Static and cyclic loading of a single pile supported by a thin bearing layer with dry sand

Kyoto University, Student Member ○Mutungi Winfred Nthuka
Kyoto University, Regular Member Ryunosuke Kido
Kyoto University, Regular Member Yasuo Sawamura
Bond Engineering Inc Fellow member Makoto Kimura

1. INTRODUCTION

Pile foundations are used for many civil engineering structures such as bridges, highways, offshore wind turbine and so on, to support the load applied from the superstructure. In ordinary state, the static load is applied to the pile foundation, while the cyclic loading may be applied to the pile foundation due to traffic, wind, etc. Although the pile foundation is supported by a bearing layer with sufficiently stiff and thick conditions, the displacement of the pile may be cumulated when the cyclic loading is applied. It is probable, therefore, that such a cumulative displacement under the cyclic loading is larger when the pile foundation is supported by a thin bearing layer. In the previous research, the bearing capacity of the pile supported by a thin bearing layer is reduced compared to the pile supported by a thick bearing layer by centrifuge model tests (Horii & Nagao, 2018) and model tests with X-ray CT test (Kido et al., 2022). However, these studies worked under only static loading condition, and the cyclic loading behavior has not been observed for the pile supported by a thin bearing layer.

The present study has conducted a static loading test and a cyclic loading test for a single pile supported by a thin bearing layer using a centrifuge device. The tendency of the change in the displacement of the pile is observed under the cyclic loading by load-control system.

2. METHODOLOGY

2.1. Loading device for cyclic loading

The loading device is shown in Figure 1. This device is composed of a mega-torque motor with a drive unit (NSK), a ball screw jack (THK, 5 kN in rated capacity, 10 kN in capacity at slow loading rate), a function generator DF1906 (NSK), a digital indicator TD-98A (Tokyo Measuring Instruments Laboratory). Cyclic loading can be controlled by any loading levels of upper and lower limits as we want up to 5 kN. Figure 2 shows an example of this cyclic loading system. The static loading is kept until the value of load measured in a test reaches to the upper limit value, and then the unloading is kept until the value of load measured reaches to the lower limit value. This cycle is repeated until the loading is manually stopped. Therefore, the amplitude of the cyclic loading is defined as the difference between the upper and lower limit values of load set by users, and the number of cyclic loading is not controlled. The frequency of the cyclic loading is kept constant in a case that there is no change in the displacement of a pile. It is expected, therefore, that the frequency of the cyclic loading is decreased due to an increase of the cumulative displacement of pile due to, for example, the thin bearing layer thickness. Static loading can be done when the upper limit value of load is set larger than the load value expected during loading tests.

2.2. Experimental conditions

In the present study, centrifugal experiments under 50*g* were conducted using the geotechnical centrifuge located at the Disaster Prevention Research Institute (DPRI) at Kyoto University. Soil chamber size is 240 mm by 240 mm by 332 mm (internal height). The model pile was made of stainless steel with a diameter *D* of 20 mm and a height of 210 mm. Model ground was composed of a bearing layer made of Toyoura sand with a relative density of 90% whereas the underlying layer was Toyoura sand of D_r = 20%. The friction layer was made of the same Toyoura sand with a D_r = 30%. The ground condition is dry for all layers, as shown in Figure 3. The properties of Toyoura sand are as shown in Table 1. The load of pile head, pile tip pressure, and displacement of pile head were measured. The loading rate was 0.1 mm/minute.

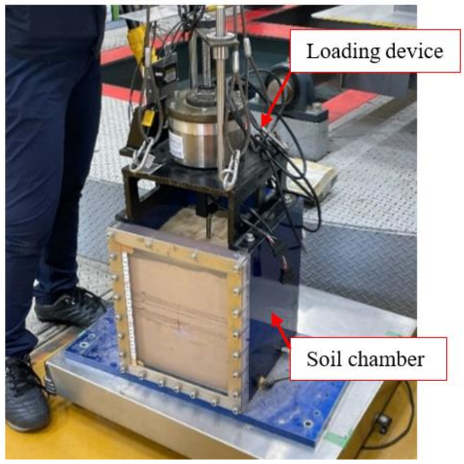

Figure 1: Loading device for static and cyclic loading

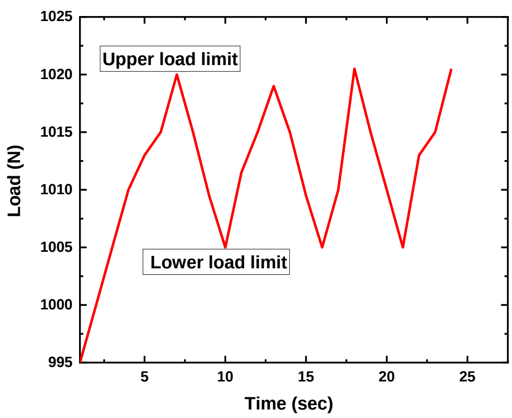

Figure 2:Cyclic load between maximum and minimum load values

Keywords: Pile; bearing layer; static loading; cyclic loading.
Contact address: C1-4-587 Kyoto University, Katsura Campus, Nishikyo-ku, Kyoto, 615-8540, TEL:075-383-3193

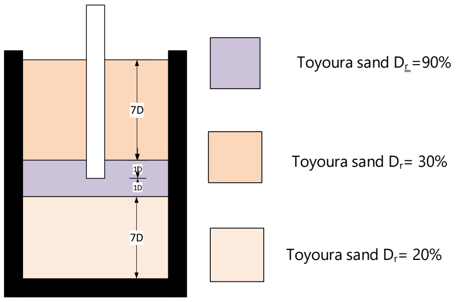

Figure 3:Ground condition with a single pile embedment

Table 1: Properties of Toyoura sand

Parameter	Value
Specific gravity G_s	2.640
Mean particle diameter (mm)	0.200
Min. void ratio e_{min}	0.585
Max. void ratio e_{max}	0.975
Cohesion c (kPa)	0
Friction angle (deg)	33.4

3. RESULTS

3.1. Load-displacement curves

All results shown in this paper are proto-type scale. Figure 4 shows the load displacement curve for both static and cyclic loading. It can be observed that the ultimate bearing capacity is around 1000 N at a normalized displacement of 0.1D. The cyclic loading was done between 1010 N and 995 N, although the upper limit load was set as 1000 N and the lower limit load was 500 N (a half of the ultimate bearing capacity), due to unexpected errors.

Figure 5 shows load displacement curve at only cyclic loading (i.e., post static loading stage). From this figure, the displacement accumulates faster in earlier stages of cyclic than in latter stages. One of possible reasons is that stiffness of the soil at the pile tip gradually increases compared to the state immediately after static loading, as cyclic loading continues. Another reason may be an increase of skin friction subjected to cyclic loading, leading a restriction of pile displacement. Figure 6 shows an expected scenario of pile displacement during cyclic loading. The downward and upward displacement is repeated due to the cycle of loading and unloading, while the former effect may be larger than the former, leading to cumulation of the downward displacement of the pile.

3.2. Pile tip pressure

The earth pressure gauge was located at the pile tip and its results are shown in Figure 7. It is found from this figure that the pressure for the cyclic loading tends to be monotonically reduced, even if the pile head load is kept almost constant, as shown in Figure 4. This probably indicates that skin frictional resistance is increased by the reduction of the end bearing capacity. Therefore, the restriction of the downward displacement, as mentioned above, may be due to the increase in skin friction during cyclic loading. This mechanism will be investigated in the future.

4. CONCLUSIONS

The ultimate bearing capacity has been shown to occur at a normalized displacement of 0.1D. The failure mechanism of both the pile head and tip occurs earlier for cyclic loading as compared to static loading case. However, more experiments need to be carried out with different bearing layer thicknesses.

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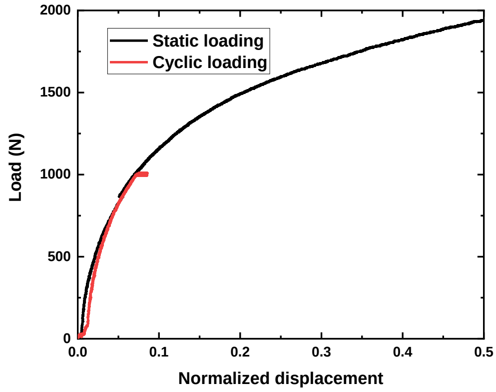

Figure 4: Load-displacement curve under static and cyclic loading

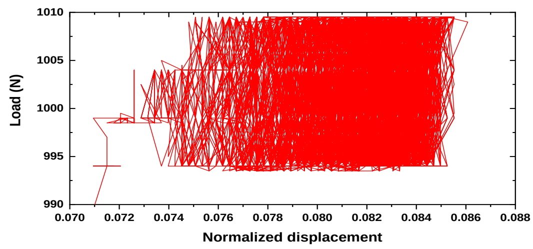

Figure 5: Cyclic loading after static loading

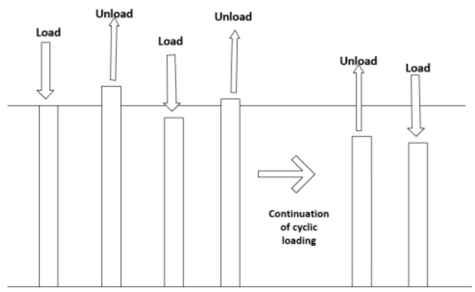

Figure 6: Illustration of pile displacement in cyclic loading

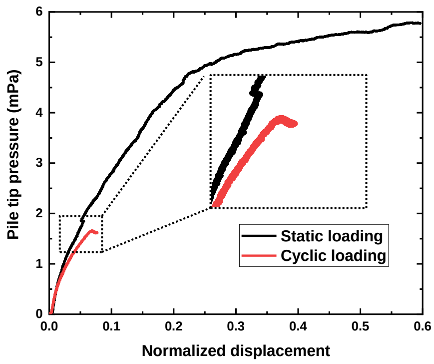

Figure 7: Pressure at pile tip

