14th U.S.-Japan Workshop on Improvement of Structural Design and Construction Practices

Seismic retrofit of the tower structure with viscous dampers

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Why was needed the seismic retrofit ?

☆ Improvement of the seismic retrofit of this building was needed, the controller escaped by intense fear in the Great East Japan Earthquake.

☆ The important facility as the main gate of Japan.

☆ Preparation for Tokyo metropolitan earthquake which may happen from now on.

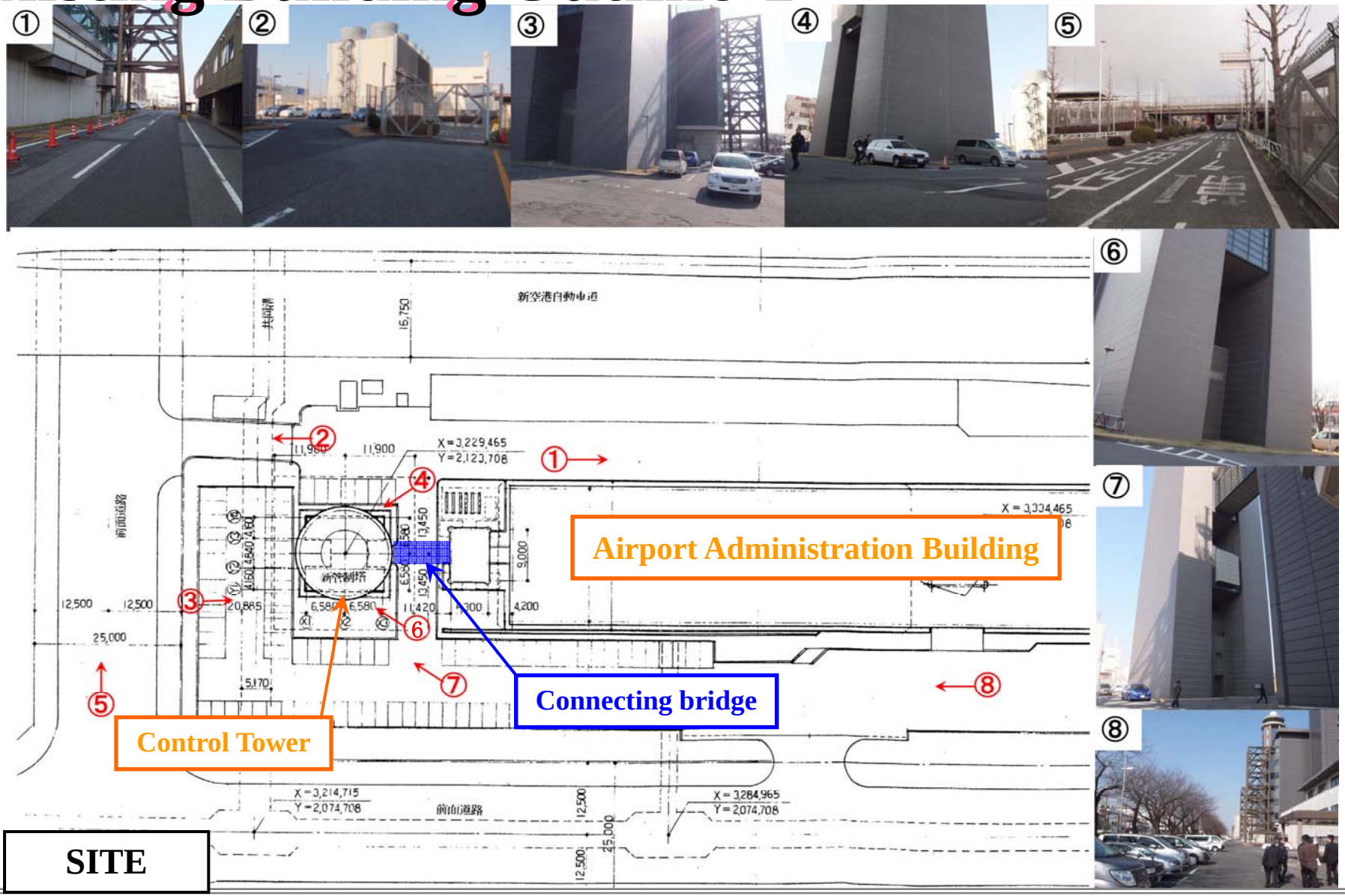
Why adopted the damping structure?

☆ The reinforcement work must be done while the building is being used.

☆ No change was allowed concerning the main electric cables and building equipment.

☆ The cost of the seismic retrofit must be kept in the limited budget.

Existing Building Outline-1



Existing Building Outline-2

Location : Chiba , Japan

Building area : 241.43㎡

Total floor area : 1778.26㎡

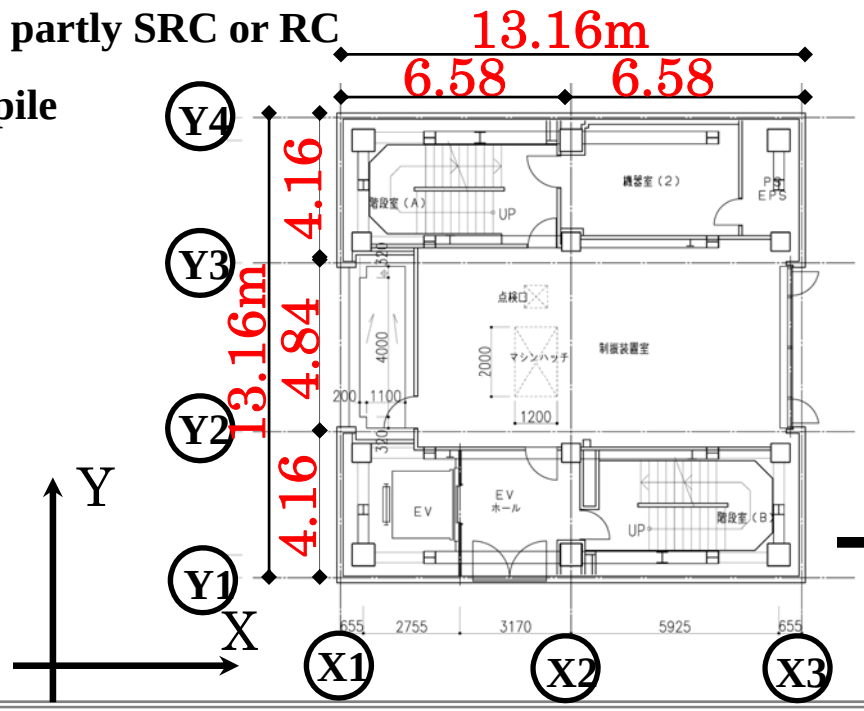
Standard floor area : 169.74㎡(13.16 sq. meters)

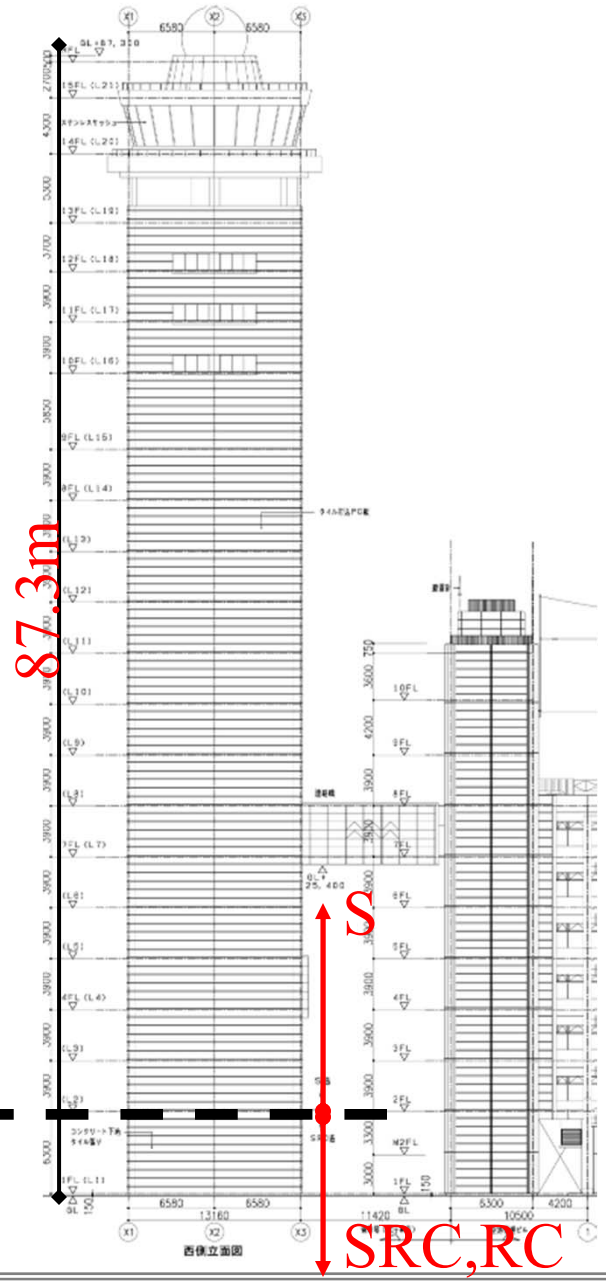
Number of floors : L21

Height of building : 87.3m

Structure : S , partly SRC or RC

Foundation : pile





Structural Planning-Structural design of Existing Building

Frame Form : S , Moment Frame with braces (L2~)

SRC , Box-frame construction(L1)

Main Frame : Column section is a shape of 550mm-box and a shape of 450mm-diameter-pipe.

Maximum depth of H-Beam is 700mm.

Maximum depth of H-Brace is 400mm.

Thickness of bearing wall is 900mm.

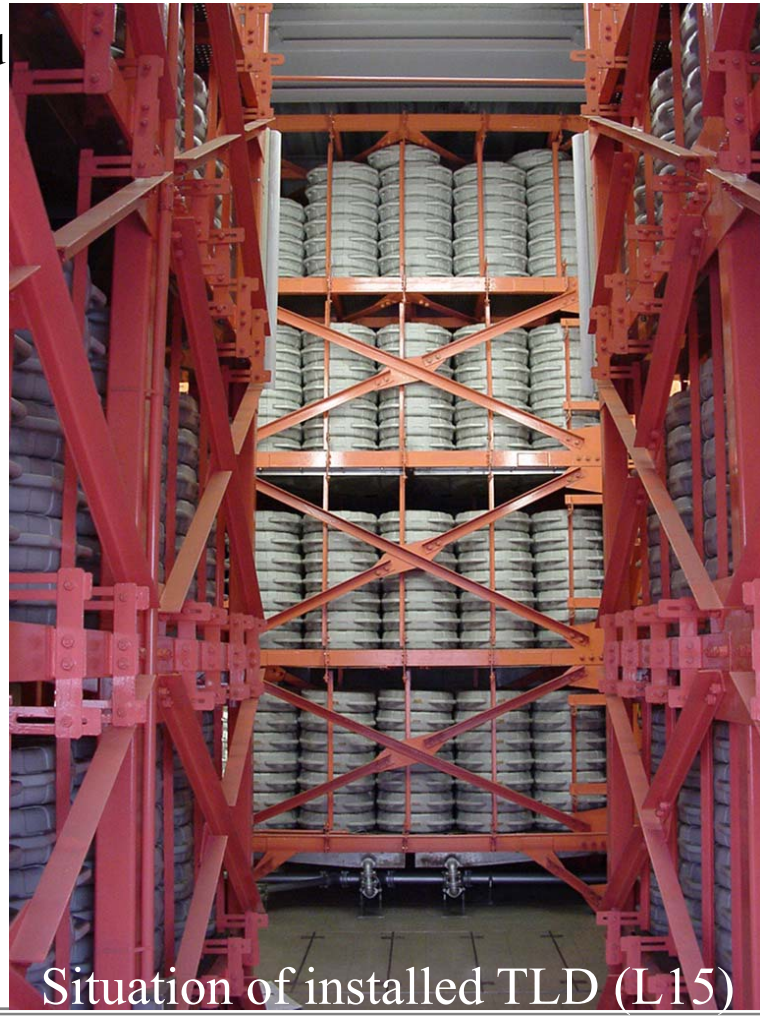
Foundation : Mat slab form(Thickness is 5m)

Cast-in-place concrete pile(Diameter is 1.5m)

Material Strength : Tensile strength of Steel is 490N/mm^2 .

Compressive strength of concrete is 21N/mm^2.

※Tuned liquid damper(TLD)is installed on the L15



Situation of installed TLD (L15)

Structural Planning-Application design of viscous dampers

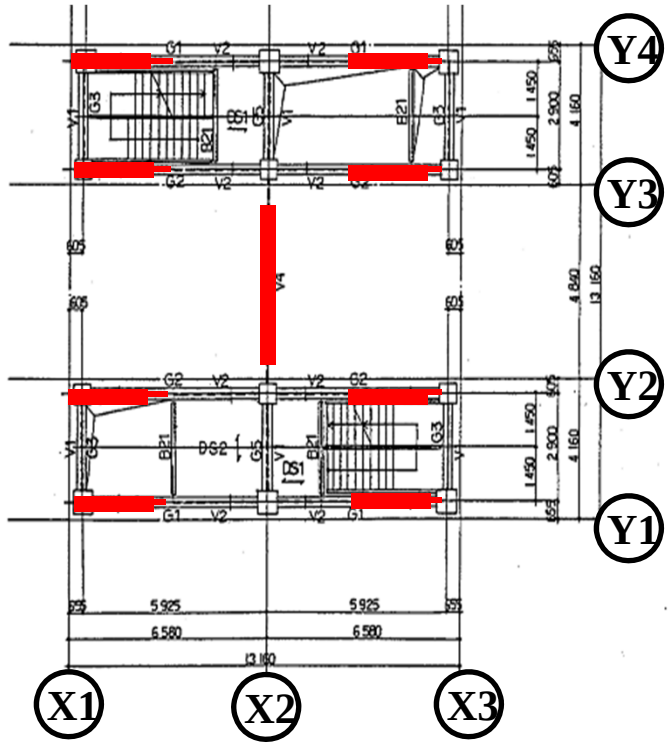


Fig. Beam plan

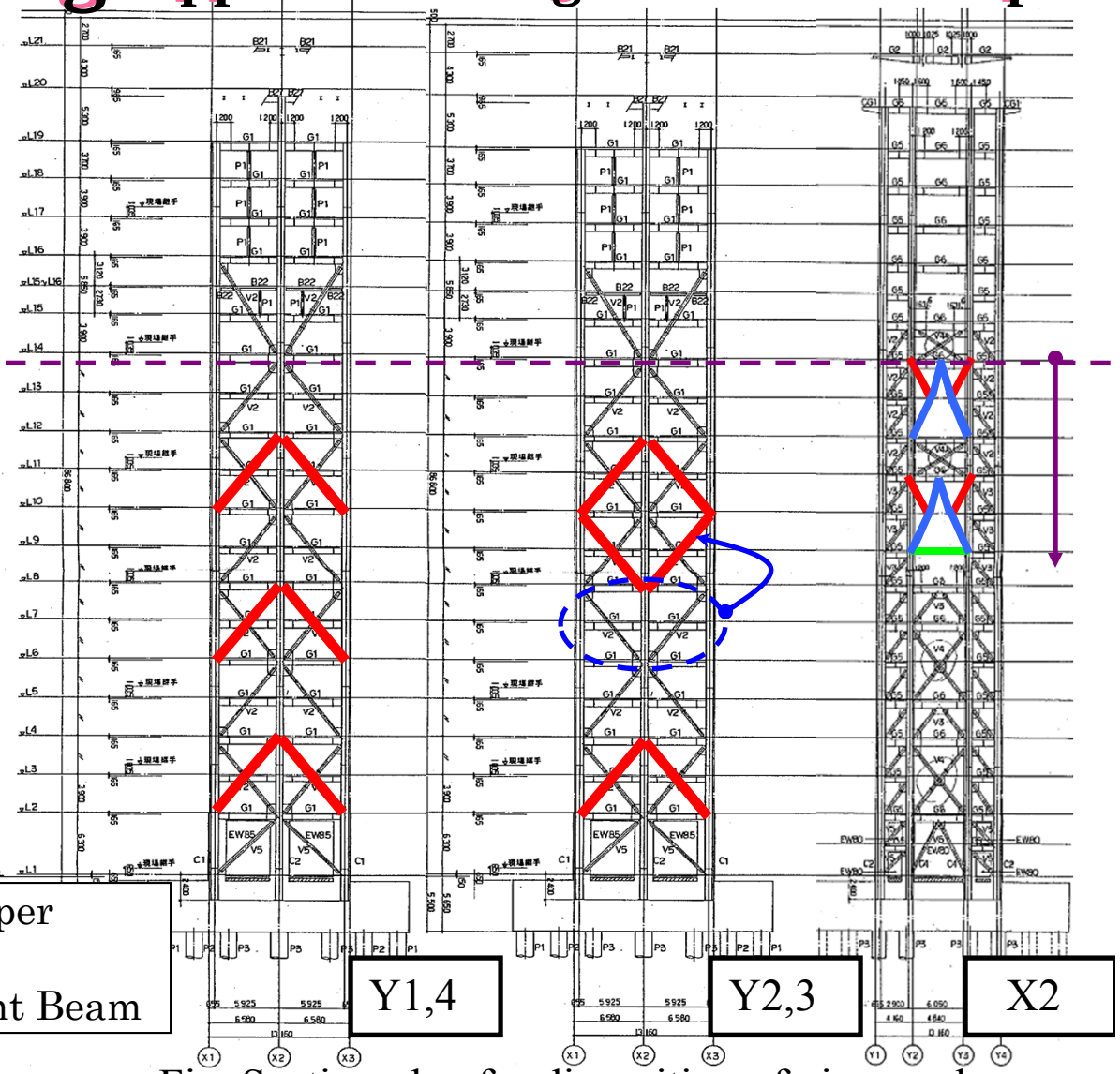


Fig. Section plan for disposition of viscous dampers

Structural Planning-type-1 of viscous dampers

[leaned arrangement type(Y2 L2-3)]

Structural Planning-type-2 of viscous dampers

[Amplification mechanism type(X2 L9-11)]

Dynamic characteristics of existing building

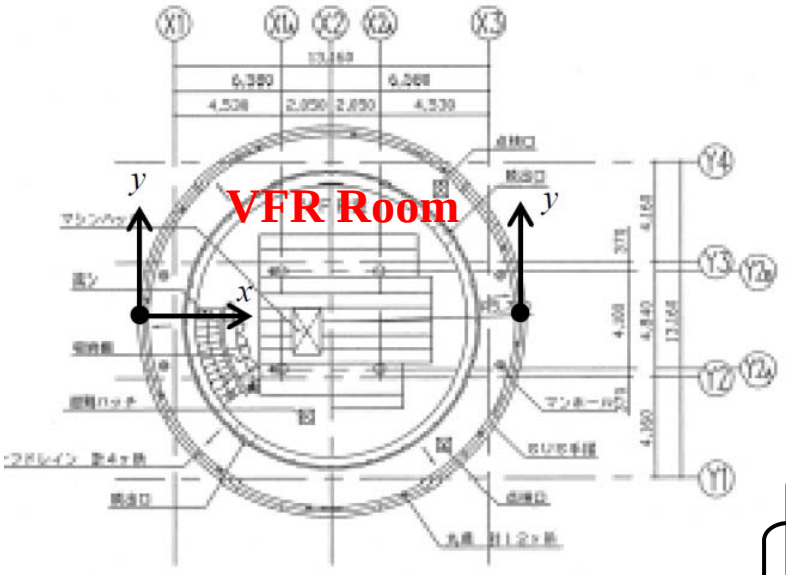


Fig. Seismographs arrangement

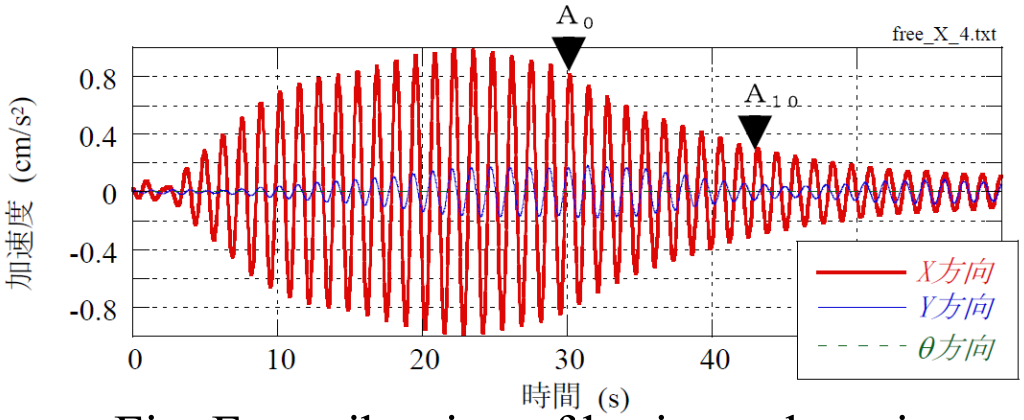


Fig. Free vibration of horizontal motion

Table. 1st natural period and damping coefficient

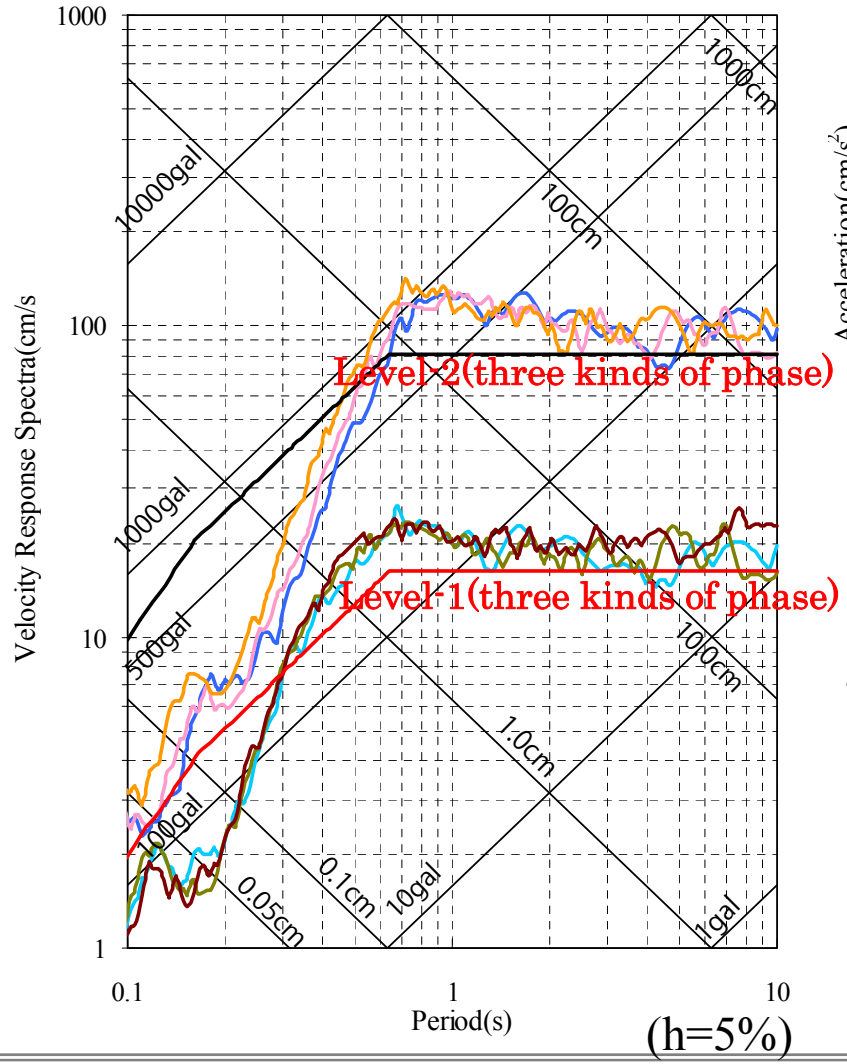
測定日	方向	Natural period(s)	Damping coefficient(%)	備考
平成４年１１月４日	X方向	１．２６	０．３６	ＴＬＤ設置前
1st(1992)	Y方向	１．３３	０．２１	ＴＬＤ容器寸法決定のため。
平成４年１２月１日	X方向	１．２８	０．３７	ＴＬＤ設置前
2nd(1992)	Y方向	１．３４	０．２７	ＴＬＤ調整周期決定のため。
平成５年１月25日	X方向	１．２９	２．００	ＴＬＤ設置直後
3rd(1993)	Y方向	１．３５	２．２０	性能確認のため。
平成６年２月10日	X方向	１．２９	１．５０	ＴＬＤ設置後１年
4th(1994)	Y方向	１．３５	１．３０	性能確認のため。
平成10年２月18日	X方向	１．３０	１．２１	ＴＬＤ設置後５年
5th(1998)	Y方向	１．３７	１．４７	性能確認のため。
平成16年３月26日	X方向	１．２８	１．７０	ＴＬＤ設置後11年
6th(2004)	Y方向	１．３６	１．２８	性能確認のため。

Before installing TLD

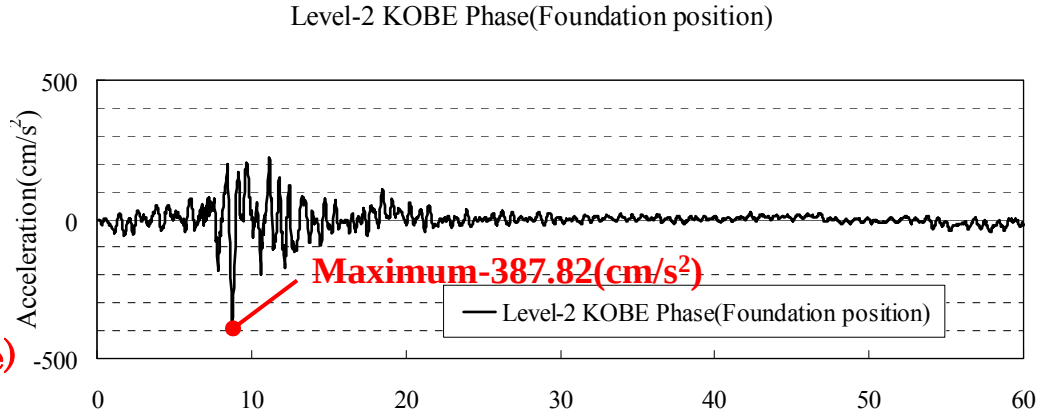
After installing TLD

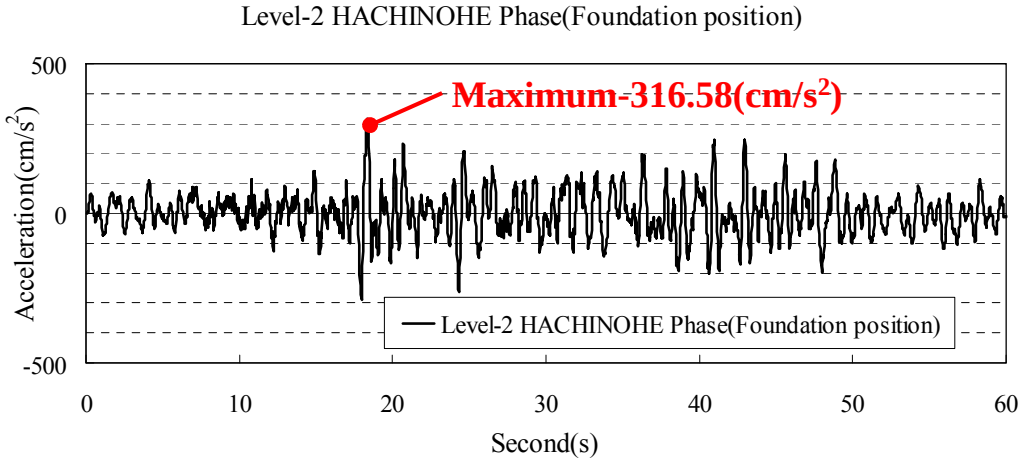
Structural Design Criteria-

Selection of Input Earthquake Motion



(h=5%)





Structural Design Criteria-

Structural design criteria of seismic retrofit building

Table. Structural Design Criteria of seismic retrofit building

			Level of input earthquake motion	
			Level-1	Level-2
Upper Structure	Proof Stress		Equal or Less than allowable stress for temporary load	2.0 Equal or Less than Plasticity rate of frame
	Inter-story drift angle		Equal or More than 1/200*	Equal or More than 1/100*
Foundation	footing	Proof Stress	Equal or Less than allowable stress for temporary load	Equal or Less than Ultimate strength
	Pile	Proof Stress	Equal or Less than allowable stress for temporary load	Equal or Less than Ultimate strength

* The top of building partly cannot meet the design criteria of Inter-story drift angle. Therefore, total inter-story drift is divided into bending deformation and shear deformation and, paying attention to shear deformation, breakage and fall of the exterior are checked.

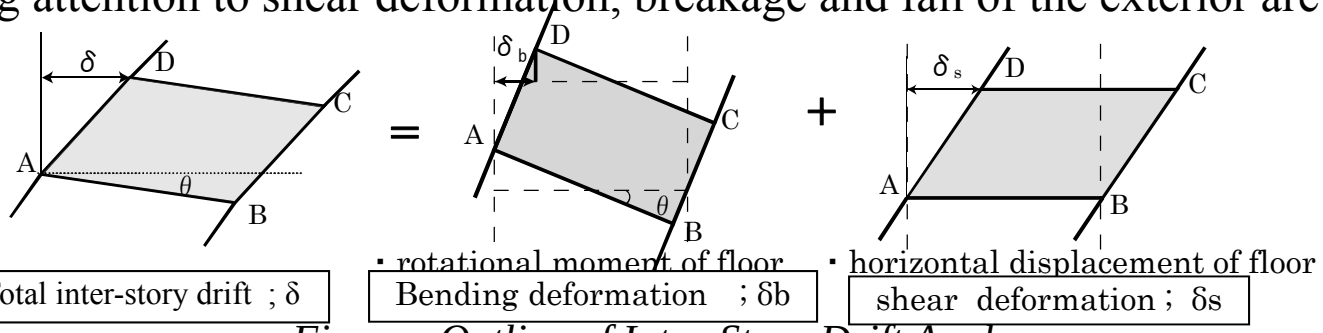


Figure . Outline of Inter-Story Drift Angle

Structural Modeling and Analysis Method(1)

1) Boundary condition: bottom of column installed on the L1 is Pin support
2) Node has six degrees of freedom, while node installed on the slab has three degrees of freedom
3) restoring force characteristics of structural element

Beam bending: end of member has rotational spring (Fig. a)
Restoring force characteristics is Bi-linear Type
Shear : center of member has shear spring (Fig. b)
Restoring force characteristics is Bi-linear Type
Brace : Axial direction spring (Fig c)
Restoring force characteristics is Bi-linear Type
Column, wall : fiber (MS) model (Fig. d)

Fig a. Beam bending model

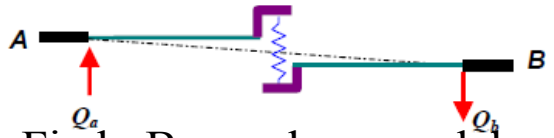


Fig b. Beam shear model

Fig c. Axial direction spring

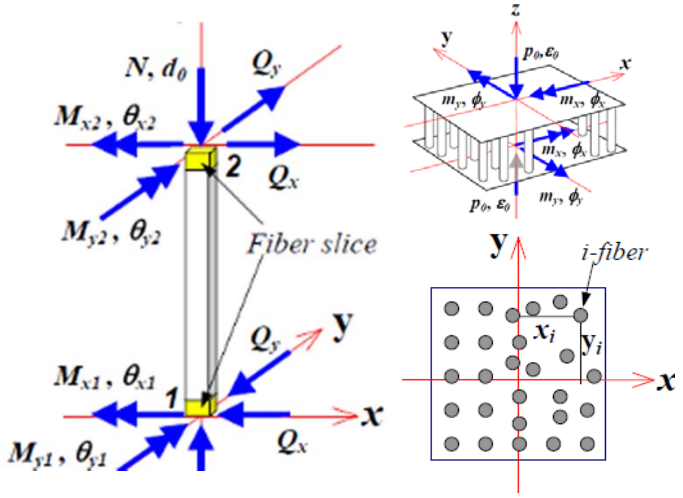


Fig d. Fiber model

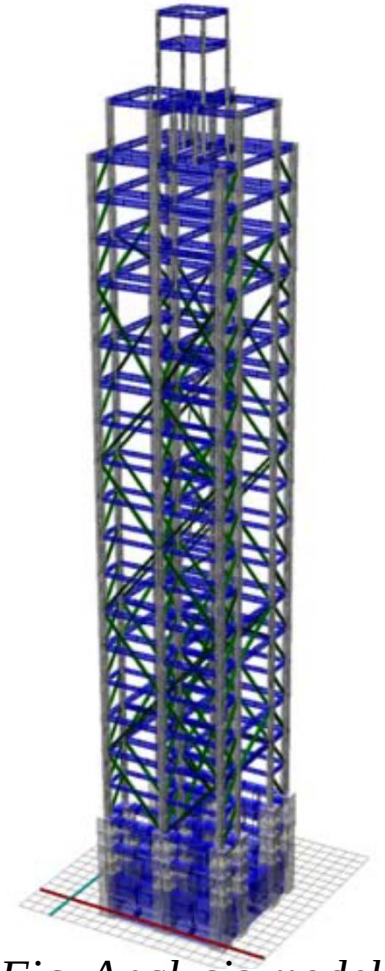


Fig. Analysis model

Structural Modeling and Analysis Method(2)

Viscous damper : Maxwell Model.(Fig e)

i)Type-1 (Leaned Arrangement Type)

・Damping coefficient ; C_1 , C_2 =750, 14.4[kN・sec/cm]

・Stiffness coefficient ; K=5800[kN /cm], constant value

ii)Type-2 (Amplification Mechanism Type)

・ Damping coefficient ; C_1 , C_2 =120, 4.0[kN・sec/cm]

・ Stiffness coefficient ; K=2352[kN /cm], constant value

・Axial stiffness of brace is slip model in consideration of a displacement loss

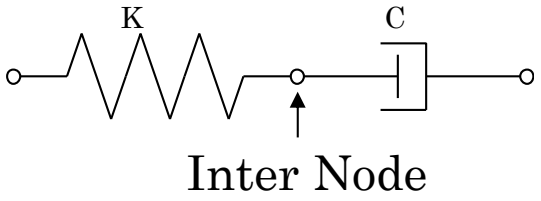


Fig e. Maxwell Model

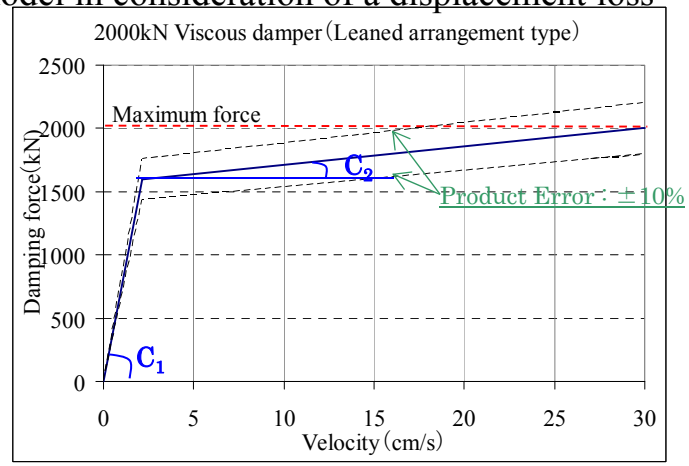


Fig . Nonlinear curve (type-1)

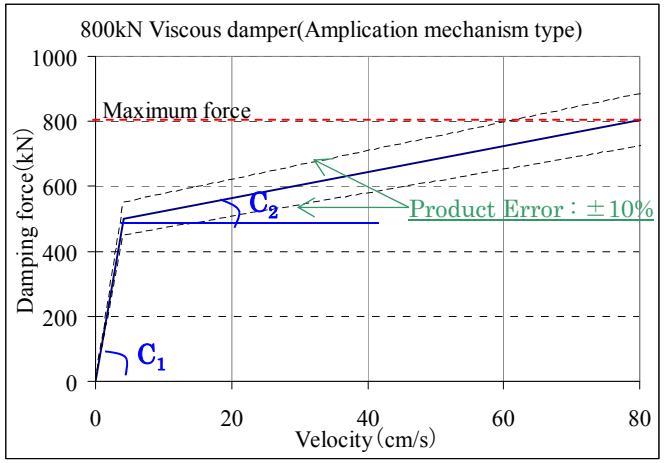


Fig . Nonlinear curve (type-2)

4) Damping; Structural Damping is type of internal viscous damping of initial stiffness coefficient and first mode damping ration(=h_1) is =0.01.

5) Stiffness;

・Shear deformation for junction of the intersection portions of column and beam must be taken into consideration.

・The rigidity of beam bending must be increased by slab. (ϕ =1.3:single-sided slab, ϕ =1.5:both-sides slab)

Analysis Result-

Comparison of Maximum Response based on damper disposition

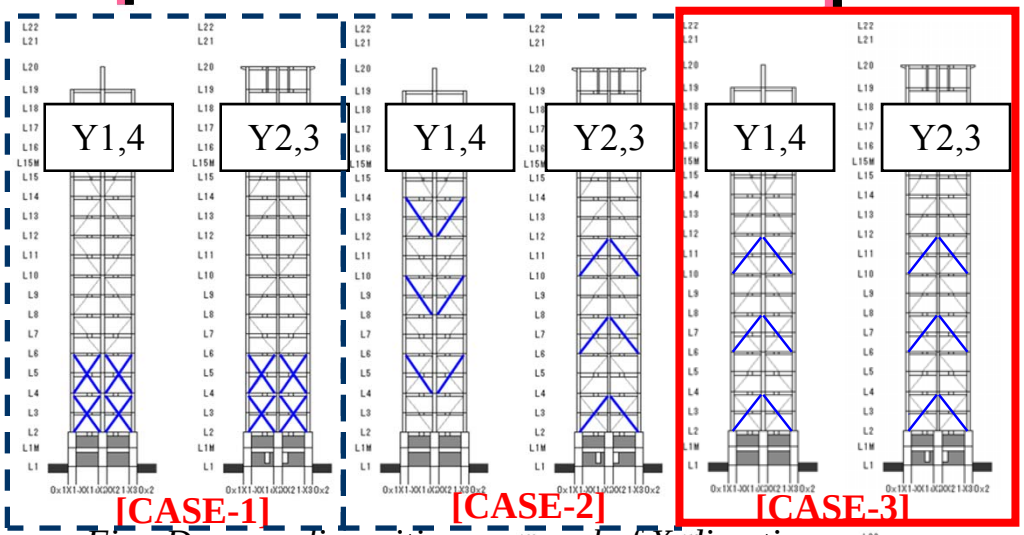


Fig. Damper disposition proposal of X-direction

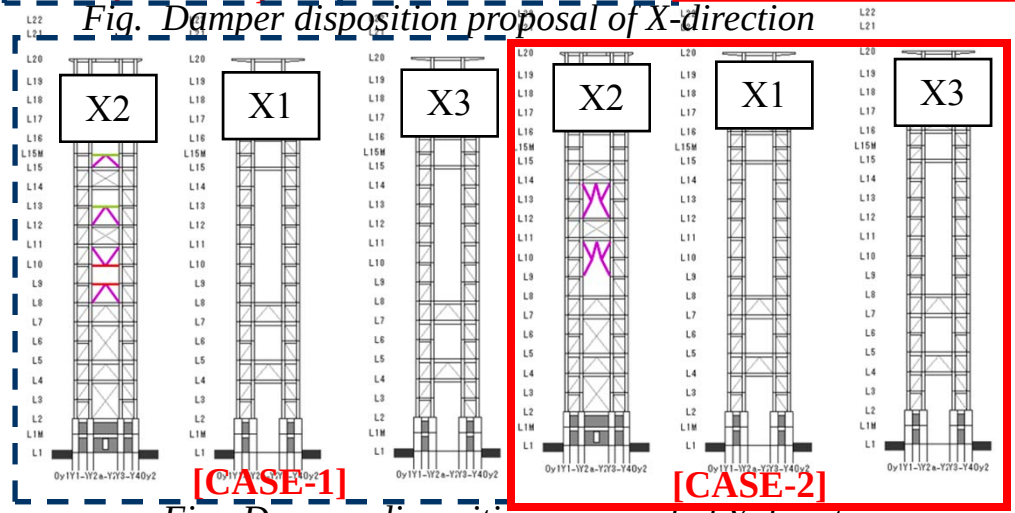
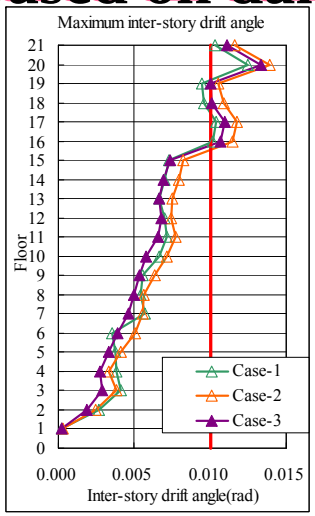
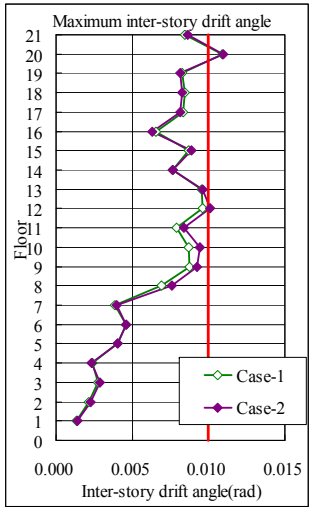


Fig. Damper disposition proposal of Y-direction





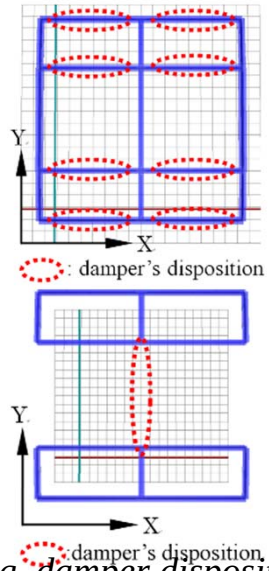


Fig. damper disposition

Table . 1st Natural period(s)

	Exsiting Model	Case-1	Case-2	Case-3
X-direction	1.31	1.41	1.31	1.31
Y-direction	1.30	1.30	1.30	

Analysis Result-Effect of viscous dampers(1)

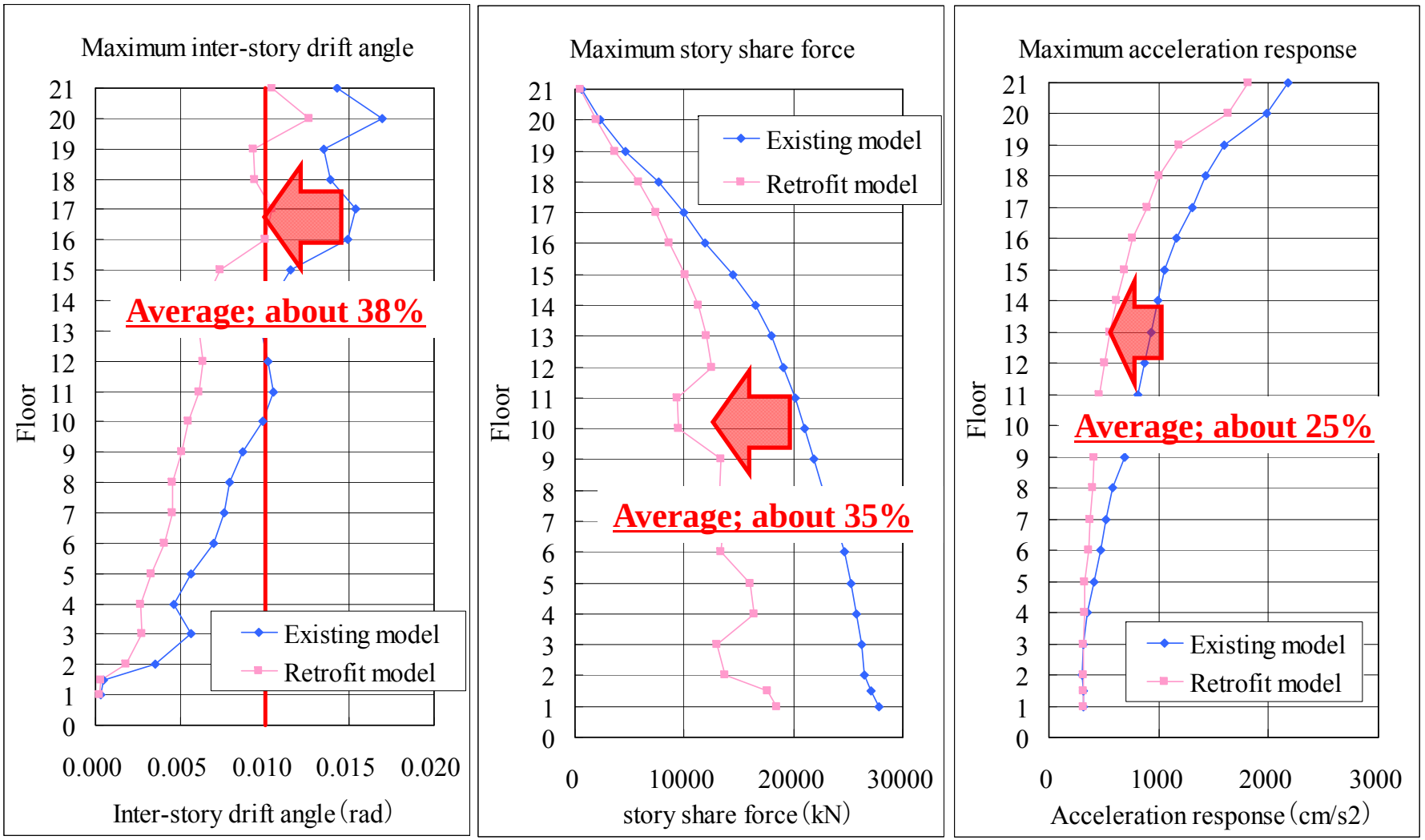


Fig. Maximum Response of X-direction

Analysis Result-Effect of viscous dampers(1)

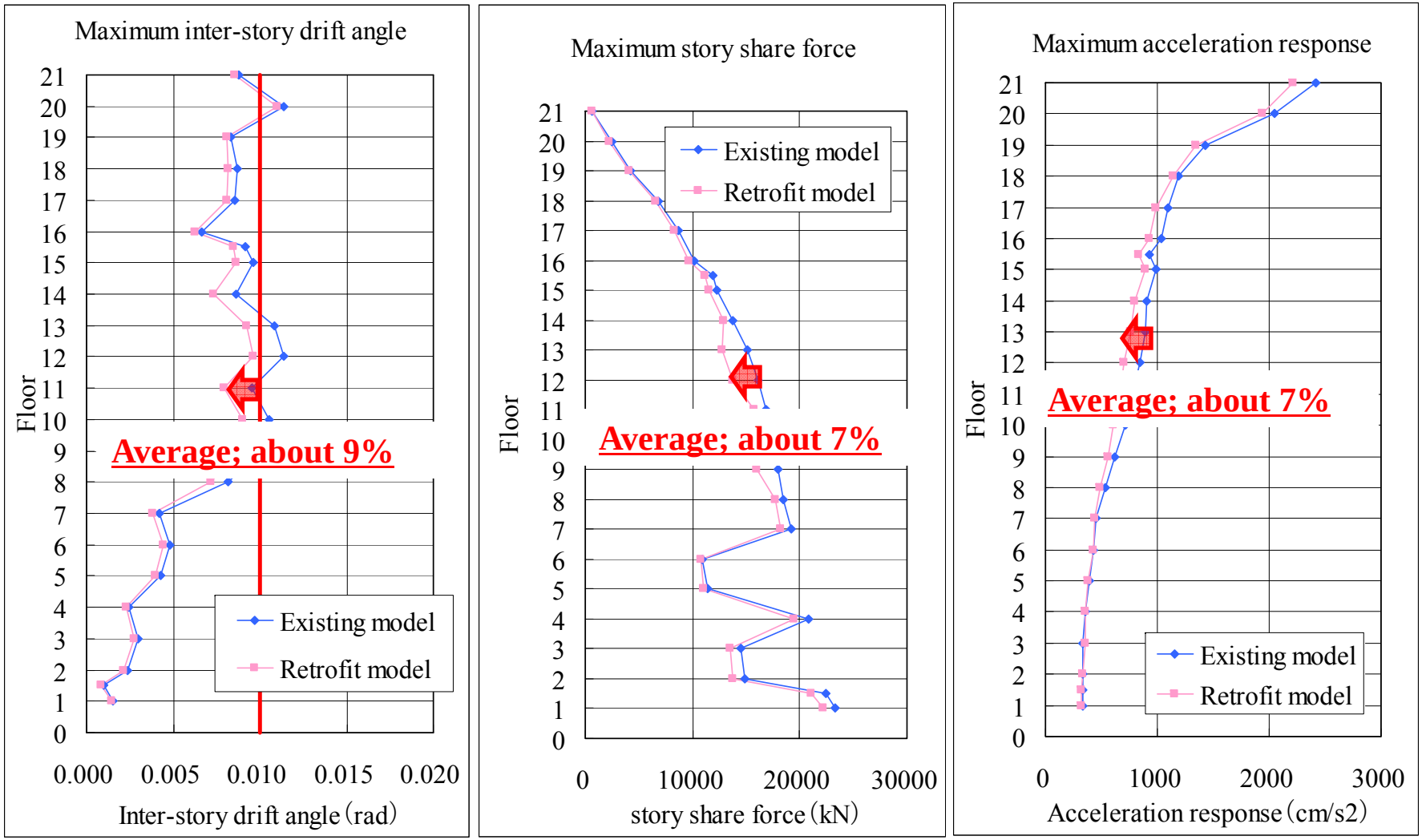


Fig. Maximum Response of Y-direction

Analysis Result-Effect of viscous dampers(2)

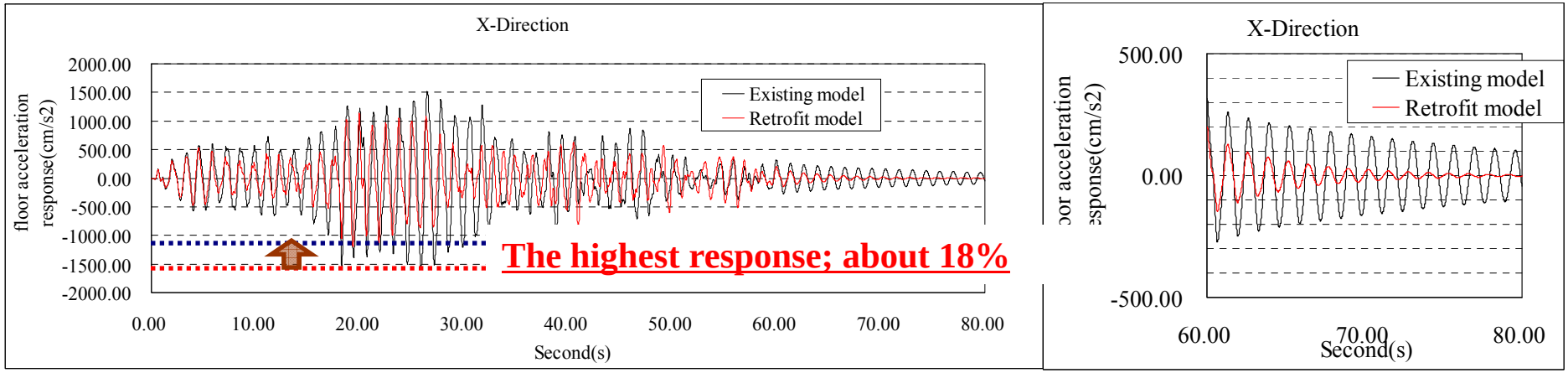


Fig. Time History of Response acceleration (X-direction / L20)

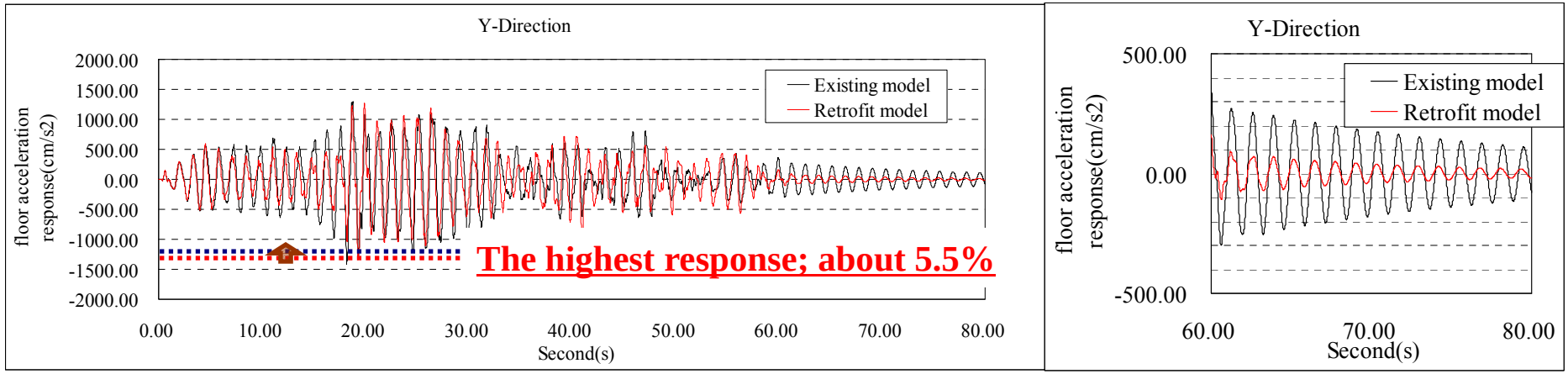


Fig. Time History of Response acceleration (Y-direction / L20)

Conclusions

☆ Earthquake-proof performance was improved with the proposed seismic retrofit using viscous dampers, in compliance with structural design criteria.

☆ After this reinforcement work ended, we are scheduled to experiment on dynamic characteristics based on microtremor measure and free vibration test.