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Verification of pile modelling technique in *FLAC3D*

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1 INTRODUCTION

In *FLAC3D* software, single pile could be represented by modelling the physical geometry of the pile using 'liner' elements or 'solid' elements to simulate the performance under vertical and lateral loading conditions. These modelling techniques require very fine meshing (discretization) to provide satisfactory performance and therefore their use is generally limited to single pile modelling situations only. For design situations involving group of piles, maintaining such fineness of the mesh would lead to unacceptable computation time even in the case with small number of piles. The 'pile-element' modelling technique available in *FLAC3D* (Itasca 2017) could yield an alternative modelling technique for such situations. In this technique, the physical geometry of the pile is not modelled, instead it is represented by 'line' structural elements with the corresponding axial and flexural stiffness of the actual pile; the 'pile-elements' interact with the soil continuum via coupling springs. However, it has been noted that the quality of performance of the 'pile-element' modelling technique is dependent on the configuration of the mesh adopted in the model.

This paper examines the characteristics of the mesh configuration to achieve the best performance with 'pile-element' modelling technique by comparing the single pile analysis results obtained with the 'liner-element' modelling technique and from other conventional pile analysis software. This exercise was then extended to pile groups in which the *FLAC3D* results from 'pile-element' modelling technique were compared satisfactorily with the results obtained from other conventional pile group analysis software.

2 INVESTIGATORY SINGLE PILE ANALYSIS

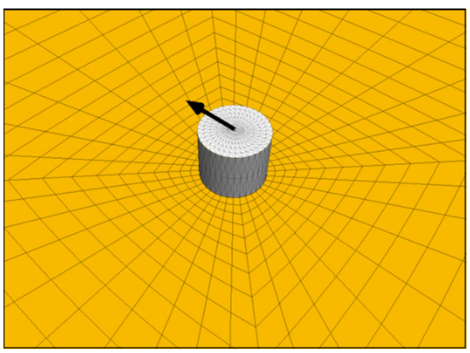
In order to verify the performance of a single pile modelled using 'pile-element' technique subject to lateral loading at pile head, two *FLAC3D* models were developed adopting a similar *FLAC3D*-mesh with an idealized elastic ground model, as follows:

- **Model A:** In this model, the physical geometry of the pile (1200mm diameter) was modelled using 'liner-elements' adopting a radial mesh in plan (Fig. 1a);
- **Model B:** In this model, the same radial model configuration as for Model A above was adopted, but with the pile modelled using 'pile-elements' placed at the centerline of the radial mesh (Fig. 1b).

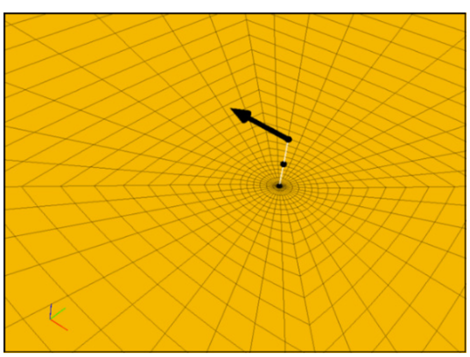
The Young's Modulus for elastic ground model was taken as E'=20+2z (MPa), where 'z' is the depth below ground level in meters, with Poisson's ratio of 0.2. The properties correspond to a 1200mm diameter steel tubular pile, with wall thickness of 20mm and E'=200GPa; pile length was taken as 21m, embedded length of 20m with 1m free-standing length above ground level.

The analysis results showed that despite the application of the same lateral load of 200kN to the above two models, the resulting lateral deflection profiles were found to be considerably different; i.e. Model B showed much higher lateral deflection compared to Model A as shown in Figure 1c. However, the corresponding results obtained using conventional pile analysis program PIGLET (UWA 2004), which is an elastic pile analysis software, gave matching results at ground level with Model A, suggesting Model B yields unacceptable results. Sensitivity analyses carried out with increased coupling spring stiffness values by 1000 times (for the Model B case) showed no impact on the results. It was therefore suspected that too fine mesh adjacent to the 'pile-elements' in Model B, within the zone which is actually occupied by the physical geometry of the pile, contributed to the excessive lateral deflection.

In order to improve the performance of the 'pile-element' modelling technique, several investigatory analyses were carried out with different mesh configurations aimed to achieve closer matching results to that of Model A. These analyses included model configurations with 'block' *FLAC3D*-mesh with different block sizes (typically as shown in Fig. 2a) with 'pile-elements' located at different positions in relation to a single 'block'. Verification analyses were performed adopting Elastic and Mohr-Coulomb models for the soil continuum. For the Mohr-Coulomb model case, Ø=36° and c'=1 kPa were adopted with the bulk unit weight of 20 kN/m^3 for soil continuum; no presence of water was assumed.



a)



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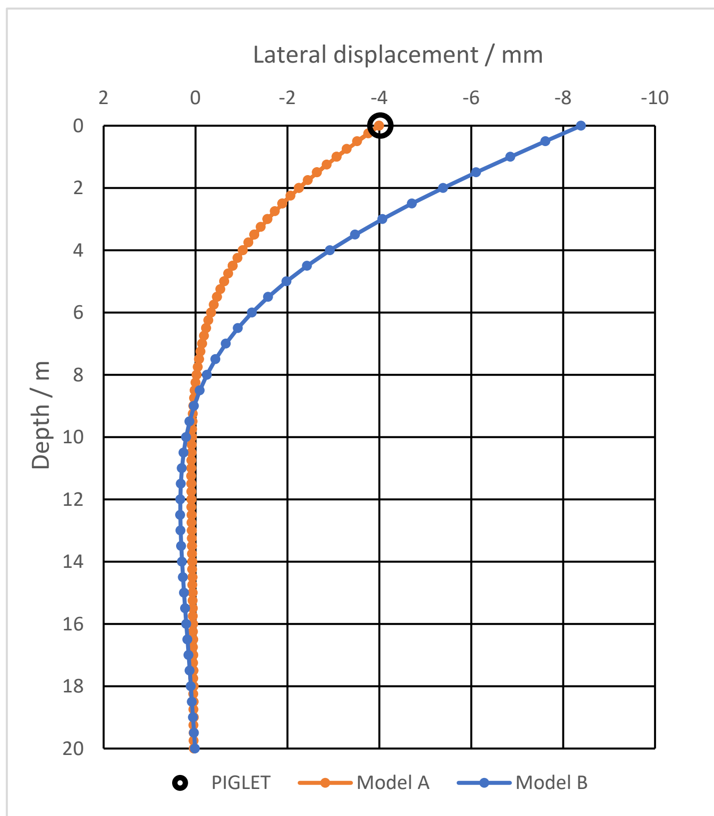
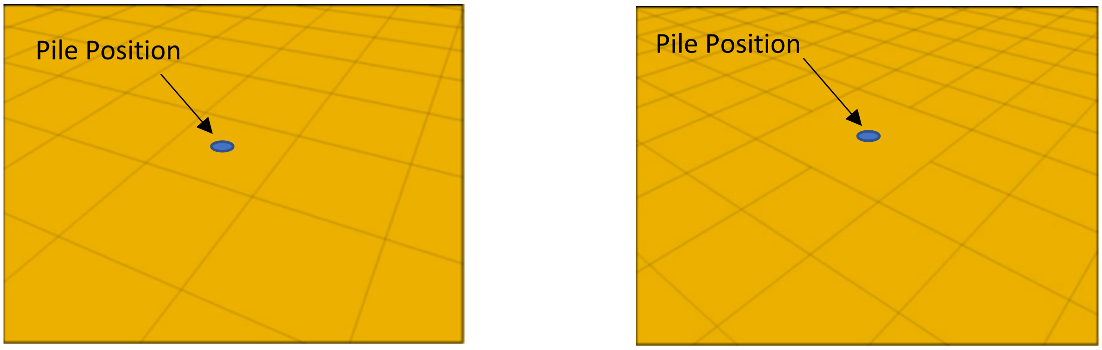


c)

Figure 1. a) Model A, b) Model B, c) Lateral deflection profile.



a) **b)**

Figure 2. a) ‘Block’ Model C, b) ‘Block’ Model D.

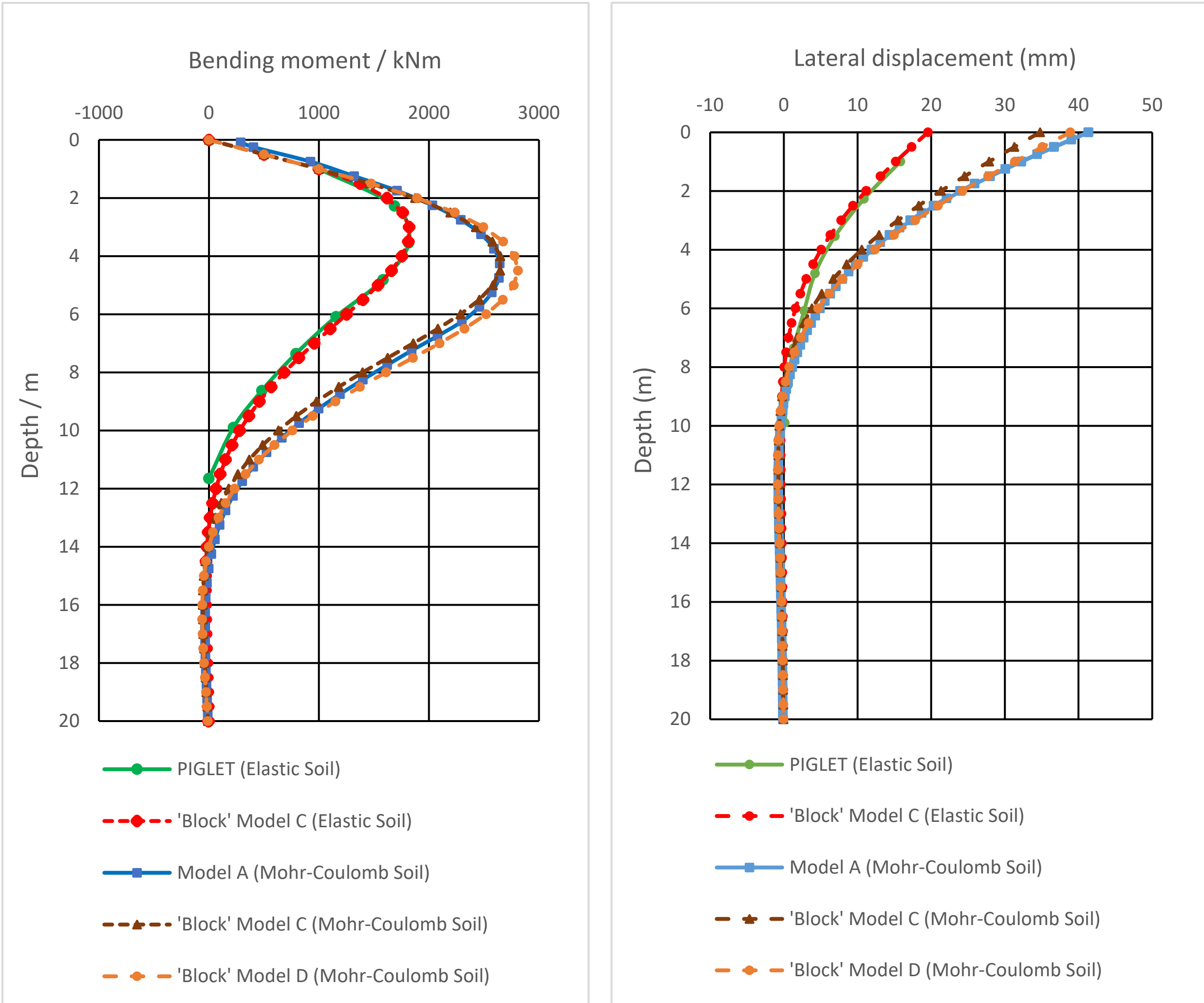
3 SINGLE PILE ANALYSIS RESULTS, VERIFICATION AND DISCUSSION

A series of analyses was performed with ‘Block’ Model C configuration (Fig. 2a) with different grid sizes in plan which includes 1.2m x 1.2m (note that the pile diameter is 1.2m) and 0.6m × 0.6m square grids with piles centered on a ‘block’ as shown on the figure.

The 1.2m grid case marginally under predicted the lateral deflection and the bending moment profile compared to the Model A results; whilst, 0.6m grid case, over predicted the results, particularly the bending moments. The analysis was therefore repeated with 1m × 1m grid (see Fig. 2a) in which the plan area of the block (1.0m^2) approximately coincides with the cross-sectional area of the pile (1.13m^2). Both the Elastic and Mohr-Coulomb soil model cases were considered. The lateral loading was increased to 1000kN for these cases (compared to 200kN used in the earlier analyses) in order to verify the results within the non-linear region of the soil behavior.

The results of bending moment and lateral deflection profiles are shown in Figure 3a and 3b respectively. For the elastic soil case, the results from PIGLET are also superimposed and they show excellent match with the *FLAC3D* results, both in terms of bending moment and deflection. The results for the Mohr-Coulomb soil case were also in good agreement with the corresponding results from Model A (pile modelled with ‘liner’ elements), particularly the bending moment, although the deflections were slightly under predicted. Further analyses were performed in which the zones surrounding the 1m x 1m grid occupied by the pile were discretized with 0.5m x 0.5m mesh (see Fig. 2b ‘Block’ Model D configuration) aimed to improve the performance further and the results are shown in Figure 3. As can be seen from the figure, for this case, the matching of the deflection profile with the Model A results was very good (significantly improved compared to Model C configuration) although bending moments were slightly over predicted. These results are very encouraging and form an excellent verification exercise for modelling piles using ‘pile-element’ modelling technique available in *FLAC3D*.

In all the above analyses, the pile was placed at the center of the grid that it was occupying (in plan). Supplementary analyses were performed with pile located at the boundary between the grids, including at a junction of four grids, and this aspect adversely impacted on the performance. However, provided the pile is away from the grid boundaries, no boundary influence was noted. The good news for the modelers is therefore, provided the pile is located away from the boundaries, satisfactory performance can be assured and the pile does not necessarily have to be exactly centered within the grid.



a) **b)**

Figure 3. a) Comparison of bending moment profiles with depth, b) Comparison of lateral deflection profiles with depth.

4 PILE GROUP ANALYSIS RESULTS AND VERIFICATION

The above exercise was then extended to pile group modelling adopting 'Block' Model D configuration (Fig. 2b) with each of the piles centered within their 1m x 1m grid. In this exercise, a substantial size pile group with a stiff pile cap was modelled in *FLAC3D* using 'pile-element' modelling technique subjected large lateral loading. A total of 66 piles were modelled with 60m x 15m pile concrete cap of 2.0m thickness; piles were placed in 4 rows which were unequally spaced and the spacing of piles for different rows were also different. The pile properties correspond to a 1.2m diameter concrete pile with embedded length of 38m and free-standing length of 1m. The piles were rigidly fixed to the pile cap and the total lateral load on the pile cap was such that the average load per pile was 1000kN. The same Elastic soil model described above for single pile analyses was adopted.

For the verification exercise, the lateral load distribution at the pile head (shear load) within the group was obtained and compared with the corresponding results from REPUTE (Geocentrix 2017), which is a pile group analysis software that could model both Elastic and Mohr-Coulomb soil models.

Typical results obtained for a row of piles are compared in Figure 4. The results show a very good match in the shear load distribution demonstrating that the relative lateral stiffnesses of the individual piles in the group are satisfactorily simulated by the *FLAC3D* model with 'pile-element' modelling technique. This is a very encouraging results and provides a satisfactory and practical means of modelling pile groups in *FLAC3D* using 'pile-element' modelling technique by appropriately configuring the *FLAC3D* mesh. The exercise was subsequently extended with Mohr-Coulomb soil model and again satisfactory verification was achieved.

The above verification exercise was carried out with a simple idealized ground model due to the limitation of the conventional pile group analysis software used for producing results that can be used to verify the corresponding *FLAC3D* results.

The findings of this exercise will provide confidence in utilizing *FLAC3D* for modelling group of piles with 'pile-element' modelling technique by adopting the good practice rules established in this paper to model layered soil stratification with non-linear soil models that are commonly encountered in design practice.

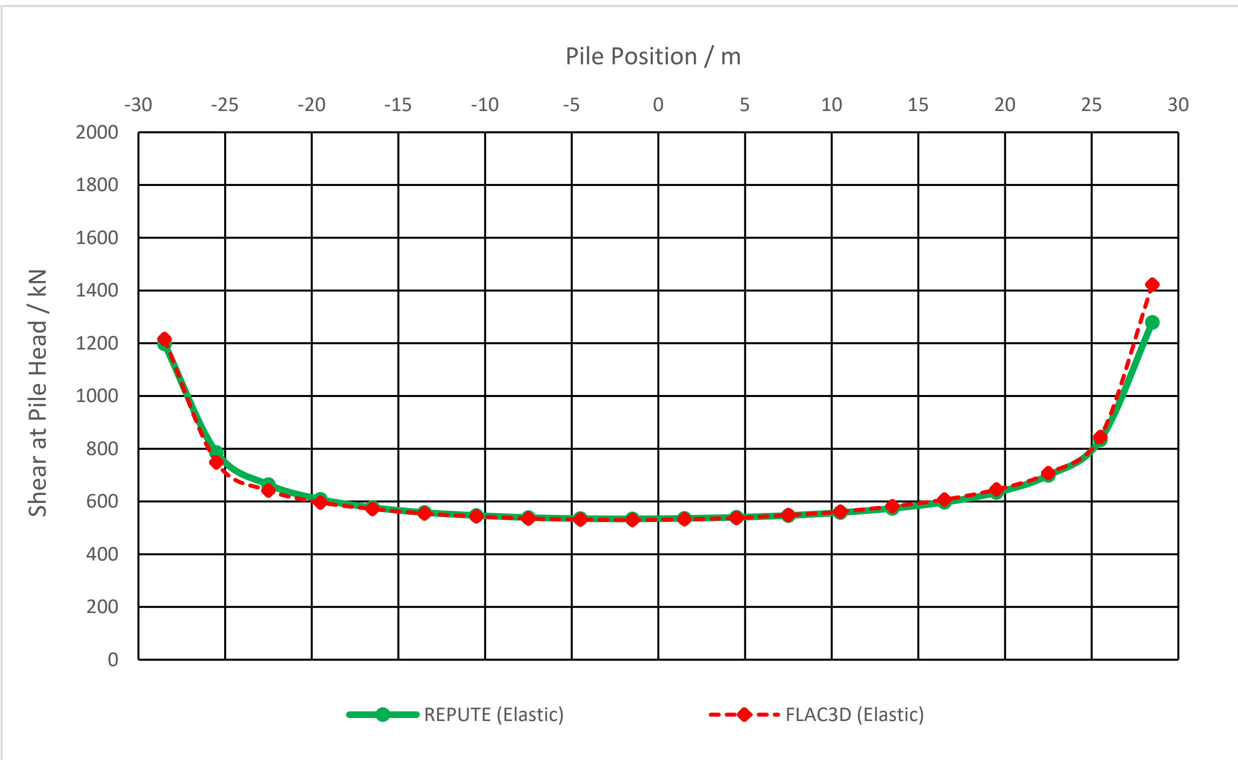


Figure 4. Pile head shear load distribution along a row of piles in a pile group.

5 CONCLUSIONS

The 'pile-element' modelling technique available in *FLAC3D* can be used successfully to model single piles and pile groups subject to vertical and lateral loading by appropriately configuring the *FLAC3D* mesh. It has been demonstrated that by adopting a square grid in plan with an area equal to the cross-sectional area of the circular pile being modelled, the 'pile-element' modelling technique gives a satisfactory performance in simulating the vertical and lateral behavior of the pile groups. The above grid size (with area equal to the cross-sectional area of the actual pile) should be complied only for the zones where the piles are located and piles should be placed away from the adjacent grid boundaries. Improved performance could be achieved by adopting finer grid zones outside the 'particular' grids in which the piles are positioned to suit the overall modelling requirements.

REFERENCES

Itasca Consulting Group, Inc. 2017. *FLAC3D – Fast Lagrangian Analysis of Continua in 3-Dimensions, Version 6.0*, Minneapolis: Itasca.

The University of Western Australia. 2004. *PIGLET – A Program for Analysis and Design of Pile Groups, Version 5.1, Technical Manual*. The University of Western Australia, Perth.

Geocentrix Ltd. 2017. *REPUTE – Onshore Pile Design and Analysis, Version 2.5.1, Reference Manual*, Geocentrix Ltd.