Proceedings of Asia International Conference on Tribology 2018, pp. 321-322, September 2018

Effects of hemispherical sliding bearings adopted to house model structures on seismic isolation

F. Oshika[1], K. Ito[1,*], B.S. Gan[3]

[1)] Department of Mechanical Engineering, Graduate School of Engineering, Nihon University,
1 Nakagawara, Tokusada, Tamura-machi, Koriyama, Fukushima, 963-8642, Japan.
[2)] Department of Architecture, College of Engineering, Nihon University,
1 Nakagawara, Tokusada, Tamura-machi, Koriyama, Fukushima, 963-8642, Japan.

[*]Corresponding e-mail: kito@mech.ce.nihon-u.ac.jp

Keywords: Hemispherical sliding bearing; house; seismic isolation

ABSTRACT – A new seismic isolation system using hemispherical sliding bearings to steel pipe pile foundation is proposed for the design of a house. Experiments were performed on model structures of a house with and without the bearings. With the bearings, the vibration of its roof was lower than that without the bearings, while an unexpected increase in vibration occurred on its floor. Detailed analyses identified that stick-slip occurred at the contact interfaces of the bearings and caused the increase in vibration.

1. INTRODUCTION

Strong earthquakes occur in many parts of the world. In Japan and many Southeast Asian countries, quite a large number of people live in alluvial plains, where the magnitude of the vibration may be amplified due to its geological properties. In such an area, steel pipe pile foundation helps to construct earthquake-resistant houses. However, about 40 to 80% of the victims of strong earthquakes have been crashed by fallen furniture [1-2]. In order to reduce the number of such victims, a house being simply earthquake-resistant is not enough. Adopting a seismic isolation system to each house is very important. However, such system for houses commercially available to date is very expensive thus not widespread at all [3].

The final goal of the whole series of study is to develop a low-cost seismic isolation system using steel pipe pile foundation with hemispherical sliding bearings [4]. A series of model experiments were performed in the past. However, the horizontal response acceleration on the floor with the bearings was 3.6 times larger than that without the bearing, which is quite unexpected thus the phenomena have not been fully understood yet. In this presentation, a set of experimental results are reported in detail. The cause of the unexpected increase is identified, and directions of further development are discussed.

2. TEST METHOD

Two types of house model structures (i.e. Structure-1 and -2) are set in a laminated box and excited by a shaker as schematically shown in Fig. 1 [7]. Structure-1 (Fig. 1 left) consists of a substructure and a superstructure. The substructure is a steel pipe pile foundation with 4 piles. Each pile is 60.5 mm in diameter, 3.2 mm in pipe thickness, and 1660 mm in length. The superstructure is composed of a footing (500 × 500 × 200 mm, 66 kg), 6 pillars (400 × 25 × 6 mm), and a roof frame (3 kg). The natural frequency of the superstructure is 5.0 Hz. Structure-2 (Fig. 1 right) is identical to Structure-1 except that a hemispherical sliding bearing is installed on the top of each pile. The bearing is composed of two sliding faces so that the pile head can rotate in any direction. No lubricant was applied on the sliding surfaces of the bearings.

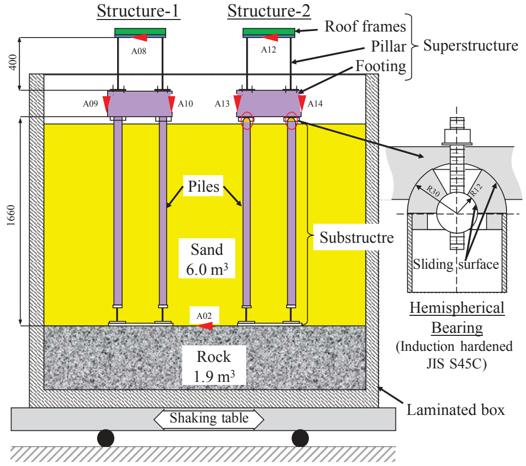

Fig. 1 Experimental set-up of house model structures.

The acceleration is measured at each point indicated by ◀ mark in Fig. 1. The rotational acceleration of the footing is defined as a half value of the difference between the vertical accelerations at A09 and A10 for Structure-1, and A13 and A14 for Structure-2, respectively. The counter-clockwise rotation is a positive direction.

The input excitation wave (i.e. a model seismic wave) is a sine wave of 6.0 Hz. The waveform at the pile fixing part (A02) is shown in Fig. 2. The amplitude increases linearly for the first 12 waves, then stable for the following 6 waves, and decreases linearly up to the 30th waves.

3. RESULTS AND DISCUSSION

In Fig. 3, the horizontal response accelerations at the roof frames of Structures-1 and -2 are compared. Once vibration originated from the excitation wave is transmitted to the roof, its motion does not stop easily due to oscillating elastic bending of the pillars. In Structure-1, the decaying time of the roof was about 24 seconds, while that of the floor (not shown) was about 8 seconds.

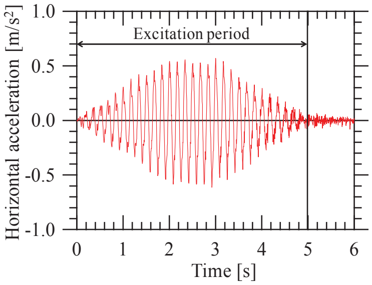

Fig. 2 The waveform at A02.

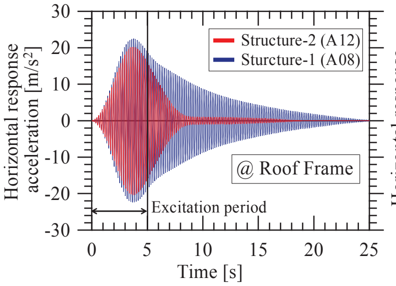

Fig. 3 Horizontal response accelerations.

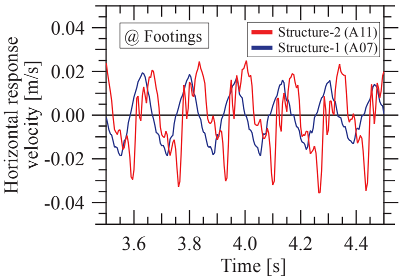

Fig. 4 Horizontal response velocities.

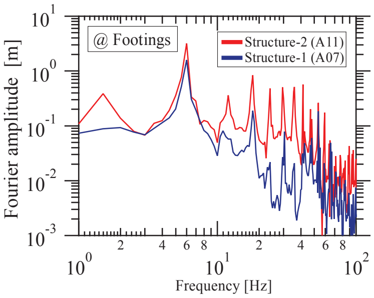

Fig. 5 Fourier spectra of horizontal response velocities (the waveform in Fig. 4).

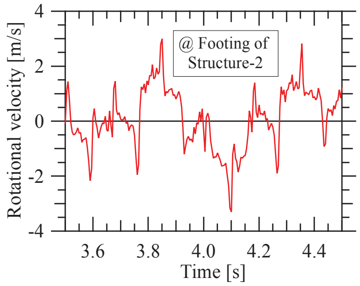

Fig. 6 Rotational response velocity.

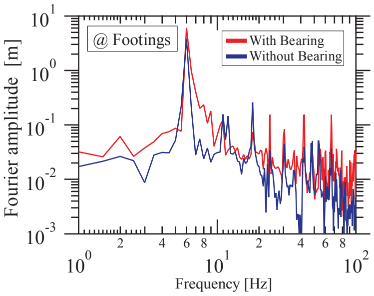

Fig. 7 Fourier spectra of horizontal response velocities (FEM simulation).

In Structure-2, the roof vibration decayed quickly as the excitation wave decayed. It seems that the bearings helped to isolate the upper structure.

The horizontal response velocities at the footings of Structures-1 and -2 are also calculated by integrating the acceleration data and shown in Fig. 4. Their Fourier spectra are compared in Fig. 5. The dominant frequency is 6 Hz for both structures. The Fourier amplitude at the 20-50 Hz range is much larger in Structure-2 than in Structure-1. By integrating the rotational acceleration of the bearing at the footing of Structure-2, the rotational velocity is calculated and shown in Fig. 6. Sharp half-peaks in 10-25 ms (i.e. 20-50 Hz in frequency) can be found. Such a sudden start-stop is characteristic to stick-slip. Therefore, it can be concluded that the stick-slip occurred at the bearings in Structure-2, which resulted in increased horizontal vibration at the footing. Stick-slip should never occur in the bearing when an earthquake occurs. It would be important to apply a proper lubricant or self-lubricating materials.

The friction should be small in the excitation period, but it can never be zero. Therefore, the friction should be sufficiently large for fast decay. Such an opposing friction property is required. In addition, friction property may change depending on various factors, such as the humidity of ambient environment. Computer simulation will be helpful in order to find the best compromise in various types of earthquakes and/or houses in a wide range of ambient conditions.

FEM simulation models are being developed by the authors. Their preliminary results are as follows. If μ_{static} >> $\mu_{kinetic}$, the spectrum of horizontal response velocity at the footing is characteristic to stick-slip (Fig. 7). If $\mu_{static} = \mu_{kinetic}$, the stick-slip does not occur. In both the cases (i.e. with the bearings), the horizontal vibration of the roof frame is lower than that without the bearings.

4. CONCLUSIONS

For the design of seismic isolation houses, hemispherical sliding bearings were adopted to the pile foundation of house model structures, and their effects on the vibration were studied. Conclusions are as follows:

(a) Reduced horizontal vibration of the roof can be achieved by the bearings.
(b) When stick-slip phenomena occur at the contact interfaces of the bearings, the horizontal vibration of the floor increases, which should be avoided.

ACKNOWLEDGEMENT

The authors express sincere thanks to Professors. Susumu Nakamura and Noriaki Sento in Nihon University for their cooperation in experiments, and Emeritus Professor Koji Kato for his valuable comments. The experiments were performed in Obayashi Co. A part of this study was funded by MEXT under the grants No. S1203003.

REFERENCES

[1] Report of Disaster Control Section, Prefectural Citizen Disaster Countermeasure Department, Hyogo Prefectural Government Office. (2008).
[2] Report of Tokyo Disaster Prevention and Emergency Association, Tokyo Fire Department. (2012).
[3] M. Takano, Report of Yano Research Institute. (2006).
[4] Yamazaki, Y., Ito, K., Gan, B. S., & Kato, K. (2012). In *47th JSME Tohoku Branch Meeting*.
[5] Gan, B. S., Sento, N., Nakamura, S., & Ito, K. (2015). Shaking table tests of pile foundation with friction-type seismic isolation bearing. in Civil Engineering, ed. by M. S. Pamulu, WiTness Press, 98-110.