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SYMPOSIUM A

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CALCULATION THE EDGE OF SLAB DEFLECTION OF MODIFIED *CAKAR AYAM* SYSTEM BY APPLYING THE DISPLACEMENT FACTOR FROM PURI'S GRAPH

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ABSTRACT
Simple method in Nailed-slab pavement ssystem analysis was proposed by previous researcher. This method uses equivalent modulus of subgrade reaction (*k*'). This modulus consists of the modulus of sub grade reaction from plate load test (*k*) and additional modulus of sub grade reaction due to pile installing (Δk). The additional modulus of sub grade reaction has been also proposed by some authors. Displacement factor was used in determining the additional modulus of sub grade reaction. The curve of this factor was proposed by Puri (2017) for soft clay, and the curve of the invers one was proposed by Hardiyatmo (2011) for stiff clay. This paper will disscuss the application of the curve of displacement factor from Puri'graph (2017) to calculate the deflectios of Modified Cakar Ayam (MCA) pavement system. Calculated deflections based on this curve were compared to the observed deflection. The deflection was calculated by using Beam on Elastic Foundation method. Full scale test result from MCA pavement system was used. The concentric and edge loading points were considered. The calculated deflection based on single-row shell of MCA pavement system was compared to the observed deflection from three-row shell. Results show that the calculated deflection in good agreement with the observation, althought it was very over-estimated about 390% to 665%. In this case, Over-estimated was caused by ignoring the end bearing resistance of shell in determining the additional modulus of subgrade reaction Δk. It could be also because of neglecting the lean concrete, shell connector, and vertical wall barrier. The Puri's graph can be used to determind Δk for MCA analysis, but in further research it should be considered the end bearing resistance of shell.

Keywords: rigid pavement; Modified Cakar Ayam System; slab deflection; subgrade modulus; displacement factor.

1. INTRODUCTION

Designing of road pavement on soft subgrade needs also about potential settlement that would be accour during and after construction and how to maintance the deformation. Hence, it is needed a such kind of system that can reduce the deflection of pavement. One of the system that can be used is *Sistem Cakar Ayam*. This system has two types; original type which uses cylindrical concrete shell and modified type which uses cylindrical steel shell (calls *Sistem Cakar Ayam Modifikasi*). In Modified *Cakar Ayam* System (MCA), the utilization of cylindrical steel shell was proposed by Ir. Maryadi Darmokumoro (Suhendro, 2006). Several analysis method of MCA were proposed such as Suhendro's Chart, Hardiyatmo method by using Beam on Elastic Foundation (BoEF), and Hardiyatmo's Chart (Hardiyatmo, 2010; Suhendro and Hardiyatmo, 2010). BoEF was used in MCA analysis such as Pempadi (2000), Muhu (2007), Afriliyani, et.al. (2017) and Agustin, et.al. 2017. MCA can be analyzed also by 3D finite element method (Suhendro, 1992; Romadhoni, 2008; Firdiansyah, 2009; Puri, 2015; Setiawan, 2015).

Hardiyatmo (2008) introduced a new method that was developed from the pavement of the MCA by changing the cylindrical foundation with short micro piles. This system is called the nailed-slab system. Hardiyatmo (2011a) proposed an analysis method for determining the additional modulus of subgrade reaction (Δk). The additional modulus of subgrade reaction is the additional modulus developed by a pile. Mean while, the modulus of subgrade reaction is the modulus considered from a slab. Puri et al. (2012) modified the Hardiyatmo method by considering the tolerable deflection or allowable deflection of a pavement slab (δ_a) as an approach to safety construction. This modified method has good validation (Puri et al., 2013). Puri (2017a) proposed curve of displacement factor ($\alpha = \delta_0/\delta_s$) for calculating the Δk.

This research is aimed to apply the analysis method of the additional modulus of subgrade reaction (Δk) by using Puri's graph (Puri, 2017a) to calculate the slab deflection of MCA system. Calculated deflection will be compared to observation results.

Hardiyatmo (2011a) used the displacement factor for determining the additional modulus of subgrade reaction. The displacement factor is the ratio of the relative displacement between piles and soils (δ_0) and the pile head settlement (δ_p). The pile head settlement is assumed to be similar to the slab deflection (δ_s). The inverse of the displacement factor is the ratio of δ/δ_0. Hardiyatmo (2011b) developed the curve of the δ/δ_0 ratio based on the full-scale test of a single pile in stiff clay. The pile and slab were connected by bolts. In this paper, the curve of the δ/δ_0 ratio based on a full-scale test of a single-pile nailed slab in soft clay is developed. The pile and slab were connected monolithically. The curve of the δ/δ_0 ratio is also presented as the curve of the displacement factor. Validation based on the single-pile nailed slab will be explained.

The analytical approach in determining the equivalent modulus of subgrade reaction (k') is given as follows (Hardiyatmo, 2011a; Dewi, 2009; Puri et al., 2012):

$$k' = k + \Delta k \tag{1}$$

Where k: modulus of subgrade reaction from plate load test (kN/m^3) and Δk: additional modulus of subgrade reaction due to pile installation under slab (kN/m^3). The modulus of

subgrade reaction from a plate load test (k) is usually taken by using a circular plate, and it should be corrected to the slab shape of the nailed slab. The secant modulus is recommended. Hardiyatmo (2011a) proposed Eq. (2) in determining the additional modulus of subgrade reaction (Δk). The relative displacement between the pile and soil is considered.

$$\Delta k = \frac{\delta_0 A_s}{\delta_s^2 s^2}\left(a_d c_u + p_0 K_d \tan\varphi_d\right) \tag{2}$$

Where δ_0 : relative displacement between pile and soil (m), δ_s : deflection of surface of slab (m), A_s : surface area of pile shaft (m^2), s : pile spacing (m), a_d : adhesion factor (non-dimensional), c_u : undrained cohesion (kN/m^2), p_o' : average effective overburden pressure along pile (kN/m^2), K_d : coefficient of lateral earth pressure in pile surroundings (non-dimensional), and ϕ_d : soil internal friction angle (degree).

Hardiyatmo (2011b) re-published the relation between δ_0/δ_s and slab deflection for a full-scale model while the pile and slab were connected by bolts. The pile diameter was 20 cm, and the length of the pile varied between 1.0 m and 2.0 m. Puri (2017a) proposed curve of displacement factor ($\alpha = \delta_0/\delta_s$) as shown in Figure 1. This curve for soft clay which the Nailed-slab System was a full-scale model while the pile and slab were connected monolitichally. Then, the Equation (2) can be rewriten as (Puri, 2017b)

$$\Delta k = \frac{\alpha A_s}{\delta_s s^2}\left(a_d c_u + p_0 K_d \tan\varphi_d\right) \tag{3}$$

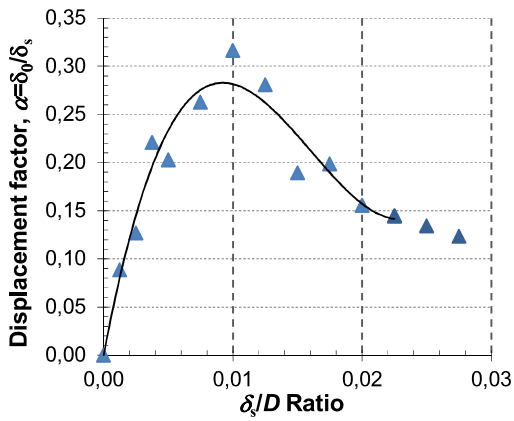


Figure 1. Curve of displacement factor α (Puri, 2017a).

Slab deflection can be calculated by BoEF while the input modulus is k' from Equation (1). Roark formula will be used for finite beam.

2. METHODOLOGY

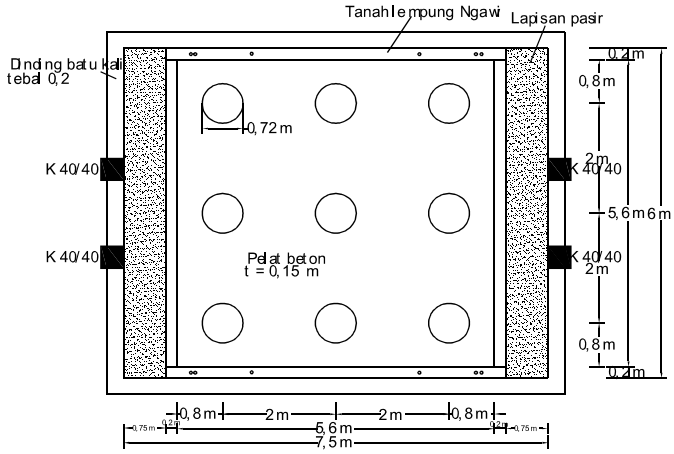
2.1. Research object

The research object was a full-scale model of MCA from Setiawan (2015). MCA was consisted a slab with 6.00 m x 6.00 m in widht and lenght and 0.15 m in thickness. The slab

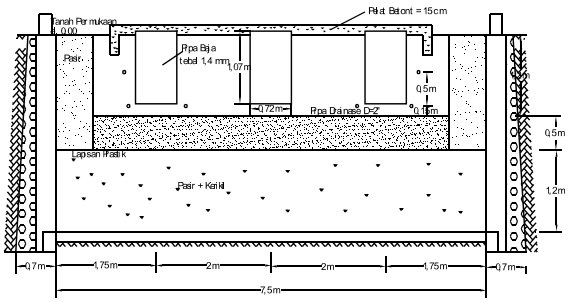
was constructed by reinforced concrete. Concrete compression strenght characteristic, f_c' was 32.16 MPa. MCA was constructed in soft clay. Soft clay properties were presented in Table 1. Vertical modulus of subgrade reaction, k_v was taken from Plate Load Test by using 30 cm in plate diameter. Nine cylindrical steel shell were installed under the slab and connected monolithically. Shell spacing was 2.00 m. Shell had dimension 0.72 m in diameter, 1.015 m in length and 1.4 mm in thickness. Schematic diagram of MCA is presented in Figure 2. This sistem was loaded by vertical compression loading on point A (edge of slab) as shown in Figure 3. Load variations were 0 kN, 20 kN, 60 kN, 100 kN. Loads was transfer to slab surface by steel plate 30 cm in diameter.

Table 1. Properties of soft clay (Setiawan, 2015)

No.	Properties	Value	Unit
1	Undrained cohesion (c)	15	kN/m^2
2	Degree of soil field density	92	%
3	Vertical modulus of subgrade reaction, k_v	5,498.4	kN/m^3
4	Soil classifaction (USCS)	CH	-



a) Plan

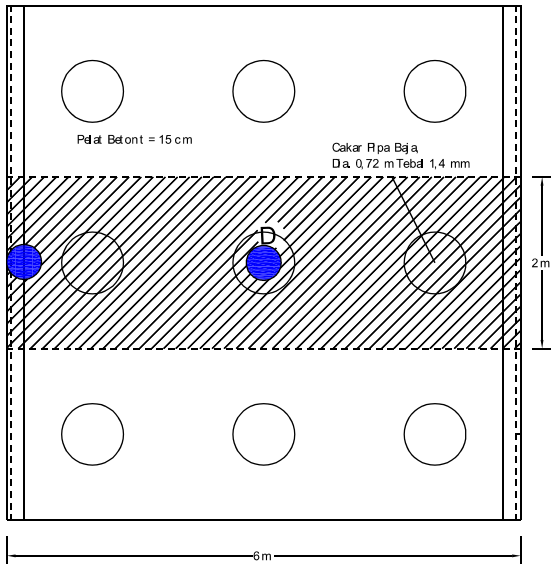


b) Cross section

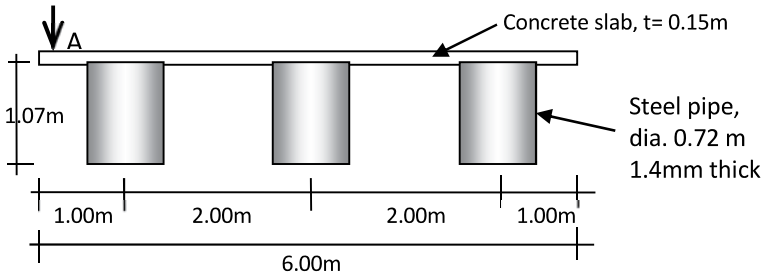
Figure 2. Shcematic diagram of MCA (Setiawan, 2015).

2.2. Method of analysis

Considered MCA in BoEF analysis was only one shell row as shown in Figure 3a. Simplication was done by neglecting the lean concrete, shell connector, and vertical wall barrier (Figure 3b). Ddeflection of surface of slab (δ_s) was taken from observation. From soil properties and MCA dimension, the *k*' was calculated. Slab deflection was calculated by input the *k*', MCA dimension and properties to BoEF.



a) Plan of one shell row to be considered



b) Cross section

Figure 3. One shell row of MCA to be considered in anaylsis.

3. RESULTS AND DISCUSSION

3.1 Equivalent Modulus of Subgrade Reaction

Vertical modulus of subgrade reaction was corrected due to plate shape and dimension according to Das (2011). Hence, the k_v was 641.48 kN/m^3. Considering the 2.00 m slab width, it was found k = 1,282.96 kN/m^3. Based on soil cohesion c_u = 15 kPa, the adhesion factor a_d was 1,0 according to Tomlinson's curve in McClelland graph (1974). Hence, unit

friction ratio f_s was 15 kPa. The surface area of shell shaft A_s was 2.30 m^2 and slab area which supported by one shell s^2 was 4.00 m^2. Slab deflection δ_s for 20 kN load was 0.558 mm. By 0.72 m in shell diameter D, we found the ratio of δ_s/D = 0.000775. Then displacement factor α from Figure 1 was 0.05. By using Equation (3), the additional modulus of subgrade reaction Δk was 772.85 kN/m^3. According to Equation (1), the equvalent modulus of subgrade reaction was 2,055.81 kN/m^3. Since the edge of slab equiped by vertical wall barrier, the equivalent modulus should be considered the adjustment factor about 1.5 (Puri, dkk., 2013). So, the equvalent modulus of subgrade reaction k' beMCA e 3,083.72 kN/m^3. Similar step of calculation also done to other load and the calculation results are presented in Table 2.

Table 2. Modulus of subgrade reaction for one shell row based on observed deflection

Load, Q (kN)	Load point A		
	δ_s (mm)	Δk (kN/m^3)	k' (kN/m^3)*
20	0,558	772.85	3,083.72
40	1,195	505.23	2,682.28
60	1,970	612.94	2,843.85
100	3,774	525.64	2,712.90

* Multiplied by adjustment factor 1.5.

3.2 Calculated Deflection

Table 3 presented the calculated deflection results. All calculated deflections were very over-estimated more than 260%, and higher than allowable deflection 5 mm (Puri, 2015). Over-estimated was caused by ignoring the end bearing resistance of shell in determining the additional modulus of subgrade reaction Δk as in Equation (2) and (3). It could be also because of neglecting the lean concrete, shell connector, and vertical wall barrier. It means that the Puri's graph (Figure 1) can be used to determind Δk. Figure 4 shows the P-δ relationship on loading point.

Table 3. Calculated deflection on loading point

Load, Q (kN)	Deflection (mm)		Defferentiation (%)
	Calculated	Observed	
20	4,273	0,631	665,77
40	8,284	1,347	593,22
60	11,204	2,215	468,71
100	18,525	4,222	390,86

The deflection along the slab is shown in Figure 5. Althought claculated deflections were very over-estimated, it can be seen that the deflection shapes of calculated deflections were similar with the observed one.

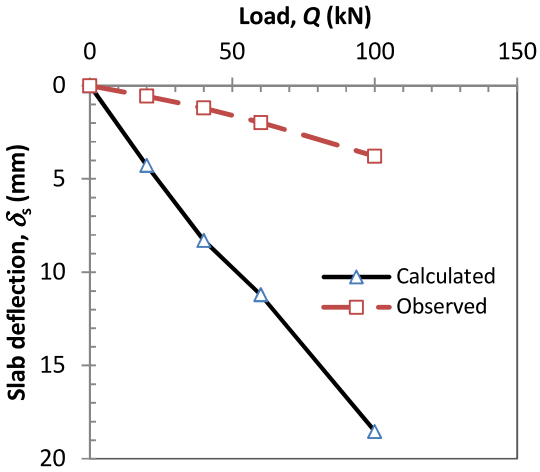


Figure 4. P-δ relationship for edge load.

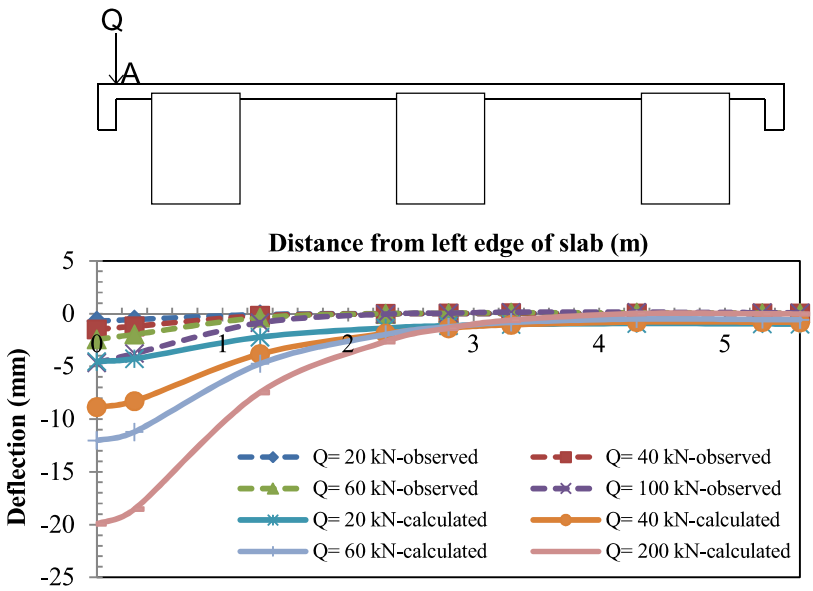


Figure 5. Deflection along the slab.

4. CONCLUSION

In this paper, the analysis method of the additional modulus of subgrade reaction (Δk) by using Puri's graph was applied to calculate the rigid pavement deflection of *Cakar Ayam Modifikasi* (MCA) system. Calculated deflections were also compared to abserved deflections. All calculated deflections were very over-estimated around 390% to 665%, and higher than allowable deflection 5 mm. Over-estimated was caused by ignoring the end bearing resistance of shell in determining the additional modulus of subgrade reaction Δk. It could be also because of neglecting the lean concrete, shell connector, and vertical wall

barrier. The Puri's graph can be used to determind Δk for MCA analysis, but in further research it should be considered the end bearing resistance of shell.

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