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EFFECT OF SAFETY FACTORS ON THE CALCULATED DEFLECTION OF 1-PILE ROW FULL SCALE NAILED-SLAB PAVEMENT SYSTEM RESTING ON SOFT CLAY DUE TO CONCENTRIC LOADINGS

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Abstract

The Nailed-slab Pavement System was proposed as an alternative improving for rigid pavement performance on soft soils. Puri, et.al. (2012a) proposed a new approach for practical purpose in designing where pile friction resistance is fully mobilized and the tolerable settlement is considered. The additional modulus of subgrade reaction due to pile installing is defined by using safety factor 2.5. Effect of variation in safety factors (SF) were not considered yet. In this paper, effect of SF variation due to slab deflection will be considered by using SF 1.0 to 3.0. The slab deflection will be calculated by using beam on elastic foundation theory. Analysis will use data of loading test on 1-pile row full scale Nailed-slab by Puri, et.al. (2013). Observed deflection data will be used to determine the additional modulus of subgrade reaction. Calculated deflection based on the additional modulus of subgrade reaction is compared to the observed deflection. Results show that SF variation affects the calculated deflections. Good results are obtained in the sense that the calculated settlement is in good agreement with observation. The SF = 1.0 is adequate for analysis. The Nailed-slab in the field will have extensive area and alot of number of installed pile under the slab. Hence, the performance of this system would be better due to reduction on the slab deflection.

Keywords: *Deflection, Nailed-Slab Pavement System, Safety Factor, Soft Clay, Subgrade Modulus*

1. INTRODUCTION

The Nailed-slab System was proposed as an alternative improving for rigid pavement performance on soft soils. It is also to gain the efficiency of construction implementation. The changing of the shell of *fondasi cakar ayam* (hen's claw foundation) by short-friction piles was proposed by Hardiyatmo (2008). The rigid pavement slab is nailed to the subgrade by installing the short piles underneath. The slab has double functions: as pavement structures and all at once as pile cap. The composite system is developed which consist of slab, piles, and soils surrounding the piles and slab. The installed piles under the slab make the slab keeps contact with the soils and increase the slab stiffness (Puri, et.al., 2011a). Then the slab height can be decreased. The decreasing of slab height can reduce the weight of the structure and will be beneficial for soft soils (Hardiyatmo dan Suhendro, 2003).

Physical modeling of nailed-slab and it's analytical study have been conducted for

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soft soils (Hardiyatmo dan Suhendro, 2003; Hardiyatmo, 2008, 2009, 2011; Nasibu, 2009; Dewi, 2009; Taa, 2010; Puri, et.al, 2011a, 2011b, 2012) and for sand (Somantri, 2013). Analysis of deflection of a nailed-slab by using equivalent modulus of subgrade reaction has been done by Hardiyatmo (2009, 2011), Puri, et.al. (2011b, 2012a, 2012b, 2013), Somantri (2013) and Puri (2015, 2017). This modular was also implemented in *cakar ayam* analysis (Puri & Ardiansyah, 2017; Afriliyani, et.al. 2017; Agustin, et.al. 2017).

The equivalent modulus of subgrade reaction is the cumulative of modulus of subgrade reaction from plate load test (k) and additional modulus of subgrade reaction due to pile installing (Δk). Hardiyatmo (2011) used the additional modulus of subgrade reaction based on the relative displacement between the pile and soils. The developing of formula was based on static theory. Puri, et.al. (2012a) proposed a new approach for practical purpose in designing Nailed-slab System where pile friction resistance is fully mobilized and the tolerable settlement is considered.

The proposed method of analysis is based on one row of pile. Practically, the Nailed-slab will be constructed by multiple rows of piles. This system will have higher capacity and stiffness. Hence, designing of the Nailed-slab System based on an analysis of the one row pile will produce a safe design (Puri, et.al. 2012a; Puri, 2015).

This paper is aimed to discuss the effects of safety factor in the additional modulus of subgrade reaction due to the prediction of deflection on nailed-slab under concentric loading. The experimental was conducted by full scale model test of one row pile nailed-slab system.

In designing the Nailed-slab, it is required an equivalent modulus of subgrade reaction due to pile bearing contribution (k'). The analytical approach of this moduli is determined by accumulating the modulus of subgrade reaction from plate load test (k) and the additional modulus of subgrade reaction due to pile installing (Δk). The equivalent modulus of subgrade reaction (k') is given as follows (Hardiyatmo, 2011; Dewi, 2009; Puri, et.al., 2011b, 2012a):

$$k' = k + \Delta k \qquad (1)$$

Where k is the modulus of subgrade reaction from plate load test (kN/m^3), Δk is the additional modulus of subgrade reaction due to pile installing (kN/m^3).

The mobilisation of unit friction resistance of pile shaft is in elastic zone (Puri, et.al. 2012a). Safety factor 2.5 is usually used in practical of determining the pile allowable bearing capacity. Then the the additional modulus of subgrade reaction due to pile installing (Δk) can be defined as

$$\Delta k = \frac{f_s A_s}{2.5\delta_a A_{ps}} \qquad (2)$$

Where δ_a is the tolerable settlement of rigid pavement slab (m), f_s is the ultimate unit friction resistance of pile shaft (kN/m^2), A_s is the surface area of pile shaft (m^2), A_{ps} is the area of plate zone which supported by single pile (m^2), and 2.5 is the safety factor.

And the Equation (2) can be written as (Puri, 2015)

$$\Delta k = \frac{f_s A_s}{SF\delta_a A_{ps}} \qquad (3)$$

The end bearing resistance of pile can be ignored for nailed-slab which resting on soft soils. Ultimate unit friction resistance of the pile shaft in saturated clay is expressed by

$$f_s = a_d c_u \qquad (4)$$

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Where a_d is the adhesion factor (non-dimensional), and c_u is the undrained cohesion of soil (kN/m^2).

The slab deflections due to the load acting on plate-supported piles can be calculated by theory of beams on elastic foundation (BoEF) (Hardiyatmo, 2009, 2011; Taa, 2010; Puri, et.al., 2011b, 2012a, 2012b; Somantri, 2013; Puri, 2015, 2017). In this case, BoEF will use Roaks formulas according to Young dan Budynas (2002). The *k* is replaced by *k'* for analysis of nailed-slab system.

INVESTIGATED 1-PILE ROW FULL SCALE NAILED-SLAB PAVEMENT SYSTEM

Detail of the procedure on 1-pile row full scale Nailed-slab is presented in Puri, et.al. (2013) and briefly described in Puri, et.al. (2014). The 1-pile row full scale nailed-slab was constructed on soft clay. The soft clay properties are presented in Table 1. The slab and piles were reinforced concrete. The concrete strength characteristic of the slab and piles was 29.2 MPa and 17.4 MPa respectively. The flexural strength of the slab was 4,397.6 kPa.

Table 1 Soft clay properties (Puri, et.al. 2013)

Parameter	Unit	Average
Spesific gravity, G_s	-	2.55
Consistency limits:		
- Liquid limit, *LL*	%	88.46
- Plastic limit, *PL*	%	28.48
- Shrinkage limit, *SL*	%	9.34
- Plasticity index, *PI*	%	59.98
- Liquidity index, *LI*	%	0.36
Water content, *w*	%	54.87
Clay content	%	92.93
Sand content	%	6.89
Bulk density, □	kN/m^3	16.32
Dry density, □$_d$	kN/m^3	10.90
Undrained shear strength, s_u	kN/m^2	20.14
CBR	%	0.83
Soil classification:		
- AASHTO	-	A-7-6
- USCS	-	CH

The Nailed-slab System Prototype dimension was 6.00 m × 3.54 m, 0.15 m in slab thickness, and the slab was reinforced by micro piles 0.20 m in diameter and 1.50 m in length. The spacing between piles was 1.20 m. This model was obtained by cutting the 600 cm × 354 cm × 15 cm Nailed-slab to 3 parts where each part consisted of one pile row. The tested 1 pile row Nailed-slab was the middle one with slab dimension 600 cm × 120 cm × 15 cm. All piles were installed under the slab and connected monolithically by using thickening slab connectors (0.40 m × 0.40 m and 0.20 m in thickness). Each end of slab is equipped by the vertical concrete wall barrier. There was a 5 cm lean concrete thickness under the slab. The slab was loaded by compression loadings with different load positions. Loads were

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transferred to the slab surface by using a circular plate 30 cm in diameter (the plate represents the wheel load contact area). Then the instrumentations were recorded. Details about testing procedure is presented in Puri, et.al. (2013, 2014).
BoEF analysis will use the "BoEF.xls software version 1.4". According to limitation of BoEF, some simplification have to be done (Puri, 2015). The pile-slab connector and vertical wall barrier were neglected. Lean concrete was also neglected. Comprehensive analysis procedure is presented in Puri, et.al (2013 and Puri (2015).

RESULT AND DISCUSSION

Modulus of Subgrade Reaction

The Eq. (3) was used to calculate the additional modulus of subgrade reaction due to one row pile installation under the slab; the results are shown in Table 2 by variation in safety factor. The tolerable settlements (δ_a) were taken by using maximum observed deflections. Equivalent moduli of subgrade reactions are included in Table 2. It seem that the □*k* and *k'* tend to decrease by increasing the load because of the increasing in slab deflection. The □*k* and *k'* tend to decrease also by increasing the safety factor.

Table 2 Modulus of subgrade reaction

Load (kN)	**δ_a=δ_s (mm)**	**Safety factor, *SF***	**Δk x 10^3 (kPa/m)**	**k' x 10^3 (kPa/m)**	**Load (kN)**	**δ_a=δ_s (mm)**	**Safety factor, *SF***	**Δk x 10^3 (kPa/m)**	**k' x 10^3 (kPa/m)**
5		1	149.32	152.62	**40**	0.93	1	16.06	19.36
		1.5	99.54	102.84			1.5	10.70	14.00
		2	74.66	77.96			2	8.03	11.33
		2.5	59.73	63.03			2.5	6.42	9.72
		3	49.77	53.07			3	5.35	8.65
10	0.27	1	55.30	58.60	**80**	2.06	1	7.25	10.55
		1.5	36.87	40.17			1.5	4.83	8.13
		2	27.65	30.95			2	3.62	6.92
		2.5	22.12	25.42			2.5	2.90	6.20
		3	18.43	21.73			3	2.42	5.72
20	0.41	1	36.42	39.72	**150**	4.52	1.0	3.30	6.60
		1.5	24.28	27.58			1.5	2.20	5.50
		2	18.21	21.51			2.0	1.65	4.95
		2.5	14.57	17.87			2.5	1.32	4.62
		3	12.14	15.44			3.0	1.10	4.40

Results of Deflection

Results of defelction analysis are shown in Fig. 1 and 2. Fig. 1 shows the *P*-□ relationship on loading point of nailed-slab. Good results are obtained in the sense that the calculated settlement is in good agreement with observation. All calculated deflection based on variation of *SF* tend to over-estimated. For *SF* = 1.0, the over-estimated about 68% for maximum load 150 kN. *SF* variation affects the calculated deflections. The over-estimated tends to increase by increasing in *SF*. It is also shown in Fig. 1

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that *P*-□ curves are in elastic zone as defined in the theory

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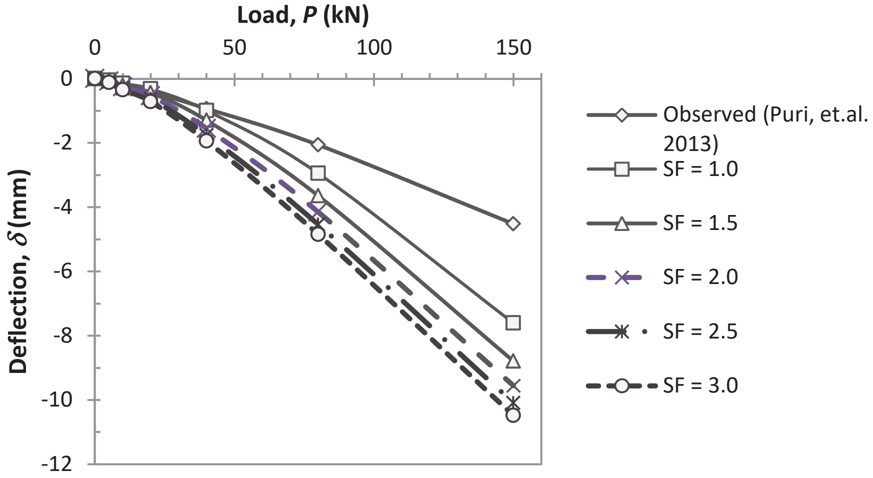

Fig. 1. *P*-□ relationship on loading point of nailed-slab.

Fig. 2 shows the distribution of calculated deflection along the slab of nailed-slab for load 40 kN. Good results are obtained in the sense that the calculated settlement is in good agreement with observation. Calculated deflections tend to over-estimated by increasing the *SF* and litle bit uplift on the both ends of slab. These similar behaviour were also occured for other loads. The utilitation of the additional modulus of subgrade reaction (Δk) can well predict the deflections, despite of the Δk theory based on elastic condition (Puri, et.al. 2012, 2013; Puri, 2015, 2017). The Δk was developed based on elastic theory; however it can well predict the deflection in plastic zone

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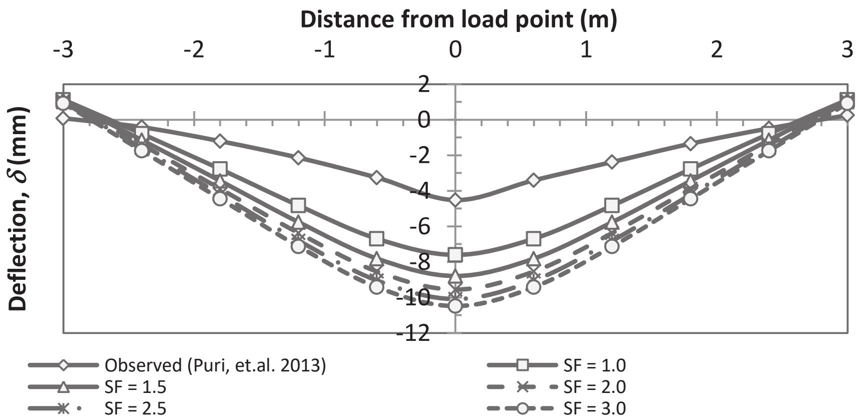

Fig. 2. Distribution of calculated deflection along the slab of nailed-slab for load 40 kN.

CONCLUSION

In this case, the additional subgrade reaction modulus (Δk) can be used for calculating the slab deflection of Nailed-slab Pavement System. *SF* variation affects the calculated deflections. Good results are obtained in the sense that the calculated settlement is in good agreement with observation especially for *SF* = 1.0. It can be concluded that the *SF* = 1.0 is adequate for analysis. Since this system will be functioned as pavement in the field, the Nailed-slab will have extensive area and installed pile under the slab will also more and more to all directions. So the performance of this system would be better due to bearing capacity and reduction on the slab deflection (Puri, et.al. 2014). Further research can be conducted for edge loadings of the Nailed-slab Pavement System.

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Isi :

1. Saudara ditugaskan mengikuti International Conference on Science, Engineering and Technology (ICoSET). Denga judul "Effects of Safety Factor on The Calculated Deflection of 1-Pile Row Full Scale Nailed-slab Pavement System Resting on Soft Clay Due To Concentric Loading" pada tanggal 8 s/d 10 November 2017 di Universitas Islam Riau, Pekanbaru.

2. Memberikan laporan kepada Wakil Direktur I paling lambat 1 (satu) minggu setelah pertemuan.

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