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DEFLECTION ANALYSIS OF NAILED-SLAB SYSTEM WHICH REINFORCED BY VERTICAL WALL BARRIER UNDER REPETITIVE LOADINGS

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ABSTRACT

The Nailed-slab System is a new proposed method to solve the problem of rigid pavement on soft soils. In this paper, Nailed-slab model tests were conducted to learn the behavior of this system. The models are presented as strip section of rigid pavement on soft clay and consist of concrete slab, short friction piles which installed under the slab, and vertical wall barrier at the end of slab. The models were loaded by repetitive loadings. Tests result will be compared to the calculated deflection by using Finite Element analysis. Further discussion about the comparison of slab deflection related to vertical wall barrier under repetitive loadings will be presented.

Keywords: Nailed-Slab System, Soft Clay, Vertical Wall Barrier, Deflection, Repetitive Loading.

INTRODUCTION

The Nailed-slab System was proposed as an alternative to solve the problem of rigid pavement on soft soils (Hardiyatmo, 2008). Hardiyatmo (2008) introduced the dimensions of Nailed-slab System which consists of 15cm-20cm pile diameter, 1.00m-1.50m pile length, and 1.00m-2.00m pile spacing. The main function of the piles is to make the pavement slab keeps in good contact with the subgrade (Puri, *et.al.*, 2011b)-it can reduce the slab vibration. Other function of the piles is to stiffer the pavement slab and it can reduce the differential settlement (Hardiyatmo, 2008). The slab, piles, and soil surrounding the piles develop a composite system which increases the bearing resistance. This system was also affected in reducing the slab thickness. Reducing in the slab thickness means reducing self weight of the construction and it will be beneficial for soft soils (Hardiyatmo and Suhendro, 2003). In other words, we can say that it is not about soil improvement but how to gain the pavement slab performance on the soft soils. The critical position of loads on rigid pavement on the soft soils is on the edge of pavement slab. This part tends to experience the maximum deflection and can also damage the pavement slab such as slab cracks/fractures, and developing the voids under the slab that can be followed by pumping. The edge of slab can be reinforced by a kind of concrete vertical wall barrier. The vertical wall barrier can significantly reduce the slab deflection of the Nailed-slab System (Puri, *et.al.*, 2011b) in case of edge loadings. The vertical wall barrier is a reinforced concrete with 10cm-12cm thickness, and is constructed vertically with 40cm-50cm in height (Hardiyatmo, 2010). The beneficial of a vertical wall barrier are: (a) to stiffer the edge of slab, since this part is a weaker part when loaded, (b) to avoid the voids development between subgrade-slab interface for life time serviceability, which is an effect of vehicle wheels that go out from the pavement and go in to the pavement repeatedly, (c) reduce the disturbance to the road shoulder, (d) as an vertical moisture barrier which is isolate the negative effects from the moisture changing of road shoulder in order that the water will not penetrate into the soil under the pavement for expansive soil subgrade. Dewi (2009) and Hardiyatmo (2011) introduced the equivalent modulus of subgrade reaction for analysis of Nailed-slab System. Hardiyatmo (2011) was proposed the method to define the additional modulus of subgrade reaction. Hardiyatmo method is modified for practical purposes by considering the fully mobilized pile friction resistance and the tolerable settlement of rigid pavement slab (Puri, *et.al.*, 2012a). These methods were successfully applied for prediction the pavement slab deflection of Nailed-slab System models by using Beam on Elastic Foundation theory (Hardiyatmo, 2011; Puri, *et.al.*, 2011b, 2012a, 2012b, 2013). The Modified Hardiyatmo method can also well predict the deflection of the

Nailed-slab under repetitive loadings. Finite Element analysis has not been conducted to analyse the nailed-slab which consider pile rows, except Puri, *et.al.* (2013). This paper is aimed to discuss the comparison of the slab deflection behavior between the Nailed-slab under repetitive loadings and monotonic loadings. The Nailed-slab models consider the vertical wall barrier on each end of slab. The experimental was conducted by model tests of one row pile Nailed-slab system.

TESTING INVESTIGATION

Soil and Nailed-slab Models Tests

Soft clay parameters are given in Puri, *et.al.* (2011b). The nailed-slab model with one row of piles consists of 6 piles, 120 cm × 20 cm × 3 cm slab, 20 cm pile spacing ($s/d = 5$), pile diameter $d = 4$ cm, and pile length $L_p = 40$ cm. The spacing between edge pile and the end of slab is a half of pile spacing ($a=s/2$). The loading test set up and Nailed-slab models (concrete slab supported by piles) are shown in Fig. 1. Slabs and piles are made by reinforced concrete. Slab reinforcement was wire mesh with 3 mm-wire diameters, and 5 cm × 5 cm meshing. Pile models were reinforced by 3mm-aluminium wire diameter. Model scale for geometry was 1 : 5. Piles and vertical wall barriers were connected monolithically to the slab. All models are presented as strip section of the rigid pavement. The Nailed-slab model was consisted of a Nailed-slab which the slab ends with vertical wall barrier (see detail in Fig.1). Loading type was monotonic and repetitive loadings. The dimension of vertical wall barrier was 2.4 cm in thickness and 10 cm depth. The photograph of the Nailed-slab testing is shown in Fig. 2 for edge loading.

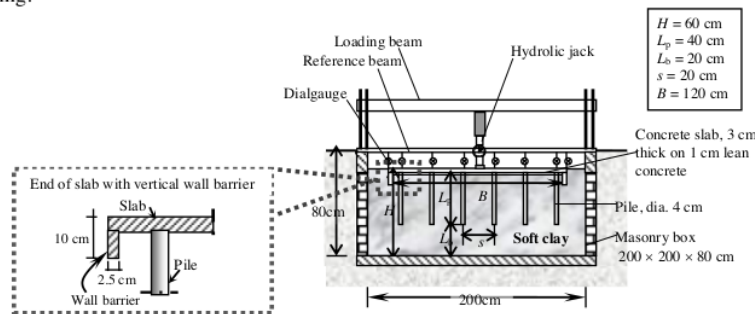


Fig. 1: Schematic cross section set-up of loading test on Nailed-slab System model.

Puri, *et. al.* (2011a) reported that the slabs and piles have modulus of elasticity $E_c = 17,000$ MPa. Soft clay properties are presented in Table 1. The load was worked on the slab through a circular steel plate with 6.0 cm in diameter and 1.0 cm in thickness. Load positions were on the point A (centric load) and point B (edge load) as shown in Fig. 3a but they worked in different loading time.

Analysis of Deflections

In the 2D finite element analysis (FEM), soft soil model was employed in the study. Likewise, the soil and material properties (model plate and pile) adopted in the model are shown in Table 1 and 2 respectively. The material properties were adjusted due to the plain strain case. The slab width is 120 cm and the length of considered section is 20 cm (perpendicular to cross section). A used mesh in plain strain FEM analysis is shown in Fig 2a. Fig 2b is one of deformed shape output.

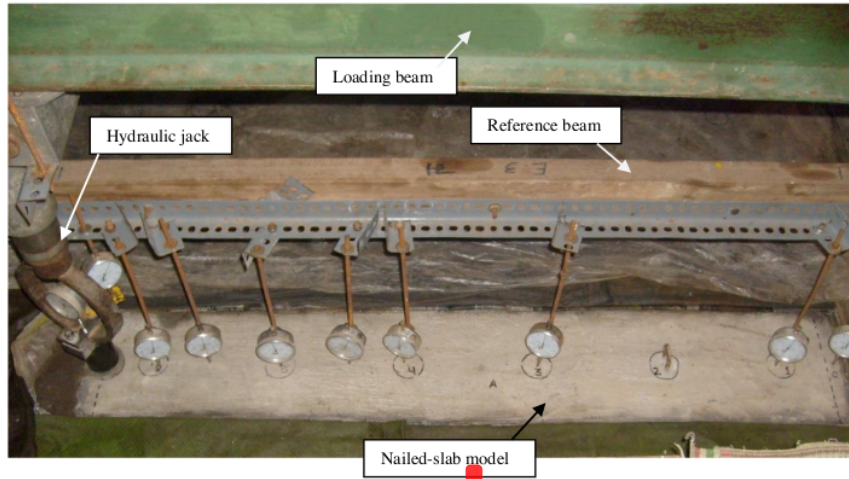


Fig. 2: A bird's-eye view of Nailed-slab model with vertical wall barrier on the each end of slab (indicated by dash-line).

Tab. 1: Soil properties in FEM analysis input (Puri, *et. al.*, 2013)

Parameter	Name	Clay	Unit
Material model	Model	Soft soil	-
Material behavior	Type	Undrained	-
Soil behavior under phreatic level	γ	17.00	kN/m ³
Young's modulus	E	1,870.00	kPa
Poisson's ratio	ν	0.35	-
Cohesion	c	21.00	kPa
Friction angle	ϕ	1.00	°
Dilatancy angle	ψ	0.00	°
Initial void ratio	e_0	0.92	-
Modified compression index	λ^*	0.05	-
Modified swelling index	κ^*	0.01	-
Interface strength ratio	R	0.80	-

Tab. 2: Model slab and pile properties in FEM analysis input

Parameter	Name	Slab	Wall Barrier	Pile	Unit
Material model	Model	Plate	Plate	Plate	-
Material behavior	Type	Elastic	Elastic	Elastic	-
Normal stiffness	EA	122,400.00	8,500.00	54,400.00	kN/m
Flexural rigidity	EI	9.18	0.44	7.25	kNm ² /m
Equivalent thickness	d	0.03	0.025	0.04	m
Weight	w	0.70	0.58	0.92	kNm/m
Poisson's ratio	ν	0.20	0.20	0.20	-

B

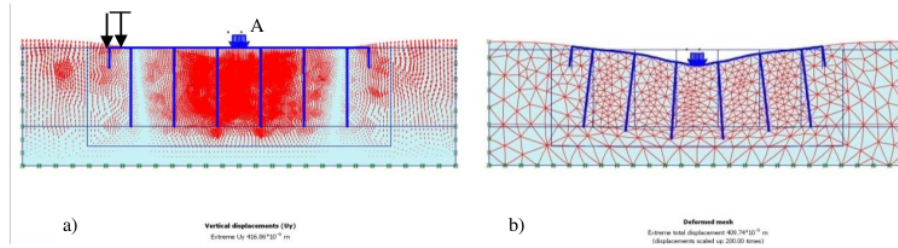


Fig. 2: Nailed-slab with vertical wall barrier in FEM analysis of plain strain: a). total displacement and undeformed shape which also shows position for center (point A) and edge (point B) loading. b). deformed shape output.

RESULTS AND DISCUSSIONS

Loading Test Results

The $P-\delta$ graph at loading point is presented in Fig. 3. It is shown that the repetitive load more influential at the higher loading which over 500 kN/m^2 . The maximum permanent deflection from edge repetitive loading is little bit higher about 27.17% than deflection from monotonic loading. The slab tends to be critical under edge loading, especially under repetitive loading. It is concluded that the deflection of the slab for edge loadings are to be more than 2 times the deflection of the center loadings. Generally, there is no significant uplift of the slab end (Fig. 4 and Fig. 5). It means that the installed piles tend to keep the slab contact with the soil. The capability of the nailed-slab system is higher due to center loading than the edge loading. In the centric loads, the system is not reached the plastic zone yet. Otherwise, the plastic zone is reached on the edge loading.

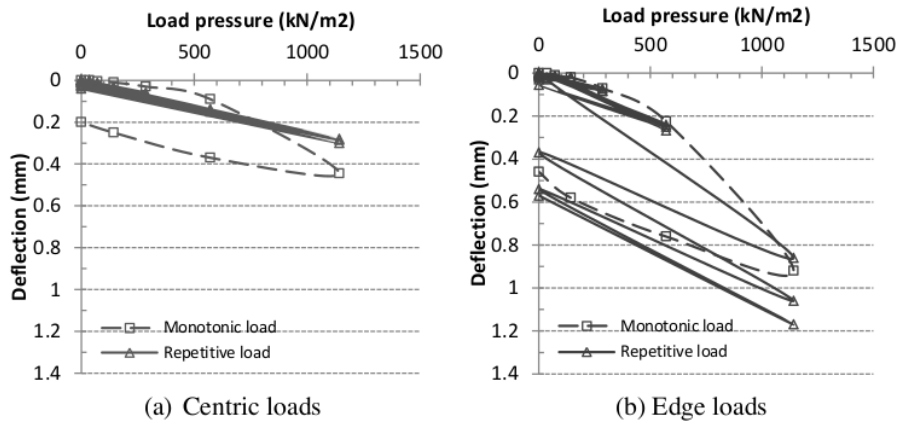


Fig. 3: The $p-\delta$ relationship on the loading point

Results of Calculated Deflections

Table 3 shows the comparison of slab deflection between monotonic loading and repetitive loading on the loading point. Deflections tend to be under-estimated for higher load in case of both centric and edge monotonic loads. The deflections tend to be under-estimated for edge loadings in case of repetitive loads. The distributed deflections along the slab are shown in Fig. 4 and 5 for different loading location. All results are shown the deflection shape in good agreement with observed for all loading types and locations. Calculated results show that the vertical wall barrier has less significant effect due to centric loads, because the end of slab was uplifted. In this case, FEM cannot differ between the edge monotonic

and repetitive loads. The deflection results are similar. The $p-\delta$ relationship on loading point of Nailed-slab under repetitive loadings with different loading location is shown in Fig. 6. As describe before, the deflection results is to be under-estimated for edge loading.

Tab. 3: Comparison of slab deflections on loading point for selected loads

Load		Load pressure (kN/m ²)		Settlement (mm)		Defference of deflection (%)
Type	Location	Original	Equivalent	Calculated	Observed	
<u>Monotonic</u>						
	Centric	1143	269	0,397	0,45	-11,78
	Edge	1143	269	0,582	0,92	-36,74
	Centric	571	135	0,173	0,09	92,22
	Edge	571	135	0,242	0,225	7,56
<u>Repetitive (on 3rd repetition)</u>						
	Centric	1143	269	0,41	0,3	36,67
	Edge	1143	269	0,582	1,17	-50,26
	Centric	571	135	0,214	0,15	42,67
	Edge	571	135	0,242	0,27	-10,37

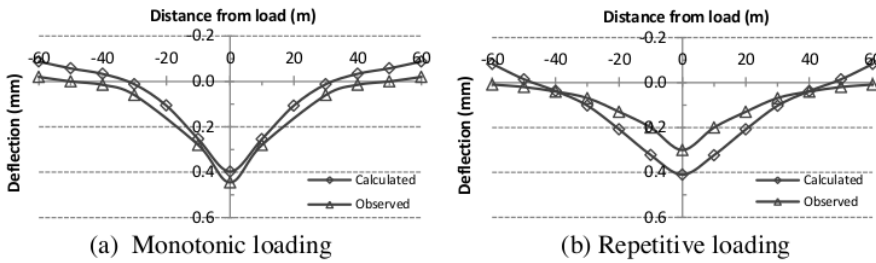


Fig. 4: Distribution of predicted slab deflection for center loadings ($p= 1,143 \text{ kN/m}^2$).

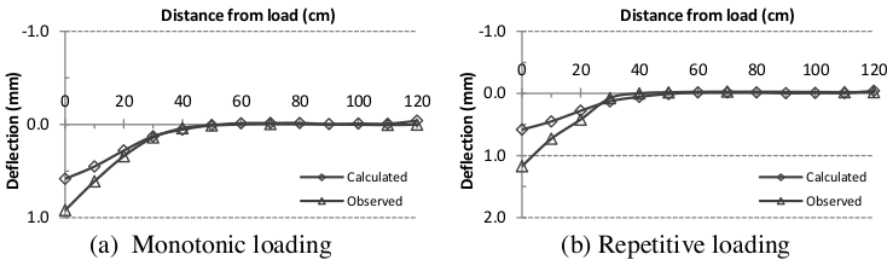


Fig. 5: Distribution of predicted slab deflection for edge loadings ($p= 1,143 \text{ kN/m}^2$).

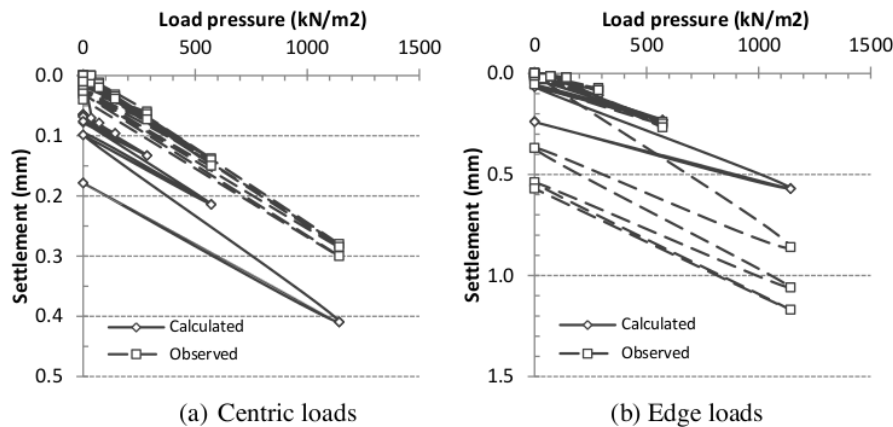


Fig. 6. The p - δ relationship of Nailed-slab model under repetitive loading with different loading location.

CONCLUSIONS

The model of Nailed-slab System which used vertical wall barrier structure was conducted and the observation and analysis of the slab deflections have been performed. The Nailed-slab model was loaded by repetitive loads. Good results are obtained in the sense of that the calculated settlement is in good agreement with observation. Although, calculated results show that the vertical wall barrier has less significant effect due to centric loads, because the end of slab was uplifted.

Technical analysis for FEM which consider the vertical wall barrier is recommended to be improved. And behavior of prototype of the Nailed-slab System under repetitive loadings is subjected to be studied for prototype Nailed-slab.

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