Soils and Foundations 2016;56(3):559–573

HOSTED BY

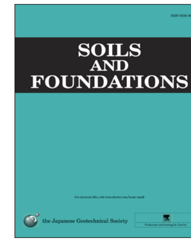
ELSEVIER

CrossMark

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf



Technical Report

Static and seismic performance of a friction piled raft combined with grid-form deep mixing walls in soft ground

Kiyoshi Yamashita*, Junji Hamada, Tomohiro Tanikawa

Takenaka Research and Development Institute, Takenaka Corporation, Chiba, Japan

Received 19 June 2015; received in revised form 2 October 2015; accepted 27 February 2016
Available online 12 May 2016

Abstract

This paper offers a case history of a friction piled raft foundation supporting a seven-story building on soft ground in Tokyo. Since the building is located on loose sandy soil, underlain by very soft clayey soil, grid-form cement deep mixing walls (DMWs) were employed as a countermeasure against soil liquefaction. To confirm the validity of the foundation design, field monitoring of the foundation settlement and the load sharing between the piles and the raft was performed over eleven years from the beginning of the construction.

At the time of the 2011 off the Pacific coast of Tohoku Earthquake, the seismic response of the soil–foundation–structure system was successfully recorded, namely, the peak horizontal acceleration of 1.21 m/s^2 was recorded on the first floor of the building. Before the earthquake, the measured settlements of the first floor were 15–29 mm; after the event, the maximum incremental settlement was 6 mm. The ratio of the load carried by the piles to the net load in the tributary area was estimated to be 0.72 before the event and increased to 0.81 at maximum about three years after the event. Based on the seismic observations, it is confirmed that the residual settlements of the piled raft were caused mainly by the penetration of the piles subjected to the moment load from the superstructure. On the other hand, it is suggested that the bending moment near the pile head was caused mainly by the horizontal ground displacement near the surface, rather than the inertial force of the superstructure. It was also found that the bending moment near the pile head was significantly small, as is expected in the design of piled raft systems. This may arise because the raft had a relatively small number of piles and was in contact with both the grid-form DMWs and the soil enclosed by them, where most of the horizontal load would be carried by the raft.

Consequently, it was found that the friction piled raft foundation combined with the grid-form DMWs showed a good performance in a ground consisting of liquefiable sand and soft cohesive soil under both seismic and ordinary conditions.

Keywords: Case history; Load sharing; Monitoring; Piled raft foundation; Settlement; Seismic loading; The 2011 off the Pacific coast of Tohoku Earthquake

1. Introduction

In recent years, piled raft foundations have been used in many countries as building foundations. The effectiveness of piled rafts in reducing average and differential settlements has been confirmed not only by favorable ground conditions, as reported by Katzenbach et al. (2000), Poulos (2001) and Mandolini et al. (2005), but also by unfavorable ground conditions, such as soft clay and/or liquefiable sand with ground improvement techniques, as reported by Yamashita et al. (2011a) and Yamashita et al. (2011b). It has become necessary to develop more reliable seismic design methods for piled raft foundations, particularly in highly seismic areas such as Japan.

In order to clarify the behavior of piled raft foundations under seismic loading, lateral loading tests on model piled rafts

*Corresponding author.
E-mail address: yamashita.kiyoshi@takenaka.co.jp (K. Yamashita).
Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2016.04.020
0038-0806/

were conducted. A large-scale lateral load test was performed by Rollins and Sparks (2002) on a group of 9 piles having a cap that was buried in fill. Horikoshi et al. (2003a, 2003b) carried out static horizontal load tests as well as dynamic loading tests on model piled rafts using a geotechnical centrifuge. Katzenbach and Turek (2005) also conducted static horizontal load tests using a geotechnical centrifuge. Matsumoto et al. (2004a, 2004b) carried out a series of 1-g static lateral load tests and shaking table tests on a small piled raft model, and the former test results were simulated using software developed by Kitiyodom and Matsumoto (2002, 2003). Furthermore, Matsumoto et al. (2010) carried out static cyclic lateral loading tests on a piled raft model with four piles to investigate the effect of the pile head connection condition. Hamada et al. (2015a) conducted static lateral load tests on a relatively large-scale model with 16 piles. Sawada and Takemura (2014) carried out static horizontal loading tests subjected to relatively large moment load and rotation using a geotechnical centrifuge. However, case histories on the monitoring of the seismic soil-pile-structure interaction of actual piled rafts are very limited (Mendoza et al., 2000; Yamashita et al., 2012, 2014; Hamada et al., 2015b).

This paper offers a case history of a friction piled raft combined with grid-form cement deep mixing walls (DMWs) supporting a seven-story building on soft ground in Tokyo. To confirm the validity of the foundation design, field monitoring of the foundation settlement and the load sharing between the piles and the raft was performed both statically and dynamically. At the time of the 2011 off the Pacific coast of Tohoku Earthquake, the seismic response of the soil–foundation–structure system was successfully recorded. The observed seismic performance of the friction piled raft during the earthquake, as well as the long-term static behavior, is discussed.

In addition, a part of the results of the field monitoring presented in this paper has been previously published (Yamashita et al., 2015).

2. Building, soil conditions and foundation design

The seven-story office building is located in Shinsuna, Tokyo (Photo 1). The building is a steel-frame structure that was completed in 2004. Fig. 1 shows a schematic view of the structure and the foundation with a soil profile. The project site is flatland, and the soil profile down to a depth of 6 m consists of fill and very soft silt. The ground water table appears approximately 1.5 m below the ground surface and there is liquefiable silty sand between the depths of 6 and 11 m. From the depths of 11–42 m, there are very soft to medium alluvial silt layers where the silt between the depths of 11 and 18 m is nearly normally consolidated with an overconsolidation ratio of about 1.1. Below the depth of 48 m, there are very dense sand strata. The shear wave velocities derived from a downhole technique were 140–240 m/s between the depths of 11 and 42 m, and those in the sand strata below the depth of 48 m were 310–350 m/s.

Photo 1. View of 7-story office building in Shinsuna.

An assessment of the potential for soil liquefaction during earthquakes was carried out using the simplified method (Tokimatsu and Yoshimi, 1983). It indicated that the loose silty sand between the depths of 6 and 11 m had the potential for liquefaction with a peak horizontal ground acceleration of 0.2 g. Hence, as a countermeasure against soil liquefaction below the raft to a depth of 12 m, grid-form DMWs were employed. The DMWs were constructed by the Cement Deep Mixing machine equipped with two mixing shafts. The spacing of the mixing shafts was 0.8 m for the mixing blades with a diameter of 1.0 m. The center-to-center spacing of the element walls was relatively large, namely, 14.4–16.5 m, and the area replacement ratio (ratio of the area of the walls to the total plan area) was 0.10. The design standard strength of the stabilized soil was 1.8 MPa.

The total load in the structural design was 378 MN which corresponds to the sum of the dead load and the live load of the building. The average contact pressure over the raft was 100 kPa. The foundation level was at a depth of 2.2 m in the central part and at a depth of 1.6 m at the north and south ends. To reduce the average and differential settlements due to the consolidation of the very soft silt layers to an acceptable level, seventy friction piles were employed as settlement reducers. The piles are PHC (pretensioned spun high-strength concrete) piles, 30 m in length and 0.6–0.9 in diameter. Fig. 2 shows the layout of the piles and the grid-form DMWs. Further details of the foundation design under working load conditions are given in a previous paper (Yamashita et al., 2011b). Under seismic loading conditions, the bending moment and shear force of the piles in the piled raft system were computed using the simplified method proposed by Hamada et al. (2015a). The analytical results showed that the horizontal load carried by the piles was less than 10% of the total horizontal load in the design.

3. Instrumentation

Field measurements of the foundation settlement and the load sharing between the piles and the raft were performed both statically and dynamically over eleven years from the beginning of the construction. The locations of the monitoring devices are