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A study on generalized scaling relations on the laterally loaded large diameter single piles in sand

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INTRODUCTION

Size effects are one of critical features of civil engineering structures and its modeling. In particular many of geotechnical structures show complicated size effects due to stress dependency of mechanical properties especially sandy soils (Iwasaki et al, 1979, Tatsuoka et al., 1989). Therefore centrifuge models can play vital roles in the physical modeling of geotechnical structures. However the trend of increasing in size of structure poses us the difficulty in modeling the actual scale as the prototype in a centrifuge using the similitude of centrifuge model, especially in small centrifuge machine. Generalized scaling relations (JSR) proposed by Iai et al. (2005) are combined relations of centrifuge model and virtual 1G model, which could model a large scale prototype in small scale centrifuge. However, there are some concerns about the applicability of the assumptions used in scaling laws of 1G model, especially of stress dependency of the soil stiffness. Study of modeling of models on the dynamic behavior of pile foundations have been conducted and verified the applicability to some extent (e.g., Tobita & Iai, 2015). However, due to the complication of dynamic event the verification of GSR is still limited in qualitative comparison.

In this study, a series of simple lateral loading tests was conducted on three single steel tubular piles with same diameter (Φ) but different flexural rigidity (EI). According to the EIs, the centrifuge accelerations were determined to have the prototype diameters of 2m and 4m. From the modeling of model study, applicability of GSR is discussed.

CENTRIFUGE MODEL AND PROCEDURES

Model setup used in this study is shown in **Fig.1**. Three 40mm outer dimeter (Φ) stainless steel (SUS304) tubular pile models with thickness t=0.3, 0.5, 0.6mm are installed in dry Toyoura sand (Dr=80%). The lateral load (P_L) was applied to the pile head at the height of 50mm from the ground surface by displacement control in one way cyclic manner. After unloading from pile top the displacement (δ_t) of 15%Φ, the displacement was imposed until the ultimate load, that is, peak load, was observed. In GSR, the scaling factor (prototype/model) of length is given by μη (μ: virtual 1G scale ratio, η: centrifugal acceleration ratio).

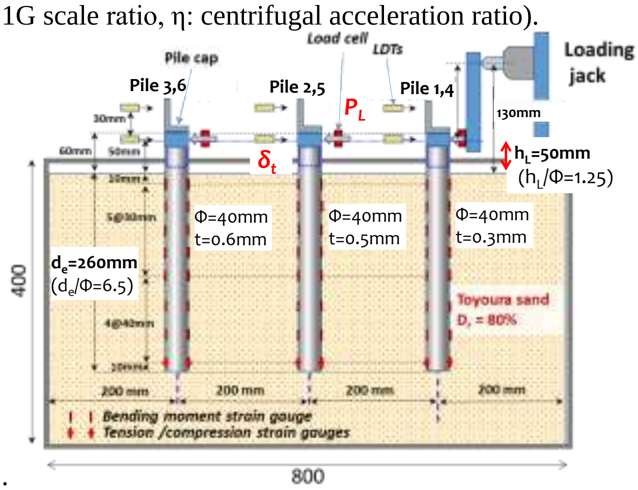

Fig.1 Lateral loading test set up and test instrumentations.

Pile	Pile 1	Pile 2	Pile 3	Pile 4	Pile 5	Pile 6
Pile diameter: Φ (mm)	40 [2m]			40 [4m]		
Pile thickness (mm)	0.3	0.5	0.6	0.3	0.5	0.6
η (centrifugal acceleration ratio)	13.1	35.3	50	26.2	70.6	100
μ (virtual 1G scale)	3.8	1.4	1	3.8	1.4	1
ημ (scaling ratio)	50			100		
Flexural rigidity: EI (kN·m²) [GN·m²]	1.72 [17.4]	2.34 [17.4]	2.78 [17.4]	1.72 [278]	2.34 [278]	2.78 [278]
Yielding moment: M_y (N·m) [MN·m]	94 [44.8]	154 [27.3]	184 [23.0]	94 [359]	154 [219]	184 [184]

Table 1 Conditions of piles [prototype scale].

Assuming the soil stiffness between prototype/model is $\mu^{0.5}$, the GSR of EI becomes $\mu^{4.5}\eta^4$ (Iai et al., 2005). Two prototype diameters, 2m and 4m, were studied by the modeling of models. Given the model EIs, three vertical 1G model scales (μ) were determined, 1, 1.42, 3.81. μ=1 is the normal centrifuge models of which η values are 50 (G) and 100 (G) for Φ=2m & 4m models respectively. The conditions of piles tested are summarized in **Table 1**. It should be noted that the pile yielding bending moment (M_y) is greater for the model pile with the larger μ value, not scaled in a prototype.

RESULTS AND DISCUSSIONS

Lateral load (P_L) and pile top displacement (δ_t) curves are drawn in model and prototype scales in **Fig.2**.

The big differences of the curves measured in the piles with different centrifugal acceleration (η) and μ values

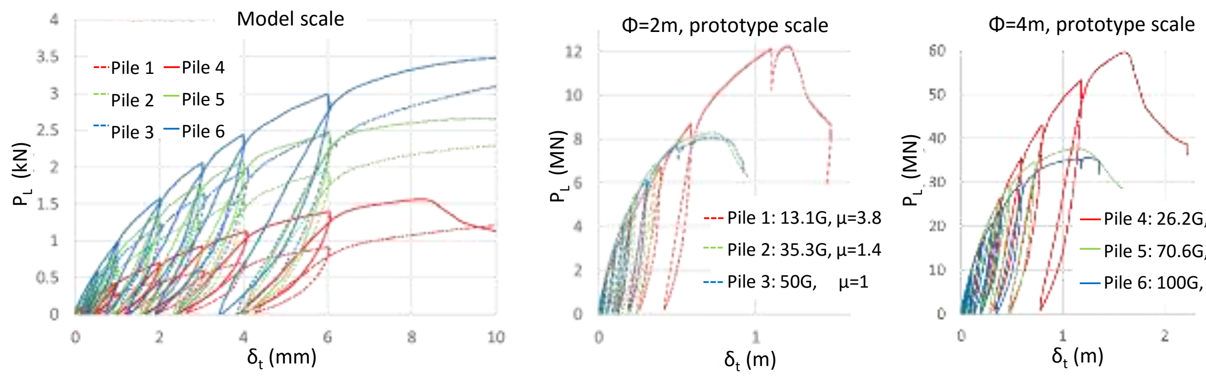

Fig.2 Lateral load and pile top displacement curves, model and prot

become a unique curve in the backbone at small displacement range for both 2m and 4m diameter piles. However at the large displacement range the prototype resistances are larger for the piles with the larger μ values. The backbone curves obtained from the cyclic load-displacement relation for Φ=4m piles are compared up to δ_t/Φ=15% in **Fig.3**. The discrepancy of the curves can been recognized from δ_t/Φ=3%.

Bending moment profiles at different displacement are depicted for Φ=4m piles in **Fig.4**. In the figure, the yielding moments (M_y) are also indicated. At the very beginning the profiles are almost the same, but from δ_t/Φ=2.5% the moment becomes smaller for Pile 4 (μ=3.8) than the other piles before the moment far below the M_y of Pile 6. This infers that the assumption of stiffness proportional to square root of stress could not be valid at this level of pile displacement. However, it should be noted that the difference could not be confirmed for the model with small μ values (1.4).

The ultimate failure of the piles were dominated by the pile structure failure as shown in **Fig.5**. This is the main reason for the larger ultimate resistance of the pile of larger μ value with the larger M_y (see Table 1). However, not only M_y, but also the over estimation of stiffness of larger μ model could affect the pile failure, which can be confirmed from **Fig.5** on the location of depth local failure. Due to the relatively smaller confinement effect for the large μ models as compared to that assumed in the GSR, the failure depth tends to be deeper than the smaller μ models.

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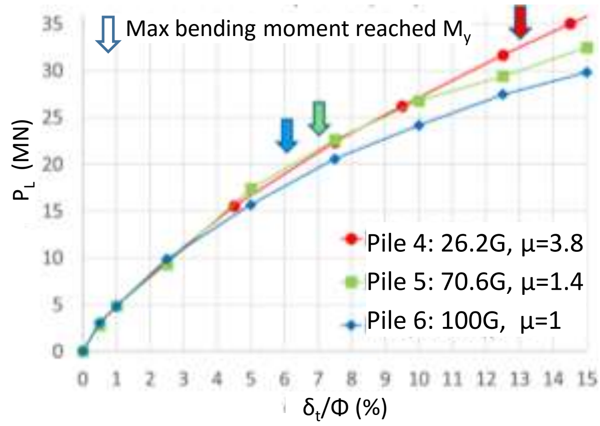

Fig.3 Back bone curves of PL- δ_t/Φrelationship:Φ=4m piles.

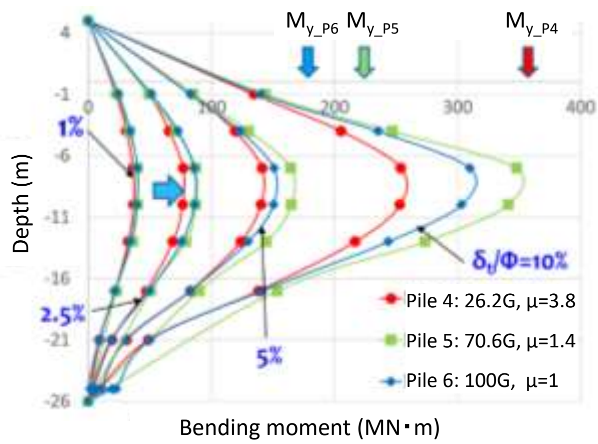

Fig.4 Bending moment profiles: Φ=4m piles.

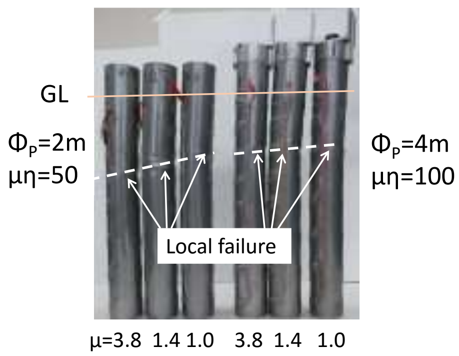

Fig.5 Failure of piles