The 14th World Conference on Earthquake Engineering
October 12-17, 2008, Beijing, China

DISCUSSIONS ON VIBRATIONS CHARACTERISTICS OF BASE ISOLATED LOW RISE BUILDING BASED ON MICROTREMOR MEASUREMENTS AND FEM

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ABSTRACT :

This paper reports an attempt to infer some vibration characteristics (especially, predominant frequency) of base isolated buildings using microtremor measurements. A comparison between the vibration characteristics of this base isolated building and a similar RC 3-story building having direct foundation is performed. The inferred vibration characteristics from microtremor measurements for both buildings are compared with the predominant frequencies of transfer functions of accelerograms recorded at both buildings during the 2003 Miyagi-ken Oki Earthquake (M7.2). 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 microtremor records, was strong in transfer functions of accelerograms recorded in this building. The vibration characteristics of both buildings were confirmed also using FEM models. As conclusion, the application of microtremor measurements could be a useful tool for inferring some vibration modes of base isolated buildings too.

KEYWORDS: Base isolated building, Microtremor measurements, FEM, Vibration characteristics, 2003 Miyagi-ken Oki Earthquake

1. INTRODUCTION

The importance of techniques to estimate the impact of seismic force on structures was realized once again after the large damages caused by the 1995 Hyogo-ken Nanbu Earthquake. Following this devastating event, several earthquake-proof systems were subsequently suggested. One of these systems is the base isolated building, which usually reduces the impact of seismic forces on structures by disconnecting the upper-structure from the foundation. This system allows the changing of proper periods of upper buildings to longer periods. However, this changing of the proper period of the former upper structure is not only for the first natural period but for the second natural periods too. In this research, the possibility of having the non-desired resonance of second natural modes of this system for a particular earthquake motion is discussed.
The predominant frequencies of the transfer functions of microtremor measurements and earthquake motion records that were obtained in these buildings are compared with the values obtained from a mathematical model using the FEM.

Photo 1. A view of experimental building without base isolation (left) and base isolated building (right)

Photo 2. High-damping rubber isolator

2. EXPERIMENTAL BUILDINGS

The target buildings were two experimental 3-stories RC buildings built in 1980, which belong to Tohoku University, Japan (Photo 1). One building was a base isolated building and other was a building with no 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 (Photo 2).

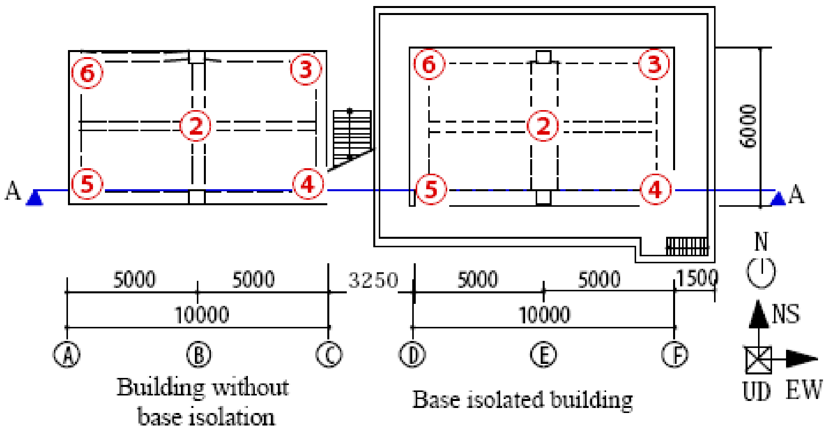


Figure 1. Location of microtremor observation points in target buildings

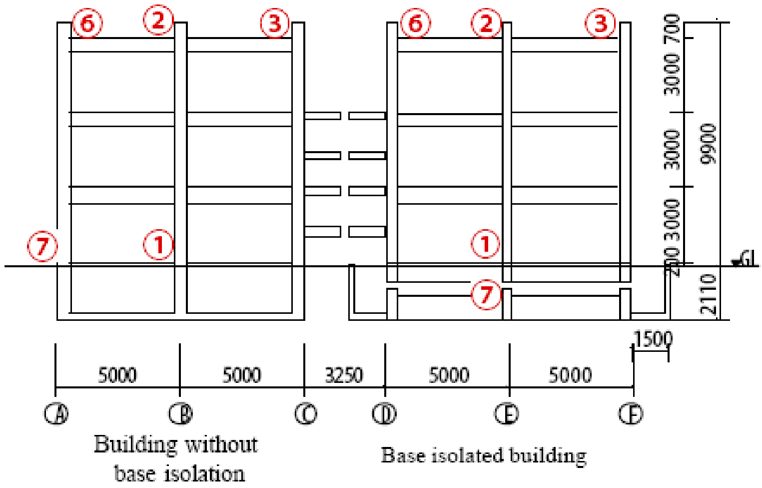


Figure 2. Location of microtremor observation points (section AA of target buildings in Fig. 1)

3. VIBRATION CHARACTERISTICS OF BUILDINGS

3.1. Microtremor Measurements

Figure 1 and 2 display the locations of microtremor measurement points. The vibration characteristics for both buildings were estimated from the NS component transfer functions of microtremor measurements, whose values are 3.03 and 4.93 Hz for building without isolation, and 1.90 and 5.97 Hz for base isolated building (see Fig. 3). To interpret the meaning of these predominant frequencies, microtremor records were filtered with these frequencies, and their waveforms are displayed in Figure 4. The waveforms obtained for 1.9, 5.91 and 3.03 Hz are in phase, meaning that those could be normal modes. Then, the predominant frequencies at 1.9 and 5.91 Hz could be interpreted as the 1st and the 2nd normal modal vibrations for base isolated building. In case of building without isolation, the value of 3.03 Hz could be the 1st normal modal vibration and the value of 4.93 Hz could be a torsional modal vibration (waveforms of ③ and ④ are in inverse phase when comparing with waveforms of ⑤ and ⑥ in Fig. 4(b)).

The assumptions for the 1st and the 2nd normal modal vibrations for base isolated building were verified after filtering microtremor records for observation points ①, ②, and ⑦. Figure 5 shows that the waveforms ① and ② are in phase for 1.9 Hz, while these waveforms are in inverse phase for 5.91 Hz. For easier understanding of these results, a graphical representation of the vibration modes is shown in Fig. 6.

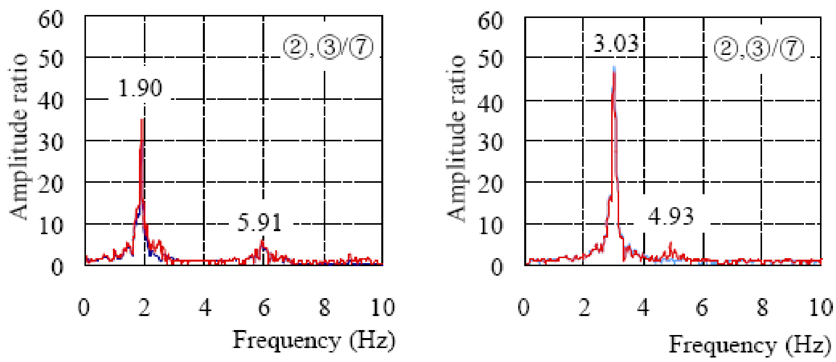


Figure 3. NS comp. transfer functions of microtremor records for building without base isolation (right) and base isolated building (left)

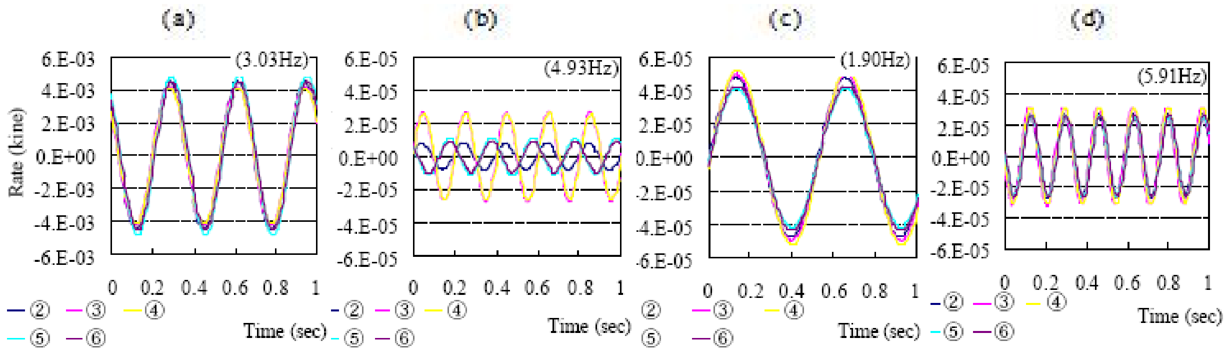


Figure 4. Waveforms obtained after filtering for building without base isolation (a) 3.03 Hz and (b) 4.93 Hz, and base isolated building (c) 1.90 Hz and (d) 5.91 Hz.

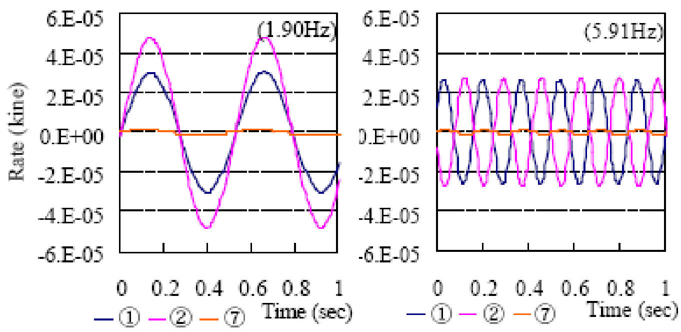


Figure 5. Waveforms for 1.90 Hz and 5.91 Hz obtained after filtering at base isolated building

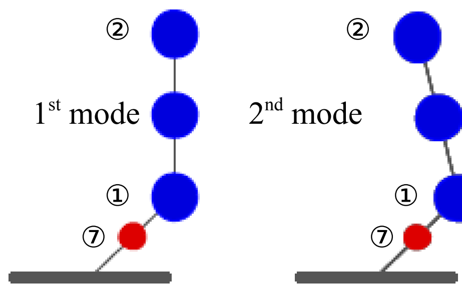


Figure 6. Graphical representation of vibration modes for base isolated building.

3.2. Earthquake Strong Motion Records

The earthquake motion of the 2003 Miyagi-ken Oki Earthquake was recorded at the ground surface close to the target buildings, where maximum acceleration was 159 Gal. Also, the maximum accelerations of 347 Gal at building without isolation and 91 Gal at base isolated building were recorded at observation points ②, respectively (Fig. 7). Figure 8 displays the Fourier amplitude spectrum of the accelerogram recorded at the ground surface, which predominant frequencies are between 1 and 5 Hz. Figure 9 shows the acceleration response spectrum, which displays that the maximum accelerations are 307 and 80 Gal (h=5% damping factor) around the 1st mode for building without isolation and for base isolated building, respectively. It shows that the maximum acceleration can be diminished when using base isolation in buildings.

Figure 10 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 2.29 and 8.26 Hz were obtained for building without isolation, and the predominant frequencies of 1.10 and 5.19 Hz were obtained for base isolated building. Similar to the data processing performed with the microtremor records, the waveforms from accelerograms records are displayed in Figure 11 after filtering corresponding frequencies. These waveforms obtained from earthquake strong motion records demonstrate that the vibration characteristics estimated from microtremor measurements are reasonably accurate.

An unexpected amplification ratio about 8 was obtained around 5.19 Hz, which is quite close to the 2nd translational modal vibration of 5.97 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.

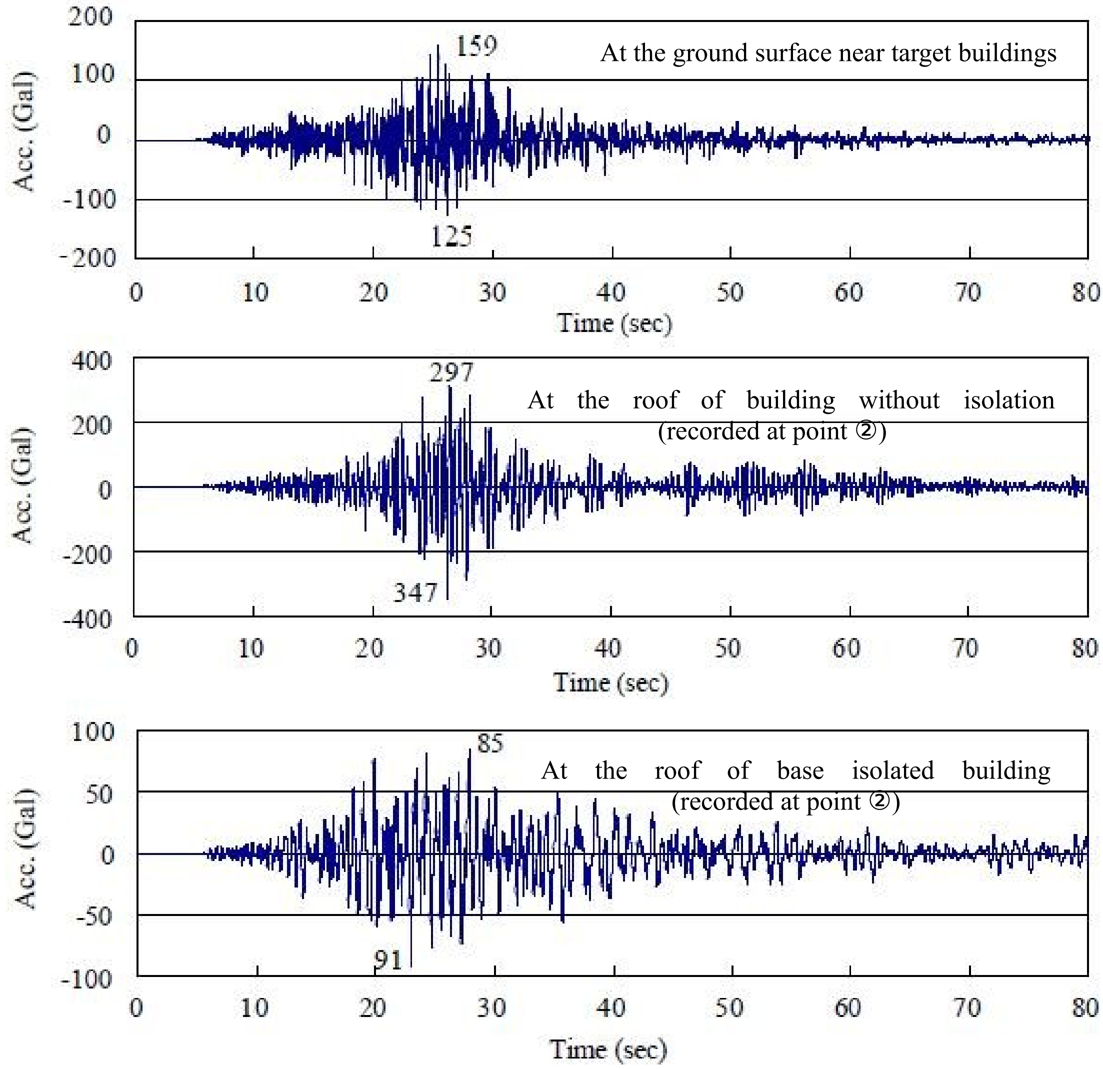


Figure 7. Accelerograms recorded at target buildings during the 2003 Miyagi-ken-Oki Earthquake.

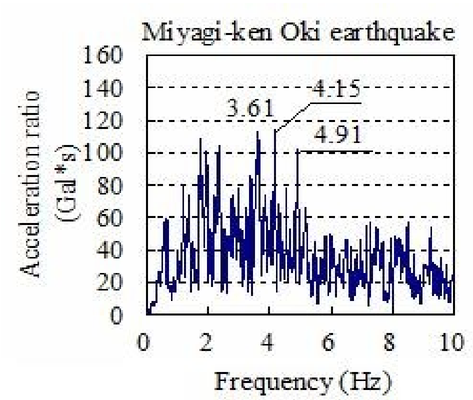


Figure 8. Fourier amplitude spectrum of accelerogram recorded at the ground surface

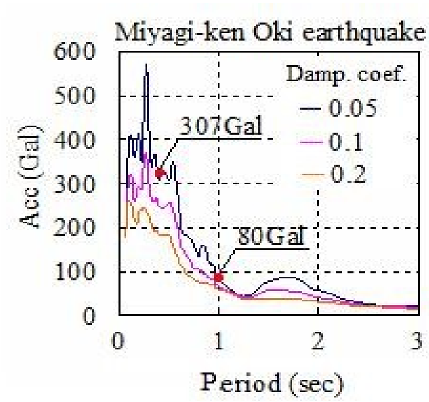


Figure 9. Acceleration response spectrum of accelerogram recorded at the ground surface

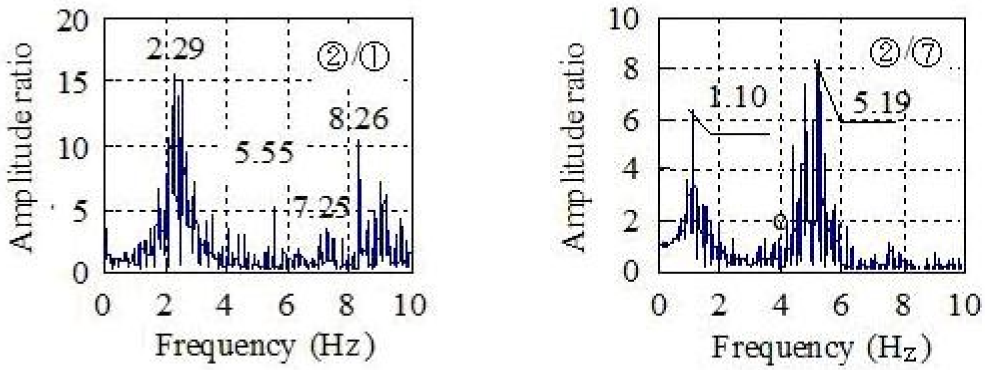


Figure 10. Transfer functions for building without base isolation (left) and base isolated building (right).

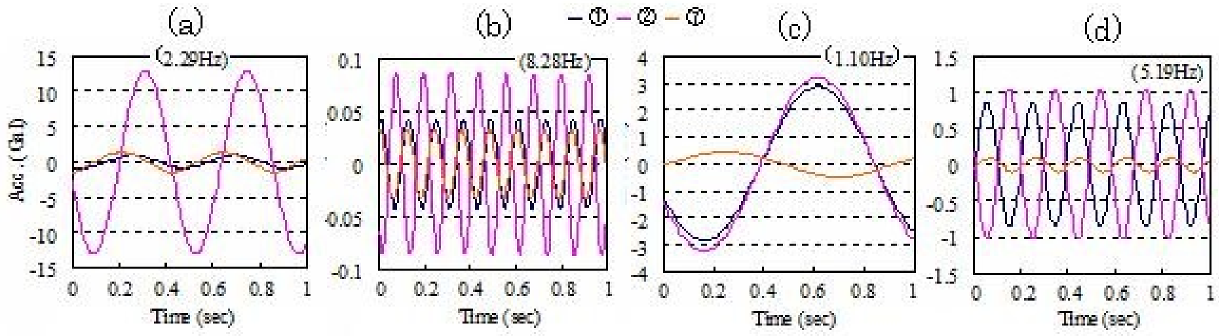
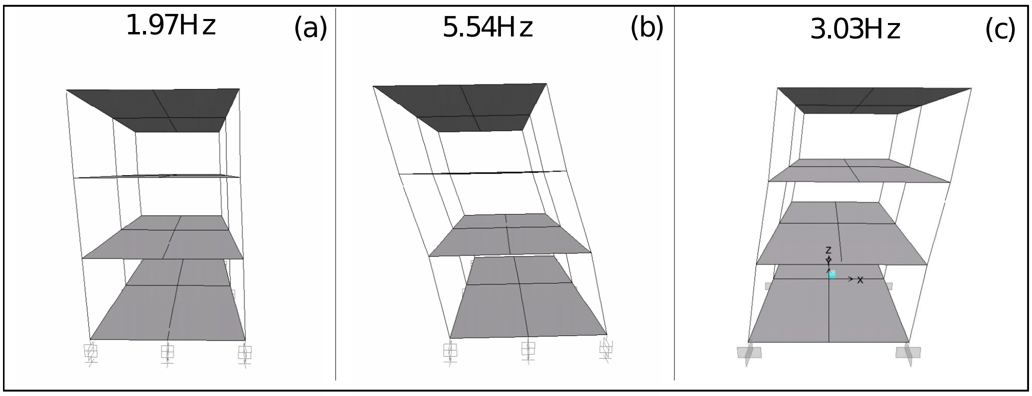


Figure 11. Waveforms obtained after filtering for building without base isolation (a) 2.29 Hz and (b) 8.28 Hz, and base isolated building (c) 1.10 Hz and (d) 5.19 Hz.

3.3. Finite Element Method

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 proper frequencies of 1.97 and 5.54 Hz for base isolated building, as well as, the proper frequency of 3.03 Hz for building without isolation are displayed in Figure 12, respectively. These proper frequencies are in concordance with the values estimated from microtremor records.



(a) 1st normal mode (b) 2nd normal mode (c) 1st normal mode

Figure 12. Vibration modes obtained from a FEM analysis for base isolated building (a) 1st normal mode and (b) 2nd normal mode, and for building without isolation (c) 1st normal mode

4. 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 microtremor measurements, and were also validated by earthquake strong motion records and by FEM modeling. From the above results, it can be concluded that the application of microtremor measurements could be a useful tool for inferring the vibration characteristics of base isolated buildings too.

5. ACKNOWLEDGMENTS

The authors wish to acknowledge Prof. Satoshi Kurita of Tokyo University of Science and Dr. Masaaki Saruta of Shimizu Corporation for their cooperation in providing various data used in this research.

REFERENCES

Saruta, M. (1999). Safety of base isolated building during earthquakes. *Journal of architecture and building science* **1999,** 97.

Sukagawa, K., et al. (1987). Research on Base Isolation System for Structure: Part 1: Outline of Research. *Summaries of technical papers of Annual Meeting AIJ*, **B**, **Structures I,** 767-768.

Sukagawa, K., et al. (1986). Research on Base Isolation System for Structure: Part 3: Study on Earthquake Response of Base-Isolated Structure. *Summaries of technical papers of Annual Meeting AIJ*, **B**, **Structures I,** 785-786.

Saruta, M., et al. (1988). Research on Base Isolation System for Structure: Part 5: High Damping Rubber Bearing. *Summaries of technical papers of Annual Meeting AIJ*, **B**, **Structures I,** 475-476.