SEISMIC RETROFIT OF HIGH-RISE BUILDING WITH DEFORMATION-DEPENDENT OIL DAMPERS

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Long-Period Ground Motions

It is pointed out that great earthquakes such as the Tokai Earthquake, the Tonankai Earthquake, and the Nankai Earthquake, may occur in the near future. When such an earthquake occurs, long period ground motions will reach the Kanto, Nobi, and Osaka plains, where Japan's three major urban areas have developed, and shake high-rise buildings violently. Since some of old high-rise buildings were designed without considering long-period ground motions, reinforcing such buildings is an important issue.

Deformation-Dependent Oil Dampers

An effective method to reinforce existing high-rise buildings is installing additional dampers. However, a problem with ordinary damper is that they require reinforcement of surrounding columns and girders to support large reaction forces generated during earthquake.
To solve this problem, we developed a deformation-dependent oil damper. The most attractive feature of this damper is to reduce the damping force at the moment when the frame deformation comes close to its maximum value. Allowing this feature, reinforcement of columns, girders, and foundations are no longer required.

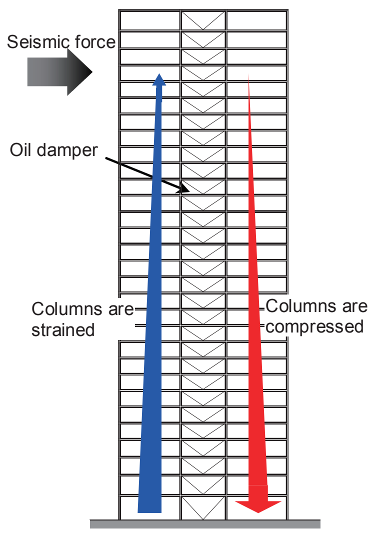

Fig. 1: Stress condition while seismic force is acting

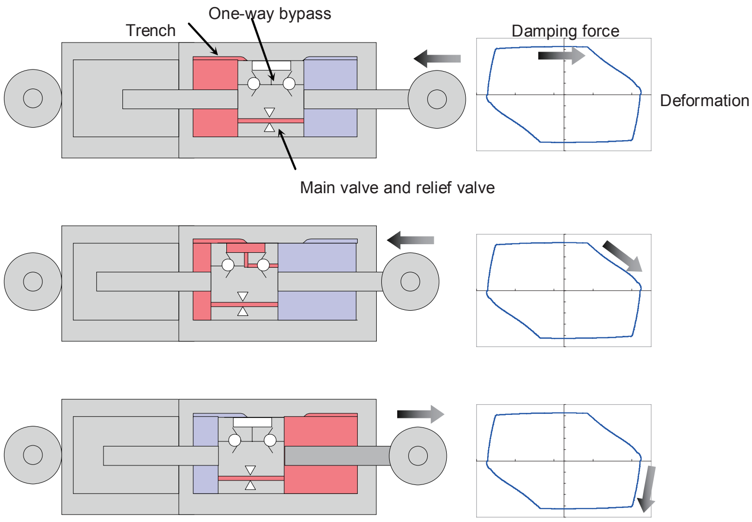

Fig. 2: Mechanism of a deformation-dependent oil damper

Application to Shinjuku Center Building

We applied the deformation-dependent oil dampers to an existing 54-story office building (Shinjuku Center Building) located at Tokyo. This building was completed in 1979. The part above the ground level is steel structure. First natural period of this building is 6.2 second along transverse (y) direction, 5.2 second along longitudinal (x) direction.
We set 12 deformation-dependent oil dampers in every 24 floors from 15th to 39th floor excpet for 27th floor. The total number is 288. Oil damper is installed between bottom of brace and base plate settled on the slab. The joint of brace and girder, and the joint of base and base plate are performed by press-bond with PC bar. No welding is required.

Fig. 3: Shinjuku Center Building

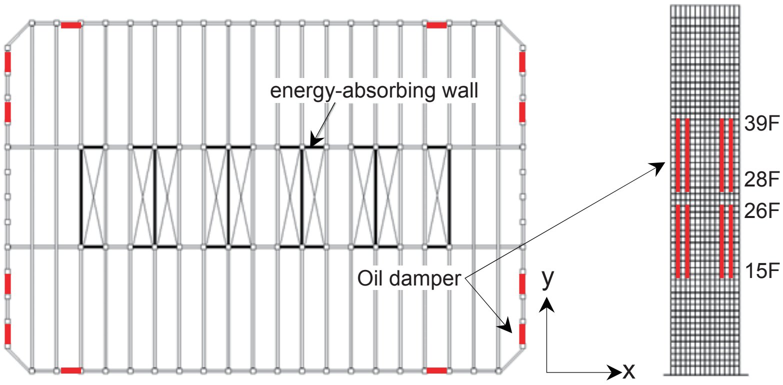

Fig. 4: Layout of oil dampers

Fig. 5: Picture of the damper

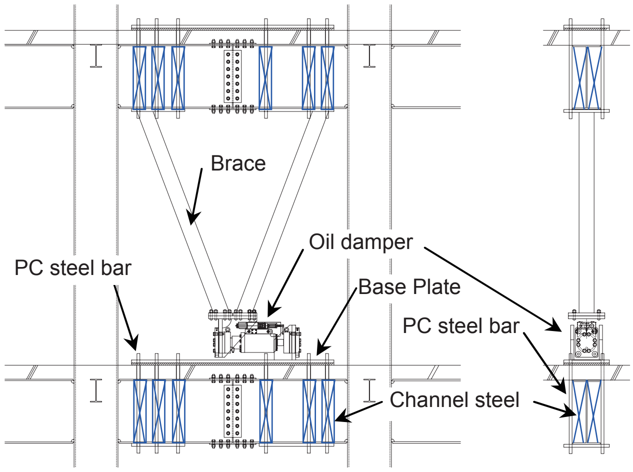

Fig. 6: Detail of attachment

Observation Results of The 2011 off the Pacific Coast of Tohoku Earthquake

Shinjuku Center Building has been recording earthquake motions since the completion of the building. The maximum values recorded from The 2011 off the Pacific coast of Tohoku Earthquake are summarized in Table 1. Figure 7-9 illustrates acclerogram and relative displacement motion between RF and 1F. As shown in the figures, the earthquake motion

Table 1: Maximum observed responses

	Maximum acceleration (Gal)		Maximum deformation (cm)	
	Longitudinal (X)	Transverse (Y)	Longitudinal (X)	Transverse (Y)
RF	236.0	161.3	49.4	54.2
28F	112.7	171.3	26.3	33.3
1F	94.3	142.1	-	-

continued for long time and the building was shaking for longer than 10 minutes.
The average story drift angle which is figured out by dividing the maximum displacement of the top floor by the height of the building was 1/399. Therefore it is evaluated that there are no damages on the main structure such as columns and girders. In the inspection of the dampers after the earthquake, no abnormality was reported such as scratch, corrosion, peeled of paint or oil leakages.

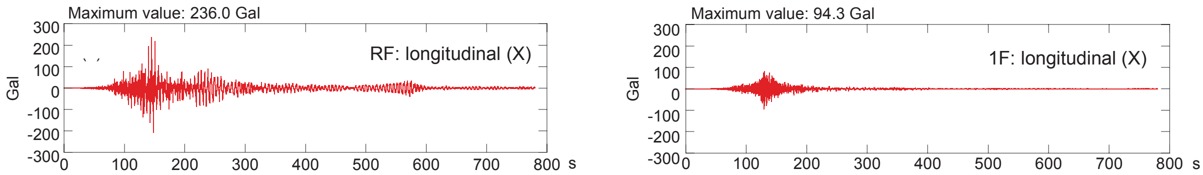

Fig. 7: Observed acceleration waveform (longitudinal direction)

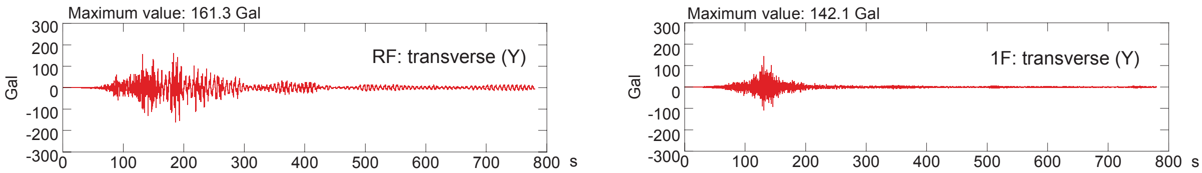

Fig. 8: Observed acceleration waveform (transverse direction)

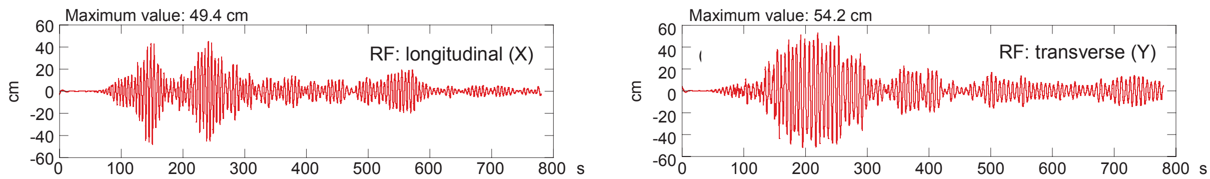

Fig. 9: Relative displacement waveform between RF and 1F

Performance Verifications

Figure 10 shows the damping ratio of 1st mode obtained from several earthquakes before / after installation of dampers and it is plotted against the amplitude of 1st modal accelerations. The damping ratios of the 1st mode for the longitudinal (x) direction and transverse (y) direction of the building were increased by these oil dampers about 0.3 and 1.4 percent, respectively.
The vibration control effect of this damper under The 2011 off the Pacific coast of Tohoku Earthquake was verified by simulation analysis. Figure 11 shows the simulated relative displacement in transverse (y) direction between RF and 1F with or without dampers. The maximum displacement at top floor was 69.8cm without the dampers and 54.5cm with the dampers (the actual observed result was 54.2cm). This indicates that the dampers reduced displacement by 22%. The maximum acceleration was 228.1 Gal without the dampers and 156.9 Gal with the dampers (the actual observed value was 161.3 Gal) and there is about 30% reduction.

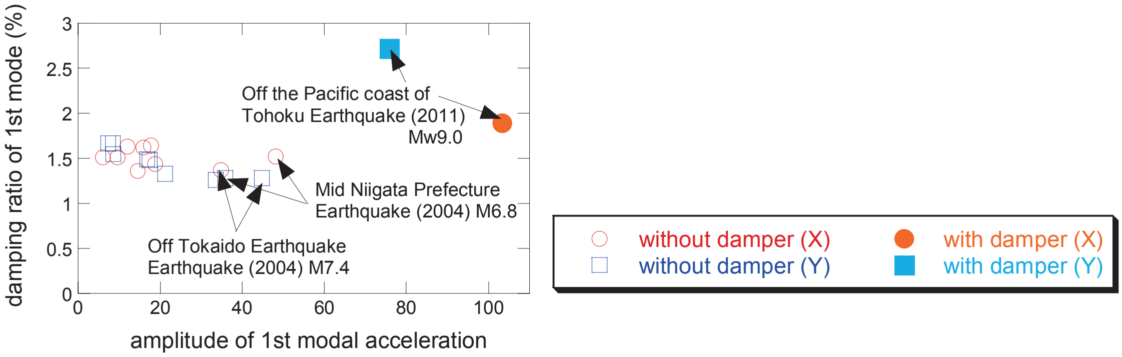

Fig. 10: Relationship between amplitude of 1st modal acceleration and damping ratio of 1st mode

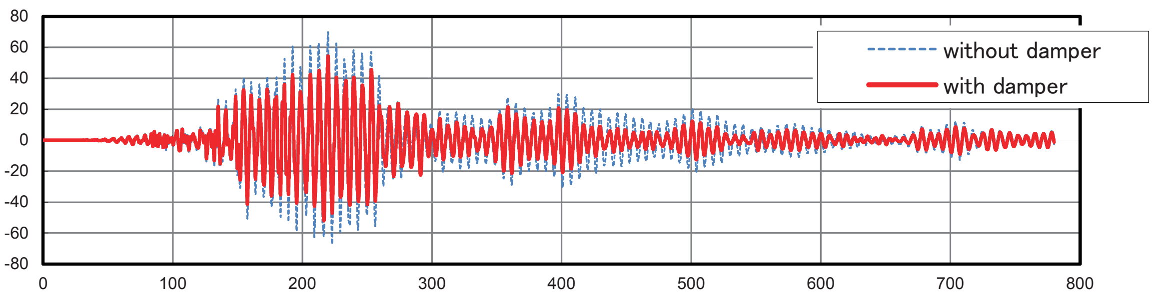

Fig. 11: The simulated relative displacement in transverse (y) direction between RF and 1F with or without dampers.

Conclusions

The authors have developed a deformation-dependent oil damper and applied to 54-story r high-rise building to reduce the vibration induced long-period earthquake ground motion. The seismic responses were observed in The 2011 off the Pacific coast of Tohoku Earthquake and simulation analyses were conducted to estimate the control performance of damper.
It is clarified that the damping ratio was higher and the relative displacement lower by 22% as compared to the building without dampers, and the observed responses of the buildings are mostly well simulated, thereby confirming the performance of the seismic retrofitting of super high-rise building with damper.

References

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