Limit Analysis of Helical Piles on Soft Soils

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ABSTRAK: Pondasi helikal mempunyai potensi untuk diaplikasikan pada tanah lunak. Studi ini meneliti perilaku pondasi helikal dibawah beban tekan, dengan menggunakan elemen hingga limit analisis yaitu software OPTUMG2. Variasi yang digunakanan adalah diameter pelat helikal yaitu 35cm (L), 25cm(M) dan 15cm (S), spasi antar pelat helikal yaitu 20cm,30cm dan 50cm dan jumlah pelat. Hasil penelitian menunjukkan bahwa semakin besar spasi pelat maka daya dukung pondasi juga bertambah besar. Untuk spasi pelat yang sama , daya dukung pondasi helikal dengan 2 pelat besar (LL) lebih besar dari pondasi helikal dengan 2 pelat LM dan 3 pelat (diameter mengecil) LMS. Studi juga menjukkan daya dukung semakin besar ketika jumlah pelat semakin banyak. Namun daya dukung pondasi 2 pelat LM lebih besar dari 3 pelat LMS. Visualisasi disipasi geser untuk LL menunjukkan bahwa untuk rasio spasi terhadap diameter 0.6-1.4 mekanisme keruntuhan adalah cylindrical shear. Demikian pula halnya untuk pondasi LM dengan s/D1-2.5.Untuk pondasi LMS ketika spasi makin bertambah besar mekanisme keruntuhan cenderung berubah dari cylindrical shear menuju individual bearing.

Kata Kunci: pondasi helikal, limit analisis, tanah lunak

ABSTRACT: Helical pile has potential application for the foundation construction on soft soils. This study investigated behavior of helical pile under compressive load using finite element limit analysis i.e. OPTUMG2. The variation of of helical plate diameters are 35cm (L), 25cm(M) and 15cm (S) with helical plate spacing of 20 cm, 30 cm, and 50 cm. In addition effect of number of helical plate was also analyzed. The results show that helical plate spacing increases the bearing capacity. For the same spacing, two helical plates (LL) have larger bearing capacity than two helical plates of different diameter (LM) and three helical plates (LMS). Number of helical plate with the same diameter was found to increase bearing capacity i.e. LLL>LL>L. However, two helical plates (LM) has larger bearing capacity than three helical plates of LMS. For LL helical piles with various spacing used in this study i.e. spacing to diameter ratio (s/D) 0.6-1.4, this study reveals that failure mechanism is cylindrical shear.Likewise is for those of LM helical piles with s/D of 1-2.5. For LMS helical pile with s/D range from 0.8-2 the failure mechanism tend to change from cylindrical shear towards individual bearing.

Keywords: helical piles, limit analysis, soft soil

1 PENDAHULUAN - INTRODUCTION

Soft soils (i.e. soft clay, silty and peat) cover about 10% or about about 2 million ha of Indonesia land. These soils have low bearing capacity and is highly compressible. On the other side as the need of land becoming for the economic development becoming high some construction has to be constructed on these problematic soils.

In the past wooden piles is widely used as foundation on soft soils. Due to environmental reason and as the wood becoming scarce, it is necessary to find alternatives type of foundation. One of the possible alternatives is helical piles.

This study investigated behaviour of single helical pile on soft soils using OPTUMG2, a geotechnical finite element limit analysis software developed by OPTUM Inc (2017). The study varied the number of plates, diameter and spacing between the plates.

1.1 *Limit Analysis*

Limit analysis was first developed by Drucker et al (1951). The method assumes small deformation, a perfect plastic (Figure 1a), as an approximation of true non-linier soil behavior and an associate flow rule (Figure 1b). It implies that plastic strains rate ε_{ij} are normal to yield surface $f(\sigma_{ij})$. For this plasticity model material, velocity and strain rate are required instead of displacement and strain (Sloan, 2013).

Limit analysis consist of lower bound and upperbound theorem. Lower bound theorem states that a body of elastic-plastic material will not collapse under a stress field that satisfies equilibrium, stress boundary condition and yield condition. Whereas upperbound theorem states that for a displacement field that satisfies strain displacement relation, associated flow rule and displacement boundary condition then the ratio of internal work is higher or equal to that actually found at collapse. Hence the upperbound of collapse load is obtained. The true collapse load is between the lowerbound and upperbound solution.

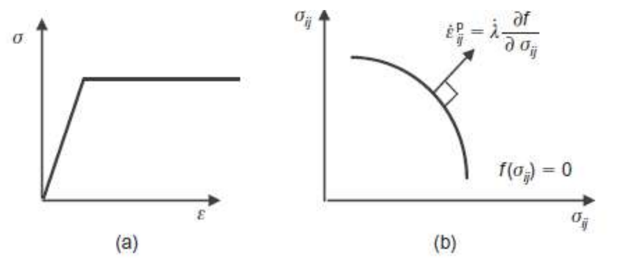


Fig. 1. Perfect plastic model(a)associated flow rule (Sloan, 2013)

1.2 *Theoretical Helical Pile Capacity*

According to Prasad and Rao (1996) helical piles is a foundation which has one or more helical plates that welded to steel rods at determined spacing. Generally bearing capacity of helical pile can be calculated using individual plate bearing method or cylindrical shear method.

Individual plate bearing method (Figure 2a) assumes that bearing capacity consist of soil bearing capacity below the plate plus the adhesion (friction) between the helical shaft with soils (Perko, 2009) . Thus the theoretical ultimate helical pile capacity, P_u, can calculated as

$$P_u = \sum q_{ult} A_n + \alpha H \pi D \qquad (1)$$

where

q_{ult} = stress under each helical plate=$9S_u$
Su= undrained shear strength
A_n= n^{th} helical plate area
α = Adhesion between soils and foundation=$2/3S_u$
H = Length from the ground surface to helical plate at the top
d = diameter helical rod

Cylindrical shear method (Figure 2b) assumes that the whole soil volume between the helical plate is mobilized into one cylindrical unit (Mooney et al., 1985). The bearing capacity is the summation of the stress at the bottom of helical pile, total shear strength formed by cylindrical soil with soil and adhesion of helical pile with soil. Based on the assumption the theoretical helical capacity can be determined as

$$P_u = q_{ult} A_1 + T(n-1)s\pi D_{avg} + \alpha H \pi d \qquad (2)$$

Where

q_{ult} = stress under bottom of helical plate=$9S_u$
T=Su= undrained shear strength
A_1= bottom helical plate area
n= number of plates
s= helical plate spacing
D_{avg}= average diameter of helical plates
α = Adhesion between soils and foundation=$2/3S_u$

Theoretically when spacing to helical diameter plate ratio(s/D) is large the mechanism is individual bearing whereas the ratio is small then cylindrical shear mechanism govern. Merifield (2010) stated that if s/D less than critical s/D ≈1.6 than the failure mechanism is cylindrical shear whereas s/D than critical s/D than individual bearing mechanism govern.

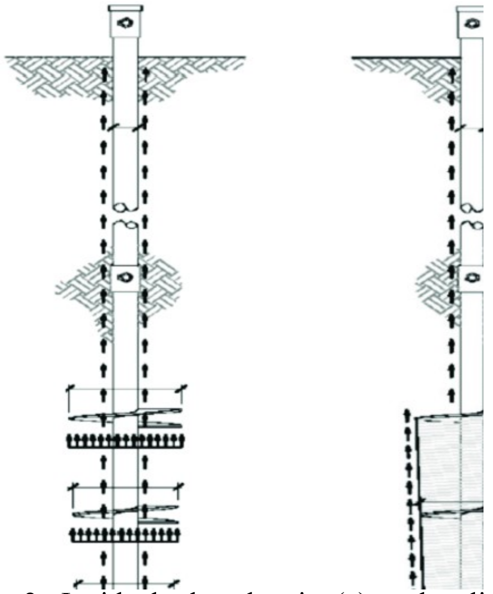


Fig. 2. Invidual plate bearing(a) and cylindrical shear (Perko, 2009)

2 METHODOLOGY

2.1 *Model Numbering*

In this study the helical pile models are named according to its helical plate diameter: large (L) i.e 35cm, medium (M) i.e. 25cm and small (S) i.e. 15cm. Spacing are 20,30 and 50cm. For example LMS20 means three helical plate size L,M and S with spacing of20cm. Table 1 presents the variation of helical piles used in this study (note: t=top;m;middle;b=bottom)

Table 1 Helical pile variation used

ID	L (cm)	s (cm)	D (cm)		
			t	m	b
L50	200	-	-	-	35
LLL50	200	50	35	35	35
LM 20	200	20	35	25	15
LM 30	200	30	35	25	15
LM 50	200	50	35	25	15
LMS 20	200	20	35	25	15
LMS 30	200	30	35	25	15
LMS 50	200	50	35	25	15

2.2 *Geometry , soil layer and load*

The model dimension is 3mx2.8m. Helical pileis 2m length, 0.5m above the ground surface, 1.5m embedded below the ground surface (Fig 3). The geometry of the model was chosen to simulate the laboratory model (Fadhilah, 2018). Helical pile is made from steel with *young modulus* E= 2 x 10^5 MPa and *yield strength* fy= 345 MPa. The whole model is axy-symmetry with helical rod is treated as connector. Helical plate is modelled as circular plate with properties of *sectional area (S), plastic section modulus (M)* dan *moment of inersia(I)*. Helical pile properties are shown in Table 2.

The ground water table is located at the ground surface. The soil consist of two layers i.e. peat and Clay layer with the properties are given in Table 2.

Helical pile is loaded with 1 kPa at the test desk (area of 2083.8cm^2). Constant load was modeled as multiplier load with distributed type load.

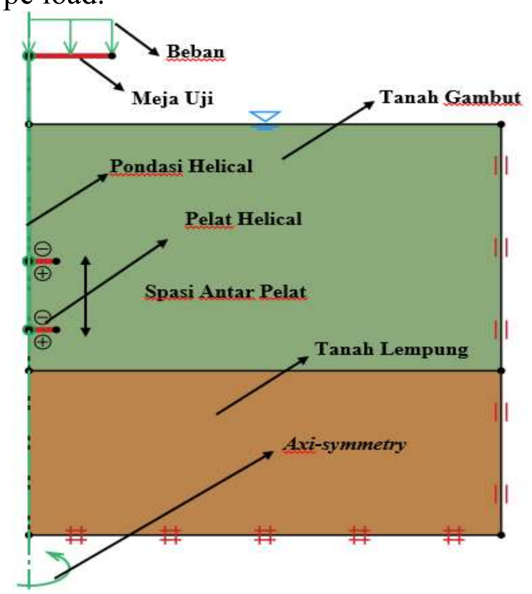


Fig. 3. Axi-symmetry model

Table 2 Helical pile properties

Var	*Rod*	Plate		
		L	M	S
L (cm)	200	-	-	-
Dia (cm)	6	35	25	15
S(cm^2)	28	962	490	177
M(cm^3)	-	4209	1534	88
I(cm^4)	-	73661	19175	331
E(MPa)	2x10^5			
fy(MPa)	345			

Table 3 Soil properties

Parameter	*Mohr Coulomb*	
	Peat	*Clay*
	Drained	*Undrained*
H(m)	1.8	1.2
γ_{sat}(kN/m^3)	12	21
γ_{unsat}(kN/m^3)	11	21
E(MPa)	0.3 - 3	50
υ	0.25	0.25
Φ(°)	25	22
C(kPa)	2	20
k(m/s)	10^{-4}	10^{-6}

3 RESULTS

3.1 *Bearing capacity analysis*

Results of the simulation with various helical plate diameter, spacing and cumber of plate are shown in Table 4. Bearing capacity is obtained by multiplying the load multiplier with area of desk test. Analysis was then conducted based on the table as shown by Fig. 4 to Fig. 6.

Table 4 Results

ID	Load Multiplier	Bearing capacity (kN)
	(A)	(B)
LL20	221.800	46.219
LL30	240.300	50.074
LL50	261.300	54.450
L50	188.600	39.300
LLL50	306.500	63.868
LM 20	202.000	42.093
LM 30	212.200	44.218
LM 50	230.300	47.990
LMS 20	198.900	41.447
LMS 30	210.800	43.927
LMS 50	219.800	45.802

Fig. 4 shows that reveals that, for the same spacing, LL has largest bearing capacity followed by LM and LMS. This trend applies to LL, LM and LMS.n general LL bearing capacity is about 10-19% larger than LM and LMS. Figure 4 shows that larger helical plate spacing increases bearing capacity, as also indicated by Fig. 5.

Fig. 6 shows that larger number of helical plates results in larger bearing capacity. LLL 50 and LL50 have bearing capacity larger than L50 I.e. about 62.5% and 38.5%. Interestingly, although LMS has larger number of helical plate than LM, it has greater bearing capacity(about 48kN compared to 45.8kN). It reveals that addition of helical plate with smaller diameter does not contribute to bearing capacity.

Fig. 7 shows comparison of LM and LL variation for various helical plate spacing. The figure reveal that larger diameter results in larger bearing capacity.

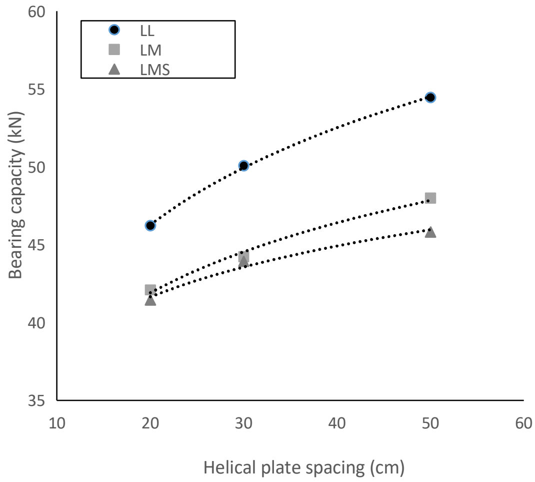


Fig. 4. Bearing capacity comparison.

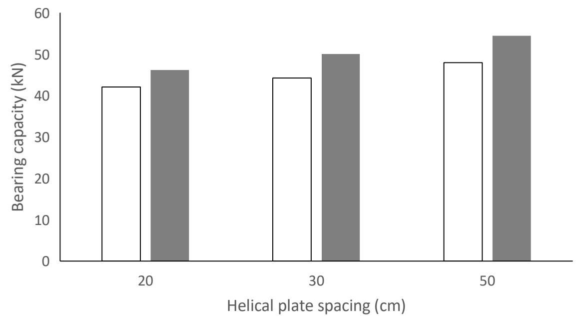


Fig. 5. Effect of helical spacing of LL variation

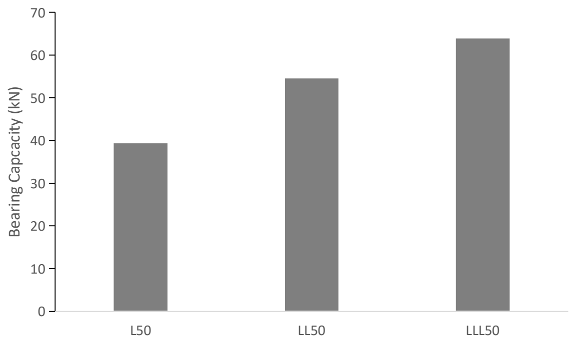


Fig. 6. Effect of number of plate

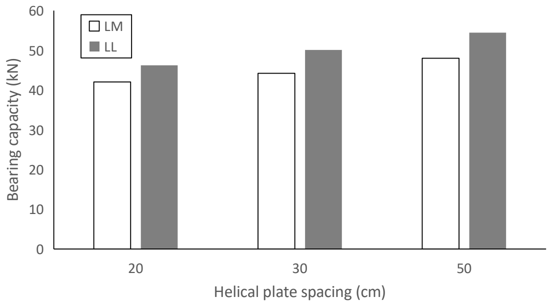


Fig. 7. Effect of diameter of helical plate

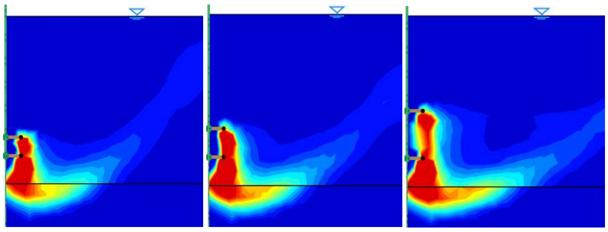
3.2 *Failure mechanism analysis*

Failure mechanism in term of shear dissipation for all variations are presented in Fig. 8 to Fig. 12. In general those figures reveal that there is no shear mobilized on the helical rod. Shear starts from the top of helical plate to the plate and soil below. It means bearing capacity contribution is mainly from the helical plate.

Fig. 8 to Figure 10 shows that generally LL(s/D=0.6-1.4), LM (s/D*=1-2.5) and LMS(s/D*=0.8-2) the mechanism is mainly cylindrical shear, as indicated by contour of shear dissipation which is continuous from helical plate at the top and at the bottom. It should be noted that for LMS50 as spacing increases there is tendency toward individual bearing failure mechanism. Fig. 8 to Fig 10 also reveal that mobilized shear area is larger as the helical plate spacing increases. This explain why bearing capacity increase as the the spacing become larger.Note:D*=average D

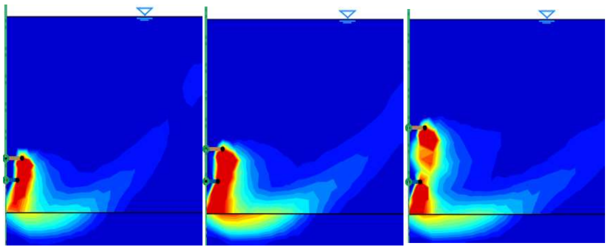
Fig. 11 shows shear dissipation considering the effect of number of helical plate i.e. L50, LL50 and LLL50. Those figures shows that area of shear dissipation increases in addition to the number of helical plates. This explains larger bearing capacity as number of helical plate increases, as presented in Table 4.

Additional variation of LS is shown also just to clarify the effect of S/D as shown by Fig. 12. It can be seen clearly than as the helical plate spacing increase the mechanism tend to be individual bearing. Fig 12b shows that the shear dissipation area is weakly connected between the top and bottom helical plate. Fig 12c shows localized shear dissipation which clearly indicates individual bearing mechanism.



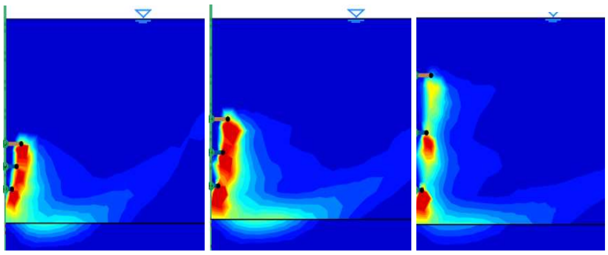
(a) (b) (c)

Fig. 8. Shear dissipation for LL20,LL30 and LL50



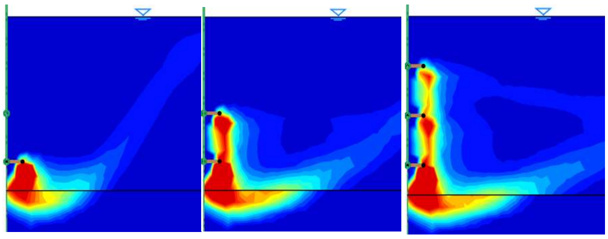
(a) (b) (c)

Fig. 9. Shear dissipation for LM20, LM30 and LM50



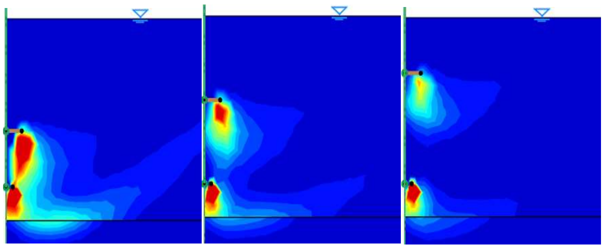
(a) (b) (c)

Fig. 10. Shear dissipation for LMS20, LMS30 and LMS50



(a) (b) (c)

Fig. 11. Shear dissipation for L50, LL50 and LLL50



(a) (b) (c)

Fig. 11. Shear dissipation for LS50, LS75 and LS100

4 CONCLUSIONS

Numerical modelling of helical pile behavior on soft soil have been conducted. This study shows that bearing capacity increases as the helical plate spacing increases. For the variation used in this study, LL have larger bearing capacity LM and LMS. Bearing capacity also increases as number of helical plate of the same diameter increases i.e LLL>LL>L. Two helical plates (LM) has larger bearing capacity than three helical plates of LMS. For LL helical piles with various spacing used in this study i.e. spacing to diameter ratio (S/D) 0.6-1.4, this study reveals that failure mechanism is mainly cylindrical shear.Likewise is for those of LM helical piles with S/D of 1-2.5. For LMS helical pile as the spacing (from 20 to 50cm) increases the failure mechanisms tend to change from cylindrical shear toward individual bearing.

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