FE analysis on the rate-dependent behaviour of geogrid-reinforced soil retaining wall

Keywords: FEM, Viscous, Geosynthetics

Tokyo University of Science, Member, Warat Kongkitkul
Tokyo University of Science, Member, Daiki Hirakawa
CRC Solutions, Member, Toshio Noguchi
Tokyo University of Science, Fellow, Fumio Tatsuoka

1. Introduction

Not only geomaterial (e.g., Di Benedetto et al., 2002; Tatsuoka et al., 2002) but also polymer geosynthetic reinforcement (e.g., Hirakawa et al., 2003) are known to exhibit more-or-less rate-dependent stress-strain behaviour due to their viscous properties. Due to interactions between the elasto-viscoplastic properties of the backfill and reinforcement, the rate-dependency of the stress-strain behaviour of the backfill reinforced with polymer geosynthetic reinforcement could be highly complicated (e.g., Tatsuoka et al., 2004). In the present study, plane strain FE analysis incorporating elasto-viscoplasticity of both sand and geogrid was performed on the behaviour of a geosynthetic-reinforced soil retaining wall (GRS-RW) model that was vertically loaded with a rough rigid footing on the crest in the laboratory (Hirakawa, 2003).

2. Details of GRS-RW model

Air-dried Toyoura sand was used as filled material and a relatively weak polyester (PET) geogrid as reinforcement. The model facing was rigid and full-height (Hirakawa, 2003; Noguchi et al., 2005).

3. FE modelling

Fig. 1 shows the FE mesh of the GRS-RW model. The sand backfill, facing and footing were modelled by four-node quadrilateral plane strain elements while the polyester (PET) geogrid reinforcement layers by non-linear truss elements. The sand elements in the respective layer in contact with the geogrid were made weaker by a factor of 0.762 compared with the original value of sand in order to model the respective geogrid reinforcement layer having a covering ratio (CR) equal to 11.1 % by a platen having CR = 100 % (Kotake et al., 1999). In the simulation, the footing load was generated by applying vertical nodal velocities to the footing. The viscous properties of sand and reinforcement were modelled by the non-linear three-component model (Di Benedetto et al., 2002; Tatsuoka et al., 2002). The details of material models and properties are given in Noguchi et al. (2005).

4. Results from FE simulation and discussions

Fig. 2 shows the simulated relationship between the average vertical footing pressure (q) and the footing settlement (s), compared with the experimental result. It may be seen that not only the overall measured q and s behaviour but also rate-dependent behaviour (i.e., jumps in q upon stepwise changes in the settlement rate ($\dot{s}$) and creep deformation during sustained loading) are well simulated.

Fig. 3 shows the simulated time histories of local vertical stress, $(\sigma_v)_{local}$, in sand immediately beneath the footing base (see Fig. 1 for the locations of the sand elements), compared with those observed in the experiment. The trend of jump in $(\sigma_v)_{local}$ upon the stepwise changes in $\dot{s}$ is well simulated. However, the $(\sigma_v)_{local}$ value at the front footing edge, close to the facing, is largely over-predicted while the values at the places behind, including the footing centre are under-predicted, despite a satisfactory simulation of the overall q and s behaviour. The reason for this discrepancy is not understood.

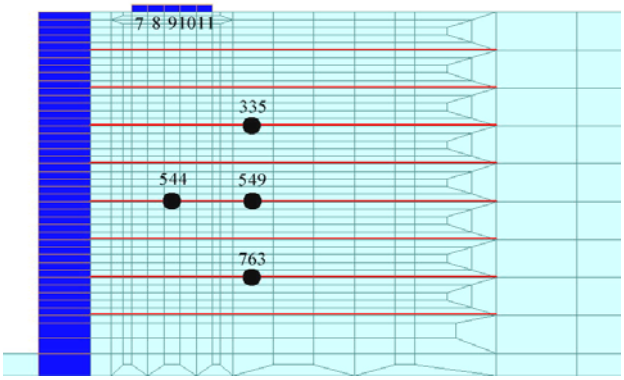

Figure 1 FE mesh for a GRS-RW model

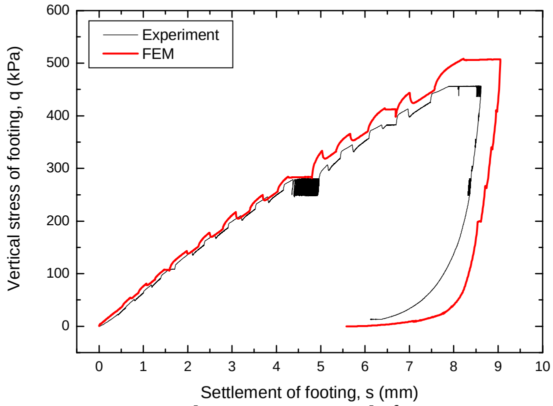

Figure 2 Measured average vertical footing pressure-footing settlement relation and its FE simulation

Despite that they are subtle, the $(\sigma_v)_{local}$ value underneath the footing base were not constant when the total footing load was sustained and during cyclic loading of footing load for a small amplitude. For example, the $(\sigma_v)_{local}$ value decreased and increased at the relations denoted as A and B, and these trends are reasonably simulated by assuming by the analysis in which the footing load was maintained constant during the respective cyclic unloading/reloading history of footing load.

Fig. 4 shows the simulated time histories of local tensile load mobilised at the locations in the geogrid depicted in Fig. 1, compared with the test results. The overall history of local tensile stress of geogrid and the general trend of its rate-dependency were reasonably simulated by FEM. The simulation of the time history of tensile load during the sustained and cyclic loading histories of footing load is not satisfactory.

5. Conclusions

The FE analysis incorporating the non-linear three-component model that models the elasto-viscoplastic properties of backfill sand and polymer geogrid reinforcement is able to realistically simulate the overall behaviour of a geogrid-reinforced soil retaining wall model vertically loaded with a rough rigid footing on the crest of the backfill. Moreover, trends of rate-dependent behaviour of the model due to the viscous properties of backfill and geogrid could be reasonably simulated by the FEM.

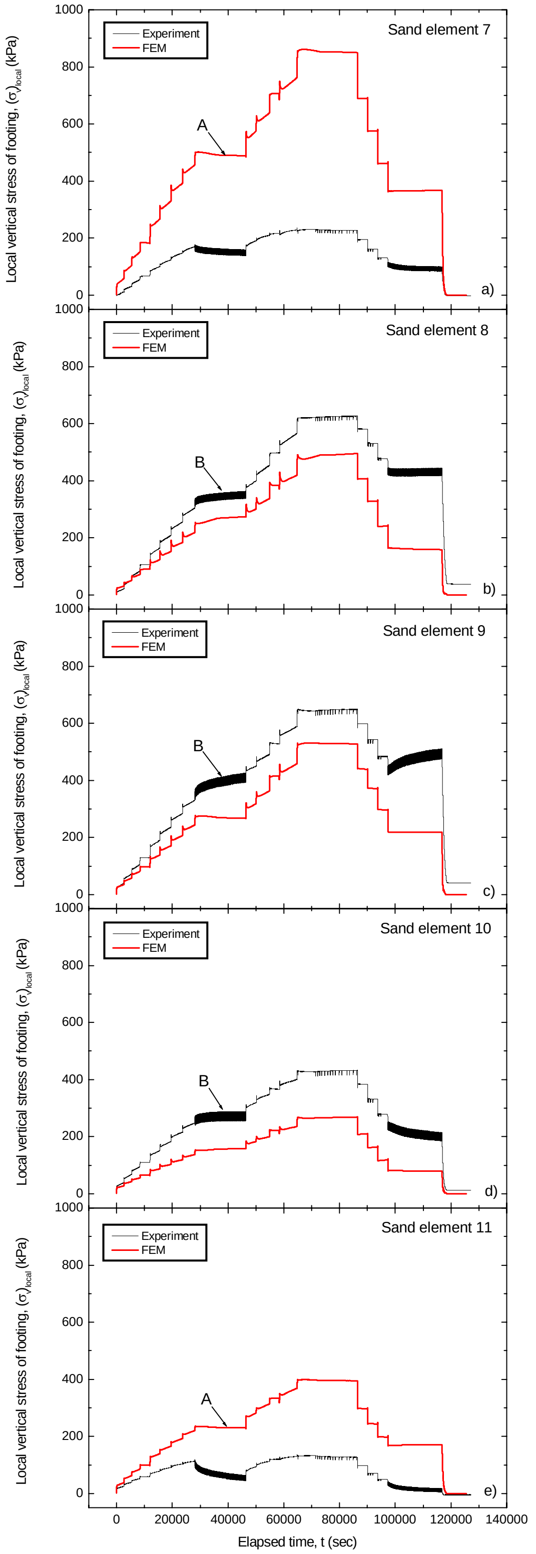

Figure 3 FE simulation of time histories of local vertical footing pressure

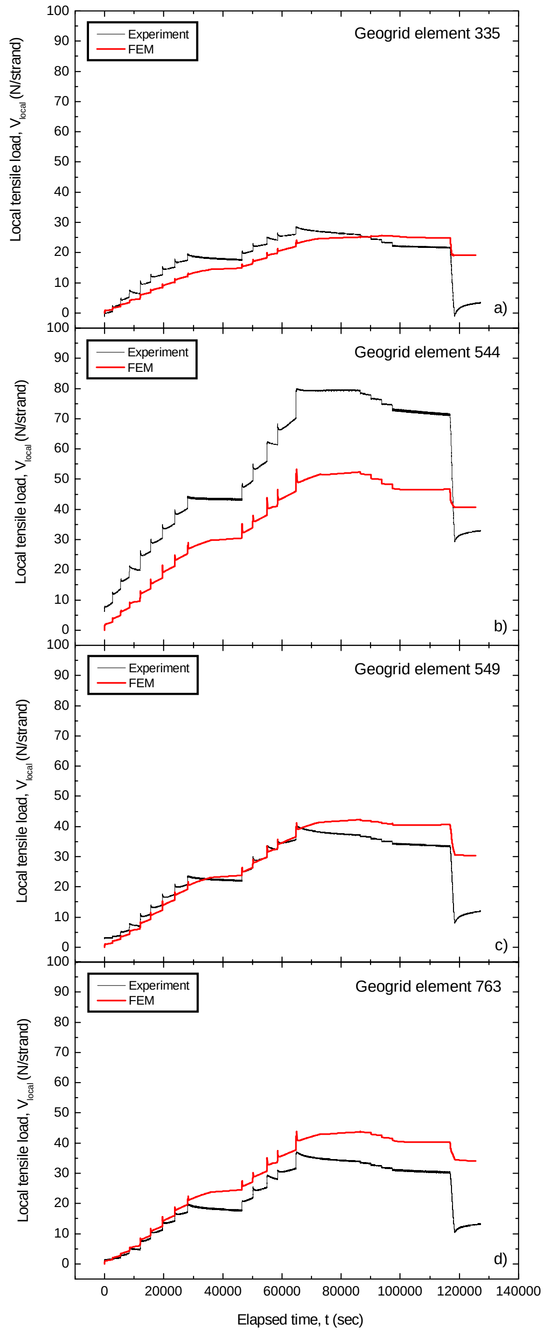

Figure 4 FE simulation of time histories of local tensile load in the geogrid

References:

1) Di Benedetto,H., Tatsuoka,F. and Ishihara,M. (2002), Time-dependant shear deformation characteristics of sand and their constitutive modeling, *S&F*, Vol.42, No.2, pp.1-22.
2) Hirakawa,D. (2003), Study on residual deformation characteristics of geosynthetic-reinforced soil structures, *Ph.D. Thesis*, University of Tokyo (in Japanese).
3) Hirakawa,D., Kongkitkul,W., Tatsuoka,F. and Uchimura,T. (2003), Time-dependent stress-strain behaviour due to viscous properties of geosynthetic reinforcement, *Geosynthetics International*, Vol.10, No.6, pp.176-199.
4) Kotake,N., Tatsuoka,F., Tanaka,T., Siddiquee,M.S.A. and Yamauchi,H. (1999), An insight into the failure of reinforced sand in plane strain compression by FEM simulation, *S&F*, Vol.39, No.5, pp.103-130.
5) Noguchi,T., Hirakawa,D., Kongkitkul,W. and Tatsuoka, F. (2005), FE simulation of rate-dependent behaviour of model geosynthetic-reinforced soil retaining wall, *Prof. of the 60th JSCE Annual Meeting*, Tokyo (submitted).
6) Tatsuoka,F., Ishihara,M., Di Benedetto,H. and Kuwano,R. (2002), Time-dependent shear deformation characteristics of geomaterials and their simulation, *S&F*, Vol.42, No.2, pp.103-138.
7) Tatsuoka,F., Hirakawa,D., Shinoda,M., Kongkitkul,W. and Uchimura,T. (2004), An old but new issue; viscous properties of polymer geosynthetic reinforcement and geosynthetic-reinforced soil structures, Keynote Lecture, *Proc. of the 3rd Asian Regional Conference on Geosynthetics (GeoAsia 2004)*, Seoul, pp.29-77.