SEISMIC RETROFIT OF THE TOWER STRUCTURE WITH VISCOUS DAMPERS

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Abstract:
This report describes the application of the viscous dampers to the seismic retrofit of the tower structure, with an example of the Air Traffic Control Tower at Narita International Airport, which was designed by AZUSA SEKKEI Co., Ltd. in 1990 and the construction was completed in 1992. After the 3/11 Great Earthquake in North East Japan in 2012, attention has been paid to alleviate the seismic motion. Thus the retrofit design was needed to the Control Tower which we completed in the summer of 2012, and the reinforcement work is scheduled to be completed in 2013. The focus of this report is to discuss the retrofit design and disposition of the viscous dampers to the existing building as we can see in the following study flow; 1) Existing Building Outline, 2) Structural Planning, 3) Structural Design Criteria, 4) Structural Modeling and Analysis Method , and 5) Analysis Result.

1. Introduction

In view of the Great East Japan Earthquake of March 11, 2011, our priority was to improve the seismic retrofit of the Air Traffic Control Tower at Narita International Airport, which is the important facility as the main gate of Japan. As the designer of existing building, AZUSA SEKKEI Co., Ltd. was chosen by applying for the Quasi-Public Proposal and undertook the retrofit design. The application of viscous dampers to the seismic retrofit of the existing building had to be directed for satisfying various limited conditions including:

1) The reinforcement work must be done while the building is being used.
2) No change was allowed concerning the main electric cables and building equipment.
3) The cost of the seismic retrofit must be kept in the limited budget.

The purpose of this report is to provide a number of case studies of the layout planning of viscous dampers and to show the response result of input earthquake motion system and then to see how viscous dampers will be effective in the application to the existing building.

2. Existing Building Outline

The existing building is located in the center of Narita International Airport, and is connected to the next airport administration building. The function of this building is core facility of an airport administrative task as a control tower for the 2nd passenger terminal building and the runways of Narita International Airport. This building consists of many different types of rooms such as control room and room for radio devices in the upper level, a connecting bridge with an airport management in the middle level, and the electric services room and building equipment room in the lower level.

Air Traffic Control Tower at Narita International Airport (Fig 1, 2)

Location: Chiba, Japan
Building area: 241.43 ㎡
Total floor area: 1778.26 ㎡
Standard floor area:169.74 ㎡(13m square)
Number of floors: +15(L21)
Height of building: 87.300m
Structure: S, partly SRC or RC
Foundation: pile

3. Structural Planning

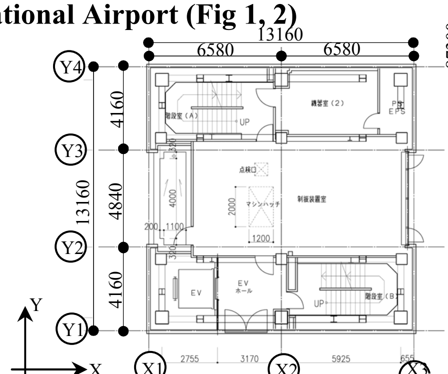


Figure 1. Floor plan for 9F

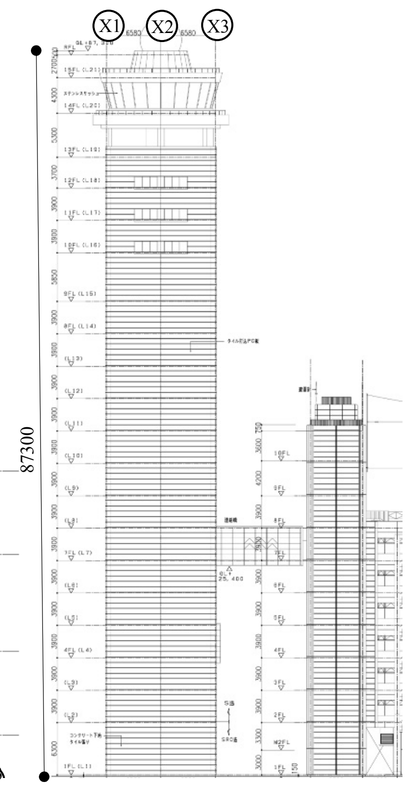


Figure 2. West side elevation view

3.1 Structural Design of Existing Building

The floor area of the existing building is 13.16 sq. meters (6.58m column spanning) in the X-direction and 4.16m (4.84m column spanning) in the Y-direction (Fig 3). The height of this 15-story building is 87.3m. Tuned liquid damper (TLD) is installed on the L15 to mitigate wind vibration. The building above the ground weighs 4210tf while the water and mixture weigh 23.2tf.

Foundation: Mat slab form (Thickness of footing is 5m)
Cast-in-place concrete pile (Diameter is 1.5m)
Frame Form: L2~ S, Moment Frame with braces
L1~1.5 SRC, Box-frame construction
Main Frame: Column section is a shape of 550mm-box (Maximum board thickness is 60mm) and a shape of 450mm-diameter-pipe (Maximum board thickness is 60mm). Maximum depth of H-Beam is 700mm. Maximum depth of H-Brace is 400mm. Thickness of bearing wall is 900mm.
Material Strength: Tensile strength of Steel is 490N/mm^2.
Compressive strength of concrete is 21N//mm^2.

3.2 Application design of viscous dampers

Viscous dampers are adopted as vibration control device, and leaned arrangement type is the direction of X, and Amplification mechanism type is the direction of Y (Fig 4). Since the controller works all day without rest, the viscous dampers must be installed on the L13 or below (Fig 5). As for Y2, Y3 frame in the X-direction on the L6 and L7, installed on the L8 and L9 in order to avoid interference with walking-flow-line from the administration building located next to it.

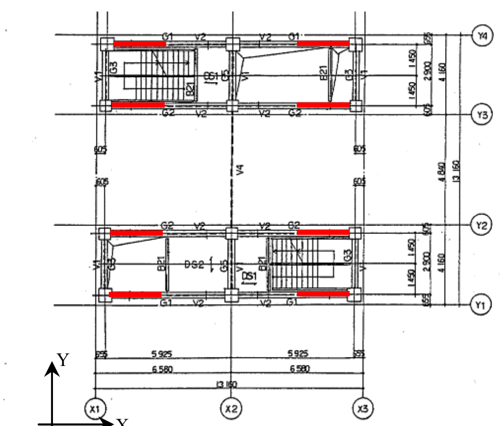


Figure 3. Beam plan for standard floor

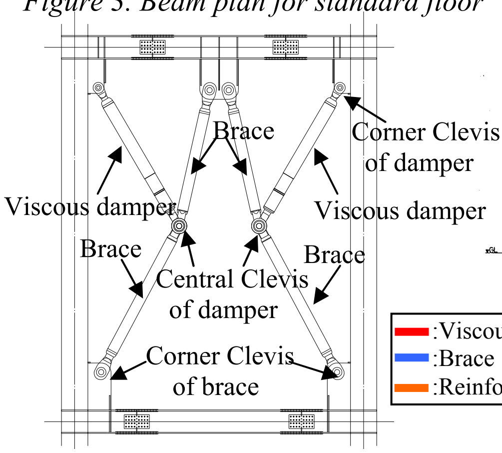


Figure 4. Amplification mechanism type

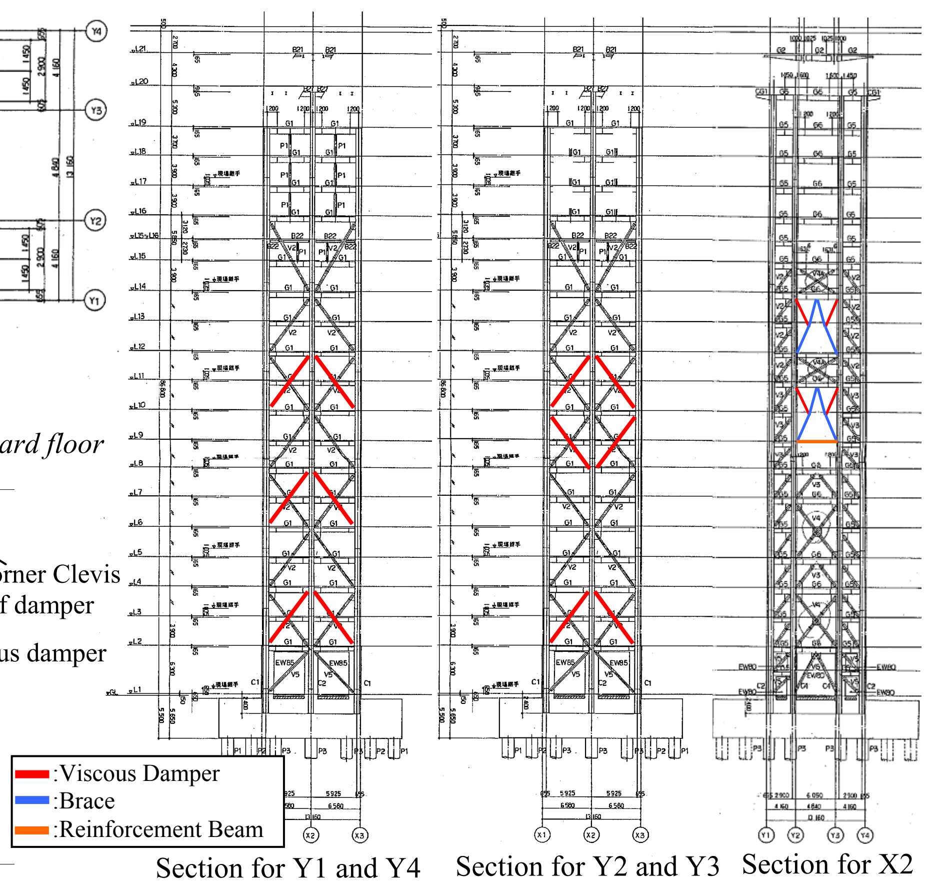


Figure 5. Section plan for disposition of viscous dampers

Table 1. Dynamic Characteristics of Existing Building

Direction	1st Natural period (s)	Damping factor (%)
X direction	1.29	2.0
Y direction	1.35	2.2

4. Structural Design Criteria

4.1 Selection of Input Earthquake Motion

Six kinds of Input Earthquake Motion are designed in compliance with Japan's building Act (Notification 1461 of the Ministry of land, Infrastructure, Transport and Tourism in 2008), where three kinds of phase difference of the scaling Level-1 and Level-2 are designed respectively.

Three acceleration histories (Level-2, GL-5.5m) are shown in Figure 6, six pseudo velocity response spectra (three kinds of phase difference of the Level-1 and Level-2, respectively) are shown in Figure 7, and maximum of six input earthquake motion in foundation position (GL-5.5m) are shown in Table 2.

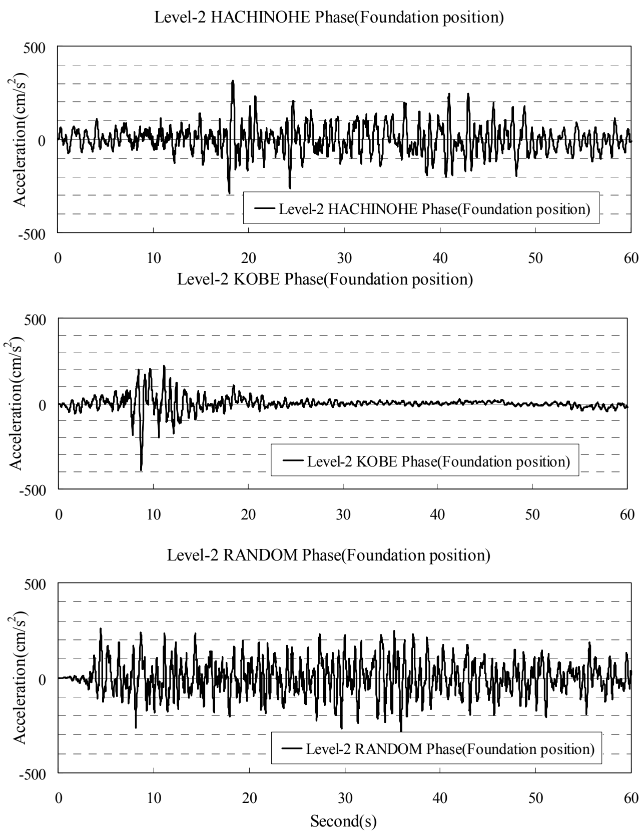


Figure 6. Acceleration history (Level-2, GL-5.5m)

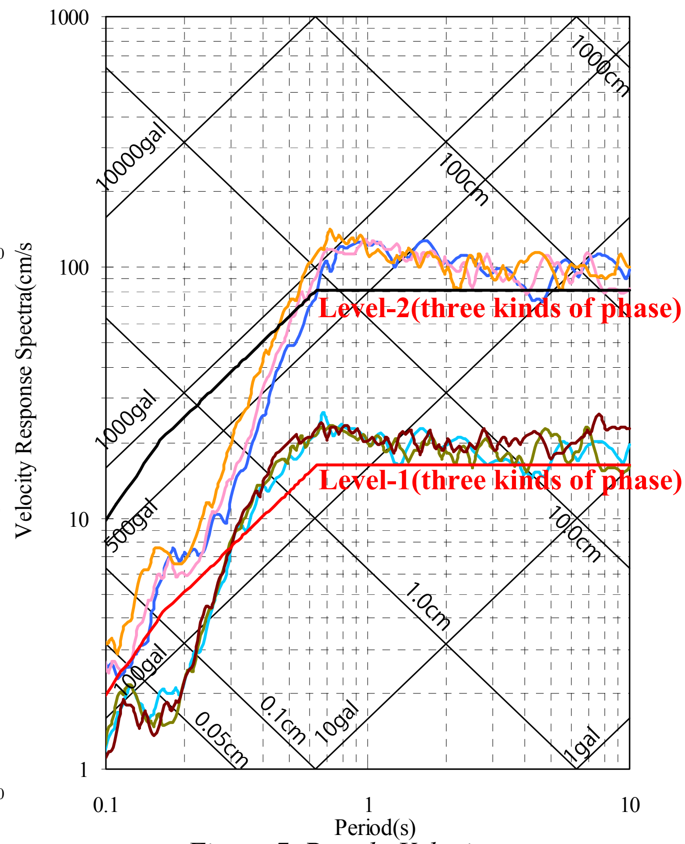


Figure 7. Pseudo Velocity Response Spectra (h=5%)

Table 2. Maximum of Input Earthquake Motion in Foundation Position (GL-5.5m)

Level	Phase	Acceleration (cm/s^2)	Velocity (cm/s)
Level-1	Random	74.81	14.16
	Hachinohe	74.48	29.98
	Kobe	84.85	19.04
Level-2	Random	320.00	71.61
	Hachinohe	316.58	155.98
	Kobe	387.82	95.68

4.2 Structural design criteria of seismic retrofit building

Structural design criteria of seismic retrofit building is shown in Tables 3, 4.

Table 3. 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 8).

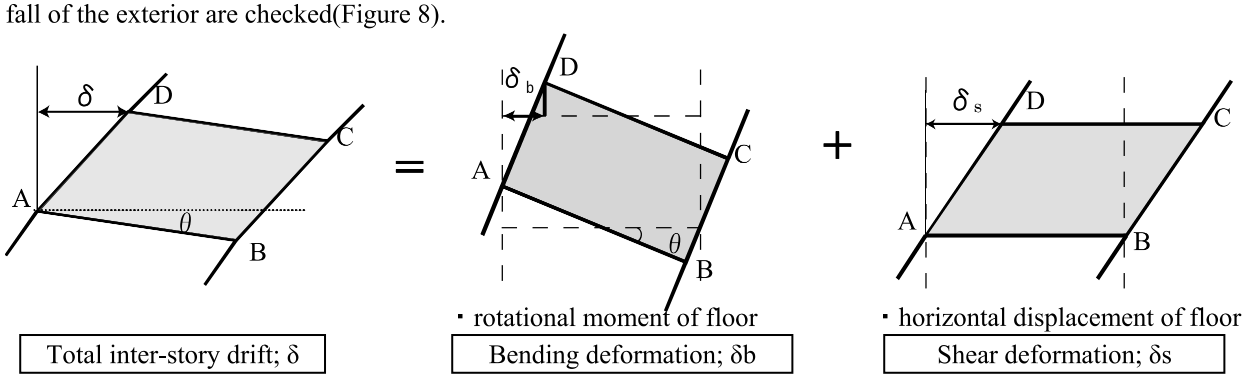


Figure 8. Outline of Inter-Story Drift Angle

Table 4. Structural Design Criteria of Main Structure Frame

frame	Level of input earthquake motion	
	Level-1	**Level-2**
Colum/Beam/Brace (S-Frame)	Equal or Less than allowable stress for temporary load	2.0 Equal or Less than Plasticity rate of frame
Colum/Beam (SRC-Frame)		Equal or Less than Elastic limit
Bearing Wall (SRC-Frame)		Not allowing Shear failure

5. Structural Modeling and Analysis Method

5.1 Analysis Method

The analysis method is verified in the time-history response analysis, using the elastic-plastic analysis program. The structural model is designed with the three-dimensional frame model of arbitrary shape which consists of a beam, a column, and bearing wall(Figure 9). The Input Earthquake Motion, which is described in 4.1, is adopted as the input force.

5.2 Structural Modeling

In the outline of structural modeling, structural element has nonlinear stability characteristics and the load is distributed as node weight. Two kinds of viscous damper are installed on an actual attachment position. In addition, setting of structural element is shown as follows,

1) Boundary condition: bottom of colum installed on the L1 is Pin support

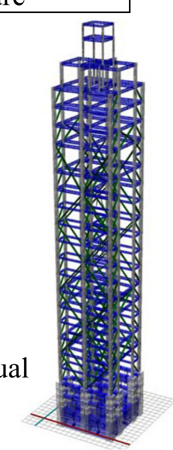


Figure 9. Analysis model

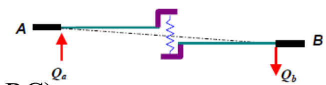
2) Node has six degrees of freedom, while node installed on the slab has three degrees of freedom
3) Restoring force characteristics of structural element

Beam bending: end of member has rotational spring.(Fig 10 (a))
Restoring force characteristics is Bi-linear Type(SorSRC)
Shear : center of member has shear spring. (Fig 10 (b))
Restoring force characteristics is Bi-linear Type
Colum, wall bending: fiber (MS) model. (Fig 10 (d))
Restoring force characteristics depending on material(SorRC)
Shear : center of member has shear spring. (Fig 10 (b))
Restoring force characteristics is Bi-linear Type
Brace : Axial direction spring. (Fig 10 (c))
Restoring force characteristics is Bi-linear Type(SorSRC)
Viscous damper : Maxwell Model.(Fig 10 (e))

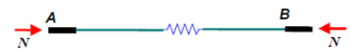
1) Type-1 (Leaned Arrangement Type, Fig 11)
- Damping coefficient ; C_1=750[kN・sec/cm], C_2=14.4[kN・sec/cm]
- Stiffness coefficient ; K=5800[kN /cm], constant value

2) Type-2 (Amplification Mechanism Type, Fig 12)
- C_1=120[kN・sec/cm], C_2=4.0[kN・sec/cm]
- K=2352[kN /cm], constant value
- Axial stiffness of brace is slip model in consideration of a displacement loss.

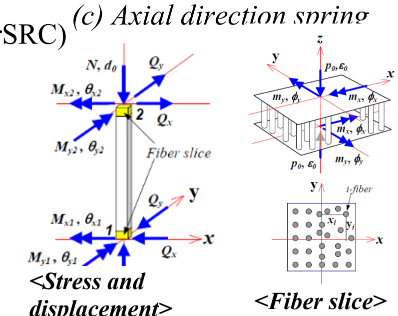
(a) beam bending model



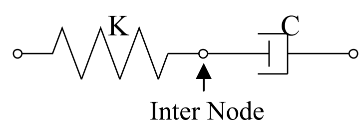
(b) beam shear model



(c) Axial direction spring



(d) Fiber(MS)Model



(e) Maxwell Model

Figure 10. Element Modeling

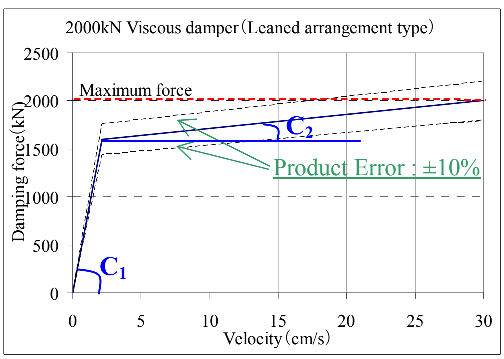


Figure 11. Nonlinear curve (Type-1 viscous damper)

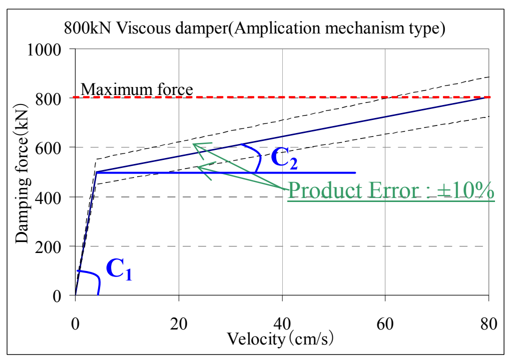


Figure 12. Nonlinear curve (Type-2 viscous damper)

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

$$[\mathbf{C}] = \frac{2h_1}{\omega}[\mathbf{K}_0]$$

Where,
[C]= Damping coefficient matrix, [K0]= Initial stiffness coefficient matrix
h_1 = Damping coefficient of first vibration mode, ω= first natural frequency of Initial stiffness coefficient

(5) Stiffness
1. Shear deformation for junction of the intersection portions of column and beam must be taken into consideration.
2. The domain which does not change column and beam element must be in the face position.
3. The rigidity of beam bending must be increased by slab.
(ϕ =1.3: single-sided slab, ϕ =1.5: both-sides slab)

6. Analysis Result

The analysis result is shown about response results of the Input Earthquake Motion of the Hachinohe phase in Level 2 only as shown in the following.

6.1 Comparison of Maximum Response based on damper disposition

Three kinds of damper disposition proposal of the X-direction is shown in fig14 and two kinds of damper disposition proposal of the Y-direction is shown in fig15. As for X-direction disposition, case1 is a proposal which removes the existing brace for the lower 2 layers and is arranged for the damper intensively, case2 is a proposal which is arranged for the damper in all the layers, and case3 is a proposal arranged at every 2 layers. Response result has been improved to the upper layer in case1. However, since 1st natural period has changed as shown in Table 5 in case 1, a bad influence also arises in the existing TLD. Therefore, the case3 was adopted as a result. As for Y-direction disposition, case 1 is leaned and horizontal arrangement type, and case2 is an amplification mechanism type. Although case1 has been best-improved in the maximum inter-story drift angle, case2 was adopted as a result in consideration to the construction cost.

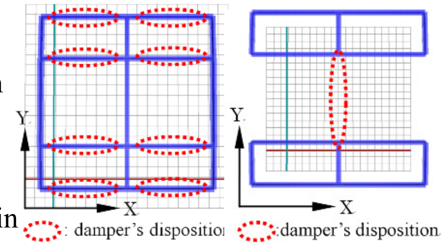


Figure13. Damper dispositon

Table 5. 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	

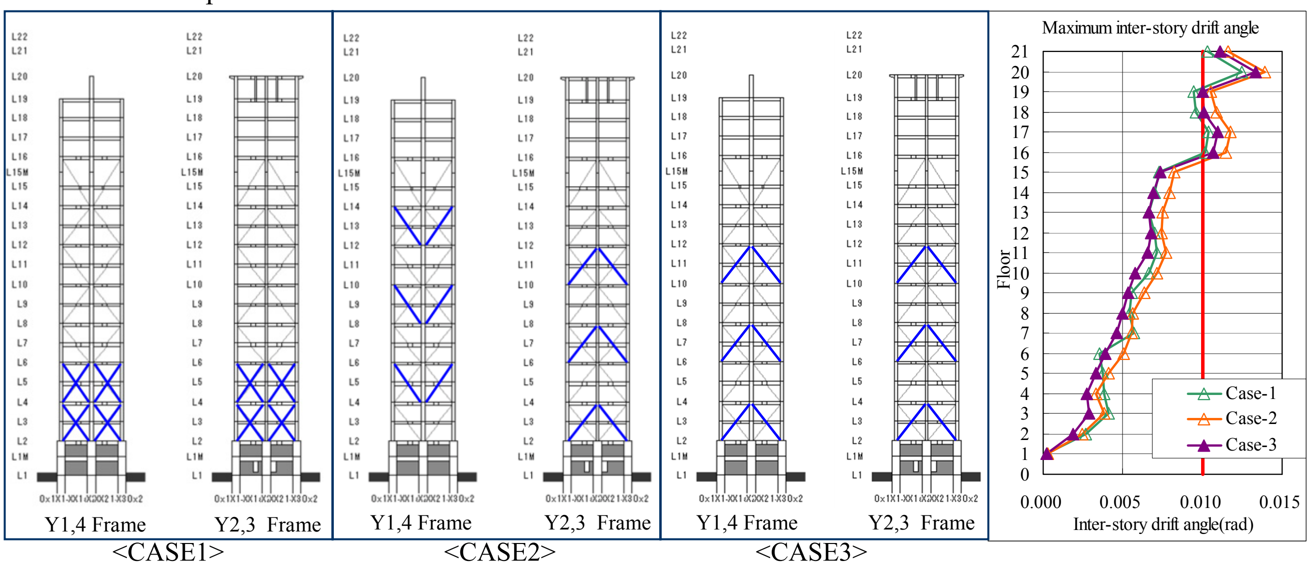
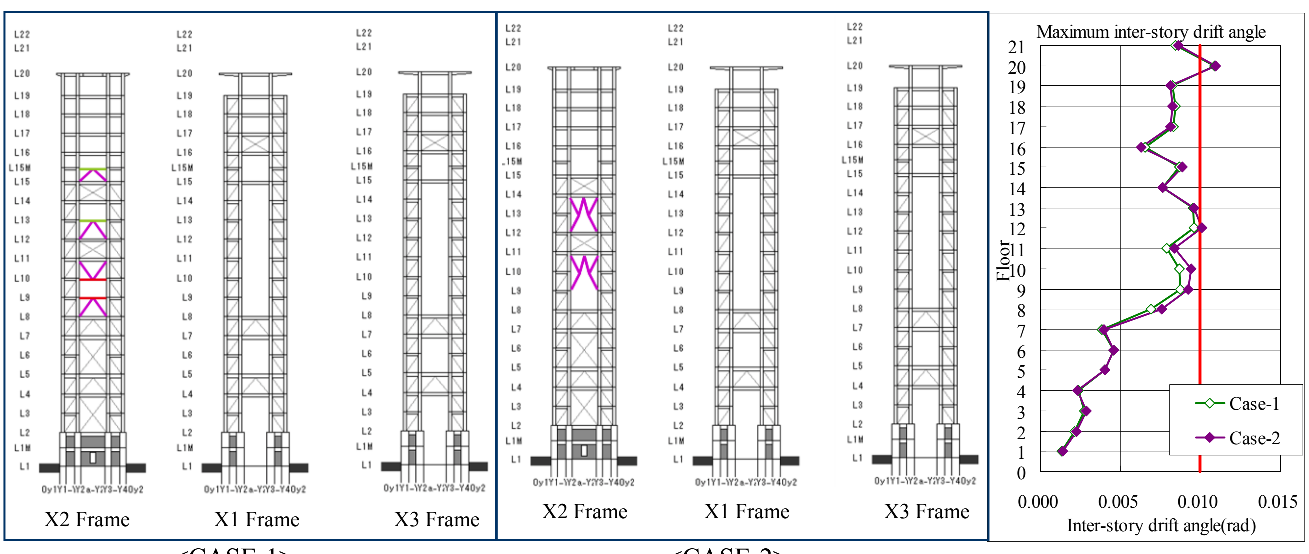


Figure 14. Damper disposition proposal of X-direction



6.2 Effect of viscous dampers

Figure 15. Damper disposition proposal of Y-direction

As for effect of viscous damper, response results of adopted seismic retrofit are shown as in the following. In addition, rate of change in 1st, 2nd, and 3rd Natural period after seismic retrofit is as slight as 1%.

6.2.1 Comparison of Maximum Response

Three kinds of the maximum response of X-direction and Y-direction are shown in Fig 16, 17.

By carrying out seismic retrofit onto the existing building, the Maximum value of inter-story drift angle is reduced by 50% in the direction of X and 16% in the direction of Y among all stories and is reduced by 25% in the direction of X and 3% in the direction of Y on VFR room (L20).

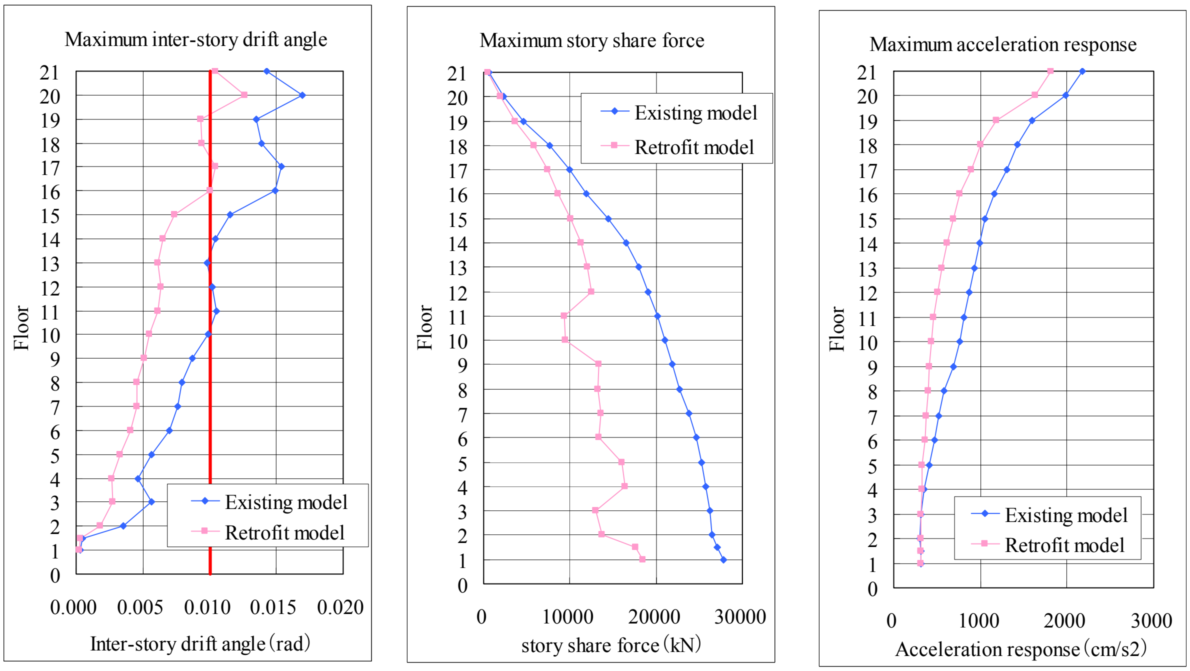


Figure 16. Maximum Response of X-direction

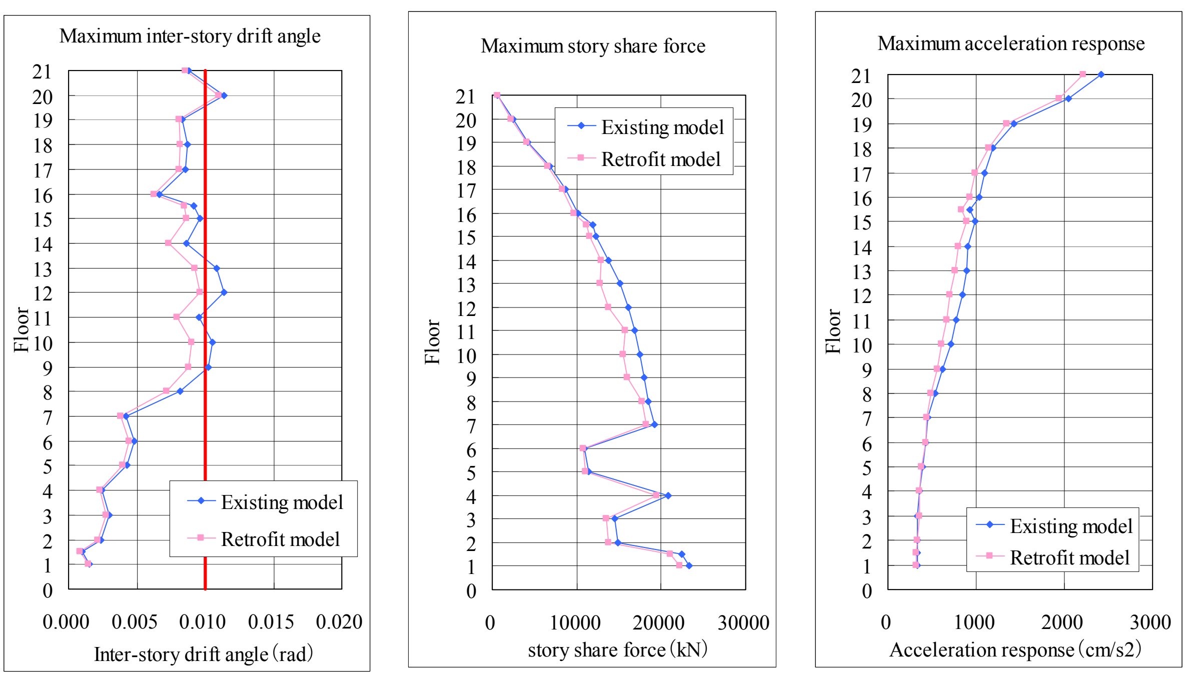


Figure 17. Maximum Response of Y-direction

6.2.2 Comparison of The time History of Responses acceleration

As the most important room, the VFR room is designed on the L20, where the maximum value in Inter-story the drift angle is shown among all stories, the time history of response acceleration in the direction of X and Y on the L20 is shown in Fig 18. By carrying out seismic retrofit onto the existing building, the highest response acceleration was reduced by 18% in the direction of X and 5.5% in the direction of Y.

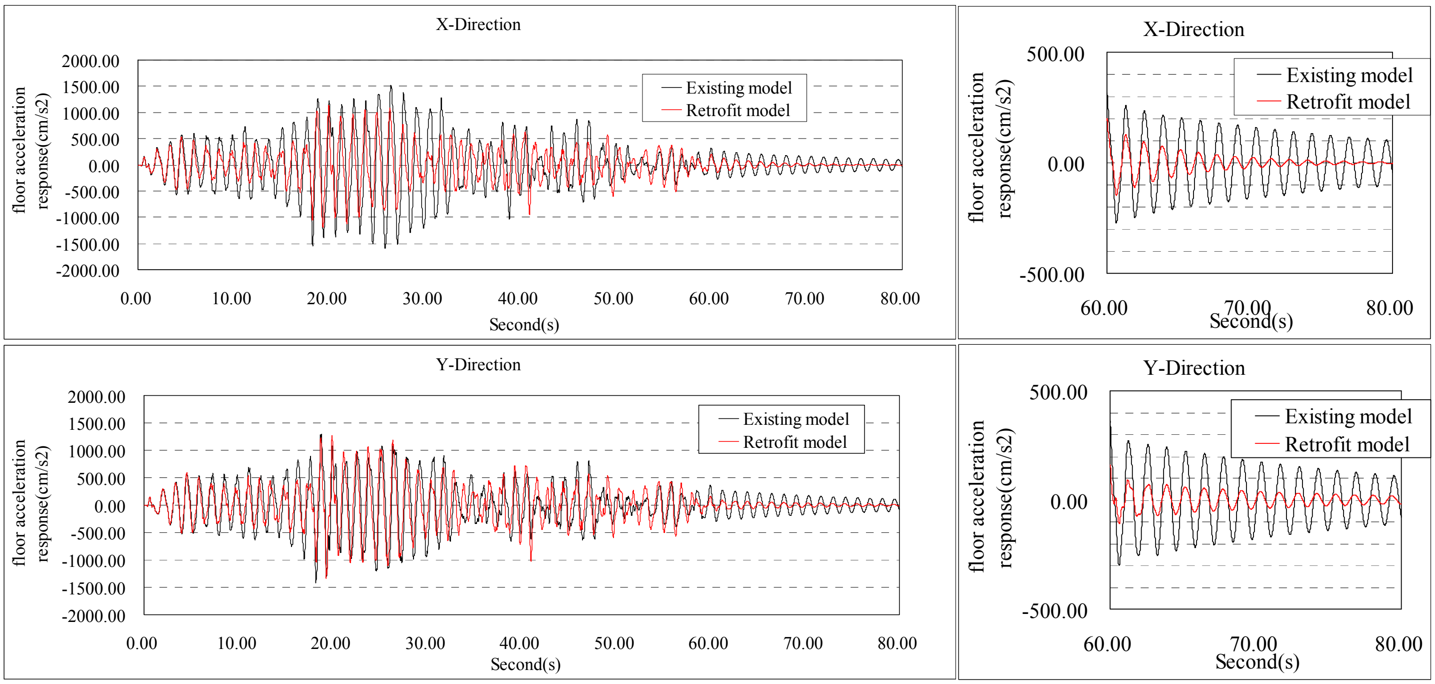


Figure 18. Time History of Response acceleration (L20)

7. Conclusions

Earthquake-proof performance was improved with the proposed seismic retrofit using viscous dampers, in compliance with structural design criteria. Moreover, after this reinforcement work ended, we are scheduled to experiment on dynamic characteristics based on microtremor measure and free vibration test and, are also scheduled to check the compatibility of the observation result with the analysis result.

8. References

[1] Wada A, Huang YH, Iwata M, 1999, Passive damping technology for buildings in Japan, Prog Struct Engng Master, Japan, 2(3) pp. 1-5.

[2] T.T. Soon, B.F. Spencer Jr., 2002, Supplemental energy dissipation: state-of-the-art and state-of-the-p ractice, Engineering Structures, Vol.24/3, pp. 243-259.

[3] Kousaka R, Tamura Y, 1998, Vibration Test of the Haneda Airport Tower Confirming TLD Efficienc y at 5-years After Installation, Architectural Institute of Japan, Japan, pp. 897-898.

[4] Hashimoto S, Tamura Y, Kousaka R, 2005, Full-scale measurement of airport tower for evaluating its dynamic characteristics, Architectural Institute of Japan, Japan, pp. 407-408.