Numerical study on vertically-loaded piled Tender Net Foundation (Part 1: Outline of analyses)

TNF method, Piled raft foundation, FEM

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1. INTRODUCTION

Tender Net Foundation (TNF system), a kind of shallow foundation with soil improvement, has been developed for foundations of low-rise buildings on soft grounds. In the TNF system, as shown in Fig. 1 and Fig. 2, a grid-shaped soil improvement layer works as the raft foundation instead of the usual raft of reinforced concrete. In the TNF system, the soft ground is improved to depths of 2 to 3 meters usually.

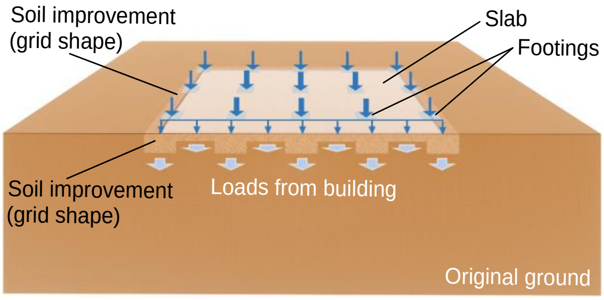


Fig. 1. Section view of a TNF system.

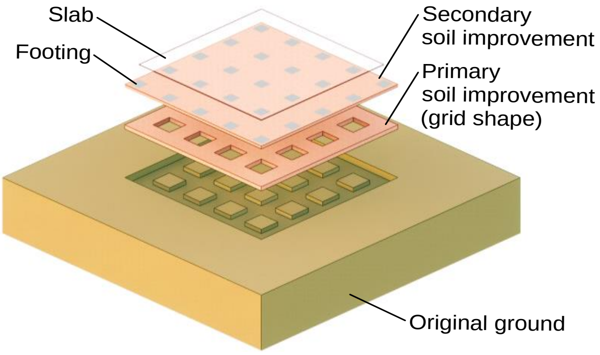


Fig. 2. Composition of TNF system.

Cong et al. (2022) analyzed the TNF system in the cases of the low-rise building constructed on soft ground with various stiffness. Through that, the TNF system was demonstrated as an efficient foundation to reduce the settlement and volume of soil improvement than normal raft foundations.

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

In part 1, FEM analysis of the TNF system alone (Unpiled TNF) is conducted to estimate the vertical load-displacement relation to confirm that the bearing capacity is secured for the vertical load of a 5-story (mid-rise) building.

In part 2, FEM analyses of Piled TNFs supported by various combinations of pile diameters, pile lengths, pile numbers, and arrangements are conducted.

2. FEM ANALYSIS OF VERTICAL LOAD-DISPLACEMENT RELATION OF UNPILED TNF

2.1. Analysis conditions

Fig. 3 shows the detailed configuration of a typical TNF system with a thickness of secondary soil improvement of 1.0 m, and a primary soil improvement of 1.5 m thick having the grid shape. The dimensions of other parts are also shown in Fig. 3.

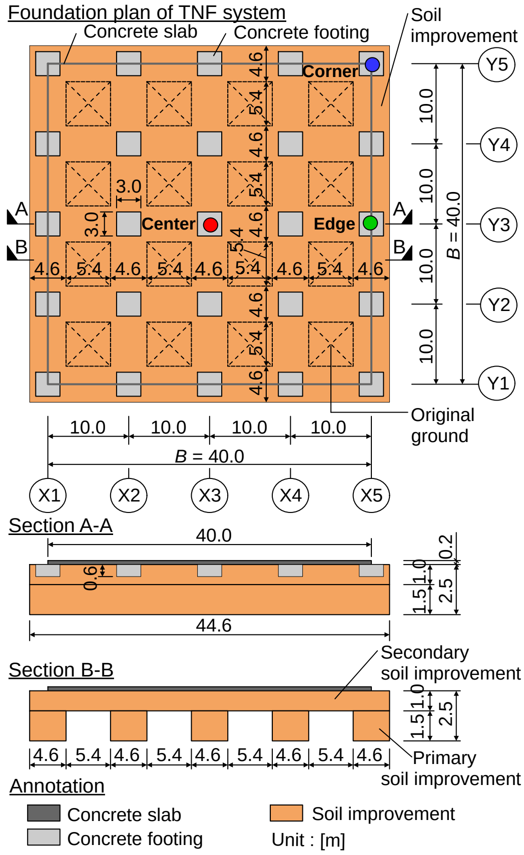


Fig. 3. Configuration of the TNF system.

The PLAXIS 3D FEM software was used for the analyses.

Fig. 4 shows the FEM analysis model with the load conditions of a 1-story building.

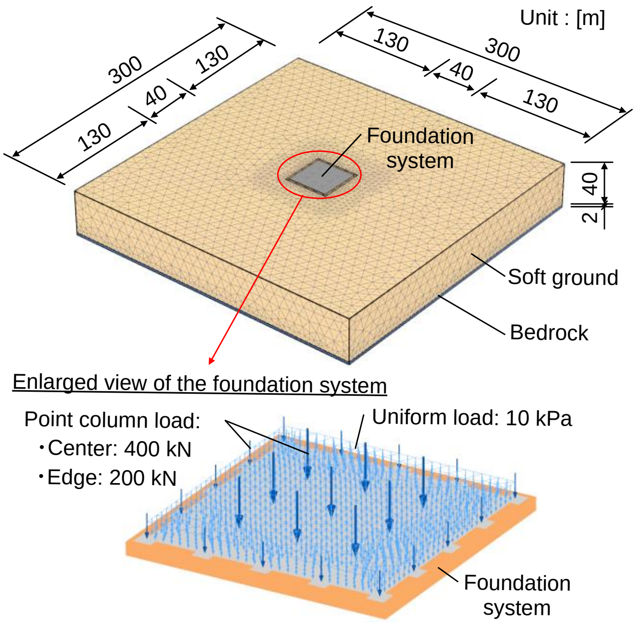


Fig. 4. FEM analysis model.

To obtain vertical load-displacement relation of the Unpiled TNF, vertical loads from the building are applied to the Unpiled TNF considering loads of 1-story to 35-story buildings. Specifically, the uniform load of 10 kPa on the ground floor is applied to the slab as shown in Fig. 4. The uniform load of 0.8 kPa on the upper floors is converted to column loads.

In this parametric study, the parameters of the ground and each part of the foundation system are listed in Tables 1, 2, 3, and 4. These parameters are used throughout all cases in this parametric study.

Table 1. Mechanical and physical parameters of the soft ground (Mohr-Coulomb model).

Parameter	Value
Young's modulus, E_s (kPa)	2,350
Poisson's ratio, ν	0.2
Unit weight, γ (kN/m^3)	16
Undrained shear strength, c_u (kPa)	20
Internal friction angle, ϕ (deg.)	0

Table 2. Mechanical and physical parameters of the bedrock (Linear elastic model).

Parameter	Value
Young's modulus, E_b (kPa)	168,000
Poisson's ratio, ν	0.2
Unit weight, γ (kN/m^3)	20

Table 3. Mechanical and physical parameters of the soil improvement of the TNF system (Mohr-Coulomb model).

Parameter	Value
Young's modulus, E_1 (kPa)	81,000
Poisson's ratio, ν	0.2
Unit weight, γ (kN/m^3)	17
Undrained shear strength, c_u (kPa)	225
Internal friction angle, ϕ (deg.)	0

Table 4. Mechanical and physical parameters of the concrete (Linear elastic model).

Parameter	Value
Young's modulus, E_c (kPa)	23,500,000
Poisson's ratio, ν	0.2
Unit weight, γ (kN/m^3)	24

E_1 in Table 3 is defined as the secant modulus E_{50} by Eq. (1) specified in the Building Center of Japan (2018).

$$E_{50} = 180 \times F_c \quad (1)$$

where F_c is the unconfined compression strength of the soil improvement (F_c = 450 kPa).

The Building Center of Japan (2019) specifies the empirical equation (2) to estimate Young's modulus E of the original ground from SPT N-value.

$$E = 2800\, N \text{ (kPa)} \quad (2)$$

In this series of analyses, N-value was assumed to be 0.8 for E_s of soft ground in Table 1 and 60 for E_b of bedrock in Table 2.

2.2. Analysis results

Fig. 5 shows the calculated deformation of the Unpiled TNF due to the vertical loads of the 5-story building. The foundation system has a dish shape due to the vertical loading. The maximum displacement occurs at the center point of the foundation and the displacement gradually decreases towards the corner and the edges of the foundation system.

Fig. 6 shows the calculated vertical load-displacement curves at the three points of center, edge, and corner of the slab (Fig. 3).

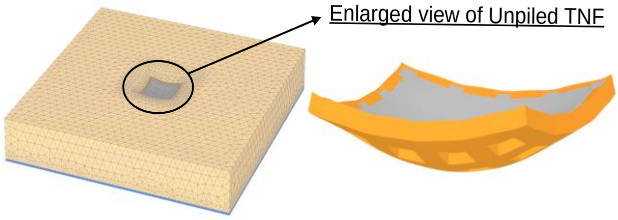


Fig. 5. Calculated deformation of Unpiled TNF due to vertical loads of 5-story building (scaled up 50 times).

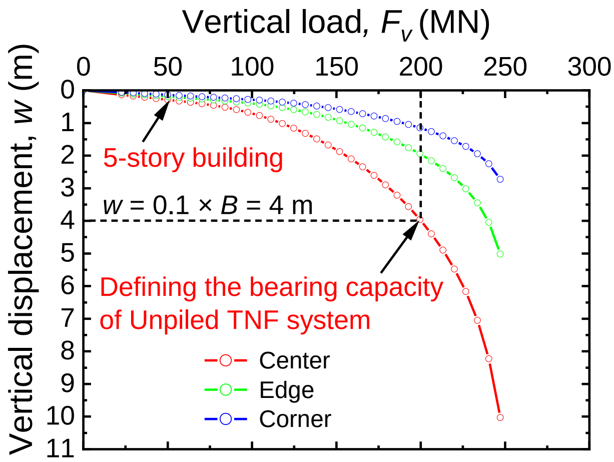


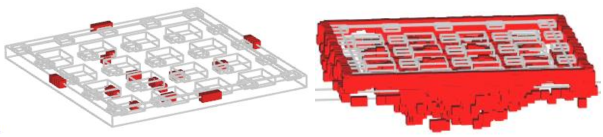
Fig. 6. Calculated vertical load-displacement curves of the Unpiled TNF.

It is seen from Fig. 6 that for vertical load F_v less than about 70 MN, the vertical load-displacement curves are nearly linear. Meanwhile, for F_v greater than about 70 MN, the vertical load-displacement curves are non-linear.

In this paper, the bearing capacity Q of the Unpiled TNF was defined as the F_v at the displacement of 4.0 m (0.1×B) at the center (Q = 200 MN).

Fig. 7 shows the failure zones (red color) of the ground at the F_v = 50 MN (5-story) and F_v = 84 MN (10-story). The failure zone of an inverse pyramid shape develops under the Unpiled TNF at F_v = 84 MN (Fig. 7b). On the other hand, the failure zones of the ground are limited at F_v = 50 MN, as shown in Fig. 7a.

Even at F_v = 50 MN, a maximum displacement of 291 mm and a differential displacement of 154 mm are caused, resulting in excessive deformation of the foundation.



(a) at F_v = 50 MN (5-story) (b) at F_v = 84 MN (10-story)

Fig. 7. Failure points (zone) of the ground.

3. CONCLUDING REMARKS

In part 2, the results of the Piled TNF are presented.

REFERENCES

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