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NUMERICAL ANALYSIS OF NAILED-SLAB PAVEMENT SYSTEM BY CONSIDERING A VOID UNDER THE END OF SLAB

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ABSTRACT: Nailed-slab System is not a soil improvement method when it constructed on the soft subgrade, but rather as an alternative method to improve the performance of rigid pavement on soft soils. The end of the slab of this system is the critical structural element. The void under the end of the slab is to be potential to develop caused by vehicle wheel paths. If this void is developed, the performance of the Nailed-slab Pavement System may be decreased. This research is aimed to learn the effects of the void under the end of the slab due to the soil stress and the deformation and inner forces of the structural elements. The numerical analysis conducted to investigate the performance of the system. The soil and structural properties was based on the previous research on the soft clay. The dimension of the void was varied in the direction of the width and depth of the void. A standard wheel load 40 kN was set on the end of the slab. Results show that significant effects occur in the soil stress due to the increase of the void dimension. Void causes tension stress in the soil. Hence, the void under the slab affects the distributed load stresses to be dominantly resisted by the slab. The displacements of structural elements tend to increase by increasing the void dimensions. The Nailed-slab System does not fulfill the allowable slab deflection 5.0 mm for the void dimensions higher than 10 cm x 15 cm.

Keywords: Rigid pavement, Void under the slab, Soil stress, Slab Deflection, Inner forces

1. INTRODUCTION

The soil under the pavement slab is an important thing in bearing the stress due to traffic loads. Compacted soil tends to transfer the stress relatively uniform in the soil. Voids could occur under the pavement slab of the Nailed-slab System. In case there is a void under the slab, the stress will distribute in non-uniformly in the soil. Concentrated stress will cause maximum stress in the soil. Otherwise, the void can cause a decreasing contact area between slab and soils. Hence, the soil bearing will decrease and the slab deflection will increase. Previous researchers concerned only in normal soil conditions under the pavement slab with no voids ([1] - [10]). The analysis of soil stresses under the Nailed-slab System can be done by a finite element method ([10], [11], [12]).

The critical structural element of the Nailed-slab System is the end of the slab [3]. The void under the end of the slab tends to be more potential developed rather than in the other area. The vehicle wheels that often running in/out from/to pavement slab can cause a void in the sub-base-slab interface for a long time loading period. It will affect the decreasing in performance of the Nailed-slab System. It is important to know the effects of the void under the slab due to the soil. This research is aimed to investigate the effects of the void under the end of the pavement slab of the Nailed-slab System due to the displacement and inner forces of structural elements and the soil stress. The considered load will be a vertical compression load on the edge of the slab.

2. METHODOLOGY

This research used soil and a one pile row Nailed-slab structural data from Puri [10]. There was the dense sand layer below the soft clay. The considered load 40 kN was **was** set on the end of the slab as a distributed load in 30 cm diameter. The boundary condition of the soil is shown in Figure 1.

The dimension of the Nailed-slab model was 6.0 m x 1.2 m and 0.15 m slab thickness. The slab is supported by 5 piles in a row. The pile diameter was 0.20 m. Pile spacing was 1.20 m. The pile-slab connections were monolithically. The pile length was 1.50 m. The models were analyzed by 2D finite element method (FEM).

In 2D FEM plain strain analysis, the soft clay was modeled by Soft soil in un-drained conditions. All structural elements were modeled by plate elements in linear-elastic behavior. Lean concrete was modeled by soil with the linear-elastic non-porous material. Soil parameters and idealization of structural elements are presented in Tables 1 and 2 respectively.

The void was set under the end of the slab (actually under the lean concrete). The dimension of voids were varied in 4 variations by depth, *h* vs. width, *w* (5 cm x 10 cm; 10 cm x 15 cm; 25 cm x 30 cm; 50 cm x 55 cm). Figure 2 shows the types of void shapes and dimensions. All analysis was done by using Plaxis software version 2018.0.0.0.

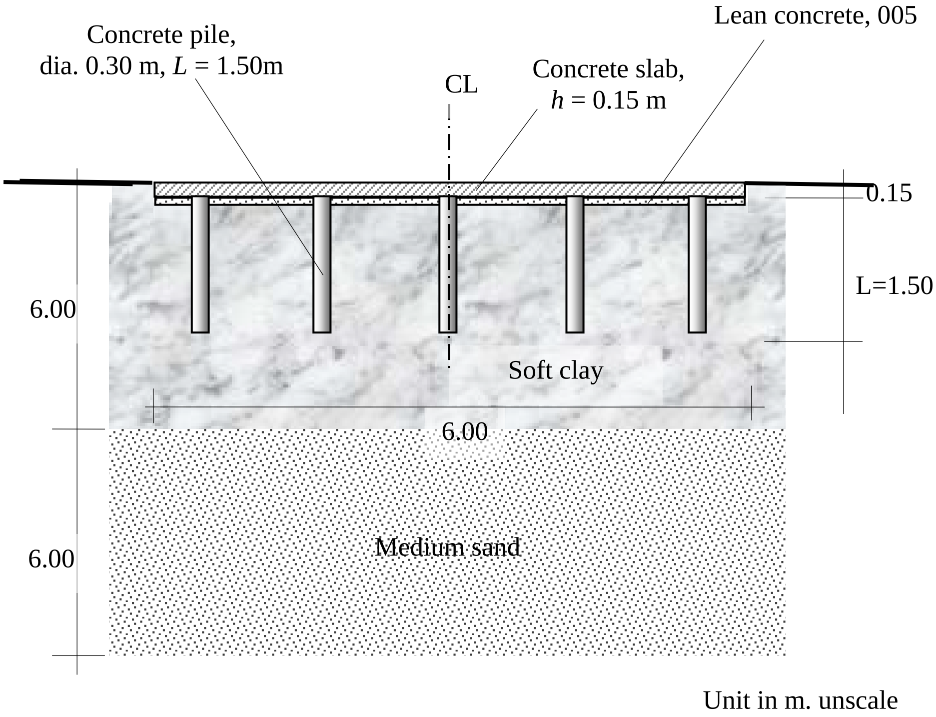

Fig. 1 Schematic model of Nailed-slab without a void.

Table 1 Model and parameters of soil [10]

Parameters	Name/ Notation	Soft clay	Medium sand	Unit
Material model	Model	Soft soil	Mohr-Coulomb	-
Material behavior	Type	Un-drained	Drained	-
Saturated density	γ_{sat}	16.300	18.000	kN/m^3
Dry density	γ_d	10.900	20.000	kN/m^3
Young's Modulus	E	1,790.000	42,750.000	kPa
Poisson's ratio	v	0.450	0.350	-
Un-drained cohesion	c_u	20.000	1.000	kPa
Internal friction angle	ϕ	1.000	47.800	^{o}
Dilatancy angle	ψ	0.000	2.000	^{o}
Initial void ratio	e_{init}	1.190	0.500	-
Modified compression index	$\lambda*$	0.044	-	-
Modified swelling index	$\kappa*$	0.009	-	-
Interface strength ratio	R	0.013	0.700	-

Table 2 Model and parameters of structural elements in FEM 2D plain strain [10]

Parameters	Name/ Notation	Lean concrete	Structural elements		Unit
			Slab	Pile	
Material model	Model	Volume element	*Plate*	*Plate*	-
Material behavior	Type	Elastic	Elastic	Elastic	-
Normal stiffness	*EA*	-	4,554,000.000	738,528.000	kN/m
Flexural rigidity	*EI*	-	8,539.000	5,649.740	kNm^2/m
Equivalent thickness	*D*	-	0.150	0.300	m
Weight	*W*	-	3.600	0.900	kNm/m
Poisson's ratio	ν	0.200	0.150	0.200	-
Unit weight	γ	22.000	24.000	24.000	kN/m^3
Young's Modulus	*E*	17,900.000	25,300.000	19,600.000	MN/m^2
Interface strength ratio	*R*	0.800	0.800	0.800	-

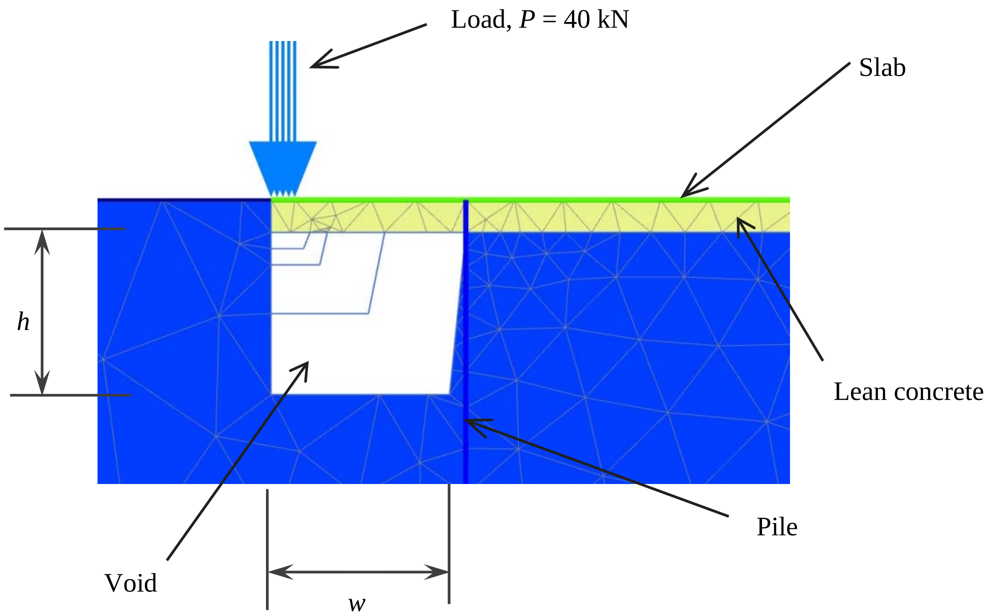

Fig. 2 Typical model of void shape and dimension under the end of edge slab.

3. RESULTS AND DISCUSSIONS

3.1 Soil Stress

Figure 3 shows the effective stress of soil in the base of the void. In the normal condition (0 x 0 void), there was the effective stress in compression condition. Otherwise, in case there was a void under the slab, the effective stresses were changed to be in tension condition. This is not beneficial for the soil because soil could not bear the tension stress. It is evident that the void cause negative effects in the soil stress. Soil can easily fail in tension stress conditions. The effective stress of soils tends to be relatively constant by increasing the void dimension. Hence, the distributed load stresses to be dominantly resisted by the slab.

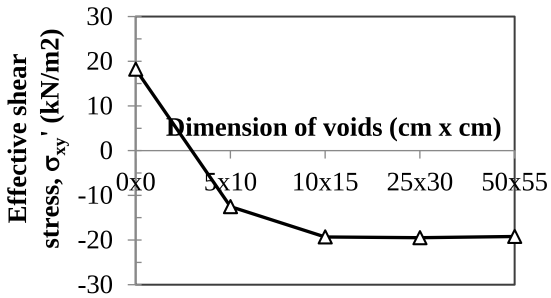

Fig. 3 Effective shear stress of soil vs. dimension of the void.

The distributed load stresses to be dominantly resisted by the slab can be proved by mobilizing the effective shear stress in the soil. The effective shear stress of soil reached a constant value in the failure condition, the slab deflection is kept increase (Fig.4).

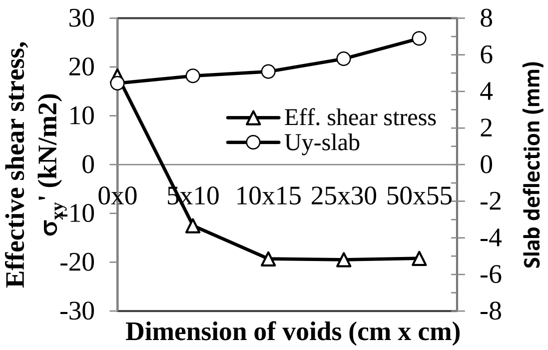

Fig. 4 Effective shear stress of soil and slab deflection vs. dimension of the void.

3.2 Displacements of Structural Elements

Figure 5 shows the deformed shape of the Nailed-slab system under the edge load with a void dimension of 25 cm x 30 cm. There was a similar behavior of the system for other void dimensions. The deformation of soil and structural elements increases by increasing the void dimension. In other word, the absence of soil under the slab effects in increasing the deformation of soil and structural elements.

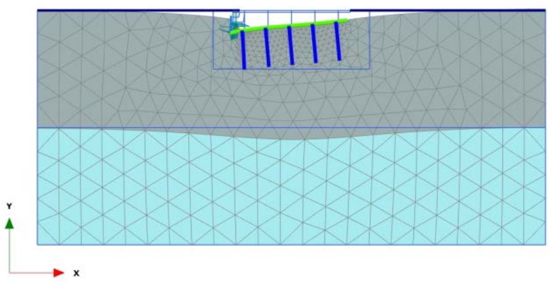

Fig. 5 Deformed shape.

The effect of the void under the slab due to the displacement of structural elements of the Nailed-slab is shown in Figure 6. The displacement of slab and pile increased by increasing the dimension of voids. Slab deflection U_y was on the load point. The void dimension higher than 10 cm x 15 cm resulted the deflection > 5.0 mm. It does not fulfill the allowable slab deflection of 5.0 mm [10]. Pile deflection U_y and U_x were on the pile head of the outer pile (left pile in Figure 5). Pile head moved down-left ward. Because of the distributed load stresses was dominantly resisted by the slab, the slab deflection tends to increase the void dimension.

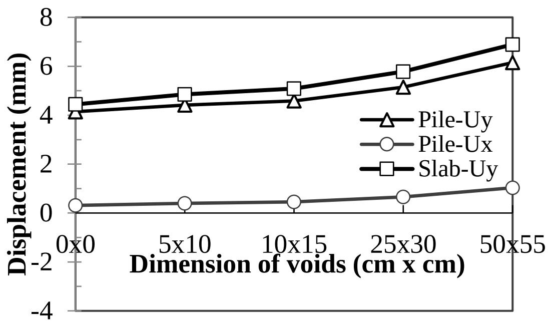

Fig. 6 The relation between the deflection of structural elements and voids dimensions.

3.3 Inner Forces of Structural Elements

Since the model of structural elements was a plate in FEM analysis, the inner forces of the system could be solved. Figures 7 and 8 are the results of the inner forces of the system. The inner forces tend to increase by increasing the dimension of the void. According to Puri [10], the nominal moment of slab section, M_n was 19.02 kNm/m. This M_n was increased by 30% for a temporary load. Refer to Figure 7, the void dimension higher than 20 cm in width can cause failure in the slab because of slab moment reached M_n.

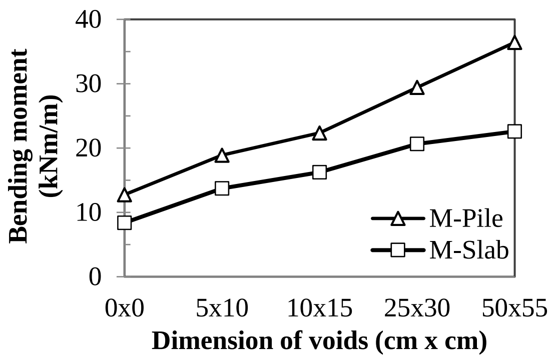

Fig. 7 The relation between bending moments and voids dimensions.

Since the bending moments of the pile head increase, the axial forces of pile decrease (Fig. 8). Increasing in the slab moment increases the pile head settlement (Fig.9). The settlement of the pile head tends to be lower than the slab deflection of about 7%-11%. It was not considered in the formula of additional modulus of subgrade reaction for simple analysis that was developed by Hardiyatmo [1]. He assumed that the settlement of the pile was similar to the slab settlement.

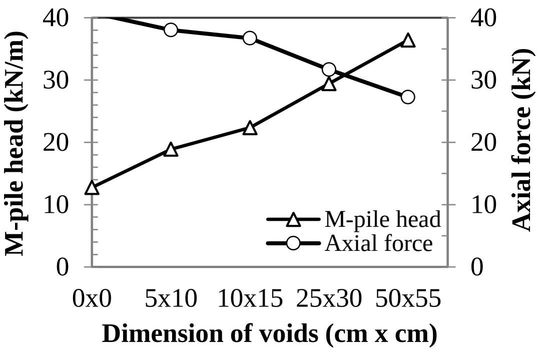

Fig. 8 The relationship between M-pile head and pile with voids dimensions.

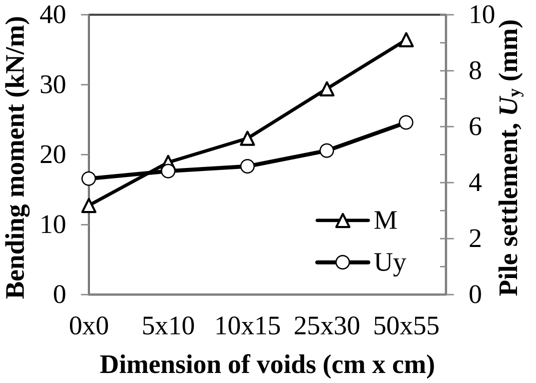

Fig. 9 The relationship between M-pile and pile head settlement with voids dimensions.

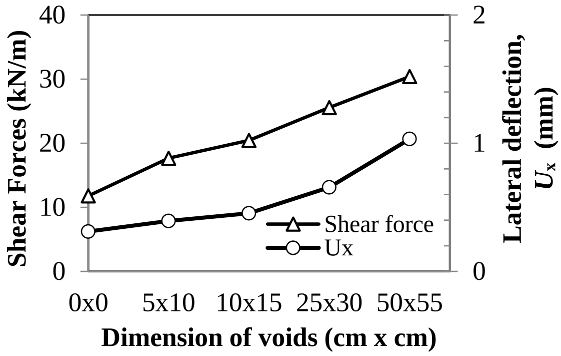

Fig. 10 The relationship between shear forces of the pile and pile head lateral deflection (U_x) with voids dimensions.

Lateral deflection of the pile head, U_x tends to increase by increasing the shear forces of the pile (Fig.10). While the shear forces increase by increasing the dimension of voids.

Changing the effective shear stress (Fig. 3) of soil around the void affects the increasing slab deflection insignificantly about 55% (Fig.6). Loading stresses were distributed dominantly in the slab through bending moments with increasing about 169%. Hence, the slab dominates to resist this bending moment by its resistance moment. Since the bigger void dimension under the end of the slab, the distributed stress load was dominantly bear by the slab.

4. CONCLUSIONS

The void under the end of the slab could change the effective stresses of soil in compression to be in tension condition. It is not beneficial for the soil because soil could not bear the tension stress. It is evident that the void causes negative effects on soil stresses. The effective stress of soils tends to be relatively constant by increasing the void dimension. Hence, the void under the slab affects the distributed load stresses to be dominantly resisted by the slab. Increasing the void dimensions under the end of the slab increases the displacements of structural elements. The Nailed-slab System does not fulfill the allowable slab deflection 5.0 mm for the void dimensions higher than 10 cm x 15 cm. Practically, avoid the development of voids under the end of the slab of Nailed-slab System.

5. ACKNOWLEDGMENTS

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