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Evaluation of Seismic Behaviour of the Insulated Pile Foundation Based on Site Model Experiment

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ABSTRACT: The authors have been exploring the feasibility of a special type of foundation, named insulated pile foundation, which consists of a raft foundation and a set of piles installed in the ground that are not connected to the raft. In this paper, seismic observation of scaled models constructed on an actual ground is described together with its simulation analysis. Scaled models include a spread foundation, a pile foundation, and a proposed insulated pile foundation. From this study, it was found that the proposed foundation can reduce the response of the foundation during earthquakes and that it also reduces the stress of piles near the pile head by a great deal.

1 INTRODUCTION

Many cast in place concrete piles of large diameter are used in late years because of their low cost, low noise and low vibration. When the building is rebuilt, pile re-use is becoming common if layout of building can be adjusted. However, once it is decided to demolish existing piles, it needs a lot of energy and money because of their large diameter. Therefore, it is thought that the demolishing of the existing cast in place concrete piles will become the problem in the near future. While on the other hand, if the existing piles could be reused as the foundations of new buildings without demolishing, it would be possible not only to reduce the cost of new pile construction and shorten work periods, but also to reduce the effects on the environment by the efficient use of resources.

In common pile foundations, the stress due to seismic inertia force of the superstructure is concentrated on the pile head because of the rigidly connection between pile head and pile cap. A lot of pile head damage by the 2011 Tohoku earthquake were reported (Architectural Institute of Japan, 2015).

The authors have been exploring the feasibility of a special type of foundation, named insulated pile foundation, which consists of a raft foundation and a set of piles installed in the ground that are not connected to the raft. It was found that the response acceleration of the superstructure with the insulated pile foundation was reduced in centrifugal model test (Jang et al., 2010).

The objective of this study is to evaluate the seismic response characteristics of structure with insulated pile foundation. Seismic observation of scaled models constructed on an actual ground is described together with its simulation analysis.

2 SEISMIC OBSERVATION OF SCALED MODEL

Photo 1 shows the scaled models constructed on an actual ground. The site is located on the diluvial terrace whose surface soil is comparatively hard.

Figure 1 shows the skeleton brief of the seismic observation system. The models consist of pile foundation, spread foundation, and the insulated pile foundation. They were constructed at Nishi-Chiba campus of Chiba University. The superstructure are blocks of reinforced concrete. The piles of pile foundation and insulated pile foundation are steel pipes with a diameter of 101.6 mm.

In insulated pile foundation, there is thin layer consisting of silica sand with a thickness of 50 mm, which is half of the pile diameter, between the bottom of the concrete block and top of the insulated piles. Geotextile (geogrid) is laid on the top of the piles for prevention of subsidence. Under the spread foundation, there is same thin layer.

Accelerometers of Three-component were set at the tops of the structures, on the free field, and underground (G. L. -10m). Strain gauges were set at the pile heads to measure the stresses.

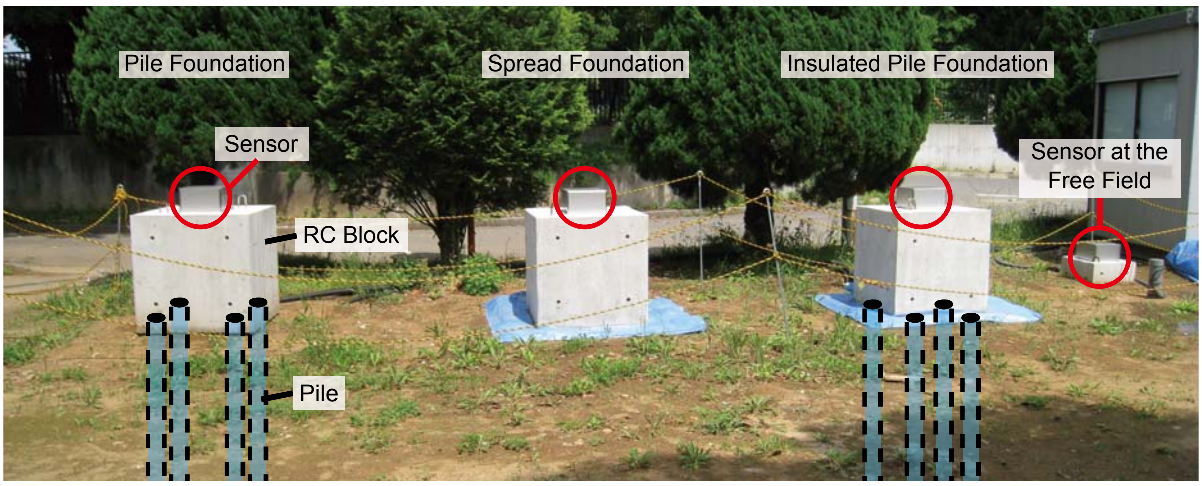

Photo 1. Scaled models constructed on an actual ground

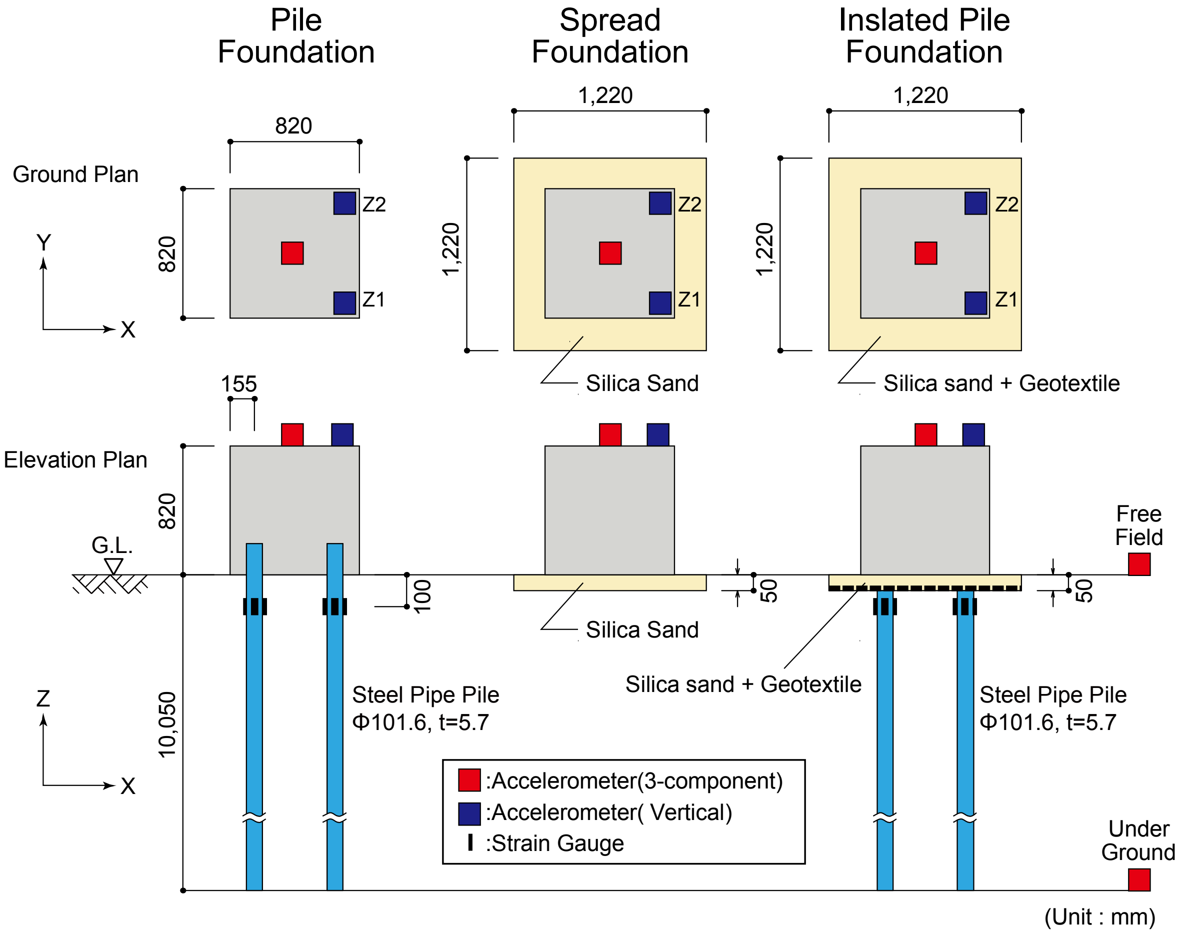

Figure 1. Skeleton brief of the seismic observation system

3 RESULTS OF SEISMIC OBSERVATION

Seismic observation was conducted to examine seismic behaviour of the structures with each foundations during the earthquakes between June 18, 2013 and February 28, 2015. Seismic response accelerations of 56 earthquakes are observed. Table 1 summaries the earthquakes with the peak ground accelerations at free field of more than 10 cm/s^2.

Figure 2 shows the relation of the peak response accelerations on the top of each structure between pile foundation, spread foundation and insulated pile foundation for the 56 earthquakes. The peak response accelerations of insulated pile foundation are roughly lower than those of the other foundations.

Table 1. List of earthquakes with PGA more than 10 cm/s^2 at free field

Year	Mon.	Day	Time	Epicentral Region Name	M_J	Focal Depth (km)	Epicentral Distance (km)	PGA at Free Field (cm/ s^2)	
								X	Y
2013	11	10	7:46	south part of Ibaraki Pref.	5.5	70	42	22.8	16.1
	12	3	15:58	Chiba Pref. eastward offshore	4.5	12	84	11.7	9.5
2014	5	5	5:18	near Izu Oshima island	6.0	162	93	30.6	33.3
	5	13	8:35	northwest part of Chiba Pref.	4.9	72	9	47.5	31.8
	6	20	1:43	northwest part of Chiba Pref.	4.4	72	17	11.1	8.7
	7	3	7:29	northwest part of Chiba Pref.	4.1	64	19	22.7	20.6
	9	16	12:28	south part of Ibaraki Pref.	5.6	47	56	25.9	21.7
2015	1	26	7:20	northwest part of Chiba Pref.	5.0	37	44	18.3	37.3

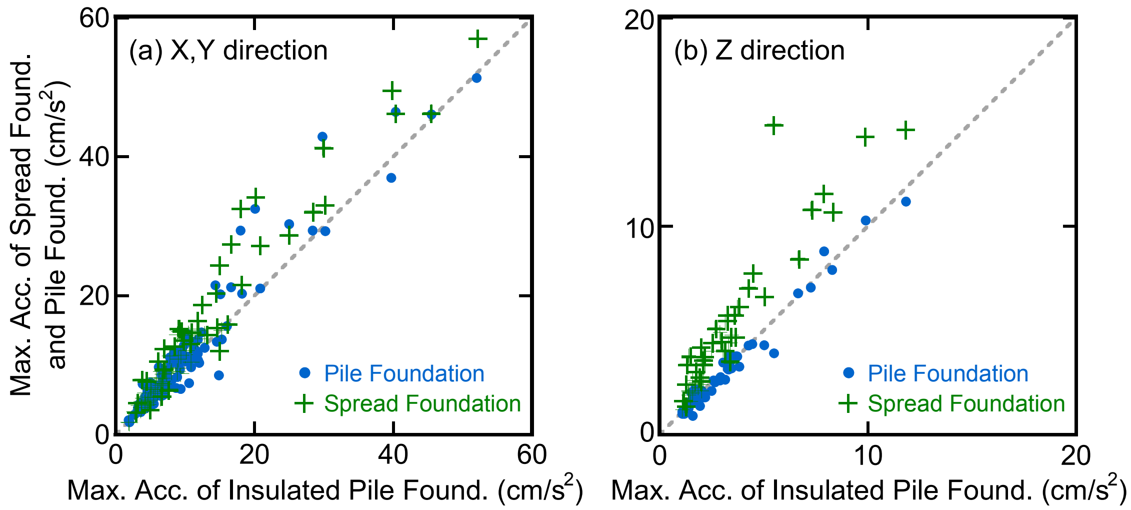

Figure 2. Relation of peak response accelerations of three components between pile foundation, spread foundation and insulated pile foundation

Figure 3 shows Fourier spectral ratios of three components on the tops of each structures against free field for the earthquake of May 13, 2014 with maximum peak ground acceleration. The peak amplitudes of horizontal components (X, Y) of pile foundation and spread foundation are roughly same. On the other hand, the amplitudes of insulated pile foundation are lower than those for pile foundation and spread foundation. The peak frequency of pile foundation and spread foundation are roughly same. The peak frequencies of insulated pile foundation appears at higher frequency. About vertical component (Z), there is amplification against free field at spread foundation, but there is no amplification at pile foundation and insulated pile foundation. It seems that insulated pile foundation has an effect of suppressing the seismic response of superstructure than the other foundations.

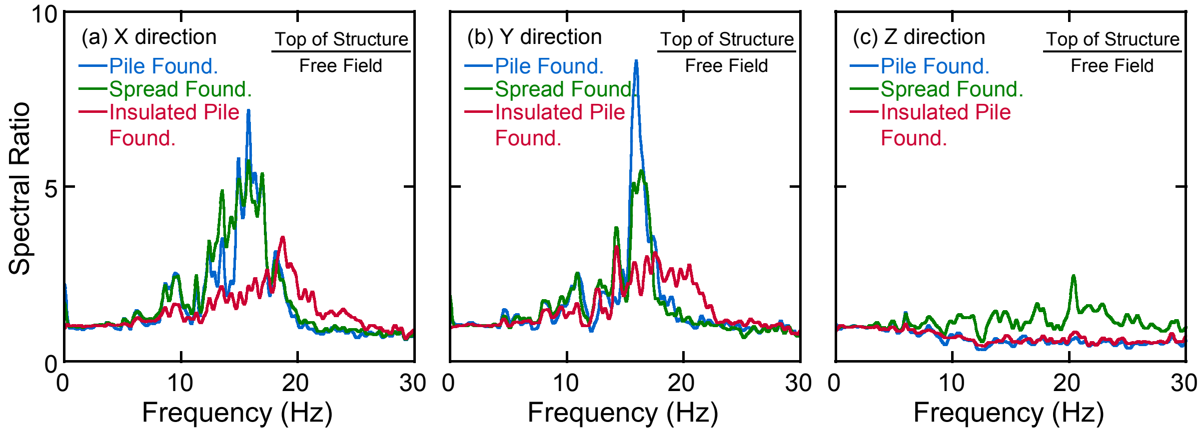

Figure 3. Fourier spectral ratios on the tops of each structures against free field

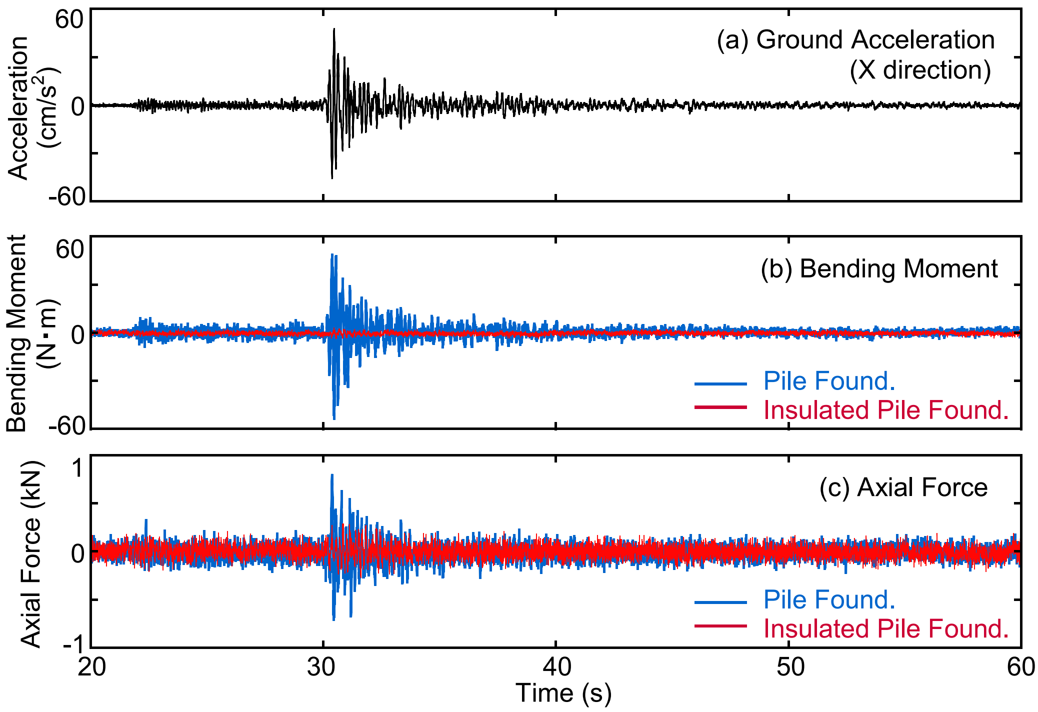

Figure 4. Time histories of acceleration, bending moment and axial force of pile head

Figure 4 shows time histories of bending moments and axial forces of the pile heads during the same earthquake as Fig. 3 based on the strain gauges, as well as that of acceleration at free field. The bending moment and axial forces of pile foundation fluctuate in response to seismic ground motion. On the other hand, those of insulated pile foundation do not fluctuate. It seems that the stress due to inertia force of the superstructure is not concentrated on the pile head of insulated pile foundation than that of pile foundation.

4 SIMULATION ANALYSIS

Dynamic response analysis was conducted to simulate the observed seismic behaviour of the insulated pile foundation and the other foundations based on the three dimensional finite element method and dynamic substructure method. A computer code ASC SASSI was used and the analysis was made in the frequency domain.

Figure 5 shows the finite element mesh layout used in the analysis. Three dimensional quarter part model was used based on the symmetry. Surrounding soil was modelled by thin layer method. Piles were modelled as solid elements with beam elements so as to fit both the bending stiffness and the axial stiffness.

Table 2 shows the dynamic properties of the surrounding soils determined based on PS logging for deep layer and multichannel analysis of surface waves for shallow layer. About the soil around pile head backfilled after the pile-driving, the S wave velocity and P wave velocity were supposed to be lowered to 100 m/s and 255 m/s respectively because of the disturbance.

The thin layer between the concrete block and the pile head consisting of silica sand is subject to different confining pressure by the weight of the superstructure. Especially, the confining pressure on the top of pile is the highest. Therefore, the S wave velocities of the thin layer were set depending on the confining pressure.

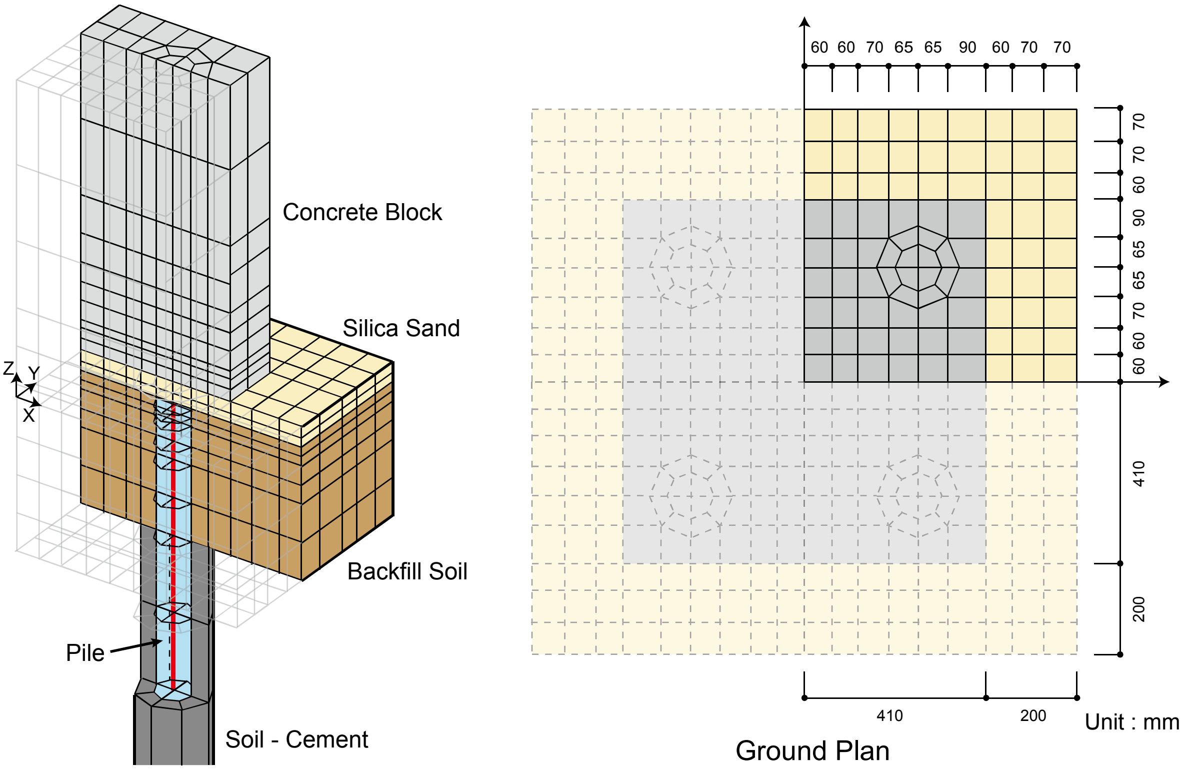

Figure 5. Analysis model (finite element mesh layout)

Table 2. Dynamic properties of surrounding soils

Depth (m)	Density (kg/ m^3)	V_S (m/s)	V_P (m/s)	damping	number of layers	Thickness of layers (m)
0.2	1,350	110	205	0.02	6	0.025×4, 0.5×2
2.0	1,350	110	280	0.02	8	0.1×4, 0.2×2, 0.5×2
3.0	1,350	150	380	0.02	2	0.5
5.0	1,350	200	470	0.02	2	1.0
7.5	1,800	260	470	0.02	2	1.25
10.0	1,800	330	620	0.02	2	1.25

Figure 6 shows the computed horizontal transfer functions on the top of each structures against free field in red line together with the observed Fourier spectral ratios for the 8 earthquakes in Table 1 in gray line. The computed transfer functions are in good agreement with the observed spectral ratios for each foundations. Insulated pile foundation also shows an effect of suppressing the seismic response of superstructure than the other foundations in the analysis.

Figure 7 shows the distributions of the computed maximum shear force and bending moment of pile together with the maximum bending moment observed by strain gauge at pile head for the earthquake of May 13, 2014. The computed bending moments at each pile heads are in good agreement with the observed ones. The bending moment at pile head of the insulated pile foundation is much less than that of pile foundation. It seems that the stress at pile head is greatly reduced in comparison with pile foundation because of the insulation of pile against the pile cap.

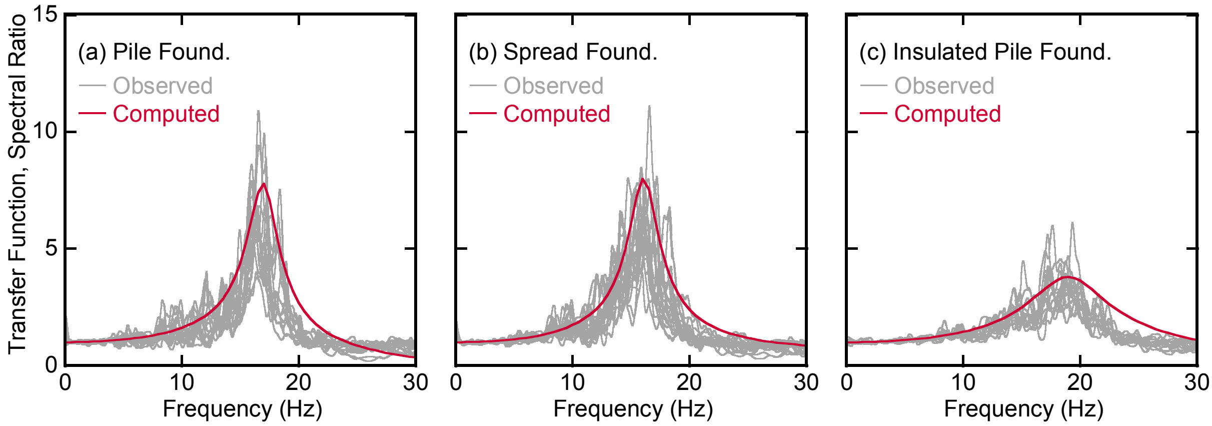

Figure 6. Horizontal transfer functions on the top of each structures against free field

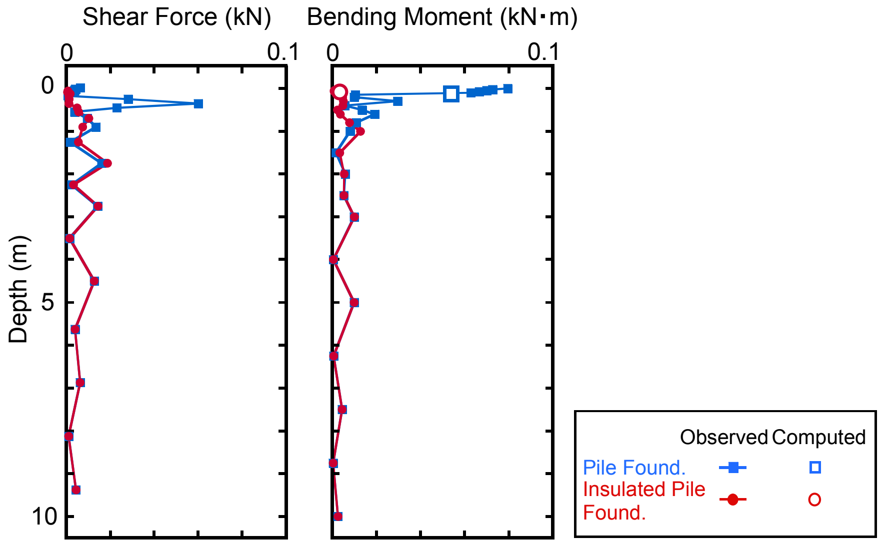

Figure 7. Distributions of the computed maximum shear force and bending moment of pile

5 CONCLUSIONS

In order to examine the seismic response characteristics of structure with insulated pile foundation, seismic observation of scaled models was constructed on an actual ground as well as simulation analysis. The following conclusions can be made through this study:

1. The peak response accelerations of insulated pile foundation are lower than those of the other foundations.

2. Insulated pile foundation has an effect of suppressing the seismic response of superstructure than the other foundations.
3. The stress at pile head is greatly reduced in comparison with pile foundation because of the insulation of pile against the pile cap.

There are limitations for the insulated pile foundation. High aspect ratio buildings with no basement room are not proper for the foundation in a similar way to spread foundation. The observed earthquakes in this study are small, and large displacement at the superstructure of insulated pile foundation might occur during big earthquake, especially in the case of liquefiable surface soil. We are going to investigate the short piles connected to the raft to control the horizontal displacement of superstructure.

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