Evaluation of the dynamic characteristics of a base-isolated low-rise RC building after the Great East Japan Earthquake

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SUMMARY:
This paper reports an attempt to infer vibration characteristics of a low-rise base-isolated building after the East Japan Great Earthquake which occurred on March 11, 2011. The building corresponds to a 3-story reinforced concrete building which was constructed for research purposes and belongs to Tohoku University, Japan. Near this base-isolated test building, similar building was constructed having direct foundation in order to compare their corresponding behavior. The vibration characteristics are estimated from ambient vibration measurements and comparison between the results for base-isolated building and non-isolated building is performed. These vibration characteristics are also compared with those results obtained from previous studies performed before the earthquake. Changes in the predominant periods of vibration are observed with larger change for the non-isolated building. The inferred vibration characteristics from ambient vibration measurements for both buildings are compared with the predominant frequencies of transfer functions of acceleration wave recorded at both buildings during the 2011 East Japan Great Earthquake. In general, the first normal mode of vibration is expected to be the predominant in base isolated buildings. However, the effect of the second normal mode detected slightly from ambient vibration records, was strong in transfer functions of acceleration recorded in this building. In general the base isolation system allows the changing of proper periods of upper buildings to longer periods. However this changing of the proper period of the upper structure is not only for the first natural period but for the second natural periods too. Therefore, the possibility of having the non-desired resonance of second natural modes of this system for a particular earthquake motion is also discussed.

Keywords: Base isolated building, Ambient vibration measurements, FEM, East Japan Great Earthquake

1. INTRODUCTION

Base isolated buildings are design to control the vibration of the upper structure by reducing its relative displacement. This is possible due to the shifting of the period of the system to longer periods. In this paper an attempt to infer vibration characteristics of a low-rise base-isolated building after East Japan Great Earthquake which occurred on March 11, 2011 is reported. The building corresponds to a 3-story reinforced concrete building which was constructed for research purposes and belongs to Tohoku University, Japan. Near the base-isolated test building, similar building having direct foundation was constructed in order to compare their corresponding behavior. The vibration characteristics of both buildings are estimated from ambient vibration measurements and comparison between the results for base-isolated building and non-isolated building is performed. These vibration characteristics are also compared with those results obtained from previous studies performed before the earthquake. Changes in the predominant periods of vibration are observed with larger change for the non- isolated building. The inferred vibration characteristics from ambient vibration measurements for both buildings are compared with the predominant frequencies of transfer functions of acceleration wave recorded at both buildings during the 2011 East Japan Great Earthquake.

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2. SELECTED BUILDING

The target buildings ware two experimental 3-stories RC buildings built in 1980, which belong to Tohoku University, Japan (Figure 1). One building is a base isolated building (left side of the photo) and the other one is a building without base isolation. The upper structures for both buildings are the same. The building without base isolation has a mat foundation, and the base isolated building possesses high-damping rubber isolators (Figure 2).

Figure 1. Target buildings

Figure 2. Detail of the rubber isolator

3. MICROTREMOR MEASUREMENTS

Figure 3 displays the locations of ambient vibration measurement points. This arrangement was selected for measurements in previous study before the East Japan Great earthquake (Sato et al, 2008). In the present study points ①, ③, ⑤ and ⑦ were measured simultaneously for both buildings.

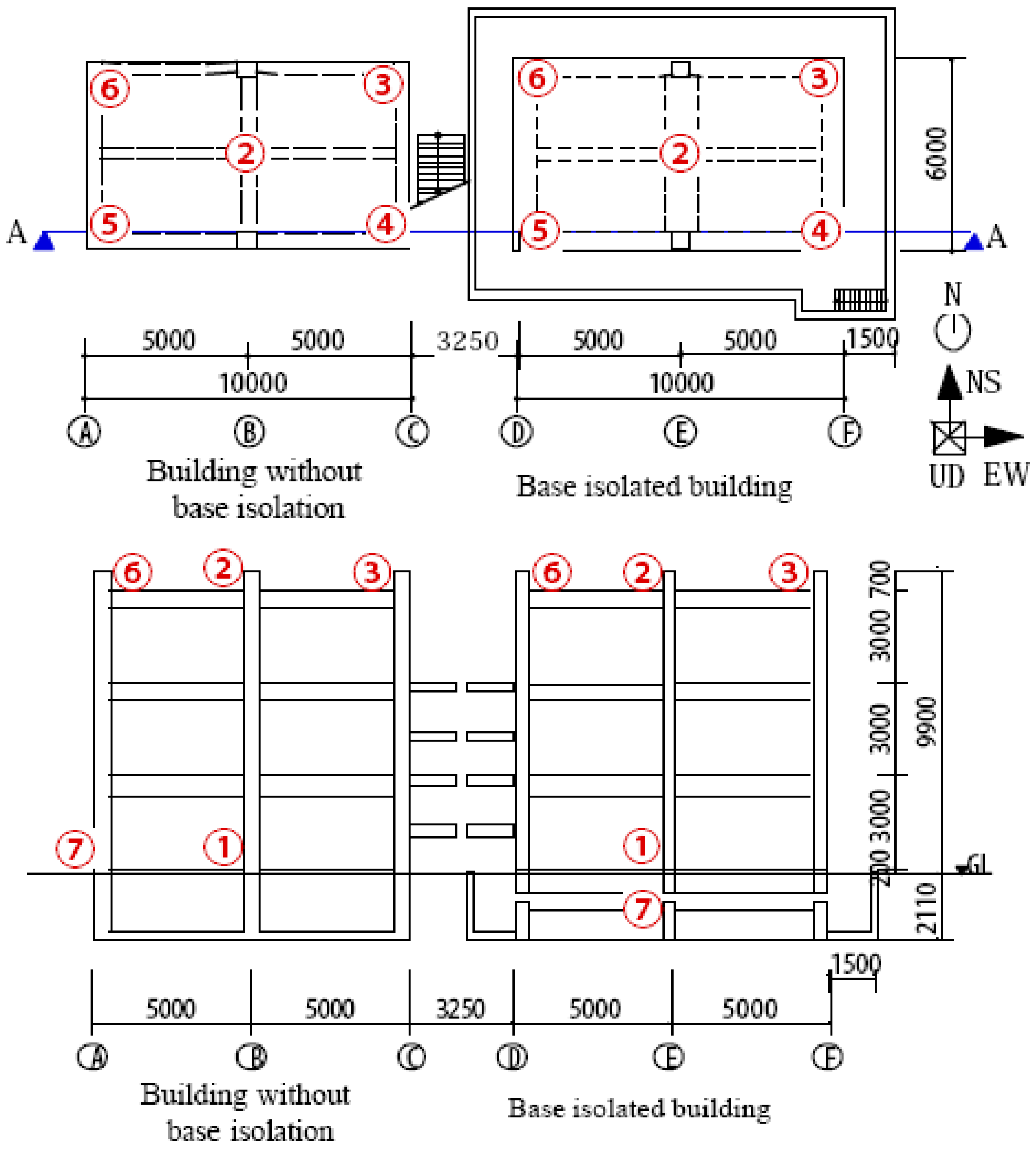

Figure 3. Location of points of measurements

The vibration characteristics for both buildings were estimated from the NS component transfer functions of ambient vibration measurements, whose values are 2.64 Hz for building without isolation, and 1.71 for base isolated building (see Figure 4). In addition to these predominant frequencies other peaks can be observed in the transfer function curve. To interpret the meaning of these peaks, wave records were filtered with these frequencies. The second peak for non-isolated building near 3.5 Hz could be a torsional mode since signals of points ③ and ⑤ are in inverse phase. In the case of isolated building, for second peak near 5.5 Hz the signals are in phase and therefore it is believed that this frequency corresponds to the second normal mode of vibration. This assumption is also verified by observing that the signal of points ① and ⑤ are in inverse phase for 5.5 Hz filtering.

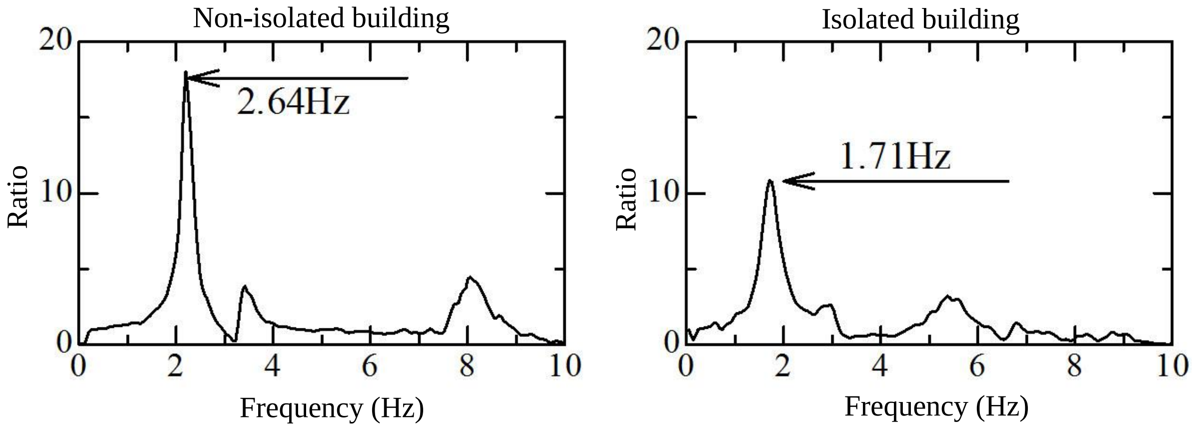

Figure 4. Transfer function of ambient vibration measurements

4. EARTHQUAKE STRONG MOTION RECORD

The earthquake motion of the East Japan Great Oki Earthquake was recorded at the ground surface close to the target buildings, where maximum acceleration was 301 Gal. Also, the maximum accelerations of 824 Gal at building without isolation and 362 Gal at base isolated building were recorded at observation points ② and ①, respectively. The maximum accelerations observed in each observation point were reported by Shimizu Corporation (2011) and are displayed in Figure 5. It can be observed that the maximum accelerations observed at top of the buildings are larger for non-isolated one. Therefore the effect of the isolation is verified according to the no amplification of the input acceleration in the isolated building.

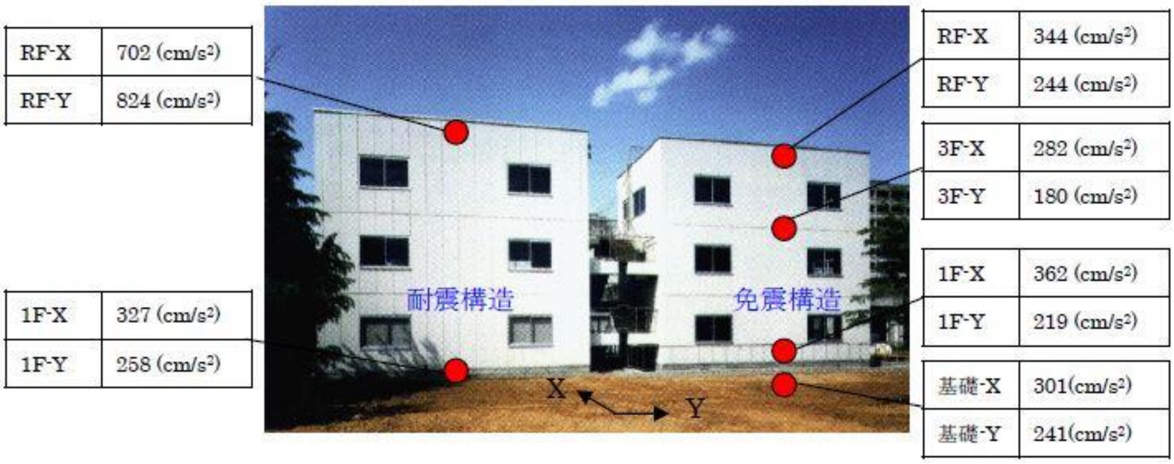

Figure 5. Maximum acceleration observed during the East Japan Great Earthquake

Figure 6 shows transfer functions between the slab foundation and the roof obtained from the accelerograms recorded at observation sites ②/⑦ and ②/① of target buildings. The predominant frequencies of 1.61 and 6.8 Hz were obtained for building without isolation, and the predominant frequencies of 0.68 and 4.19 Hz were obtained for base isolated building.

These results obtained from earthquake strong motion records demonstrate that the vibration characteristics estimated from ambient vibration measurements follows the obtained tendency. An unexpected amplification ratio was obtained around 4.19 Hz, which is quite close to the 2nd translational modal vibration of 5.5 Hz; meaning that there is the risk of having resonance phenomenon for this 2nd translational modal vibration when the input earthquake motion has predominant frequency close to this value. In previous study (Sato et al, 2008) the predominant frequencies obtained from the record of the Iwate-Miyagi inland earthquake (2008) and Sanriku south earthquake (2003) were of 0.95 Hz and 1.12 Hz respectively. This decreasing value of the predominant frequency with successive earthquake is due to the apparent or equivalent stiffness of the isolator during input motions. That is for large earthquake like the East Japan Great Earthquake large deformation of the isolator is expected to occur and therefore the equivalent or secant stiffness will be lower producing lower frequencies content in the dynamic response of the building. However it is also necessary to investigate the deterioration of the isolator due to the aged.

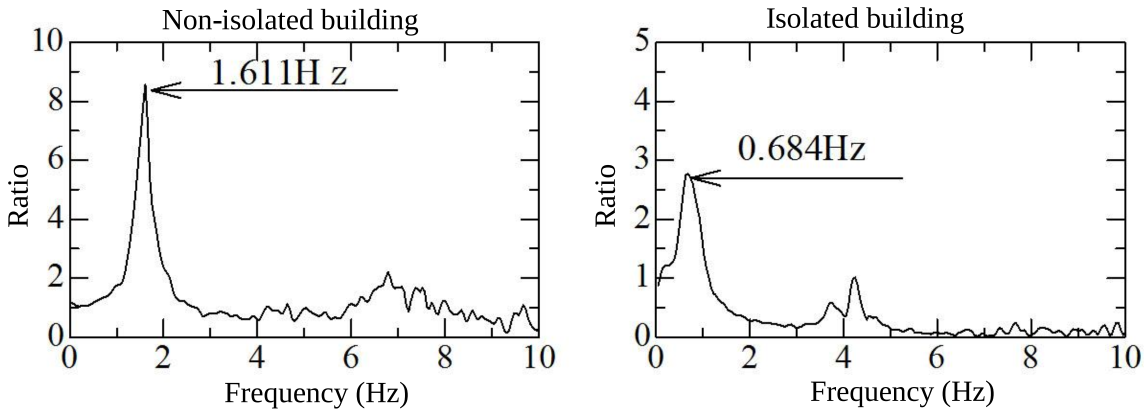

Figure 6. Transfer function from earthquake record

5. FINITE ELEMENT METHOD MODEL

Finite element model was constructed using link elements to simulate the behavior of the isolators. Upper structure is a common reinforced concrete frame. The characteristics of the materials were assumed those specify in the original project. However the deterioration of the materials are not taking into account. The purpose of the FEM analysis is to determinate the possible value for initial stiffness of base isolations, and to verify again the risk of resonance. The value of the initial stiffness obtained after making inverse analysis with FEM was 72 kN/cm. The predominant frequencies of 1.91 Hz, 4.80 Hz and 11.49 Hz for base isolated building are displayed in Figure 7, respectively. These proper frequencies are in concordance with the values estimated from ambient vibration records.

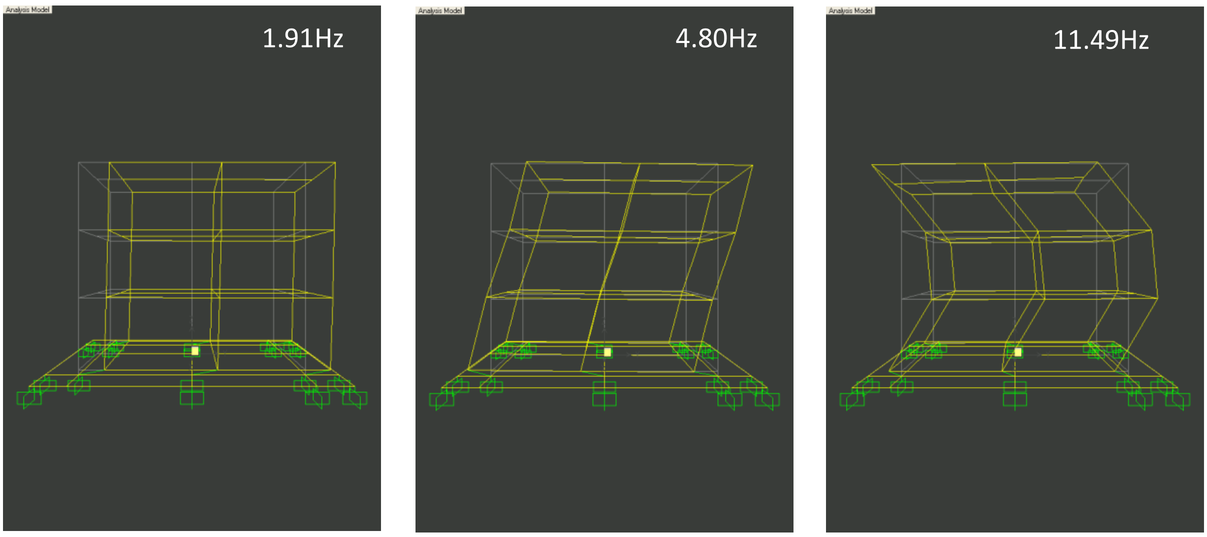

Figure 7. FEM model vibration modes

Table 1 summarizes the FEM results and the measured data analysis. The results are presented for the isolated building and for the non-isolated building. Analytical results and results from ambient vibration measurements are in good agreement while the results obtained from the earthquake record differ from FEM results. In the case of the isolated building this is explains by the apparent lower stiffness for large deformation of the isolator and in the case of the non-isolated building could be due to the deterioration of the structure during the strong earthquake.

Table 1. Comparison of predominant frequencies from FEM analysis and records data results

Method	Isolated Building		Non-isolated building	
	NS	EW	NS	EW
Finite Element Method	1.87 Hz	1.91 Hz	2.91 Hz	3.29 Hz
Ambient Vibration Measurements	1.71 Hz	1.71 Hz	2.64 Hz	2.64 Hz
Earthquake Record	0.68 Hz	0.73 Hz	1.61 Hz	1.86 Hz

The results from ambient vibration measurements before and after the East Japan Great Earthquake, the results from analysis of the earthquake records and the FEM analysis results are summarized in Table 2. The comparison of the ambient vibration measurements before the earthquake (2006) and after the earthquake (2011) shows a decrement in the predominant frequency for both non-isolated and isolated buildings. In the case of non-isolated building this reduction is due to the damages of the building during the big earthquake. In the case of the isolated building the results indicate that the initial stiffness of the isolators have suffered some deterioration which is reflected in the lower value of the frequency after the earthquake. The predominant frequency also decreases with the size of the earthquake having lower frequency for the East Japan Great Earthquake.

Table 2. Comparison of predominant frequencies from FEM analysis and earthquakes data results

Analysis source	Earthquake Magnitude	Predominant Frequency (Hz)	
		Non-isolated building	Isolated Building
Ambient vibration 2006		3.03	1.91
Ambient vibration 2011		2.64	1.71
Sanriku south earthquake 2003	M 7.1	2.41	1.12
Iwate-Miyagi earthquake 2008	M 7.2	2.31	0.95
East Japan Great Erthquake 2011	M 9.1	1.61	0.68
Modal analysis		2.91	1.87

6. CONCLUSIONS

The vibration characteristics of two similar super-structures but with different types of foundation were discussed in this paper. The values of these vibration characteristics for both buildings were estimated using ambient vibration measurements, and were also validated by earthquake strong motion records and by FEM modeling.

Analytical results and results from ambient vibration measurements are in good agreement while the results obtained from the earthquake record differ from FEM results. In the case of the isolated building this could be explained by the apparent lower stiffness for large deformation of the isolator and in the case of the non-isolated building could be due to the deterioration of the structure during the strong earthquake.

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