Numerical study on mitigation of liquefaction risk using Tender Net Foundation (TNF)
(Part 2: Results of analyses)

Liquefaction
Numerical analysis
TNF system

Int. member ○ Ali Vakilazadsarabi, Takeuchi Construction Inc.
Int. member Kinji Takeuchi, Takeuchi Construction Inc.
Int. member Yasuo Tomono, Takeuchi Construction Inc.
Int. member Han Vo Cong, Takeuchi Construction Inc.
Int. member Tatsunori Matsumoto, Kanazawa University

1. INTRODUCTION

In Part 2 of the series papers, the analysis results of the TNF system described in Part 1 are presented.

2. ANALYTICAL RESULTS

Fig. 1 is the record of the Tottori earthquake, Yonago station, EW, occurred in 2000 (K-NET, 2021), used for the input acceleration.

Fig. 2 shows the horizontal response accelerations in the *x*-direction of the slab with or w/o TNF at point P2. It is seen that the absolute maximum acceleration is 5.69 m/s^2 in the TNF system, which is a little bit higher than 5.29 m/s^2 in the Footing foundation. The response accelerations at points P1, P3, and P5 were almost equal to that at point P2 in both foundations.

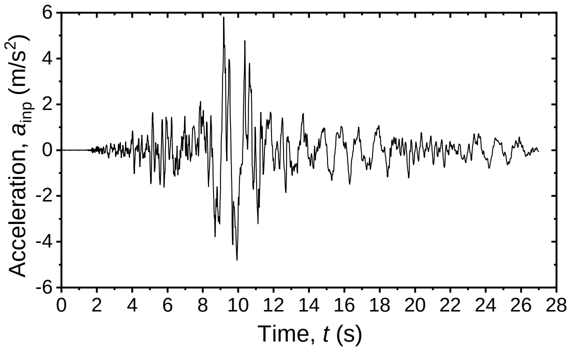

Fig. 1. Input acceleration used in the analyses (Tottori earthquake, K-NET, Yonago station, EW, 2000).

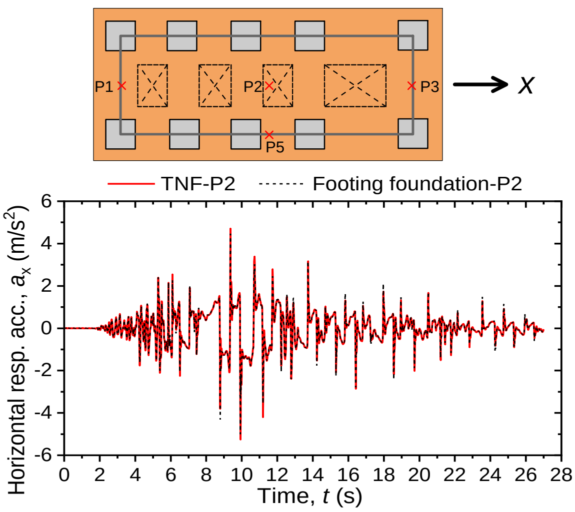

Fig. 2. Horizontal response accelerations of the slab during the earthquake.

Fig. 3 compares the vertical displacements *w* at points P1, P2, and P3 of the TNF system and the Footing foundation during the earthquake. It is seen that the vertical displacements of the TNF system is much less.

Fig. 4 shows the time histories of the vertical displacements during and after the earthquake. After the earthquake terminates, vertical displacements continue to increase gradually due to the dissipation of the excess pore water pressures generated during the earthquake. The increments of the vertical displacements during the consolidation stage are almost the same in both foundations. The final vertical displacement of the TNF system at point P2 is 112 mm smaller than that of the Footing foundation.

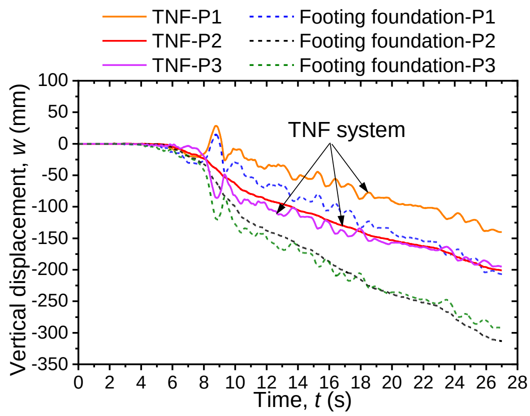

Fig. 3. Vertical displacements of the slab during the earthquake.

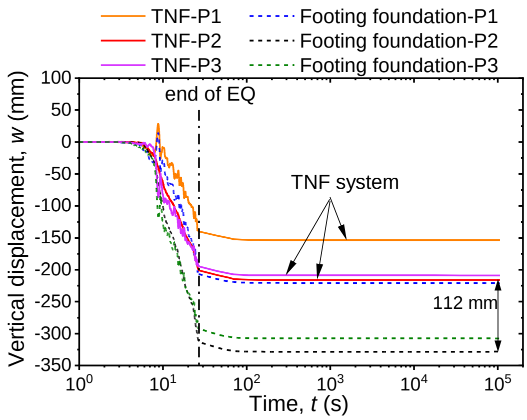

Fig. 4. Vertical displacements of the slab during and after the earthquake.

Fig. 5 shows the shear stress τ_{xz} vs. shear strain γ_{xz} during the earthquake at a depth of 1.5 m. The ranges of γ_{xz} and τ_{xz} in the case of the TNF are less than those in the case of the Footing foundation, indicating that the TNF system mitigates the liquefaction of soils surrounded by the TNF grid-shaped walls.

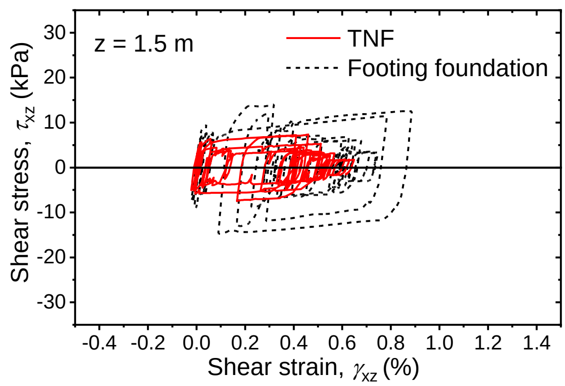

Fig. 5. Shear stress τ_{xz} vs. shear strain γ_{xz} during the earthquake at a depth z = 1.5 m (soil surrounded by the TNF grid-shaped walls).

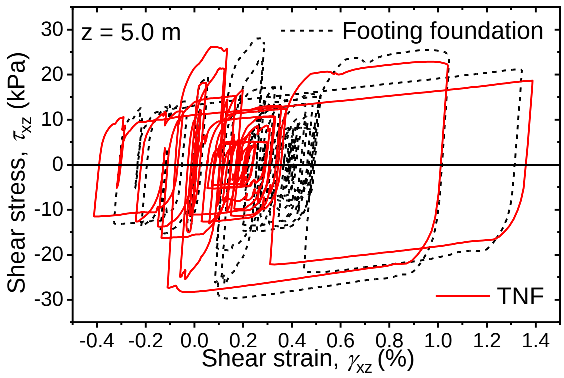

Fig. 6. Shear stress τ_{xz} vs. shear strain γ_{xz} during the earthquake at the depth z = 5.0 m.

Fig. 6 is the τ_{xz} vs. γ_{xz} for the soil at a depth of 5 m. It is seen that the time histories of τ_{xz} vs. γ_{xz} is almost similar between the two foundations. Although figures are not shown, behaviors of the ground below the depth of 5 m were identical between the two foundations.

Fig. 7 shows the distributions of vertical displacements of the slab and the ground surface along the centerline at characteristics time instants at t = 9 s when the maximum input acceleration occurred, 27 s when the earthquake terminated, and two days after the earthquake.

At t = 9 s (□), the vertical displacements of the ground surface outside the foundation area are similar between the two cases of the TNF system and the Footing foundation. On the other hand, the vertical displacements of the slab are smaller in the TNF system than those in the Footing foundation.

At the end of the earthquake (t = 27 s, ×), the vertical displacements of the ground surface outside the foundation area in the case of the Footing foundation are partly less than those in the TNF system. But the vertical displacements and bending deformation of the slab are considerably smaller in the TNF system than in the Footing foundation case.

Two days after the earthquake (○), the vertical displacements due to the consolidation of the ground terminated practically. Increments of the vertical displacements of the foundation and the ground from t = 27 s to t = 2 days are very similar between the two foundations. The total vertical displacements of the slab in the TNF system are much less than those of the Footing foundation. The bending deformation of the slab at the end of the earthquake remained during the consolidation stage in both foundations. However, the bending deformation of the TNF system is much less than that of the Footing foundation.

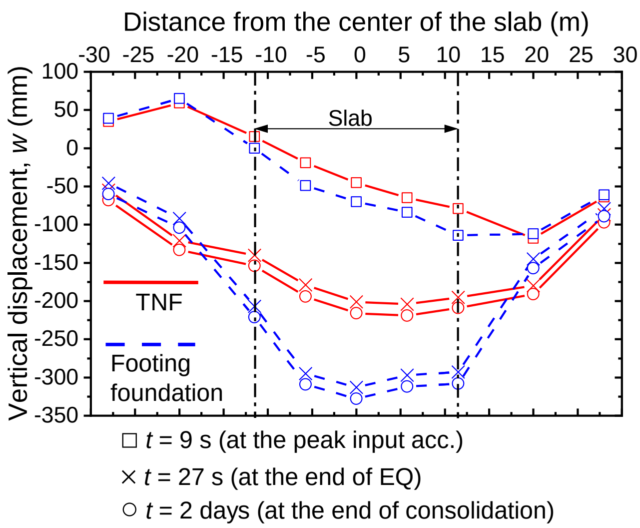

Fig. 7. Vertical displacements of the slab during and after the earthquake in the TNF system and the Footing foundation.

The total vertical stress σ_z acting on the TNF ranges mostly from 40 to 60 kPa, while σ_z acting on the Footing foundation ranges mostly from 10 to 40 kPa (see Fig. 8). This result is a possible reason why the vertical displacement of the TNF during the earthquake was smaller than that of the Footing foundation.

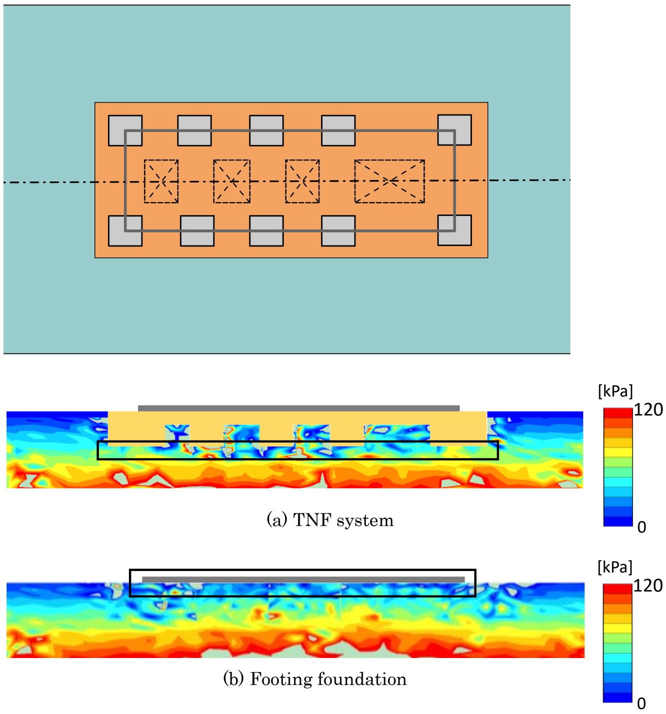

Fig. 8. Total vertical stress σ_z along the center line at the end of the earthquake in cases of the TNF and the Footing foundation.

3. CONCLUDING REMARKS

In this study, FEM numerical analyses of a TNF system for the foundation of a two-storied storehouse on the liquefiable ground in Tokyo were carried out to investigate the performance of the TNF system during and after an earthquake. Similar analyses of a footing foundation without TNF soil improvement (Footing foundation) were also conducted for comparison purposes.

This research demonstrated that the TNF system significantly reduces the vertical displacements of the foundation system in the liquefied ground during the earthquake compared with the Footing foundation. According to the analytical results, larger total vertical stresses acting on the bottom of the TNF contribute to the reduction of the vertical displacement of the TNF system during the earthquake. The uneven vertical displacements of the TNF system are much less than those in the Footing foundation.

Increments of the vertical displacements of the two foundations during the consolidation stage after the end of the earthquake were similar. The total vertical displacements of the TNF system are suppressed compared with those of the Footing foundation.

In conclusion, the TNF system has noticeable advantages over a conventional Footing foundation, and the TNF system has a promising potential to be applied to liquefiable grounds.

REFERENCE

K-NET strong-motion seismograph network (2021): Website: https://www.kyoshin.bosai.go.jp/.

Vakilazadsarabi, et al. (2023): Numerical study on mitigation of liquefaction risk using Tender Net Foundation (TNF) (Part 1: Outline of analyses), 58th Annual Meeting of Japanese Geotechnical Society, Fukuoka, Japan (to be presented).