Behavior of Rikkyo Univ. Chapel Building Retrofitted by Seismic Isolation in The 3.11, 2011 Earthquake, Japan

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SUMMARY:
The old masonry chapel building of Rikkyo University, Tokyo, Japan was originally constructed in 1920. The building is located inside Tokyo down town in Japan. As the result of the screening of the seismic performance of the existing building, the seismic performance was quite low and the seismic isolation retrofit was carried out to avoid the bad influence for the architectural view of interior as well as exterior.
"The 2011 off the Pacific coast of Tohoku Earthquake" named by the Japan Meteorological Agency (JMA) occurred on 11th of March, 2011 in Japan. The seismic intensity of main shock at the epicenter was 7 in JMA scale. The intensity at the site of Rikkyo University, Tokyo was 5 lower in JMA scale. The ground and floor response motions were recorded by the accelerometers. From the acceleration records, the big reduction of input ground motions into the seismically isolated Chapel Building was obtained.

Keywords: masonry building, seismic isolation, retrofit, behaviour in earthquake, acceleration records

1. OUTLINE OF THE EARTHQUAKE

The 2011 off the Pacific coast of Tohoku Earthquake" named by the Japan Meteorological Agency (referred as JMA) occurred on 11th of March, 2011 in Japan. The moment magnitude (Mw) was 9.0 at the epicentre. The seismic highest intensity of main shock was 7 in JMA scale at Kurihara city, Miyagi prefecture. The intensity in Japan in this earthquake is shown Fig.1(JMA HP). According to this figure the intensity at the site of Rikkyo University, Tokyo was 5 lower (5-) in JMA scale as shown in Fig. 1.

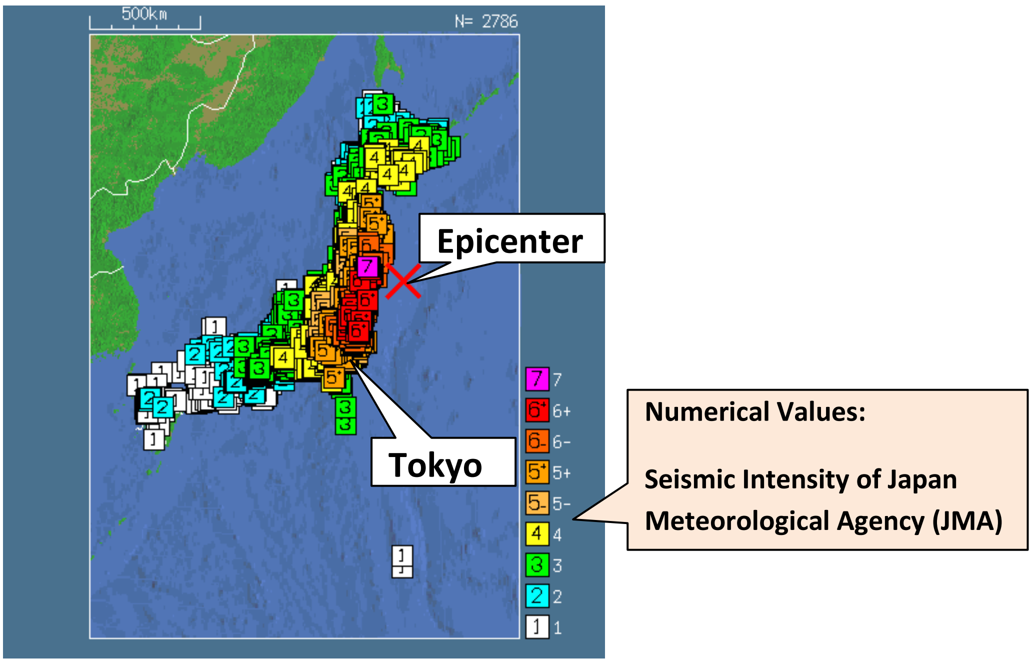


Figure 1. The seismic intensity in JMA scale in the 3.11, 2011 Earthquake

2. OUTLINE OF THE RIKKYO UNIV. CHAPEL BUILDING

This building is located at Nishi-Ikebukuro, Toshima-ku, in Tokyo. One story, partially 3 story Chapel Building of the Rikkyo University. This chapel building is a historical and monumental symbol of this university. Structural style is masonry outer wall, inside reinforced concrete thin wall and wooden roof. This building was originally designed by Murphy and Dana Architects, USA in 1920. In 1923 Kanto Great Earthquake, structural elements such as roof, masonry outer walls, etc. were damaged and repaired by small changing of original structure. Height of building is 12.63 m, total area is 505.33 m^2 and length of longitudinal span is 27.5 m and 10.76 m in transverse span.
Photo. 1 shows the exterior view of before retrofitting and Photo. 2 shows the interior view of Building.

Photo.1. Exterior view of the building

Photo.2. Interior view of the building

3. RETROFITTING BY SEISMIC ISOLATION

3.1 Outline of retrofitting

On the process of making the retrofitting plans the emphasized features are not to change the exterior and interior view because of keeping the high valuable historical architecture. Finally the seismic isolation technology was adopted for retrofitting method.
The seismic isolation devices are inserted between the existing first story floor and the newly constructed footing floor. For the isolation devices the combination of laminated natural rubber isolators and the led rubber dampers is used.
The view of devices and the location of devices are shown in Photo. 3 and Fig. 2, respectively.

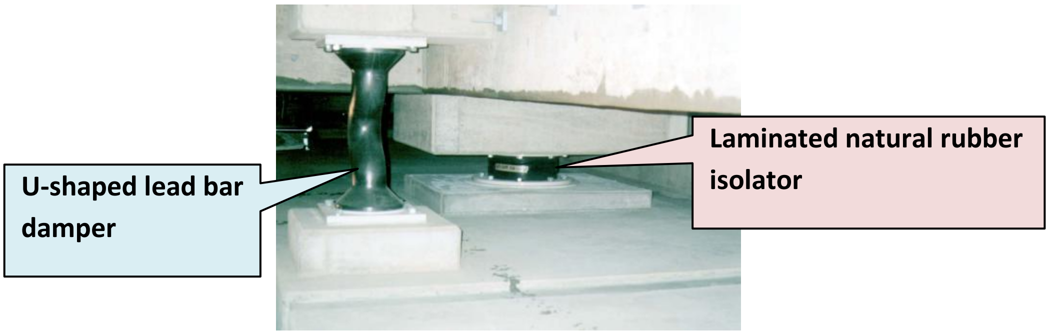


Photo. 3. The view of seismic isolation devices

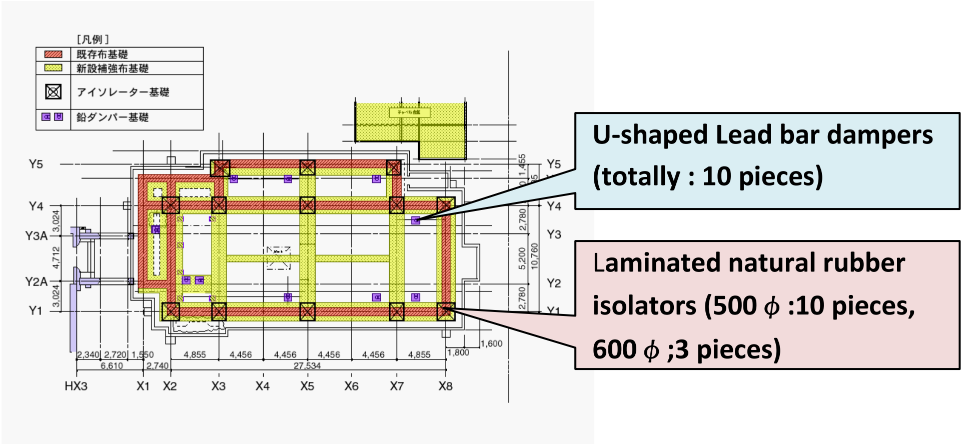


Figure 2. Location of seismic isolation devices

3.2 Earthquake resistant design

The nonlinear response analysis is generally used for the earthquake resistant design in Japan. For the vibration model of analysis, the three degree of lumped mass model of each story is used. The upper masonry structure has big stiffness corresponding to 0.1 second of natural elastic period. The restoring force characteristics of seismic isolation story is shown in Fig. 3 (M. Seki et al.) and the adopted values relating to the restoring force characteristics are summarized in Table 1(M. Seki et al.). According to the Table, the period of isolation story after yielding of lead bar dampers becomes 3.0 seconds and very small yielding force coefficient of 0.049 are employed for the isolation story.

The nonlinear response analysis is carried out for the various kinds of input ground motions, such as El Centro NS, Taft EW, Hachinohe NS and artificial waves, etc. The designed performance criteria of seismic isolators and the upper structure subjected against the big earthquake called as Level two in Japanese code are shown in Table 2 (M. seki et al.).

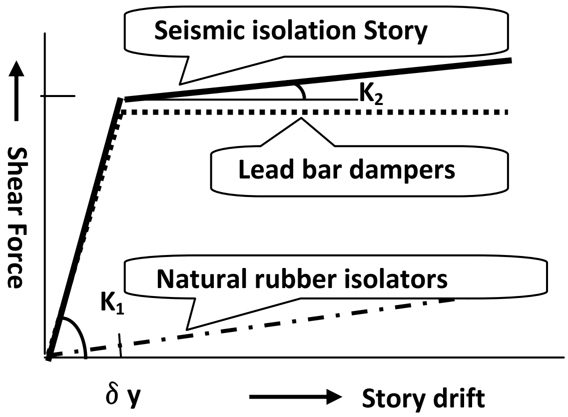


Figure 3. Restoring force characteristics of seismic isolation story

Table 1. Restoring force characteristics of the isolation story

Yield shear force :Qy (KN)	1188
Yielding shear force coefficient	0.049
Yielding story drift :δy (mm)	9.1
Natural period corresponding to elastic stiffness :(K_1) (sec)	0.86
Natural period corresponding to nonlinear stiffness :(K_2) (sec)	3.00

Table 2. Designed performance criteria for level 2 input ground motions

Seismic isolation story	Shear force coefficient	Less than 0.2
	Maximum story drift	25 cm
Upper structure	Shear force coefficient	Less than 0.2
	Stress of structural members	Within allowable stress

4. OBSERVATION EARTHQUAKE RECORDS

The accelerometers with three components are installed at the chapel building with seismic isolation system and the main building without seismic isolation system. The location of buildings and accelerometers are shown in Fig. 4. At the chapel building two accelerometers are on the ground and the first floor located just above the seismic isolation devices and at the main building one accelerometer is on the second floor.

The time history acceleration data of EW component recorded at 3.11 2011 earthquake are shown in Fig. 5. Long term duration such as about 300 seconds can be emphasized in these figures. The effect of seismic isolation is illustrated by comparing with no isolation main building is shown in Fig. 6. And observed digital acceleration values are shown in Table 3. According to the observed data, the ground acceleration of 148.7 cm/s^2 in NS (+)side component and 162.1 cm/s^2 in EW (+)side component are reduced to 56.1 cm/s^2 and 59.8 cm/s^2, respectively. Namely big reduction ratio could be obtained such as about one thirds values. On the other hand the accelerations of the main building without seismic isolation system are 315.7 cm/s^2 in NS (+)side component and 475.0 cm/s^2 in EW (+)side component therefore acceleration increased about three times of the ground accelerations, respectively. Finally we could obtain that the acceleration of chapel building became one sixth in NS component and one eighth in EW component, respectively and big effect of seismic isolation could be obtained comparing with the conventional ordinary building.

The nonlinear response simulation was carried out. As for the vibration model one degree of freedom model was employed because of the stiffness of the upper structure is relatively rigid due to the masonry wall. The restoring force characteristics of Table 1 were used for the isolation story and the recorded acceleration digital data was used for the input ground motions. The time history of acceleration of isolation story (Chapel building 1F) is shown in Fig. 5 and the analysed acceleration values are also summarized in Table 3. Form these data it can be obtained that the response analysis can simulate well the observed data. Fig. 7 shows the orbit of NS and EW component displacements of the isolation story which is calculated by the numerical integration to the observed acceleration data. From this figure the maximum peak to zero displacement forced to the isolation story became over 4.0 cm.

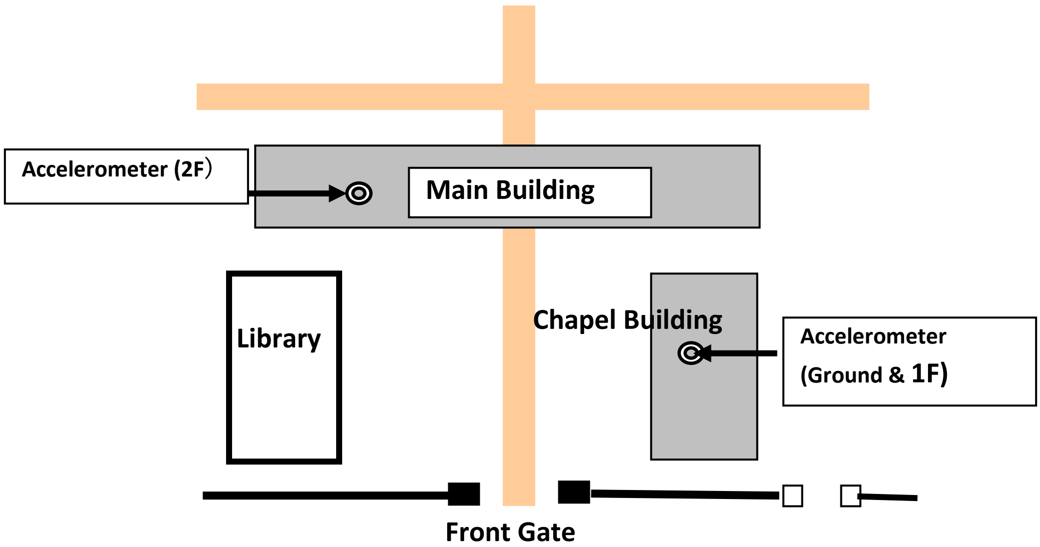
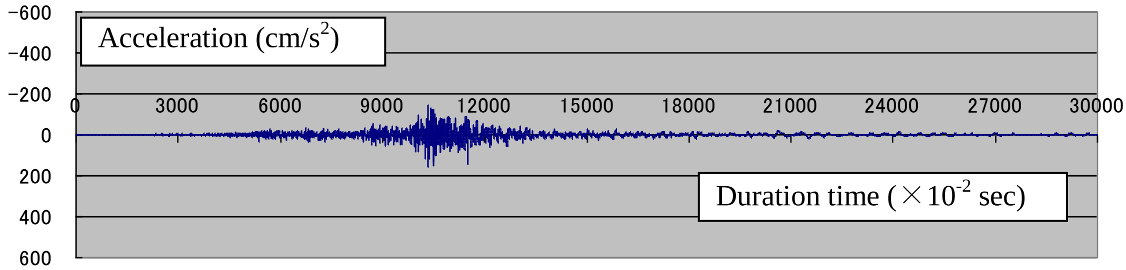
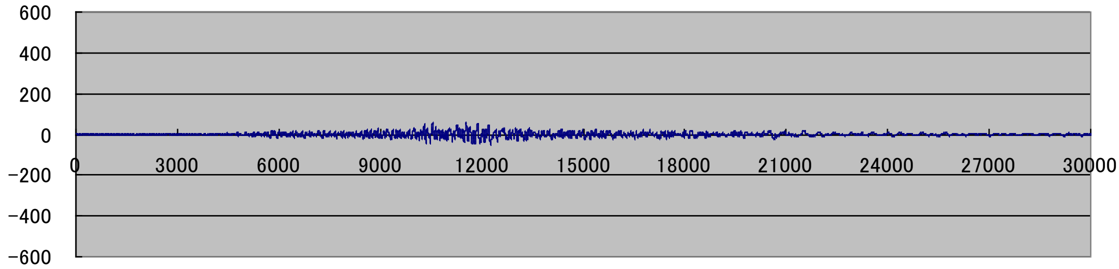


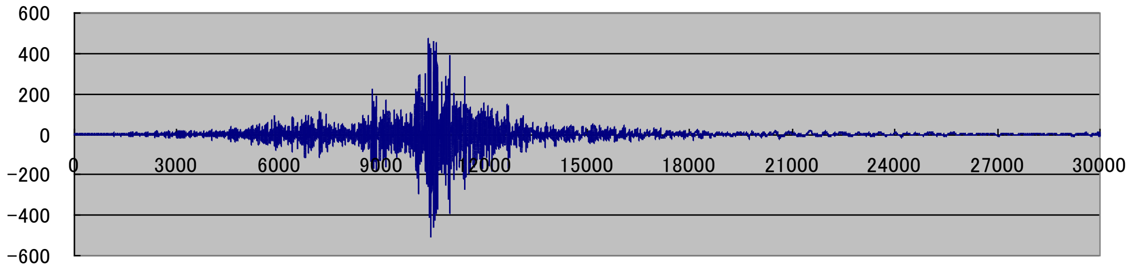
Figure 4. Rikkyo university campus and location of accelerometers



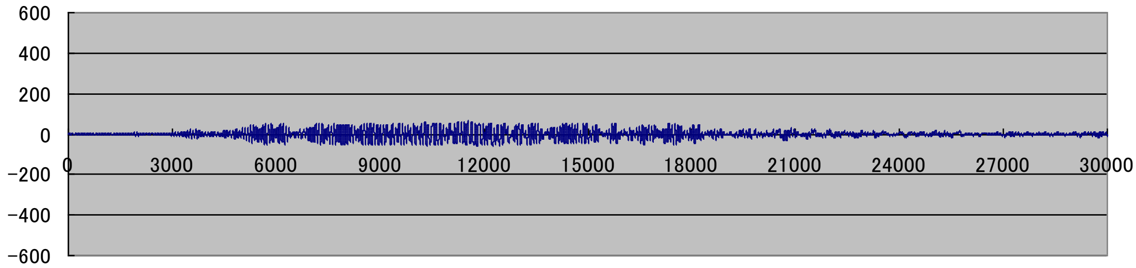
(a)Ground (EW direction); Observation



(b)Chapel Building 1F (EW direction); Observation



(c)Main Building 2F (EW direction); Observation



(d)Chapel Building 1F (EW direction); Analysis

Figure 5. Acceleration time history data (Observation and Analysis)

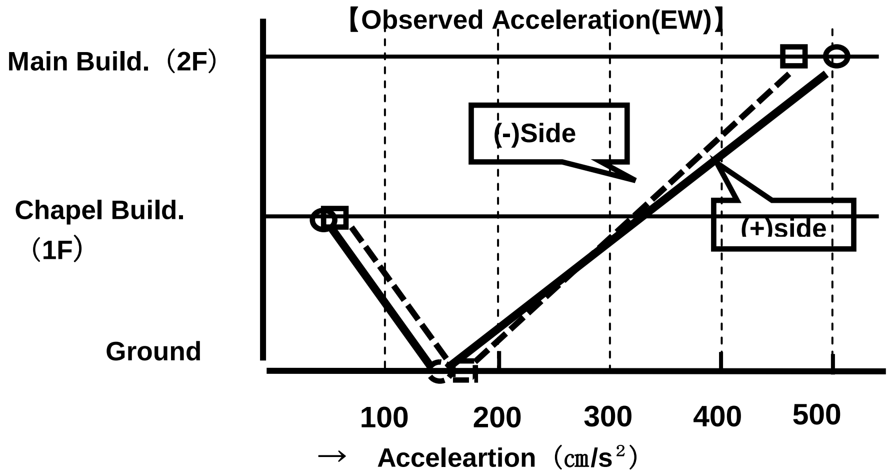


Figure 6. Comparison between isolation building and conventional building (EW direction)

Table 3. Acceleration and story drift (Observation and Response analysis)

Observed location	Compared items		Observation NS	Observation EW	Response analysis NS	Response analysis EW
Above isolator (Chapel build.)	Relative story drift (cm))	+side	—	—	3.0	3.2
		-side	—	—	-4.6	-4.2
	Absolute acceleration (cm/s^2)	+side	56.1	59.8	65.3	63.8
		-side	-44.0	-52.9	-58.4	-58.9
Non isolated build.	Absolute acceleration (cm/s^2)	+side	315.7	475.0	—	—
		-side	-236.3	-510.1	—	—
Ground	Absolute acceleration (cm/s^2)	+side	148.7	162.1	Same as observation	
		-side	-120.7	-148.0		

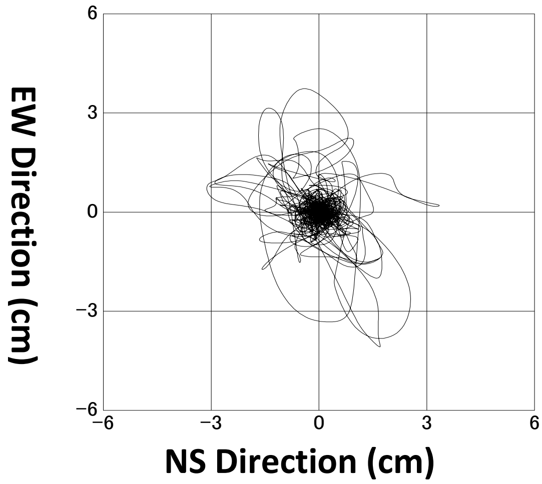


Figure 6. Orbit of NS and EW component displacements of the isolation story (Observation)

5. CONCLUSION

The concluding remarks are as follows;

(1) Rikkyo university located at Tokyo is far from about 300 km from the epicentre of 3.11 2011 earthquake in Japan. Seismic intensity was 5 lower in JMA scale and maximum ground peak acceleration was about 150 cm/s^2. The duration time is more than 300 seconds and this has been generally worried that it may affect the behaviour of the long period buildings such as seismic isolation buildings or super high rise buildings.

(2)Rikkyo university chapel building was retrofitted by the seismic isolation system in 1999. The accelerometers were installed at the conventional masonry building as well as at the isolation building in order to compare the isolation effect between these two buildings.

(3)In 3.11 2012 earthquake, the isolation building had no damage and got the acceleration records. According to the recorded data, the big isolation effect could be obtained comparing with the conventional neighbouring building and the seismic isolation system was confirmed as one of quite useful earthquake resistant technology.

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REFERENCES

Seki, M., Miyazaki M., Tsuneki Y. and Kataoka K.(2000). A Masonry School Building Retrofitted by Base Isolation Technology. *12th world Conference of Earthquake Engineering*.

JMAhttp://www.seisvol.kishou.go.jp/eq/shindo_db/db_map/201103/11/A20110311144618120026038062100560142516600870237429590J84D5117002064_map.html (Japan Meteorological Agency)