Discussion

Behavior of Geosynthetic-Encased Stone Columns in Soft Clay: Numerical and Analytical Evaluations

Discussion by:
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1. Introduction

The authors presented numerical analysis of an embankment underlain by soft clay improved with geosynthetic-encased stone columns and comparison of results with analytical methods developed by Raithel & Kempfert (2000), Pulko *et al.* (2011) and Zhang & Zhao (2014). The authors conclude that among the three methods, the results of R&K generally show better agreement with the results of FEM than the results of PEA and ZZ methods. The readers would like to address that statement and point to some shortcomings and inconsistencies regarding the use of analytical procedures according to R&K and PEA methods.

2. Discussion

When comparing R&K and PEA methods, it should be considered that both are based on the same fundamental assumptions. The methods differ only in treatment of the stone column (SC). In the R&K method, the SC is considered as a rigid plastic material with constant volume at yield. On the other side, the PEA method assumes elastoplastic behavior with the ability to take into account the SC dilation. Another difference with minor influence on calculation results is that the R&K method assumes finite strains, while the PEA method assumes small strain theory. Due to these differences, the calculated settlements according to the PEA method will always exceed the values of the R&K method, if the equivalent input data are used (Pulko *et al.*, 2011). Because in the paper the PEA method is shown to produce settlements lower than the R&K method, the readers believe that the soil stiffness used for both methods was not the same but is unfortunately not given in the paper.

From theoretical equations behind both methods, it is evident that under constant SC volume and considering small strain theory ($\varepsilon_v = \varepsilon_1 - 2\varepsilon_r = 0$), the total settlement s can be obtained with the integration of axial strains ε_1 over depth, which can be related to the geosynthetic tensile force $\Delta F_g(z)$:

$$s = \int_0^H \varepsilon_1 \, dz = \int_0^H 2\varepsilon_r \, dz = \int_0^H \frac{2\Delta F_g(z)}{J} dz = \frac{2}{J}\int_0^H \Delta F_g(z) dz \tag{1}$$

If the SC volume is constant, then the settlement is proportional to the area under the graph of geosynthetic tensile force $\Delta F_g(z)$. If the SC is compressible, then the settlement is even larger. In Fig. 5 of the paper (Fig. 1 below), the areas under the graphs of tensile force for the R&K method are significantly smaller than for the FEM and PEA methods. This does not support the authors' conclusion that the R&K method produces settlements in line with the FEM results, while the PEA method produces smaller settlements.

3. Conclusions

Under given assumptions both analytical methods (R&K and PEA) are able to provide comparable results in good agreement with FEM, as long as equivalent material data are taken into account. When using simplified elastic methods, the determination of equivalent stiffness is essential to provide comparability with the results of advanced nonlinear FEM. Any comparison of different analytical methods without proper representation of the equivalent input data (*i.e.* stiffness) is incomplete and can lead to misleading conclusions.

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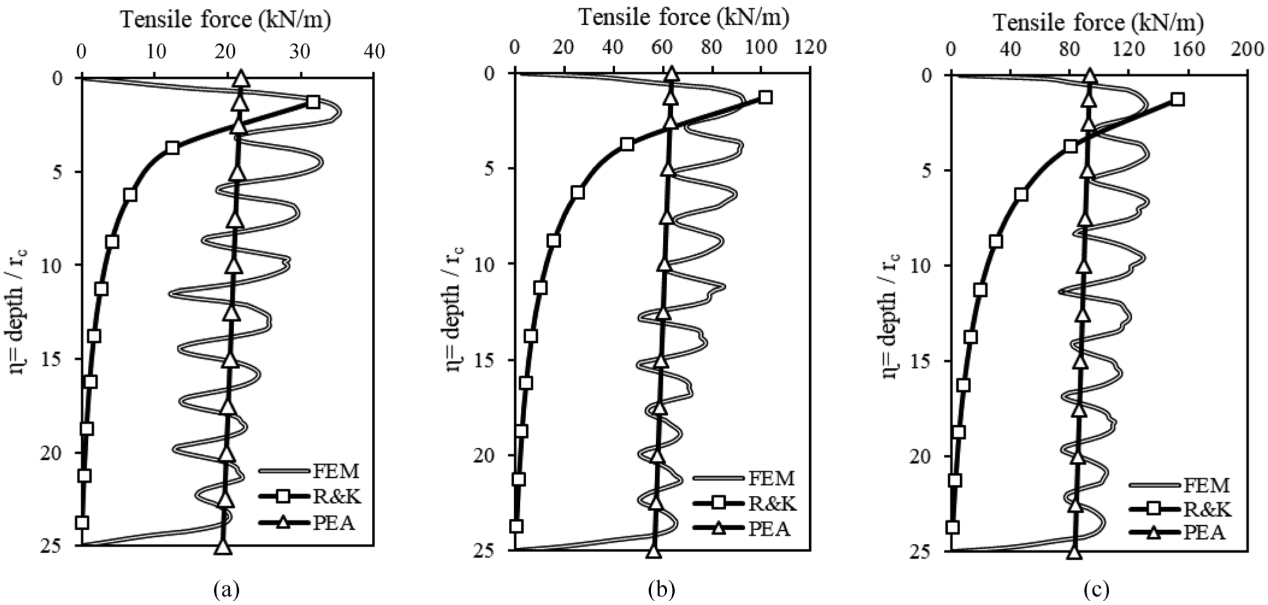

Figure 1 - Tensile force *vs.* depth ratio for different geosynthetic stiffnesses; (a) Tensile force for J = 500 kN/m, (b) Tensile force for J = 2000 kN/m, (c) Tensile force for J = 4000 kN/m (Fig. 5 after Alkhorshid *et al.*, 2018).

References

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Closure by authors

1. Introduction

The authors would like to thank the writers' interest in the paper and constructive comments. The writers present some theoretical statements about PEA and R&K methods. It is stated that both methods come from same fundamental assumptions, except for the column behavior which is treated as a rigid plastic material in R&K and is expected to have an elastoplastic behavior in PEA. It is also commented that another difference is that PEA presumes small strain theory while R&K assumes finite strains. Then it concluded that these differences cause PEA values always to exceed R&K values if equivalent input data are employed.

2. Reply to the Discussion

Both methods, PEA and R&K, use the oedometric modulus of the soil, which can be obtained from $E_{oed,ref}$ presented in Table 1 of the paper ($E_{oed,ref}$ = 1850 kPa). Thus, the R&K greater settlements than the PEA settlements can not be due to the different input data since in both methods the very same value of soil stiffness was used.

Considering the values of tensile forces, the result for R&K shown in Fig. 5 of the paper was produced using the values of radius variation for different depths obtained from the following equation (Raithel & Kempfert, 2000):

$$\Delta r_c = \frac{K_{a,c}\left(\frac{1}{a_E}\cdot\Delta\sigma_{v,s} + \sigma_{v,0,c}\right) - K_{0,s}\cdot\Delta\sigma_{v,s} - K_{0,s}\cdot\Delta\sigma_{v,0,s} + \frac{(r_{geo} - r_c)\cdot J}{r_{geo}^2}}{\frac{E^*}{\left(\frac{1}{a_E} - 1\right)\cdot r_c} + \frac{J}{r_{geo}^2}} \qquad (1)$$

where $k_{a,c}$, a_E, $\Delta\sigma$, $\Delta\sigma_{v,s}$, $\sigma_{v,0,c}$, $K_{0,s}$, $\sigma_{v,0,s}$, r_{geo}, r_c and J are coefficient of active earth pressure of column, area replacement ratio, applied stress at the top of unit cell, increase of vertical stress on soft ground, initial stress on the column before loading, coefficient of lateral earth pressure at rest for soft soil, initial stress on soft soil before loading, radius of the surrounding geotextile, column radius and geosynthetic tensile stiffness.

The discussion also addresses the constant stone column volume and the assumption of incompressible column material. Hence, the values of tensile forces calculated using R&K were double-checked considering the constant stone column volume and it was found that R&K predictions were wrongly plotted. Thus, the correct values are now presented as R&K2 in Fig. 2.

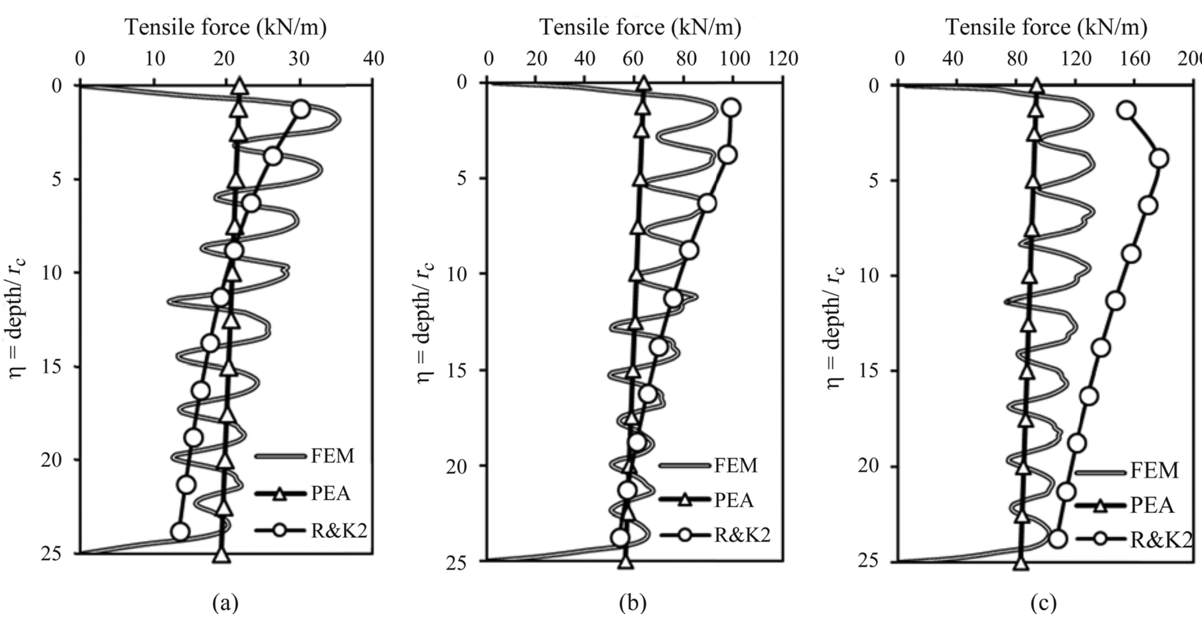

Figure 2 - Tensile force *vs.* depth ratio for different geosynthetic stiffness; (a) Tensile force for J = 500 kN/m, (b) Tensile force for J = 2000 kN/m, (c) Tensile force for J = 4000 kN/m.

3. Conclusion

The writers suggest that under equivalent material data both methods, PEA and R&K, can provide comparable results in good agreement with those of FEM. Since both methods take E_{oed} of soil into account, the calculations were made using the same value ($E_{oed,ref}$ = 1850 kPa) for both methods. The authors do not believe that using different oedometric modulus for the soil would be fair for the comparisons between predictions from different methods. In addition, Khabbazian *et al.* (2011) presented a discussion on PEA method and in Fig. 1 of their paper, PEA settlements were compared with those from FEM for different diameter ratios ($N = r_e/r_c$). They also found that settlements predicted by PEA were smaller than those from FEM.

PEA is capable of producing results that are in good agreement with FEM. Yet, the settlement results shown in Fig. 3 of the paper suggest that under constant value of geosynthetic tensile stiffness (J = 2000 kN/m) and different diameter ratios ($N = r_e/r_c$), R&K radius variations and settlements were in better agreement with those from FEM. On the other hand, under constant diameter ratio (N = 3.5) and different tensile stiffness values both methods can provide satisfactory results (Fig. 2).

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