The Effect of Initial Stress to 3D Settlement Analysis

Martin Wijaya
Universitas Katolik Parahyangan

Delaneira Princess Seourin, Bondan Widi Anggoro
PT Geotechnical Engineering Consultant

Paulus Pramono Rahardjo
Professor of Geotechnical Engineering - Universitas Katolik Parahyangan

ABSTRAK: Berbagai metode telah di rekomendasikan selama bertahun-tahun untuk mengestimasi penurunan kelompok tiang. Dengan seiring berkembangnya alat untuk melakukan analisa numerik, pemodelan penurunan kelompok tiang tidak lagi dibatasi oleh beban kolom dan geometri tiang namun dapat diperluas untuk memperhitungkan pengaruh dari aktifitas konstruksi seperti timbunan, galian dan juga pengaruh dari geometri permukaan tanah yang tidak horisontal yang mempengaruhi tegangan awal sebelum dilakukan analisa penurunan. Didalam makalah ini, simulasi numerik dengan mempergunakan MIDAS GTS NX dilakukan untuk mengevaluasi efek dari aktifitas konstruksi dan geometri permukaan tanah yang tidak horisontal terhadap analisa penurunan.

Kata Kunci: kelompok tiang, penurunan, analisa numerik, metode elemen hingga, 3D, tegangan awal

ABSTRACT: Variety of methods have been proposed over decades in order to estimate pile group settlement. Due to the development of numerical tools, modelling settlement of pile group is no longer limited to the column load and pile geometry but also can be expanded to consider the effect of construction activities such as fill and excavation and non-horizontal surface geometry which affects initial stress prior to settlement analysis. In this paper, numerical simulation carried by using MIDAS GTS NX is conducted in order to evaluate the effect of construction activities and non-horizontal surface geometry to the settlement analysis

Keywords: pile group, settlement, numerical analysis, finite element analysis, 3D, initial stress

1 INTRODUCTION

Settlement analysis of pile group has long been a classical problem in geotechnical engineering. Most of the approach in analysis settlement of pile group is by assuming horizontal soil surface, and settlement is a function of load, pile geometry and soil parameters. However, it is important to note that as civilization progress, construction goes from the city flat area to the sloping mountainous region where significant cut and fill activities are required prior to pile construction. As construction activities becomes more complicated, robust method to cover such unconventional factors becomes necessary.

Pile group settlement analysis typically separated into two types:

1. Type A: Only maximum total settlement due to pile group is estimated.
2. Type B: Settlement distribution beneath the building is estimated and hence possible to obtain differential settlement.

In analysis type A, maximum settlement is typically assumed to be located at the centre of the raft foundation and only maximum settlement is obtained such as in empirical method based on foundation geometry, Skempton (1953), Meyerhof (1959), equivalent raft method, Tomlinson (1977), Terzaghi and Peck (1948), Poulos (1993) and empirical method based on in situ test, Schmertmann (1970), De Beer and Martens (1957), Tomlinson and Woodward (2008).

In empirical method based on foundation geometry, Skempton (1953), Meyerhof (1959), settlement of pile group δ_g is a function of settlement of single pile δ_i multiplied with geometrical factor (f) and can be represented as:

$$\delta_g = \delta_i f\left(B, D, L, s, r\right) \tag{1}$$

where B is width of pile group, D is pile diameter, L is pile length, s is spacing, r is number of rows in pile group.

In Equivalent raft method, Tomlinson (1977), Terzaghi and Peck (1948), Poulos (1993), load is assumed to be distributed at certain commencement depth below the pile cap or raft (typically 2/3 of pile length). The distributed load is converted into stress by using an equivalent raft which gets wider as the depth increases (typically 2V:1H) as shown in Fig. 1. The distributed stress can then be used to compute settlement i.e. due to consolidation, Skempton and Bjerrum (1957) or based on strain influence method, Poulos (1993).

Empirical method based on in situ test which is commonly employed to estimate settlement of shallow foundation, De Beer and Martens (1957), Schmertmann (1970) can also be extended for piled foundation by assuming the piled foundation can be replaced with equivalent raft located at commencement depth, Tomlinson and Woodward (2008).

The problem with analysis type A is that it does not provide differential settlement which might occurs. On the other hand, a number of code such as SNI 8460 (2017) requires differential settlement of building to be considered. Hence, analysis type B such as pile interaction analysis, Poulos and Davis (1980), Poulos (1968), Poulos and Mattes (1971) or by employing numerical analysis such as finite element method (FEM) in 2D, Celik (2019) and 3D, Hamderi (2018), Gowthaman and Nasvi (2017) start to flourish.

In pile interaction analysis, Fig. 2, the settlement of single pile (pile i) is affected by settlement of its adjacent piles (pile j) through interaction factor α_{ij} which is a function of spacing and geometric factor such as length and diameter pile j. Settlement of every pile can then be determined provided that load on every pile, settlement of single pile due to applied load and geometric factor (pile coordinate, diameter and length) are known. The problem with pile interaction analysis is it is based on Mindlin's equation which is applicable for homogeneous isotropic half-space which is rarely encountered in practice where soil layer is highly non uniform.

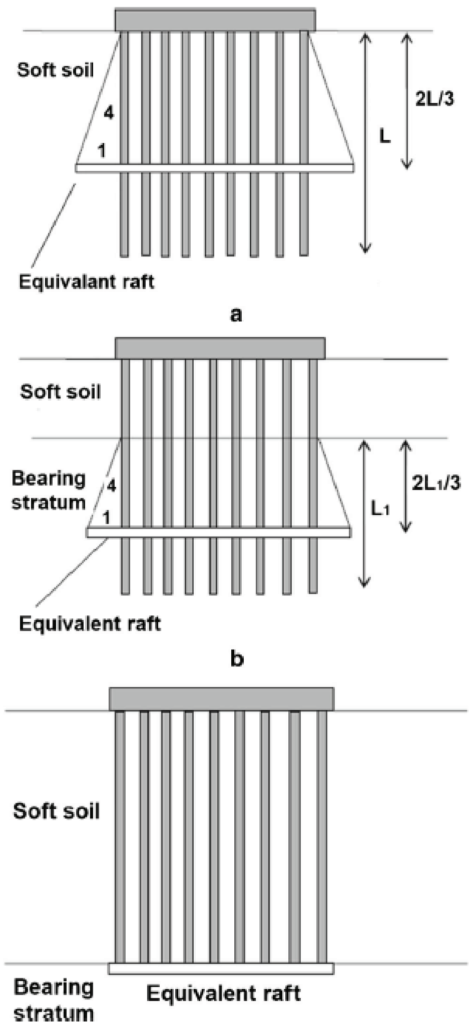


Fig. 1. Equivalent Raft Method, Celik (2019), Tomlinson (2001).

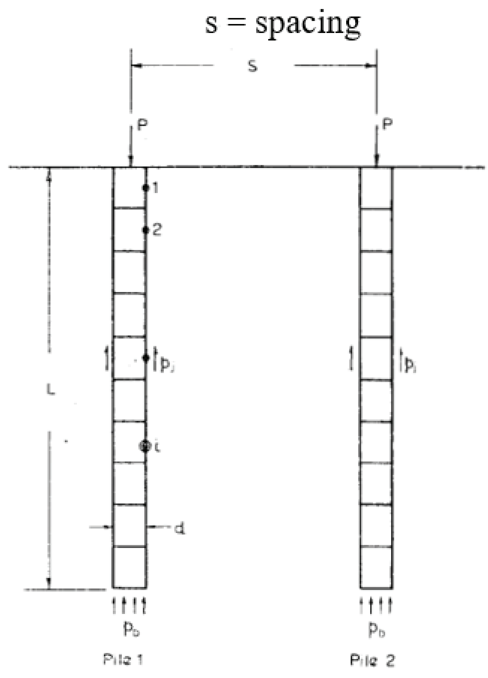


Fig. 2. Pile Interaction, Poulos and Davis (1980)

In the recent years, due to the development of numerical software, soil structure interaction based on finite element analysis has flourished and start to be a custom in conducting settlement analysis under 2D, Celik (2019) and 3D, Hamderi (2018), Gowthaman and Nasvi (2017), Janda et al. (2009) conditions. There are a number of advantages in employing FEM such that it is possible to model non homogeneous soil layer with complicated material model, comprehensive effect of construction staging (i.e. excavation, fill, structural reinforcement, tunneling) and non-horizontal soil surface.

Despite of FEM capability in modelling such complex geometry and staging construction, settlement analysis is commonly conducted by assuming horizontal surface without considering complicated construction process for practical purposes. However, it is important to note initial stress due to model geometry and change in stress due to construction activity Soomro et al. (2018) might affect settlement analysis.

In this paper, 3D finite element analysis by using MIDAS GTS NX is conducted in order to assess the effect of construction activity such as excavation, fill and non-linear soil surface to the settlement analysis. Comparison is conducted by performing another analysis where construction activity is not considered and soil surface is horizontal.

2 METHOD

Assessment on the effect of construction activity is carried based on a parking lot building construction in Bali. The parking lot is constructed on top of mountainous area where non-horizontal soil surface is quite significant due to sloping ground. Soil investigation is carried by conducting 3 boreholes with SPT with locations are shown in Fig. 3. The boreholes are located diagonally across the building plan area. Based on the surface contour and soil investigation data, 2 types of 3D model which are shown in Fig. 4 (Model A) and Fig. 5 (Model B) are constructed. Fig. 4a shows the geometry of the model prior to construction where the whole mountainous area is modelled. Fig. 4b shows the post construction geometry where excavation to the cut off level, fill construction (shaded in black colour mesh) for levelling are modelled. As the purpose of the paper is to evaluate the effect of initial stress to the settlement analysis result, the displacement due to construction activities are reset to zero. Fig. 5 shows the geometry when the construction activities are not considered. Material parameters are shown in Table 1.

Table 1. Model Parameters.

Name	Mohr Columb E (kPa)	 ν (-)	 γ (kN/m^3)	 c (kPa)	 ϕ (^{0})
01. Fill	10000	0.3	18	5	30

Name	Hardening Soil u	 g	 $E_{50,ref}$ (kPa)	 $E_{oed,ref}$ (kPa)	 $E_{ur,ref}$ (kPa)	 ϕ (^{0})	 c' (kPa)
01. Silt	0.2	18	5150	5150	30897	25	9
02 Medium Sand	0.2	16	11135	11135	66812	30	0.00
03 Very Dense Sand	0.2	20	37183	37183	223099	39	0.00
04. Medium Sand	0.2	19	20589	20589	123532	35	0.00
05 Dense Sand	0.2	20	22924	22924	137543	38	0.00
06 Gravel	0.2	21	36162	36162	216971	41	0.00

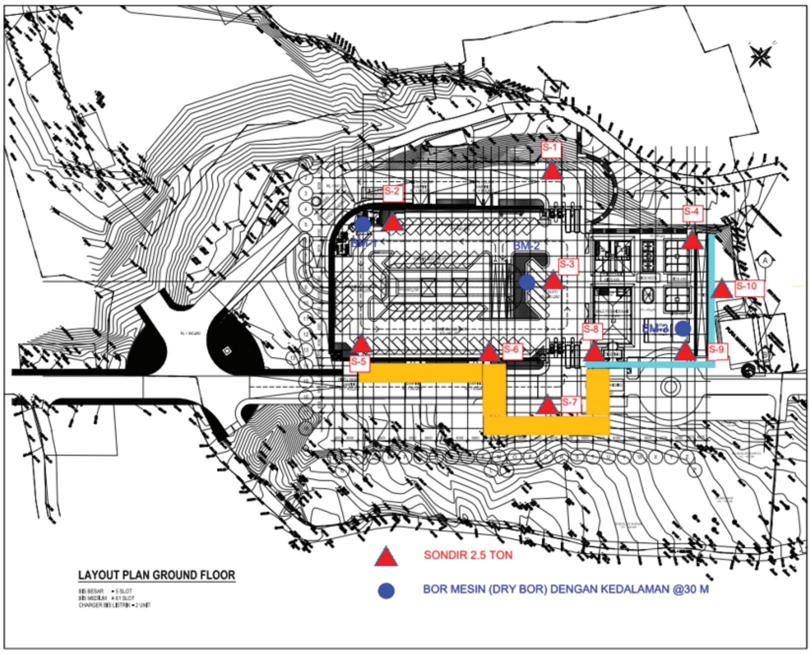
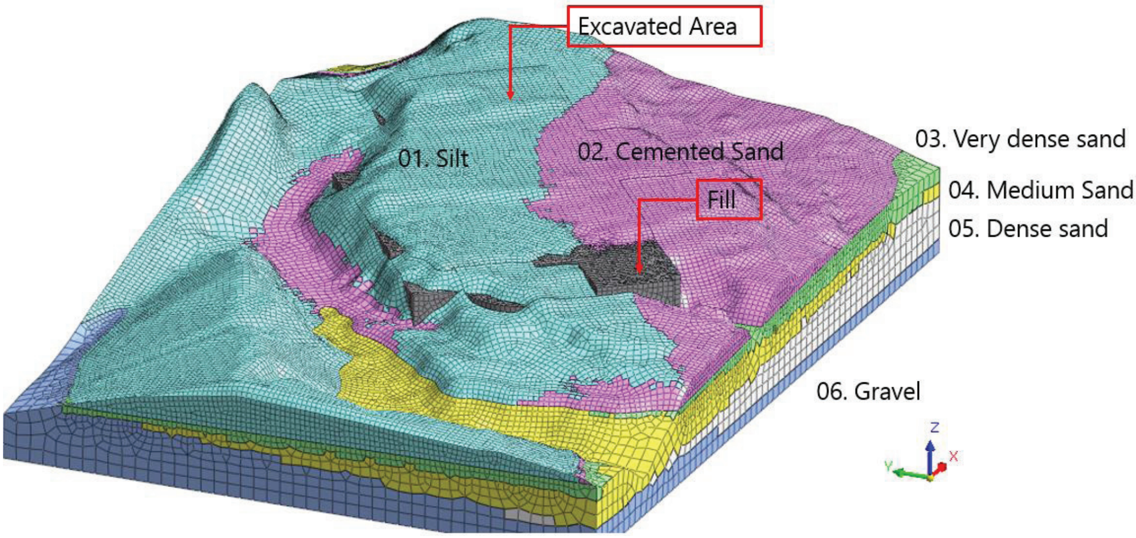
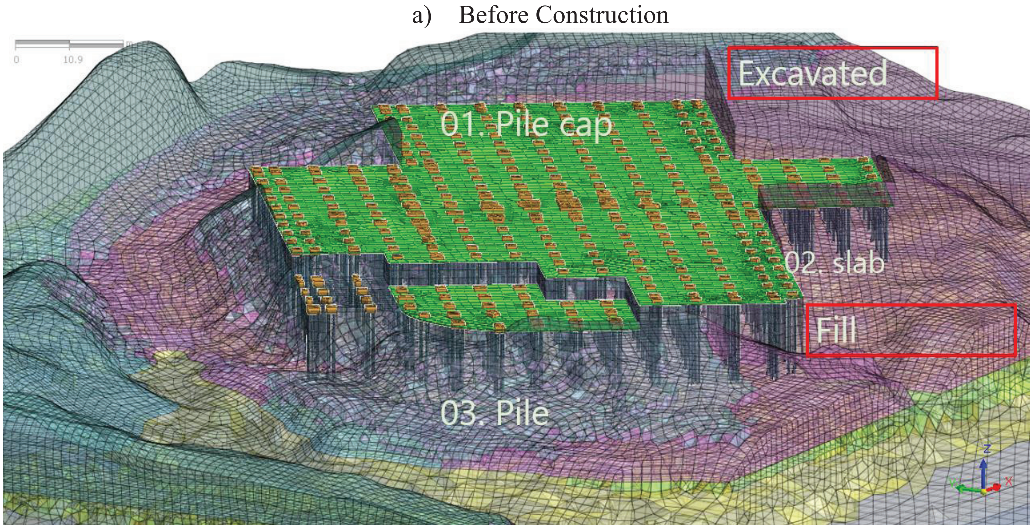


Fig. 3. Borehole Data.



a) Before Construction



b) After Construction

Fig. 4. 3D Model A.

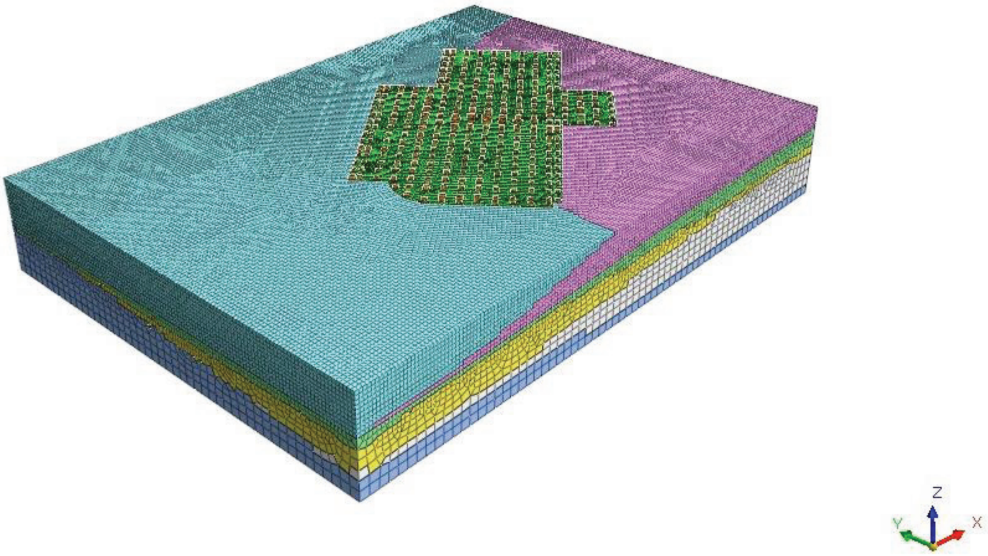


Fig. 5. 3D Model B.

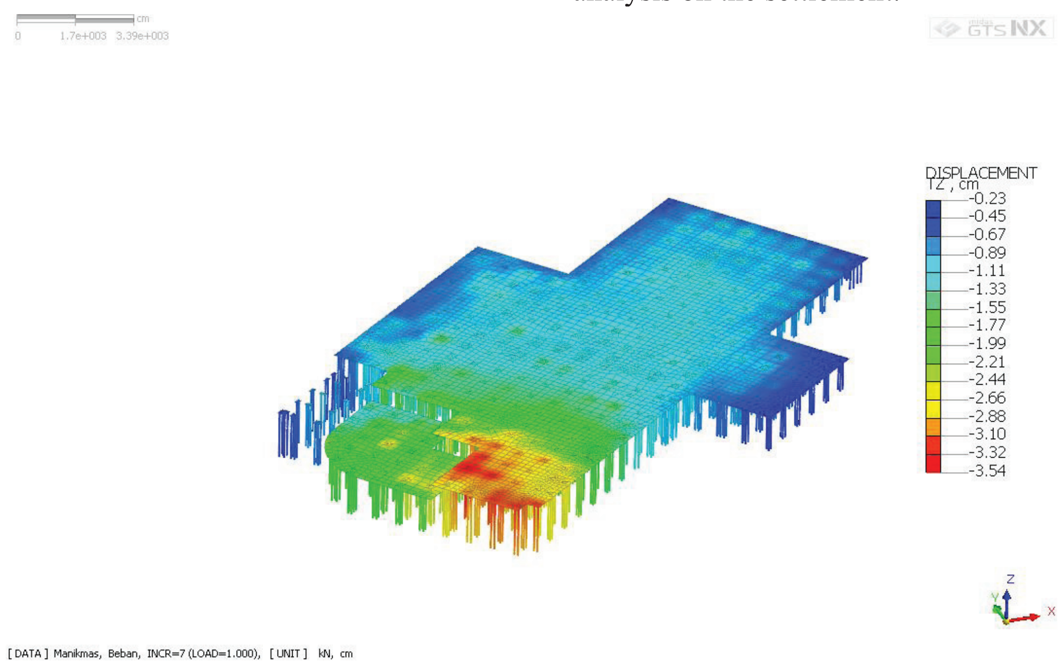
3 ANALYSIS AND RESULT

In settlement analysis, it is usually of interest to reset displacement to zero prior to applying column load. This is commonly done to determine additional deformation due to column load.

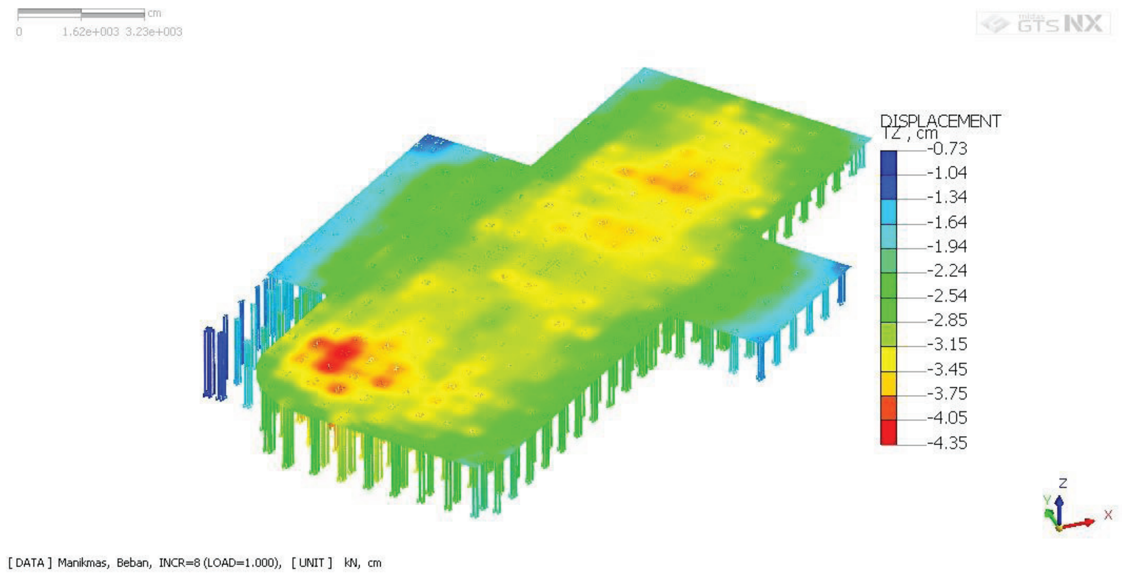
Comparison between settlement produced by model A and model B after pile installation is shown in Fig. 6. It is shown that while the maximum settlement is quite similar (3.54 cm for model A and 4.35 cm for model B), the settlement distribution is significantly different.

In model A, excavated area (center of the raft) experience very small settlement compared to fill area. Settlement at the excavated area is only about 1 cm. On the other hand, in model B, there is no excavation and fill activities, hence settlement is not realistic as it does not consider the effect of construction history as indicated with high settlement at the center of the raft (around 3 cm).

This comparison shows construction activities such as fill and excavation, as well as surface geometry highly affect the initial stress of soil prior to settlement analysis and hence must be considered in order to obtain realistic analysis on the settlement.



a) Settlement for Model A



b) Settlement for Model B
Fig. 6. Settlement Result.

4 CONCLUSIONS

In this paper, the effect of construction activities such as fill and excavation and also the surface geometry to the settlement analysis has been evaluated by using 3D finite element analysis. Comparison is made by conducting 2 FEM analysis where in the first analysis, construction activities such as fill and excavation as well as surface geometry is modelled. In the second analysis, soil surface is assumed to be horizontal and the construction activities are not modelled. The comparison shows that without considering the construction activities, settlement is unrealistic. Hence, it is important to model construction activities and surface geometry especially on the mountainous area in order to model a more realistic initial stress which leads to more realistic settlement profile.

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