Numerical study on vertically-loaded piled Tender Net Foundation (Part 2: Results of analyses)

TNF method, Piled raft foundation, FEM

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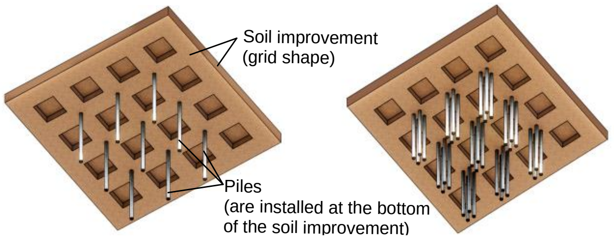
1. INTRODUCTION

In part 2 of the series papers, the performance of the TNF system supported by piles (Piled TNF system) (Fig. 1) is investigated numerically for the reduction of differential displacement as well as average displacement.



(a) $n = 9$ (b) $n = 9 \times 4$

Fig. 1. Bottom view of examples of Piled TNF system.

2. NUMERICAL ANALYSES OF PILED TNF

2.1. Analysis conditions

Table 1 shows the mechanical and geometrical properties of the piles used in the analyses. The parameters of the ground and each part of the foundation system are listed in Tables 1, 2, 3, and 4 in Part 1 (Vo-Cong et al., 2023).

"Embedded beam" prepared in PLAXIS 3D was employed for modeling piles. Maximum shaft resistance was set to be 20 kPa which is equal to the undrained shear strength c_u of the soft ground.

Table 1. Mechanical and geometrical properties of the piles.

Parameter	Value
Young's modulus, E (kPa)	40,000,000
Poisson's ratio, ν	0.2
Unit weight, γ (kN/m^3)	24
Outer diameter, D (m)	0.40 ~ 1.00
Inner diameter, d (m)	0.27 ~ 0.74
Length, L (m)	20 ~ 40

In the numerical analyses, diameter D, length L, number of piles n, and arrangements were varied as shown in Fig. 2. The piles were set beneath the primary soil improvement layer below the locations of concrete footings. Vertical loads of the 5-story building described in Part 1 were applied in all the cases.

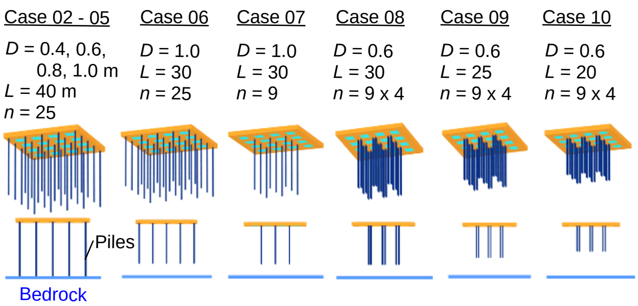


Fig. 2. Analysis cases.

2.2. Analysis results

Fig. 4 shows the calculated deformation of a Piled TNF system (Case 09: $D = 0.6$ m, $L = 25$ m, $n = 9 \times 4$). It is seen that dish-shaped deformation of the TNF occurred.

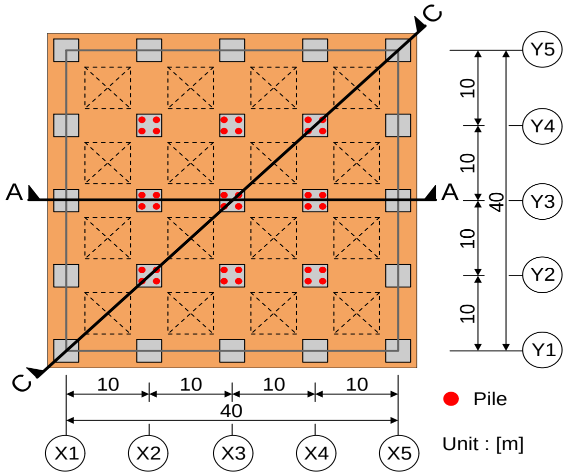


Fig. 3. Plan view of Piled TNF ($n = 9 \times 4$).

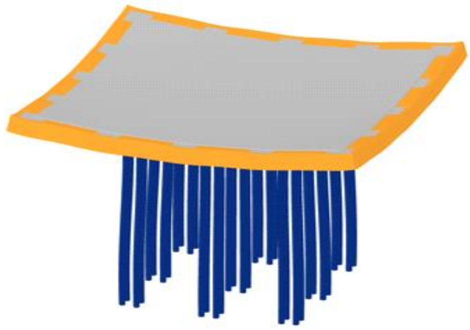


Fig. 4. Calculated deformation of Piled TNF (Case 09).

Fig. 5 and Fig. 6 show the calculated distributions of vertical displacements of the slab and the ground along Section A-A and Section C-C (see Fig. 3), respectively.

Case 01 is the TNF system without pile (Unpiled TNF). Cases 02 to 05 are four cases of the TNF system supported by piles that reach the bedrock (namely, end-bearing pile cases). Cases 06 to 10 are five cases of the TNF system supported by friction piles (friction pile cases). Case 06 is a fully piled TNF where 25 piles are arranged evenly beneath the whole area of TNF. Meanwhile, Cases 07, 08, 09, and 10 are the TNF system supported by small centered pile groups. In Case 07, one large-diameter pile ($D = 1.0$ m) is arranged below nine concrete footings. In Cases 08, 09 and 10, four slender piles ($D = 0.6$ m) are arranged below nine concrete footings.

It is seen from Figs. 5 and 6 that the displacements and the differential displacement in the end-bearing pile cases (Cases 02 to 05) are much lower than those in Case 01. Although the displacements in the friction pile cases are larger than those in the end-bearing pile cases, the differential displacement in the friction pile cases is comparable to, or a little bit larger than those in the end-bearing pile cases.

Fig. 7 shows the distributions of inclination angle along Section A-A. It is seen from Fig. 7 that the inclination angles in all cases except Case 02 in the end-bearing pile cases are less than the limit value. However, the axial stress of the center pile exceeds the allowable compressive stress of pile σ_{pa} in Case 02 ($D = 0.4$ m), and is nearly equal to σ_{pa} in Case 03 ($D = 0.6$ m) (see Fig. 8). Hence, Case 04 ($D = 0.8$ m) and Case 05 ($D = 1.0$ m) are acceptable in the case of the end-bearing pile.

It can be seen from Fig. 8 that the axial stresses of the center piles in all the friction pile cases are below σ_{pa}.

Let us return to Fig. 7. The inclination angles in Case 07 (n = 9) are less than those in Case 06 (n = 25). Note that D and L are the same in both cases. The Piled TNF with the small centered pile group is an efficient foundation system for reducing the differential displacement than the fully Piled TNF, as advocated by Horikoshi and Randolph (1996) for piled rafts.

However, the inclination angle of Case 07 still exceeds the limit value (see Fig. 7).

The inclination angles in Case 08 are much less than those in Case 07 and less than the limit value. Note that L = 30 m in both cases. As mentioned earlier, one large-diameter pile (D = 1.0 m) is arranged below nine concrete footings in Case 07, while four slender piles (D = 0.6 m) are arranged below nine concrete footings in Case 08.

To find an efficient pile length, analyses of Case 09 (L = 25 m) and Case 10 (L = 20 m) were conducted. It is seen from Fig. 7 that Case 09 is an efficient foundation for reducing the inclination angle.

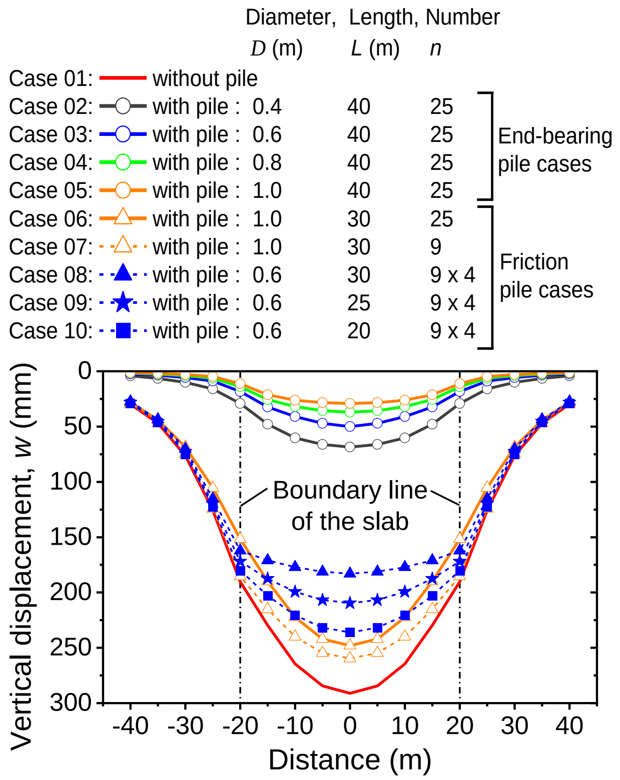


Fig. 5. Calculated distributions of vertical displacements of the slab and the ground along Section A-A.

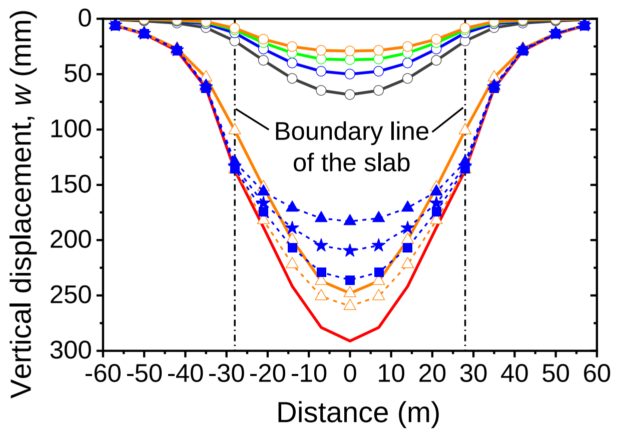


Fig. 6. Calculated distributions of vertical displacements of the slab and the ground along Section C-C.

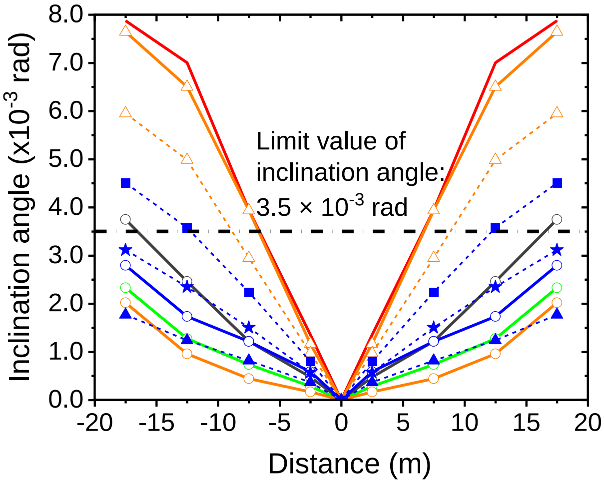


Fig. 7. Distributions of the inclination angle along Section A-A.

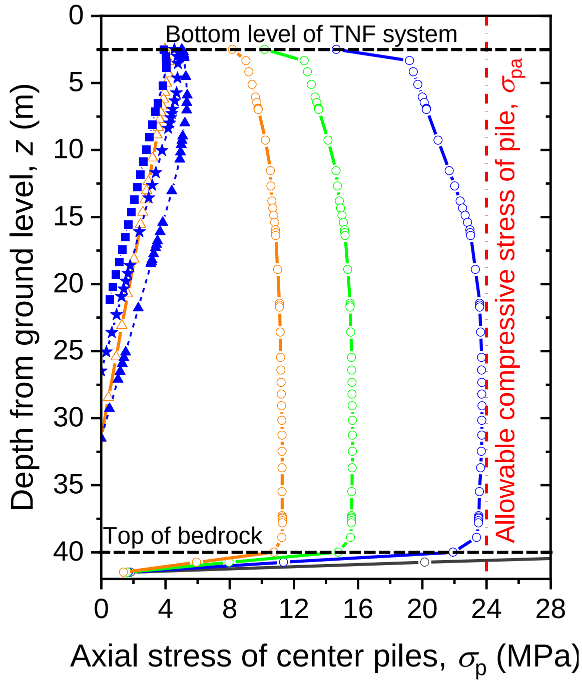


Fig. 8. Axial stress of the center piles.

3. CONCLUDING REMARKS

In this series of papers, numerical analyses of a TNF system supported by piles (Piled TNF) on the very soft ground were carried out aiming at reducing differential displacement as well as average displacement.

In part 1, FEM analysis of the Unpiled TNF was conducted to estimate the vertical load-displacement relation. It was demonstrated that the bearing capacity of the Unpiled TNF was enough for the vertical load of a 5-story building. However, excessive differential displacement occurred.

In part 2, FEM analyses of Piled TNF supported by various combinations of pile diameters, pile lengths, pile numbers, and arrangements were conducted. It was concluded that the Piled TNF with the small centered pile group is an efficient foundation system for reducing the differential displacement than the fully Piled TNF.

REFERENCES

Vo-Cong et al (2023): Numerical study on vertically-loaded piled Tender Net Foundation (Part 1: Outline of analyses). 58th Annual meeting of Japanese Geotechnical Society, Fukuoka, Japan (to be presented).

Horikoshi, K., and Randolph, M. F. (1996): Centrifuge modelling of piled raft foundations on clay. Géotechnique, 46(4), 741-752.