Seismic behavior of piled raft foundation by near and far earthquakes observations

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ABSTRACT

Seismic observations on piled raft foundation subjected to unsymmetrical earth pressure have been conducted just after the 2011 off the Pacific coast of Tohoku Earthquake. The seismically monitored building is a seven-story building with three basement floors, subjected to unsymmetrical earth pressure, located in Tokyo, Japan. Accelerations of the building, dynamic sectional forces of the piles and dynamic earth pressures on both sides of the embedded foundation and those beneath the raft were observed during over 550 seismic events including an earthquake with a magnitude of M8.1. The maximum acceleration of 0.358 m/s^2 was observed on the building foundation. Based on the seismic records, it was confirmed that a lateral inertial force of the building was transferred to the subsoil through the raft. Comparing to different seismic type, the bending moments on piles due to far earthquake having relatively long period were larger than those due to near earthquake.

Keywords: piled raft foundation, seismic observation, unsymmetrical earth pressure

1. INTRODUCTION

Piled raft foundations are recognised one of the most economical foundation systems for vertical load, that the foundation are applies for lots of building for many countries. It is important and necessary to develop more reliable seismic design methods for piled raft foundations, especially in highly active seismic areas such as Japan. However, only a few case histories exist on the monitoring of the soil-pile-structure interaction behavior during earthquakes.

The purpose of this study is to clarify the seismic performance of piled raft foundations based on seismic observation records. The static and seismic observation records on a piled raft foundation subjected to unsymmetrical earth pressure have been reported by Hamada et al. (2014, 2015). In addition to the results, this paper focuses on two seismic observation records during the seismic events on May 25 and 30, 2015. A magnitude of the event on May 25 is M5.5 and an epicenter of the event is near the monitored building, North Saitama. Whereas, those of the event on May 30 are M8.1 and far from the monitored building, Ogasawara islands, depth of 682 km. The earthquake having an epicenter far from the monitoring building has relatively long period and the ground deformation might be relatively large at the same acceleration level.

Accelerations of the building, dynamic sectional forces of the piles and dynamic earth pressure on both sides of the embedded foundation as well as that beneath the raft were observed. In this study, comparing to two deferent type events, sectional forces on piles due to input acceleration are discussed.

2. MONITORED BUILDING AND SOIL CONDITIONS

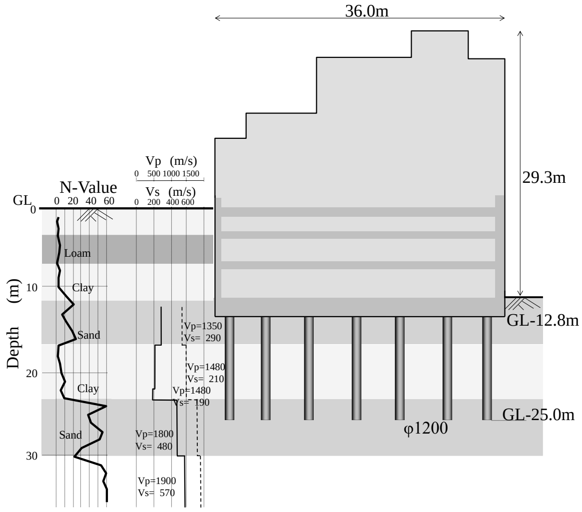


Figure 1 Schematic view of monitored building and foundation with soil profile

The seismically monitored building, which is seven-story residential building with three basement floors, is located in Tokyo, Japan. The building subjected to unsymmetrical earth pressure is a reinforced concrete structure, 29.3m high, with a 71.4m by 36.0m footprint. Figure 1 shows a schematic view of the building and its foundation with a typical soil profile. The soil profile consists of fine sand layer just below the raft with SPT N-values from 10 to 20 and clay strata including humus between depths of 17 m and 24 m from the ground surface with unconfined compressive strength of about 140 kPa. Below the depth of 24 m, there lies a Pleistocene fine sand layer with SPT N-values of 40 or higher. The shear wave velocities derived from a P-S logging system were about 200 m/s between the depths of 17 m and 24 m, and 480 to 570 m/s in the sand layers below the depth of 24 m. The ground water table appears at a depth approximately equal to the basement level.

The average contact pressure over the raft was 159 kPa. If a conventional pile foundation were used for the building foundation subjected to unsymmetrical earth pressure, the piles should carry large lateral load not only for seismic condition but also for ordinary condition, where a design horizontal seismic coefficient of "lateral load over building dead load" was 0.15 for ordinary condition and 0.34 for severe seismic condition.

On the other hand, if a raft foundation were used, clay layer below sand layer just below the raft has a potential of excessive settlement while the sand layer has enough bearing capacity for the dead load of the building and lateral frictional resistance between the raft and the subsoil can be reliable.

Consequently, a piled raft foundation consiting of cast-in-place concrete piles with 1.2 m in diameter and 12.2 m in length was employed, where the lateral load can be resisted by both the piles and the frictional resistance beneath the raft. Natural frequency of the building is 1.7 Hz and ground natural frequancy is 4Hz at the lower ground surface and 2Hz at the higher ground surface assumed from shear wave velocity (200 m/s) and thickness of the strata (12m and 25m).

3. INSTRUMENTATION

Figure 2 shows the layout of the piles with locations of monitoring devices. Axial forces and bending moments of the piles were measured by a couple of LVDT-type strain gauges on Pile 2D (2-D street), Pile 5G (5-G street) and Pile 5D (5-D street). Eight earth pressure cells and a pore-water pressure cell were installed beneath the raft around the instrumented piles. Three sections of Pile 5D at depths of 1.0 m, 2.0 m and 9.14 m below the pile head and those of Pile 5G at depths of 1.0 m, 1.7 m and 8.19 m were measured

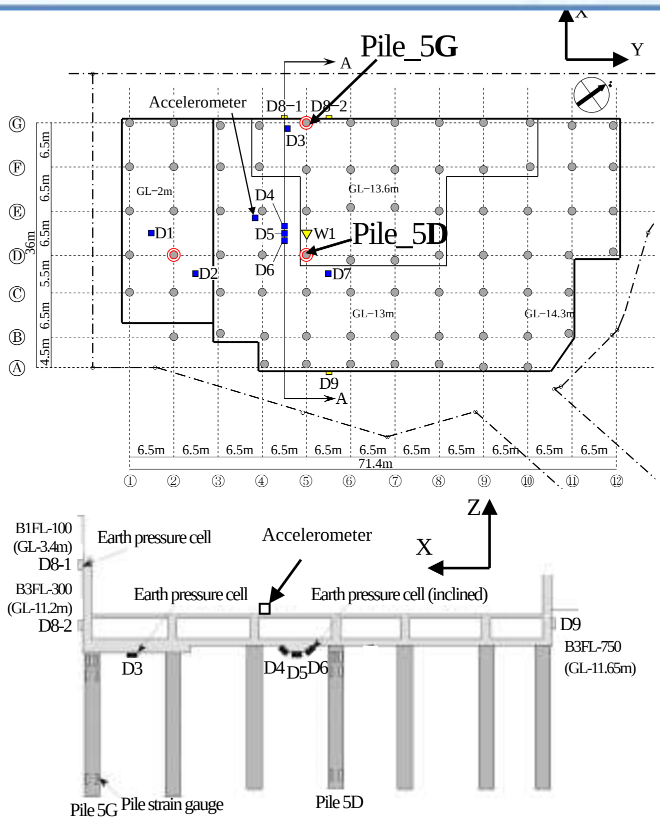


Figure 2 Foundation profile with locations of monitoring devices

during earthquakes.

Earth pressure cells of D4 and D6 were set obliquely on the soil around Pile 5D, in order to evaluate a frictional resistance beneath the raft by the difference of the earth pressure from the two earth pressure cells. Earth pressure cells of D8-1, D8-2 and D9 were set on the embedded side wall in order to evaluate a lateral force acting on the side wall of the building.

As for the seismic observation, the NS, EW and UD accelerations of the building on the third basement floor (B3F) was recorded by triaxial servo accelerometers. The horizontal components of the triaxial accelerometer were oriented to the longitudinal direction and the transverse direction of the building as shown in Figure 2. In this paper, the transverse direction and the longitudinal direction of the building are called X-direction and Y-direction, respectively. The axial forces and the bending moments of two piles, the contact earth pressures between the raft and the soil as well as the pore-water pressure beneath the raft were also measured during earthquakes in common starting time with the accelerometers. The triggering acceleration is 0.004 m/s^2 on the B3F and the sampling rate is employed at 100 Hz. Minimum available values of acceleration, strain and earth pressure are 2.4×10^{-4} m/s^2 , $1.0\times10^{-4}\mu$ and 5.0×10^{-6} kPa, respectively.

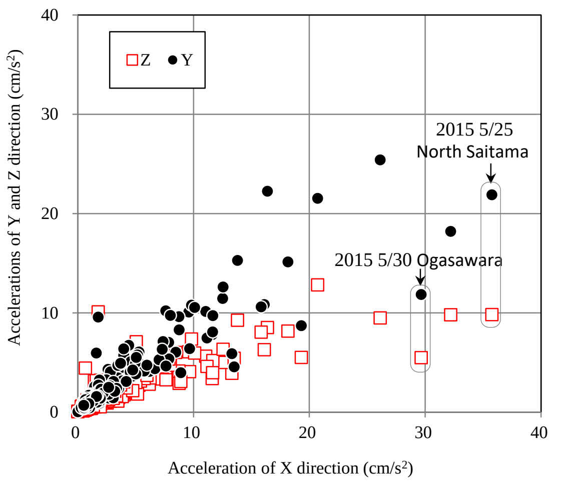


Figure 3 Maximum accelerations of seismic events

4. SEISMIC RESPONSE OF PILED RAFT FOUNDATION

4.1 Observed seismic events

Accelerations of the building, dynamic sectional forces of the piles and dynamic earth pressure on both sides of the embedded foundation as well as that beneath the raft were observed during 555 seismic events from March 23 in 2011 to Sep 26 in 2017, including an earthquake with a magnitude of M8.1. The maximum acceleration of 0.358 m/s^2 was observed on the building foundation. Figure 3 shows observed maximum accelerations of these seismic events .

Figure 4 shows locations of the monitored building and epicenters of relatively large seismic events. Large earthquakes of April 11 and 16, 2011, just after the Pacific coast of Tohoku Earthquake have attacked the monitored building site. This paper focuses on the seismic event on May 25 and 30, 2015.

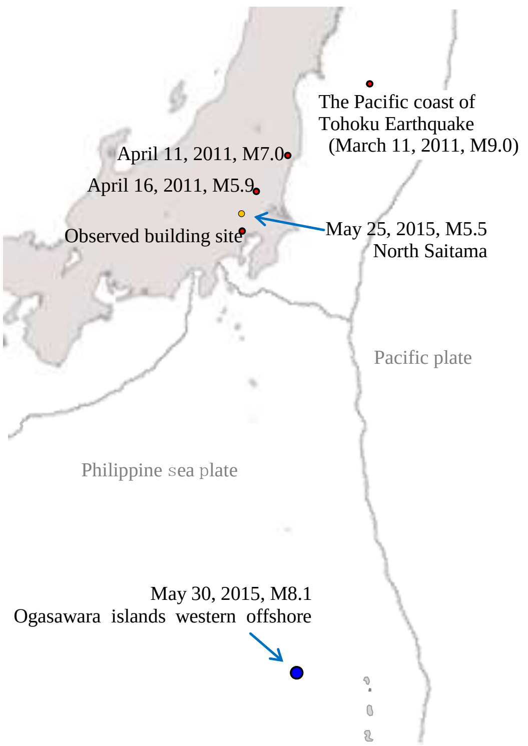
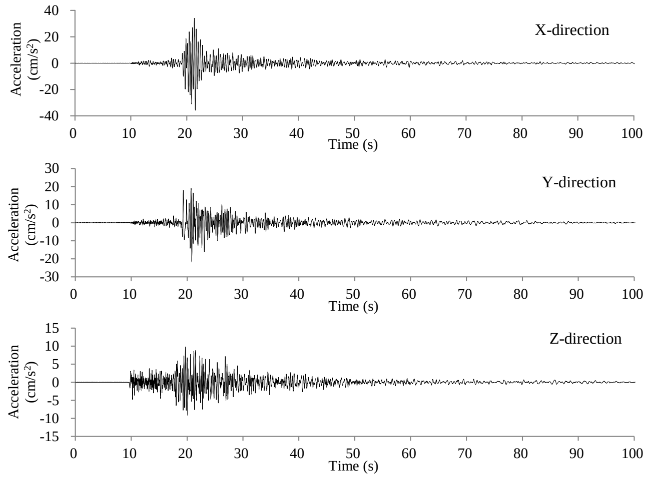
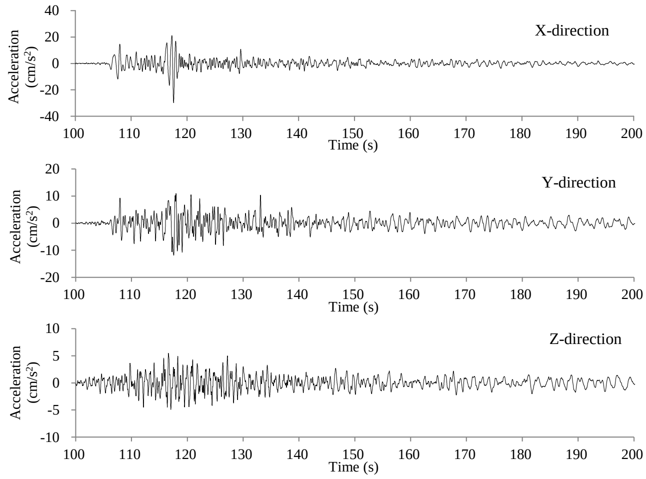


Figure 4 Locations of monitored building and epicenters of seismic events



(a) North Saitama, May 25, 2015 (M5.5)



(b) Ogasawara, May 30, 2015 (M 8.1)

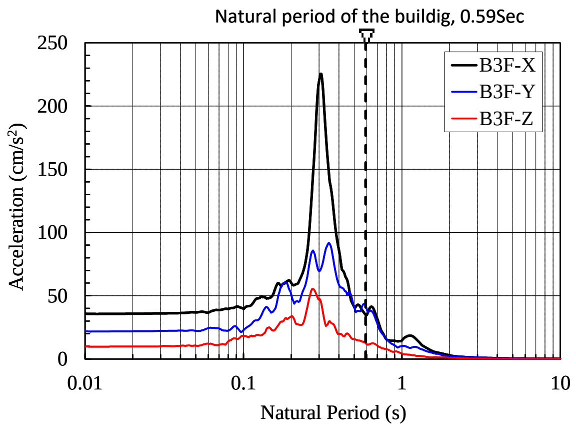
Figure 5 Time histories of the measured accelerations at B3F

4.2 Observed seismic responses of foundation

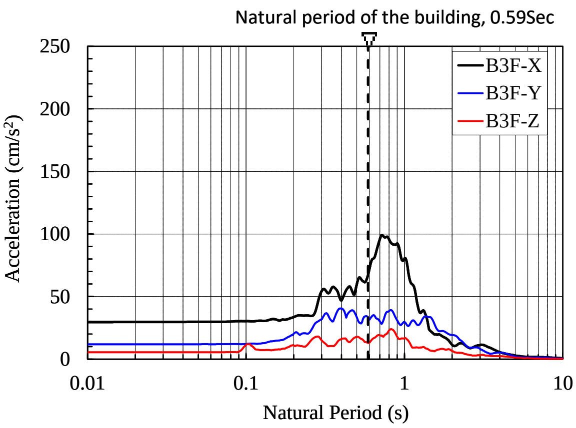
Figure 5 shows the time histories of the measured accelerations during the seismic event on May 25 and 30, 2011. A magnitude of the event on May 30 is M8.1 and an epicenter of the event is Ogasawara ocean area. Those of the event on May 25 are M5.5 and North Saitama, in which the maximum acceleration of 0.358 m/s^2 was recorded in X-direction.

Figure 6 shows the acceleration response spectrum of the observed accelerations. A natural period of the building is 0.59 sec. The domain periods of the input motion of North Saitama and Ogasawara are 0.3 sec and 0.7 sec, respectively. Therefore, it is considered that upper part of the building would be oscillating during Ogasawara event larger than during North Saitama event in X-direction. The building would be oscillated at the first mode during Ogasawara event, whereas as the second mode during North-Saitama event.

Figure 7 shows the relationship between peak accelerations and incremental peak strains on pile



(a) North Saitama, May 25, 2015 (M5.5)



(b) Ogasawara, May 30, 2015 (M 8.1)

Figure 6 Acceleration response spectrum (h=5%)

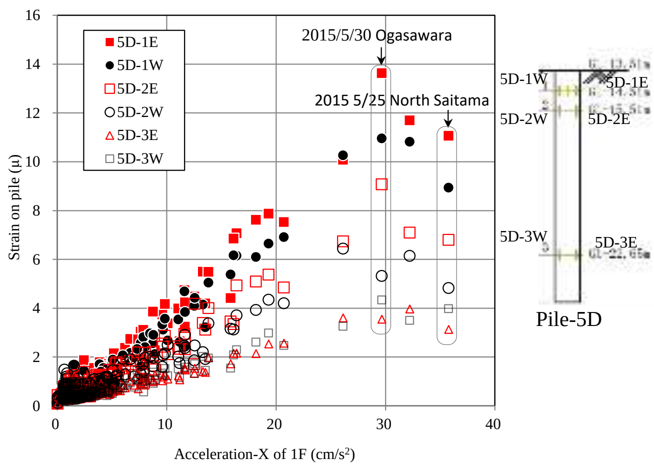


Figure 7 Peak strain on monitored piles

during 555 events. The peak strains almost depend on peak accelerations. However, the peak acceleration during the North Saitama event is larger than that during the Ogasawara event, whereas the peak strains during the former event are smaller than those during the later event.

Figure 8 shows the relationship between the horizontal acceleration in X-direction and the bending moment of Pile 5D at the pile head, the bending moment was closely related to the inertial force of the

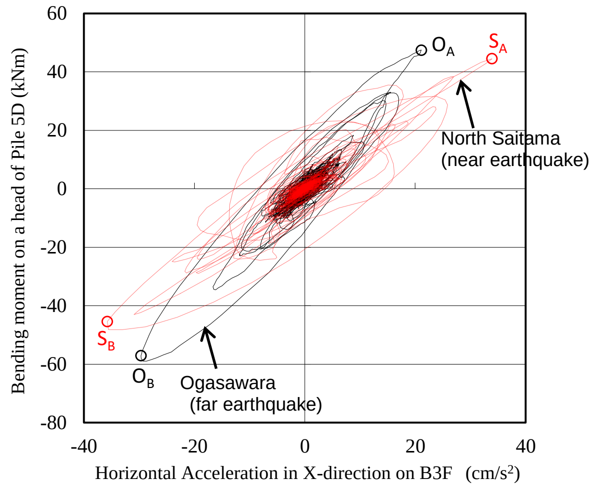


Figure 8 Bending moment on a pile head versus horizontal acceleration on the B3 floor (Pile 5D)

building. Time S_A, S_B, O_A and O_B indicated in the figures are corresponding to the time of the peak acceleration. The bending moments occurred by far earthquake, Ogasawara were larger than those by near earthquake, North Saitama. The oscillating at upper part of the building during Ogasawara event might be larger than those during North Saitama event judging from a relationship between a natural period of the building and domain periods of the input motion. However, it is considered that the bending moments are generated by not only inertial force of superstructure but also ground deformation which is large during far earthquake.

5. CONCLUSION

Seismic observations on the piled raft foundation subjected to unsymmetrical earth pressure were performed just after the 2011 off the Pacific Coast of Tohoku Earthquake. Based on the two different types of seismic records due to near earthquake and far earthquake, it was found as follows;

1) The incremental peak strains on piles due to far earthquake were larger than those due to near earthquake, whereas the peak acceleration at far earthquake was smaller than that at near earthquake.
2) The bending moments on piles were closely related to the horizontal acceleration of the building. The bending moments due to far earthquake were larger than those due to near earthquake.
3) The oscillating of the superstructure during far earthquake might be larger than those during near one. However, it is considered that the bending moments are generated by not only inertial force of superstructure but also ground deformation which is large during far earthquake.

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measurements, especially for the seismic observations.

6. REFERENCES

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