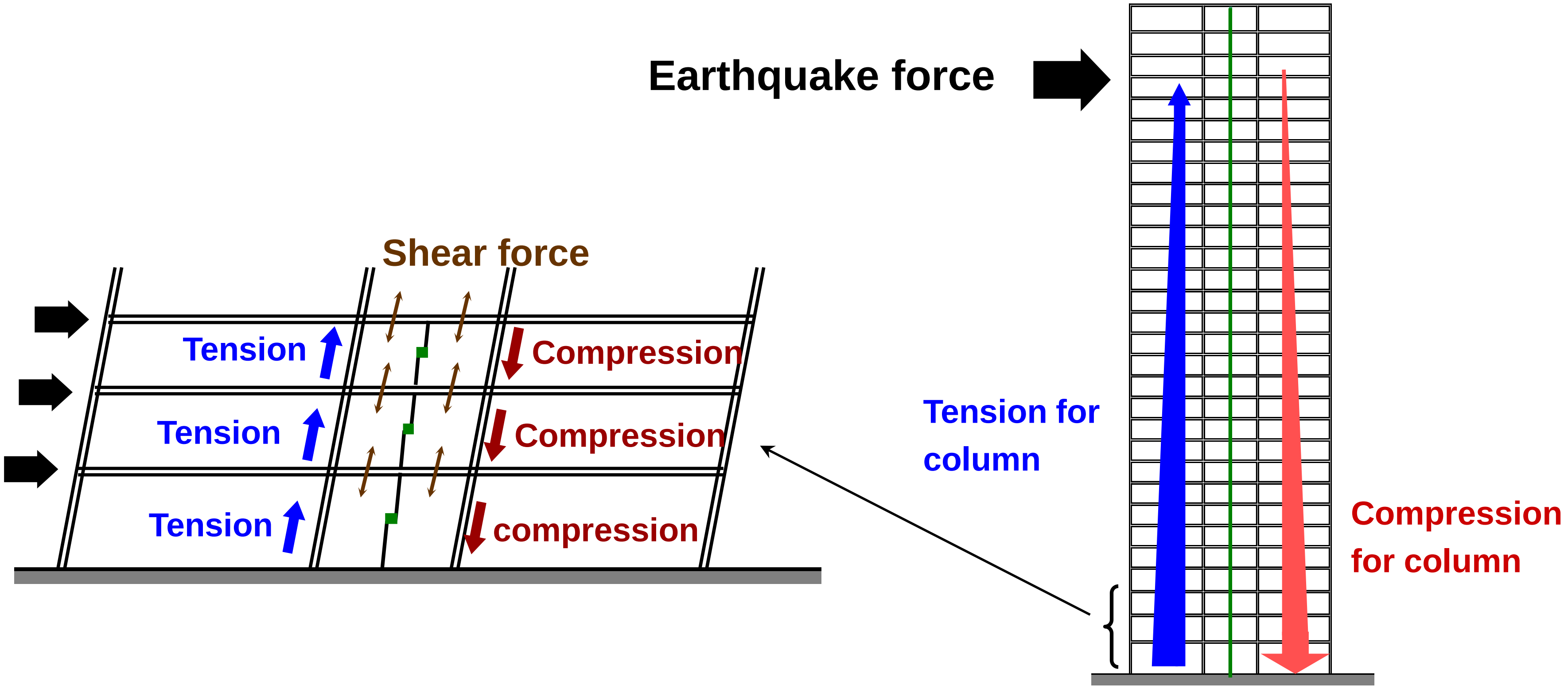
Oil damper

Necessity of Vibration Control

After Kimura Y., Taisei co.

■ Background

- Lack of capacity against the unexpected strong ground motions
- Columns at lower stories exceed the allowable stress

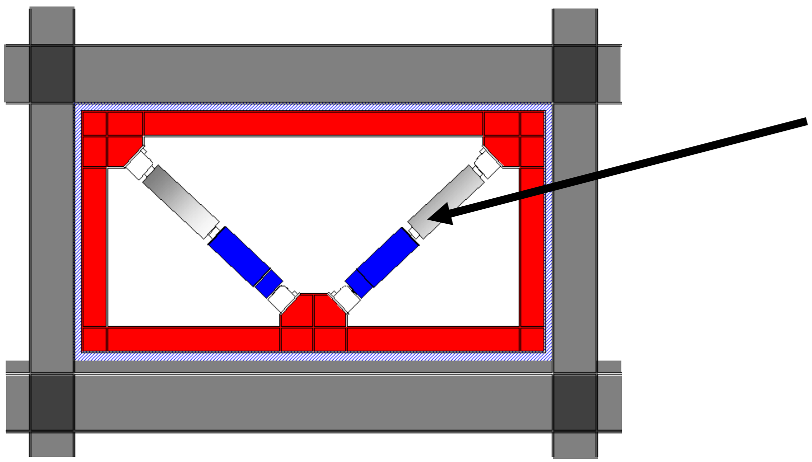


Oil damper (T-RESPO)

■ Characteristics

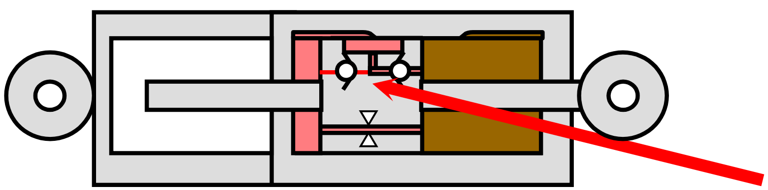
After Kimura Y., Taisei co.

- **Additional stress doesn't occur against the beams and columns**



Oil damper with the controlled axial force

<u>Mechanism of the controlled axial force</u>



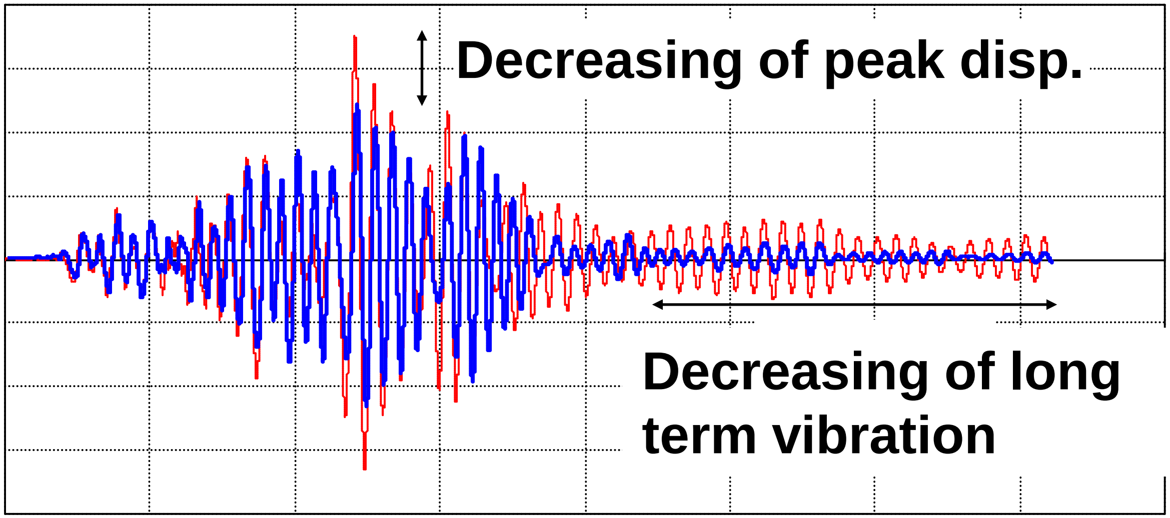
Damping force decreases beyond the designed displacement

Effect of Vibration Control

After Kimura Y., Taisei co.

■ Decreasing of response displacement

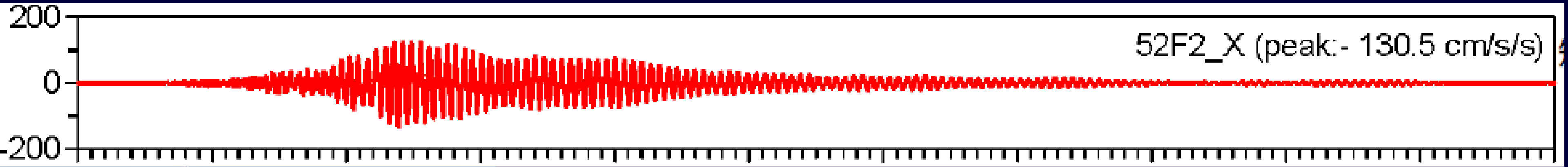
- **Peak displacement decreases**
- **Long term vibration decreases after terminating earthquake**



Nonlinear time history analysis

red line	**before installing dampers**
blue line	**after installing dampers (T-RESPO）**

Passive Control of High Rise Building



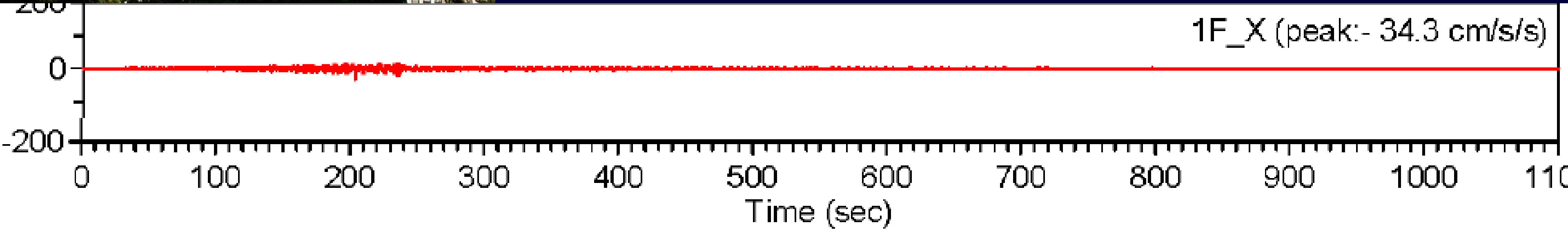
Big Earthquakes having Long Period Components（3.11,2011 Earthquake)

Osaka Fusakishima City Office

55F,B2F H=256m

800km from epicenter

Fundamental Period (T): 7.0 sec



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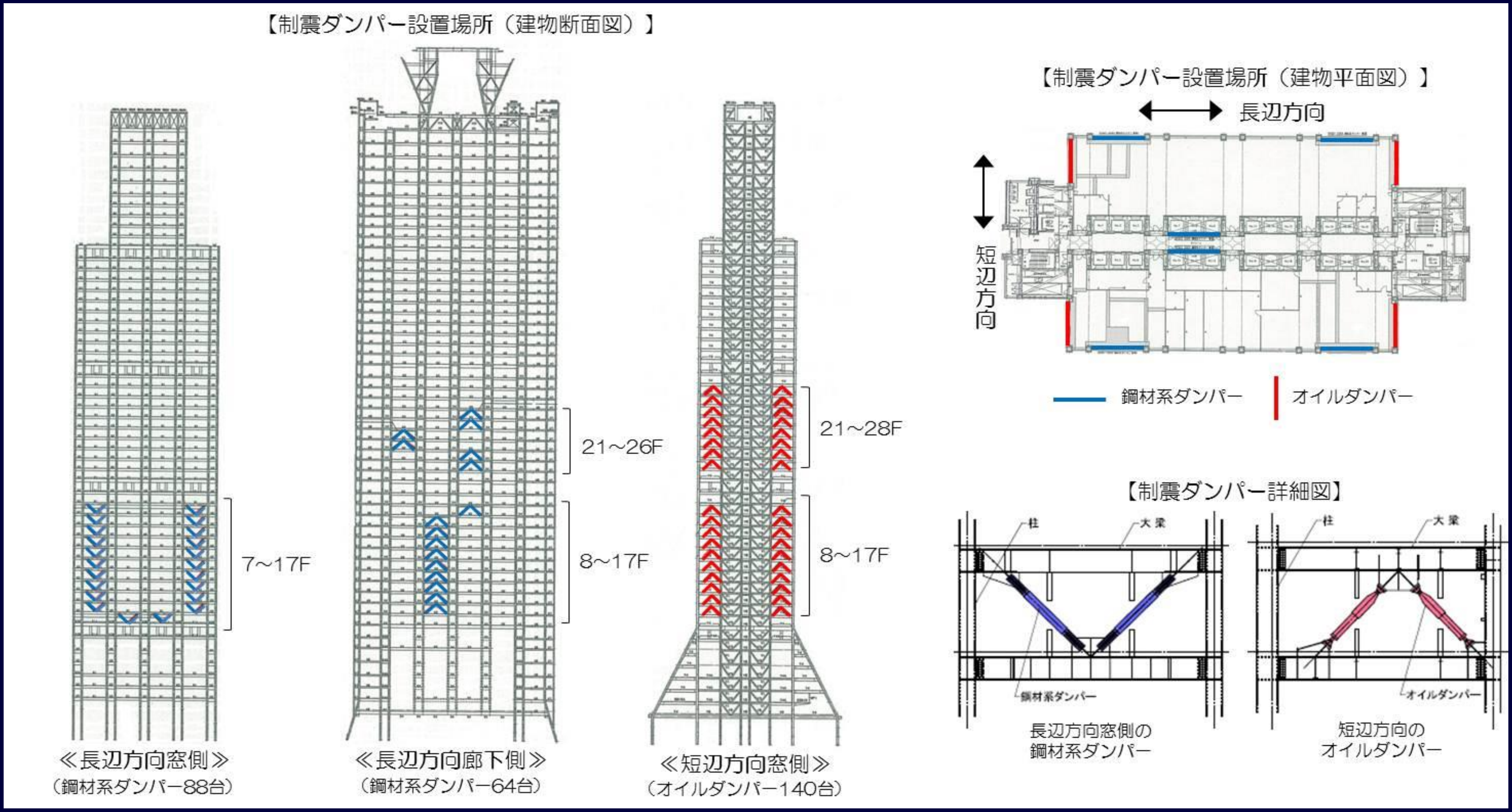
Passive Control of High Rise Building

Big Earthquakes having Long Period Components



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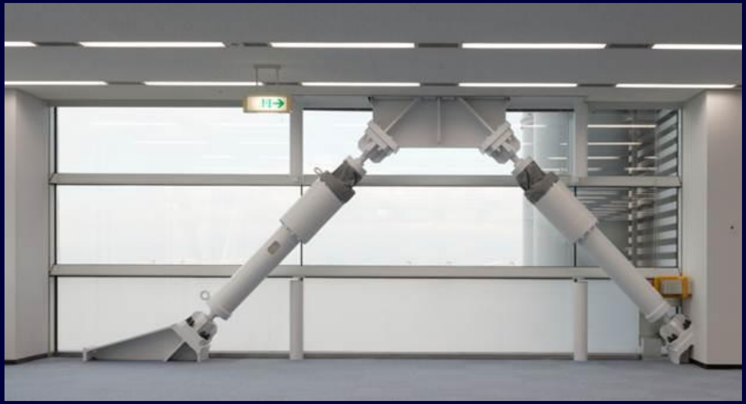
Passive Control of High Rise Building

Big Earthquakes having Long Period Components



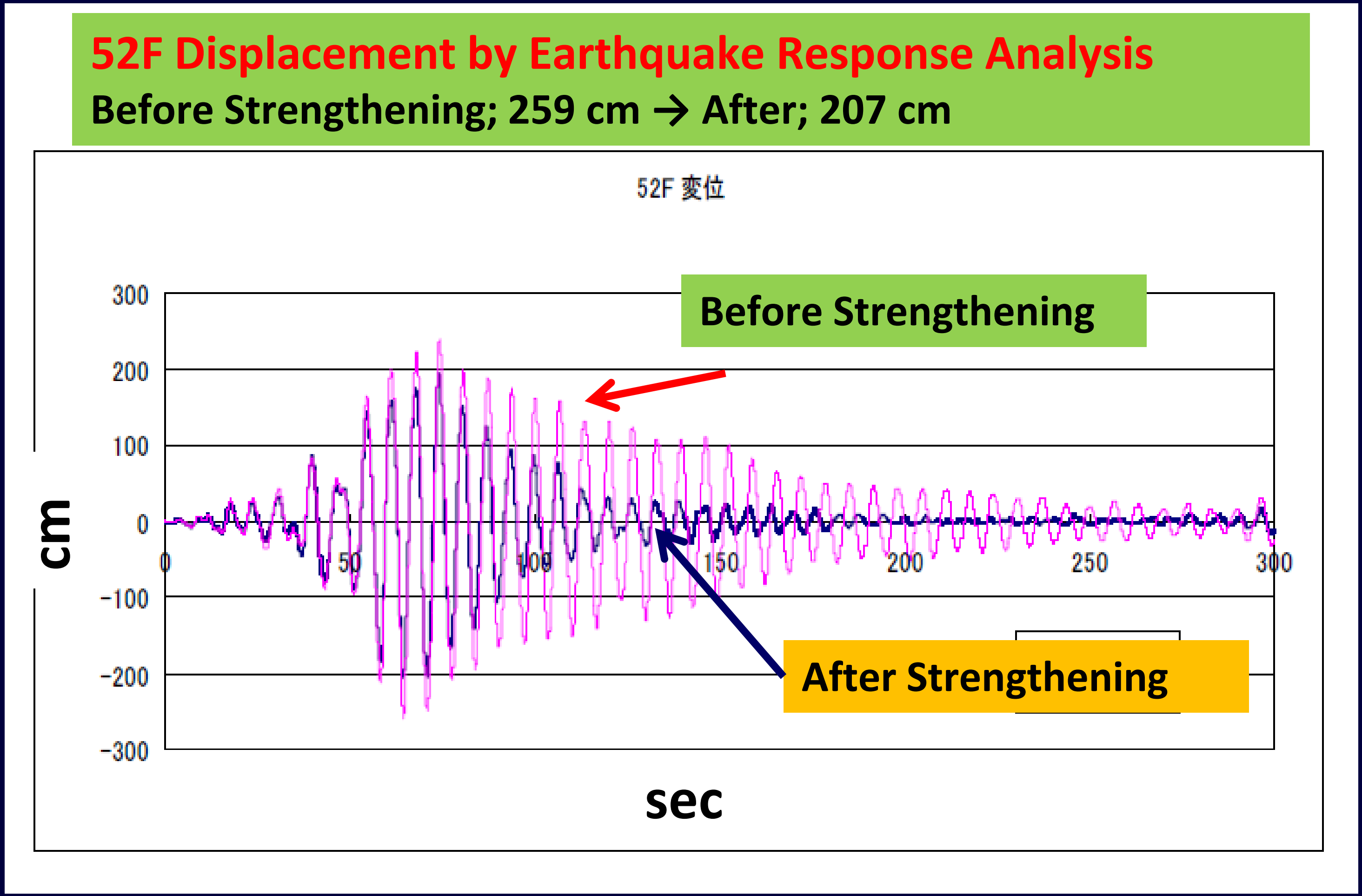
Oil Damper

Steel Damper

http://www.pref.osaka.lg.jp/otemaemachi/saseibi/cyosyukitorikumi25.html

Passive Control of High Rise Building

Big Earthquakes having Long Period Components



http://www.pref.osaka.lg.jp/attach/13203/00078593/230624file3-2.pdf

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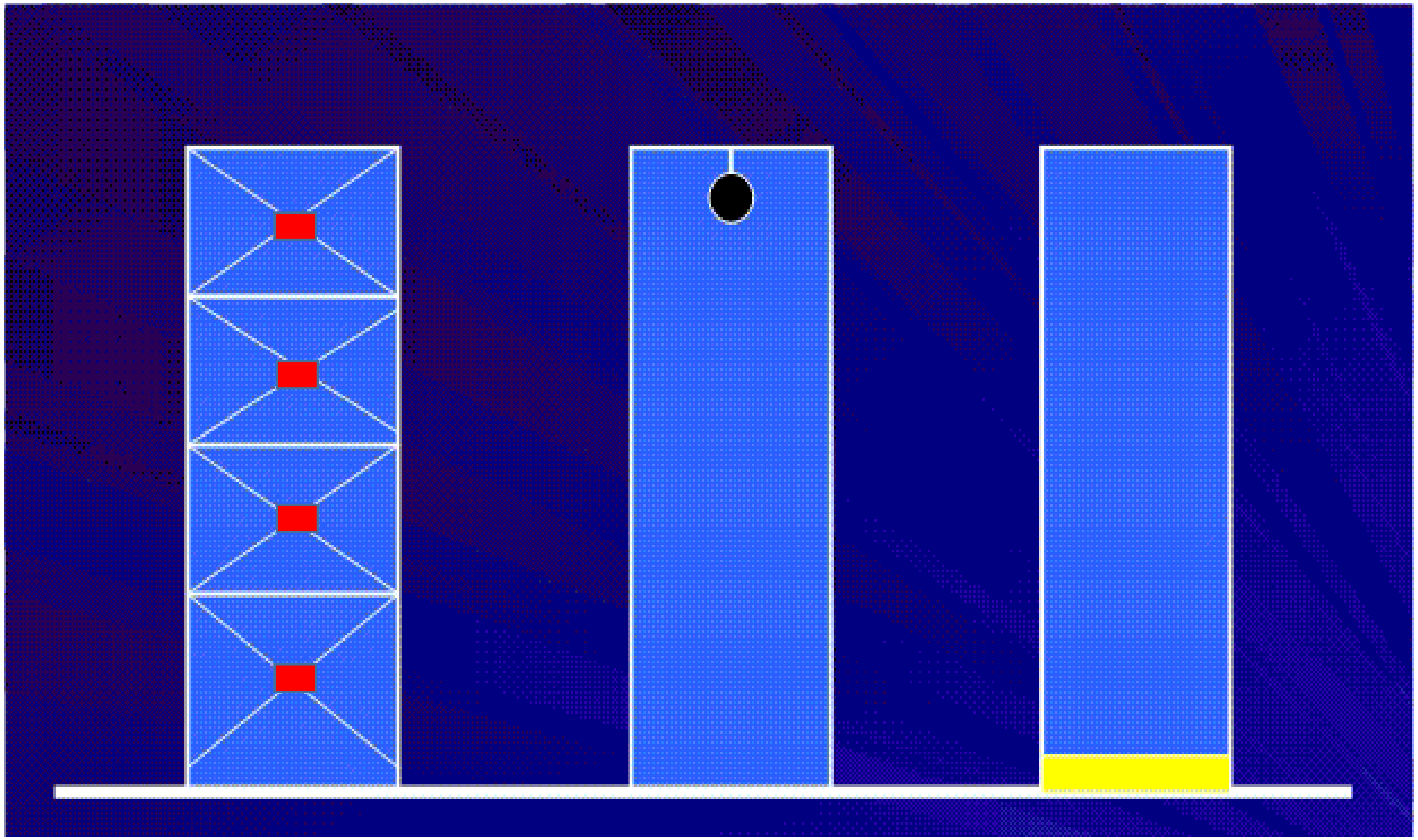
Three Types of Vibration Control



Passive Damper	Tuned mass Passive Damper	Super Active Base Isolation

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Passive Vibration Control System: The biggest TMD (Tuned Mass Damper) in Japan

Shinjuku Mitsui Building, Japan

www.mitsuifudosan.co.jp/corporate/news/2015/0514/st

Passive Vibration Control System: The biggest TMD (Tuned Mass Damper) in Japan

Outline of the Building

1. **Original Building**
- Completion: Sept. 1974
- Story: 55F, B3F
- Height: 210m
- Structure: S (Upper Structure), RC/SRC (Basement)

2. **Retrofitted Building**
- Completion: April 2015
- Vibration control devices: TMD, Oil dampers

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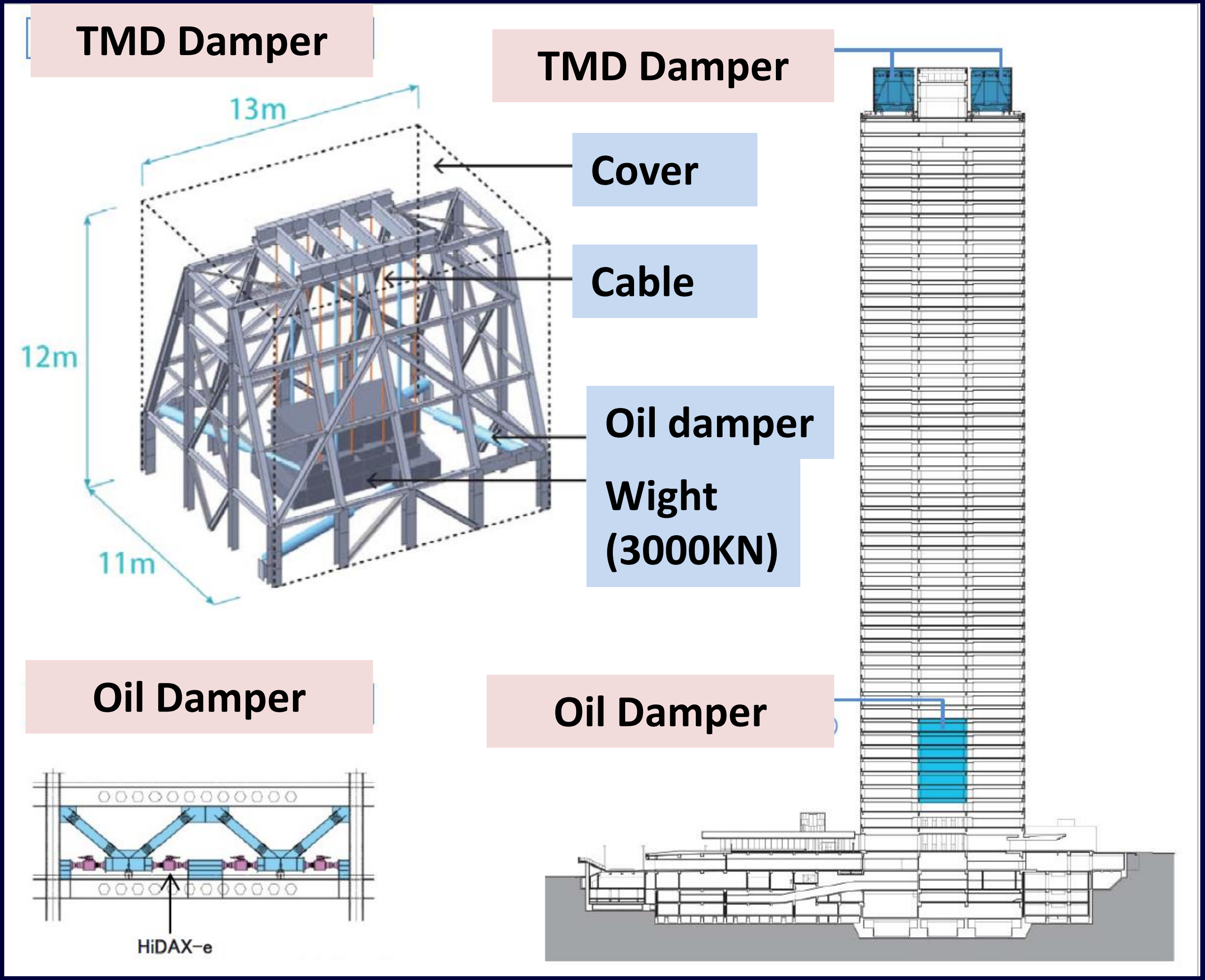
Passive Vibration Control System: TMD (Tuned Mass Damper)



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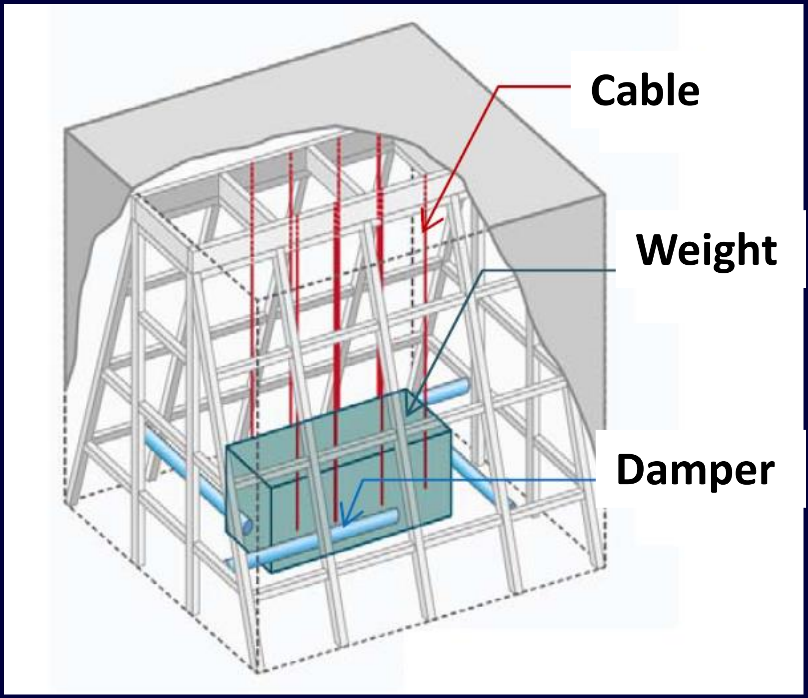
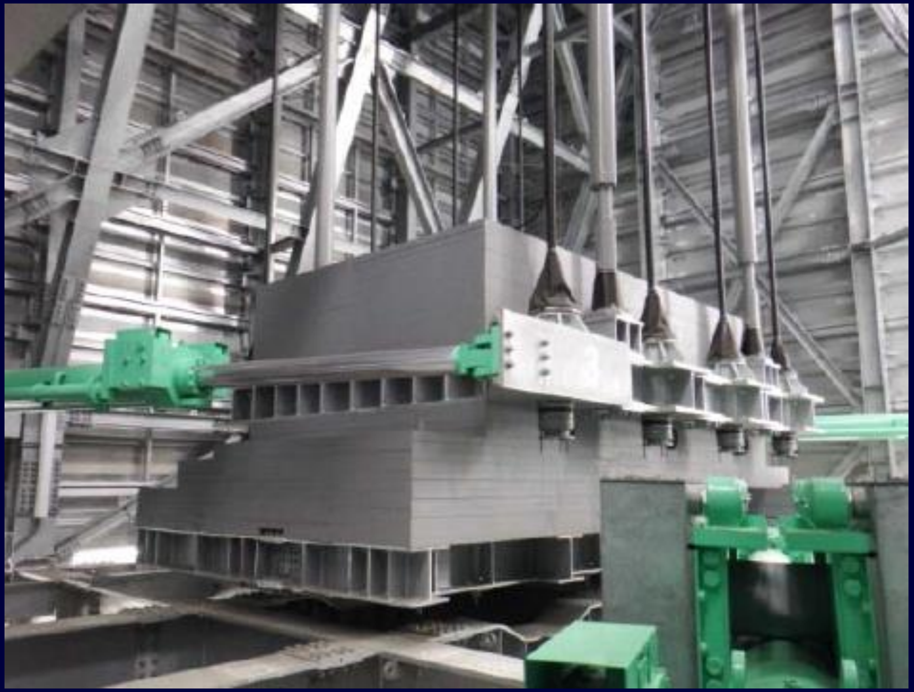
Seki M., UTCB Lecture note, May 2017, BRI, Japan

Passive Vibration Control System: TMD (Tuned Mass Damper)

Detail of TMD





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Conclusions

1. **More than 3000 buildings were completed in Japan and will increase more.**

2. **Vibration control can make the more flexible design easier than conventional structural design.**

3. **Effect against wind and earthquake was obtained and found to be effective for high quality buildings.**

Thank you for your attention