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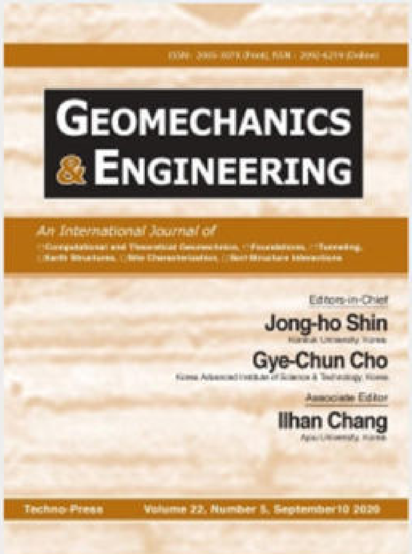

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Table of Contents

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CONTENTS

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Simplification analysis of suction pile using two dimensions finite element modeling

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Abstract. This paper presents the results of parametric analyses to compute the axial capacity of a suction pile using 2D and 3D finite element approaches. The study is intended to simplify the process of analyzing suction piles from 3D to 2D model. The research focuses on obtaining the coefficient to be applied into the 2D model in order to obtain results that are as close as possible to the 3D model. Two 2D models were used in the analysis, namely the plane strain and axisymmetric models. The analyses were performed using two actual offshore soil data of the North and West Java Indonesia. The study reveals that the simplification of model through 2D Finite Element is achievable by applying the appropriate coefficient to the stiffness parameters. The results show that the simplified model of the 2D FEA provides more conservative results (with the difference between 2% to 7%) than the 3D FEA.

Keywords: suction pile; 3D FEA; 2D FEA; simplification analysis

1. Introduction

One of the types of foundation that is commonly used in offshore is suction pile. Suction piles (also called suction caissons or suction anchors) are a long steel cylinder topped with a pile top or cap especially for mooring applications (Tjelta, T. I. 2001, Samui and Kim 2013, Sadeghipour Chahnasir *et al.* 2018, Toghroli *et al.* 2018b, Zidan and Ramadan 2018). According to (Erzin and Gul 2013, Malekpoor and Poorebrahim 2014, Al-Mahbashi *et al.* 2015, Hosseinpour *et al.* 2018, Yilmaz and Fidan 2018, Zandi *et al.* 2018), the advantages of suction piles are that they are relatively easy to be installed and retrieved cost efficient and reliable (Tjelta, T. I. 2001, Andersen, K. H. and Jostad, H. P. 1999). However, the design process of a suction anchor is often distinctive and requires more consideration to be applied in common soil-pile modelling software; the load inclination, load attachment point and interface strength for instance, need to be carefully considered (Tjelta, T. I. 2001, Edgers, L. Lars Andersen dan H. P. Jostad. 2009, Bhargava *et al.* 2003, Khorami *et al.* 2017b, Heydari and Shariati 2018). Therefore, 3D Finite Element Analysis (FEA) is commonly used in analyzing suction pile for design purposes (Sinaei *et al.* 2012, Shariati *et al.* 2015, Shafaei *et al.* 2017). The FEA, is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis (Shariati *et al.* 2010, Arabnejad Khanouki *et al.* 2011, Daie *et al.* 2011, Shariati *et al.* 2011, Jalali *et al.* 2012, Sinaei *et al.* 2012, Mohammadhassani *et al.* 2013, Shariati 2013, Shariati *et al.* 2013, Mohammadhassani *et al.* 2014a, Mohammadhassani *et al.* 2014b, Shariati *et al.* 2014a, Shariati *et al.* 2014b, Toghroli *et al.* 2014, Toghroli Ali *et al.* 2014, Shariati *et al.* 2015, Safa *et al.* 2016, Shahabi *et al.* 2016, Tahmasbi *et al.* 2016, Toghroli *et al.* 2016, Khorami *et al.* 2017a, Khorami *et al.* 2017b, Khorramian *et al.* 2017, Chahnasir *et al.* 2018, Heydari and Shariati 2018, Hosseinpour *et al.* 2018, Ismail *et al.* 2018, Paknahad *et al.* 2018, Sadeghipour Chahnasir *et al.* 2018, Sedghi *et al.* 2018, Shariat and Shariati 2018, Shariat *et al.* 2018, Toghroli *et al.* 2018c, Wei *et al.* 2018, Zandi *et al.* 2018).

This study is proposed to simplify the process of analyzing suction piles from 3D to 2D FEA. Hence, the analysis becomes relatively simpler, faster and cheaper compared to the 3D analyses (Singh *et al.* 1992, Maleki and Bagheri 2008, Tahmasebinia *et al.* 2012). The simplified model is not intended to fully replace the 3D model but can be used as an alternative for simple cases or for basic analyses. Two 2D models were used in the analysis, i.e., the plane strain and axisymmetric models, and the results were

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then compared to the 3D FEA. The analyses were performed using two actual offshore soil data of the North and West Java Indonesia. The modelling was done with PLAXIS, both PLAXIS 3D (Ismail *et al.* 2018, Paknahad *et al.* 2018, Wei *et al.* 2018) and 2D (Mohammadhassani *et al.* 2015). The calibration factor and other adjustments were made to obtain a justifiable pile capacity to ensure the stability of the pile in practice.

The evaluation of performance in calculating the capacity of suction anchors structures in clay focuses on soil-structure interface elements modelling (Khorami *et al.* 2017a). With regard to this, this study focuses on vertical capacity modelling and its simplification method using 2D and 3D finite element approaches.

2. Methodology

Generally, this study consisted of two stages. The first stage was comparing the results from the 3D model with the 2D plane strain and axisymmetric models using simple normally consolidated clay with soil properties as listed in Table 1. Mohr-Coulomb model with cohesion equal to the undrained strength ($c = s_u$) and the friction and dilatancy angles equal to zero ($\varphi = \psi = 0$), were used in the analysis.

In this study, the geometry of the suction pile was modelled based on (Toghroli *et al.* 2018a). The analyses were conducted using PLAXIS 3D and PLAXIS 2D. Figs. 1-2 illustrate the 3D (Brinkgreve *et al.* 2016a) and 2D (Brinkgreve *et al.* 2016b) finite element model of the suction pile, respectively. The objective of this stage is to gain a better understanding on the process of modeling in 3D and 2D analyses and to determine the coefficient to adjust the results of the 2D models based on the 3D model.

The second stage was using real-case soil data for the model and to verify or adjust the coefficient from the previous stage. The real soil data obtained from Northern Java Sea and West Madura Indonesia were used in the model, as displayed in Tables 2 and 3. The suction pile was modeled as plate with the material properties similar to that of (Shahabi *et al.* 2016) as shown in Table 4. Based on (Pollestad 2015), the stiffness is very large in order to ensure that the caisson remained rigid. On the other hand, the interface between soil-structure was 0.65 as proposed by (Toghroli Ali *et al.* 2014, Sedghi *et al.* 2018).

Table 1 Soil Parameters used in analysis

Parameter		Value	Unit
Name	Symbol		
Soil Weight	γ_{sat}	15	kN/m^3
Modulus Young	E'	5000	kN/m^2
Poisson Ratio	ν'	0.35	-
Shear Strength	s_u	50	kN/m^2
Friction Angle	ϕ_u	0	°

Table 2 Soil parameters of Northern Java Sea

Parameter	Layer 1	Layer 2
Soil Description	Clay	Clay
Depth (m)	0-10	10-22
Soil Weight (kN/m^3)	4.5	9.0
Shear Strength (kPa)	2-18	80

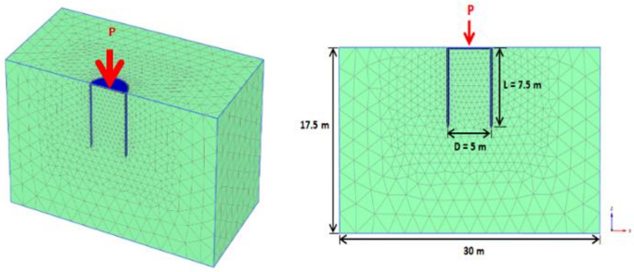
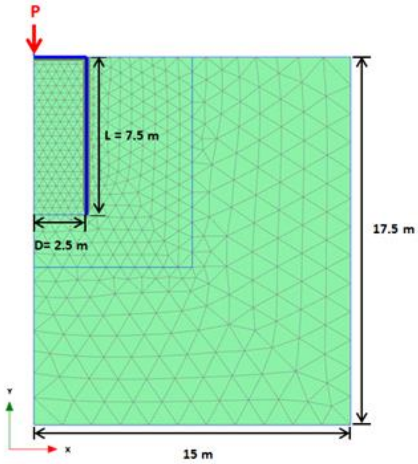
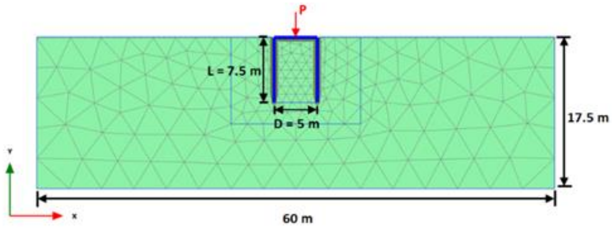


Fig. 1 3D modelling of suction pile



(a) Axisymmetric model



(b) Plane strain model

Fig. 2 2D modelling of suction pile

Table 3 Soil Parameters of West Madura Indonesia

Parameter	Layer 1	Layer 2
Soil Description	Clay	Clay
Depth (m)	0-20	20-25
Soil Weight (kN/m^3)	3.7	6.2
Shear Strength (kPa)	2-10	20-28

Table 4 Parameters used for suction pile (Pollestad 2015)

Description	Parameters
EA	1.40 E+11 kN/m
EI	2.90 E+07 kNm^2/m
Thickness	0.05 m
v	0.15

3. Result of analyses using generic soil data

In the process of modelling the 2D FEA axial capacity, an issue occurred in calibrating the stiffness of the pile to match the 3D FEA model. The results of the analyses are illustrated in Fig. 5, for the 3D and 2D FEA, respectively. The results of the analyses showed very similar failure pattern of the models as depicted in Fig. 5 for the 3D and 2D analyses, respectively.

The calibration factor was achieved through iteration process and is used for comparing the results between the 3D and 2D models based on the percentage of error of ultimate stress of the suction piles using several diameters, i.e. 2.5 m, 5.0 m, and 10.0 m. It can be seen from the graph that generally, by increasing the coefficient value, the results from the 2D analyses will be getting closer to the 3D analysis as shown in the percentage of errors. The coefficient exceeded the value of 30; the reduction of errors became insignificant. Therefore, the value of 30 was selected for this study as the coefficient to multiply the stiffness factor in the 2D analyses. The results of the analyses are presented in details

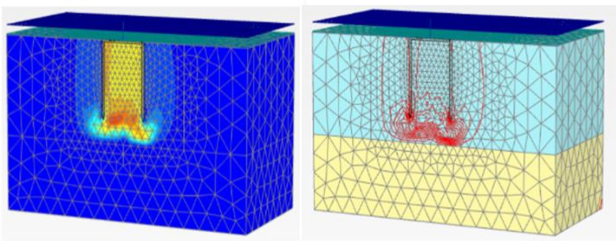


Fig. 3 Results of 3D FEA

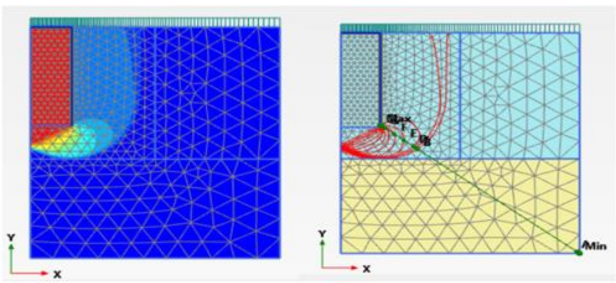


Fig. 4 Results of 2D FEA axisymmetric model

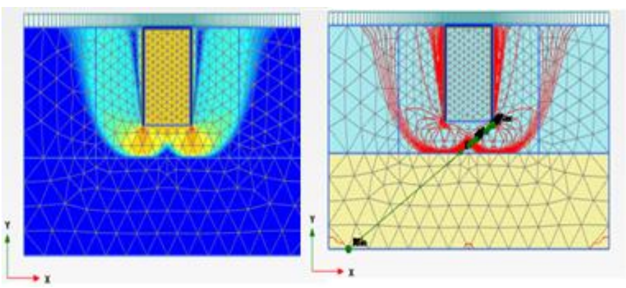


Fig. 5 Results of 2D FEA plain strain model

Table 5 Comparison results between 3D and 2D analyses using coefficient of 30

Table 5 Continued

Model	Ultimate Stress (kN/m^2)
3D	320
2D Axisymmetric	315
2D Plain Strain	306

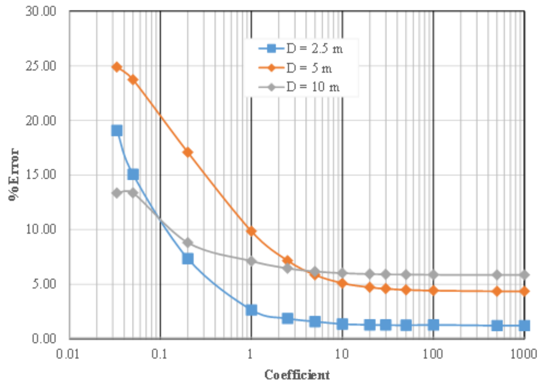


Fig. 6 Calibration factor graph

4. Result of analysis using actual soil data

In order to validate the previous results, the comparison analyses were also performed using actual soil data of offshore Northern Java and West Madura Indonesia as presented in Fig. 3, respectively. In the analyses, the stiffness parameters of the suction pile such as EA and EI for the 2D FEA are multiplied with the coefficient factor obtained from the previous analysis. The results of the analyses of the offshore Northern Java (ONJ) can be seen in Fig. 8 for the 3D and 2D FEA, respectively. Based on the analysis, the results from the 2D models are relatively close to the 3D model. The differences are between 3% and 7% as shown.

The results of the analyses of the offshore West Madura (OWM) are illustrated in Fig.10 for the 3D and 2D FEA, respectively. Based on the analysis, the results from the 2D models are relatively close to the 3D model. The differences are between 3% and 5% as shown.

The difference of running times between the 3D and 2D analyses is significant. Based on the results, the 2D analyses are at least 60 times faster than the 3D analysis. Therefore, the simplified model will be very helpful for basic analyses using various parameters of suction pile. Nevertheless,

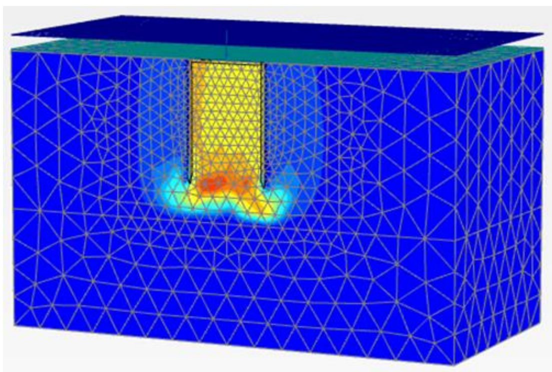
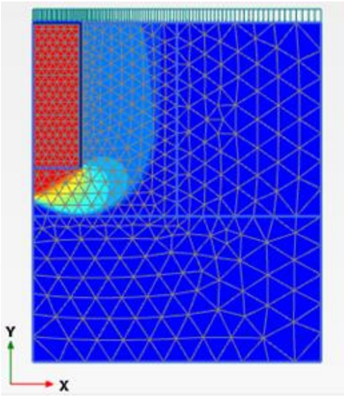
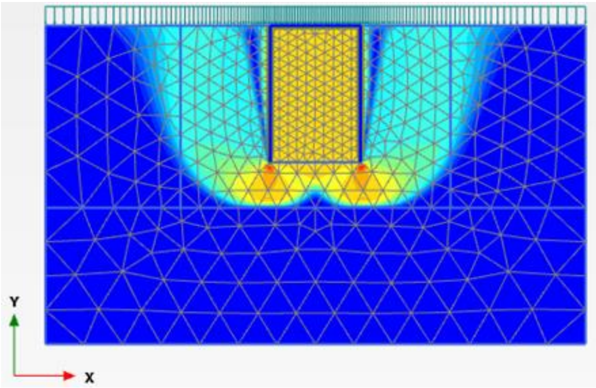


Fig. 7 Results from 3D FEA on ONJ



(a) Axisymmetric model



(b) Plane strain model

Fig. 8 Results from 2D FEA on ONJ

Table 6 Comparison results between 3D and 2D analyses for ONJ

Model	Ultimate Stress (kN/m^2)
3D	110
2D Axisymmetric	106
2D Plain Strain	102

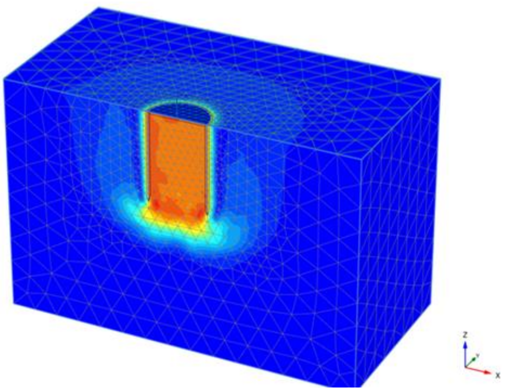


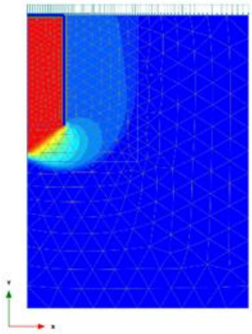
Fig. 9 Results from 3D FEA on OWM

Table 7 Comparison results between 3D and 2D analyses for OWM

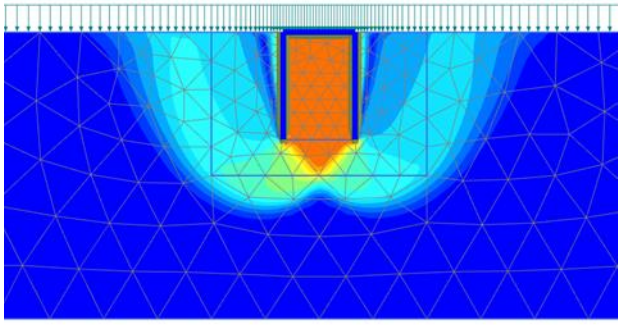
Model	Ultimate Stress (kN/m^2)
3D	46.1
2D Axisymmetric	44.8
2D Plain Strain	43.8

Table 8 Running time for each model used in the analysis

Model	Running time
3D	±1 hour 30 minutes
2D Axisymmetric	±1.5 minutes
2D Plain Strain	±0.5 minutes



(a) Axisymmetric model



(b) Plane strain model

Fig. 10 Results from 2D FEA on OWM

further analyses using 3D models are still required for detailed analyses or detailed design stage.

5. Conclusions

In this study, applying the coefficient of 30 to the stiffness parameters such as EA and EI to the 2D model will provide relatively close results to the 3D FEA. Both the 2D analyses presented more conservative results than the 3D FEA with the differences between 3% and 7%. This study presents our preliminary results for comparing 3D and 2D analyses using FEM for suction piles. Further research is proposed with more variation of soil data and geometries of the suction piles to allow the corrected factor to be validated more accurately. Further research is also needed for applying lateral loads or combination loads between vertical and lateral loads.

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