BEHAVIOR OF NAILED-SLAB SYSTEM ON SOFT CLAY DUE TO REPETITIVE LOADINGS BY CONDUCTING FULL SCALE TEST

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Abstract

The Nailed-slab System is not a soil improvement method, but rather as an alternative method to improve the performance of rigid pavement on soft soils. The installed piles under the slab were functioned as slab stiffeners. This research is aimed to learn the behavior of Nailed-slab System under repetitive loadings and its consideration for practical application. The full scale Nailed-slab System was conducted on soft clay which consisted of 6.00 m x 3.54 m slab area with 0.15 m in slab thickness, 15 short micro piles (0.20 m in diameter, 1.50 m in length, and 1.20 m in pile spacing) as slab stiffeners which installed under slab. Piles and slab were connected monolithically, then in due with vertical concrete wall barrier on the two ends of slab. The system was loaded by vertical repetitive loadings. Results show that the installed piles under the slab which embedded into the soils were functioned as slab stiffeners and were able to response similarly in 3D. This system has higher resistance due to vibration. Thereby, the Nailed-slab system is promising for practical application.

Key Words: *rigid pavement**,** soft clay, nailed-slab, micro piles, bearing capacity, repetitive loads.*

Abstrak

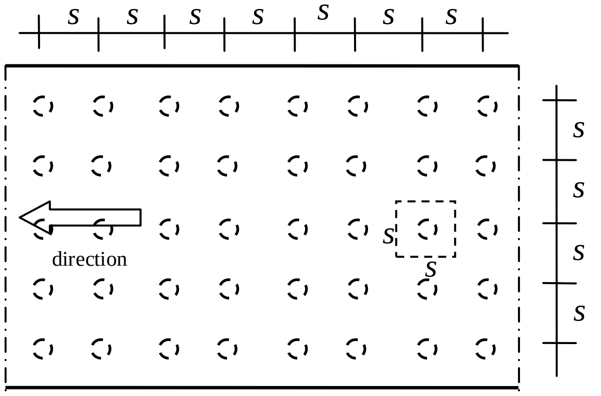
Sistem Pelat Terpaku bukanlah metode perbaikan tanah melainkan salah satu alternatif metode meningkatkan kinerja perkerasan kaku pada tanah lunak. Tiang-tiang yang dipasang di bawah pelat berfungsi sebagai pengaku pelat sehingga beban dapat disebar lebih luas ke tanah lunak. Penelitian ini bertujuan untuk mempelajari perilaku Sistem Pelat Terpaku akibat beban repetitif dan kemungkinan aplikasi lapangan. Pelat terpaku skala penuh telah dibangun pada lempung lunak yang terdiri atas; pelat 6,00 m x 3,54 m dengan tebal 0,15 m, 15 buah tiang mikro yang pendek (berdiameter 0,20 m dan panjang 1,50 m) sebagai pengaku pelat dan dipasang di bawah pelat. Tiang-tiang dan pelat dihubungkan secara monolit, serta dilengkapi dengan dinding penahan tepi pada kedua ujung pelat. Sistem ini dibebani dengan beban repetitif. Pelat Terpaku skala penuh pada lempung lunak memperlihatkan perilaku lendutan pelat akibat beban menunjukkan bentuk yang *smooth*. Hal ini mengindikasikan bahwa semua tiang mampumemberikan respon yang sama dalam 3-D. Sistem ini mempunyai ketahanan yang lebih tinggi terhadap vibrasi. Dengan demikian, Sistem Pelat Terpaku menjanjikan untuk aplikasi lapangan.

Kata kunci: *perkerasan kaku, lempung lunak, Sistem Pelat Terpaku, tiang mikro, kuat dukung, beban repetitif.*

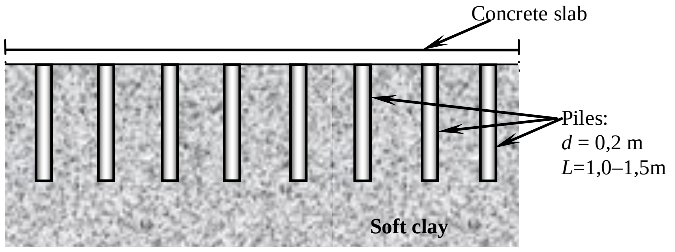
INTRODUCTION

Nailed-slab System was proposed as an alternative solution for solving the problem of rigid pavement on soft soils. This system consists of a thin reinforced concrete slab, and short piles attached underneath. The composite system (consists of piles, slab, and soils surrounding the piles) is expected to be formed to bear the loads. This system is recommended to use the thin pile cap (about 0.12 m to 0.25 m in thickness). Utilization of thin pile cap is beneficial for soft soils (Hardiyatmo and Suhendro, 2003). The piles are short micro piles with 0.12 m to 0.20 m in diameter, 1.0 m to 1.5 m in length, and 1.0 m to 2.0 m in pile spacing (Hardiyatmo, 2008). The slab has double functions, as a pile cap and as a pavement slab. Fig.1 shows the typical of nailed-slab construction. Piles were installed form a line in width and length directions (Fig.1a). Piles under the slab were connected to the slab monolithically (Fig.1b). Each end of slab can be equipped by the vertical concrete wall barrier to reduce deflection of edge slab.

The installed piles under the slab were functioned as slab stiffeners with the result that the load can be spread widely to soft soils (Puri, et.al., 2013c). In the bargaining, piles also function as anchors which can make the slab keeps in contact with the soils (Hardiyatmo, 2008; Puri, et.al., 2011a, 2013c). Hence, the pumping can be avoided and pavement durability can be longer.



Plan view



b) Longitudinal section

Figure 1 Typical of nailed-slab in rigid pavement construction (Hardiyatmo, 2008)

Several analytical study and model tests had been conducted by Hardiyatmo (2008, 2009, 2011), Taa (2010), Puri, et.al.(2011a, 2011b, 2012a, 2012b, 2013a, 2013b). The full scale individual nailed-slab on stiff clay (Nasibu, 2009; Dewi, 2009), and full scale nailed-slab with 3 pile-rows (Puri, et.al., 2013c and 2013d) also had been conducted. There is no field application yet.

The result of monotonic loading on full scale nailed-slab system shows that the system has higher bearing capacity (Puri, et.al., 2013d). Piles gave similar responses to all directions. The position of single wheel load has no significant effect to maximum deflection and bearing capacity. Strain on pile and slab rebars were occurred in safety condition due to 40 kN single wheel load. Those are indicating that the Nailed-slab System is promising for practical application.

This research is aimed to learn the behavior of Nailed-slab System under repetitive loadings and its consideration for practical application.

TESTING INVESTIGATION

Detail about testing pond and used materials in this full scale test were published in Puri, et.al., (2013d) and re-explained briefly in this paper. Repetitive loading procedures are presented below. All testing was conducted in Soil Mechanics Laboratory, Gadjah Mada University.

Soil Pond and Materials

Nailed-slab will be conducted on soft clay. A 6 m x 3.7 m soil pond was conducted by digging the existing soil until the depth of 2.5 m. On the 2 longer side was retained by masonry walls and supported by some temporarily girder. The anchorage system was built near the pond. Separator sheets were set on the pond walls and base to avoid the effects of surrounding existing soils. A 2.15 m of pond depth was filled by soft clay which taken from District Ngawi, East Java, Indonesia. The soft clay properties are presented in Table 1. The slab and piles were reinforced concrete. The concrete strength characteristic of slab and piles were 29.2 MPa and 17.4 MPa respectively.

Dimension of Full Scale Nailed-slab

The dimension of Nailed-slab System was 6.00 m × 3.54 m, 0.15 m in slab thickness, and the slab was stiffened by installing micro piles underneath. Micro piles dimension was 0.20 m in diameter and 1.50 m in length. The spacing between piles was 1.20 m. 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 piles configuration and other nailed-slab detail are shown in Fig. 2. Fullscale model represents a three pile rows of rigid pavement section.

Testing Procedures

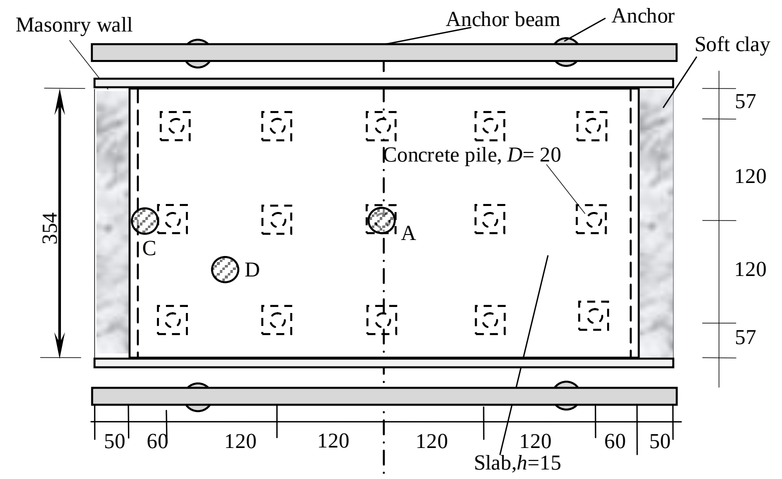
The steps in construction of fullscale Nailed-slab can be briefly described as follows: the pond was filled by soft clay until the soil thickness reach 2.15 m. Soft clay was spread about 15 cm in thickness per layer with controlled water content, and then it was compacted by 3 passing of manual compaction. Each soil layer thickness was decreased to about 10 cm per layer. Soft clay was cured by covering its surface with plastic sheet and wet carpet. Some soil investigations were conducted, i.e. soil boring, vane shear test, CBR test, and plate load test. After that, 15 concrete piles were driven by pre-drilled method and then continued by hydraulic jacking until the pile top reach the design level. Two piles were instrumented for measuring surface concrete strain and rebar strain. Some piles were tested for compression bearing capacity, tension capacity, and lateral bearing capacity.

Table 1 Soft Clay Properties (Puri, et.al., 2013d)

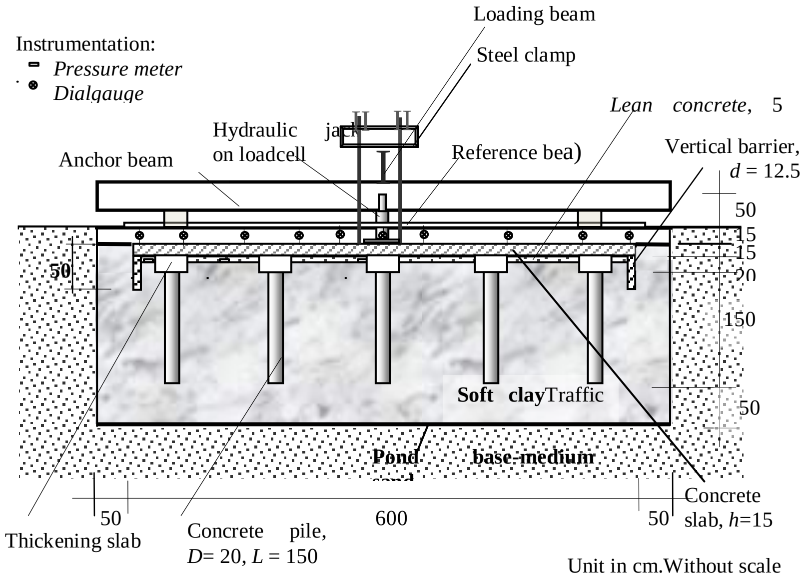
No.	Parameter	Unit	Average
1	Specific gravity, G_s	-	2,55
2	Consistency limits:		
	- Liquid limit, *LL*	%	88,46
	- Plastic limit, *PL*	%	28,48
	- Shrinkage limit, *SL*	%	9,34
	- Plasticity index, *PI*	%	59,98
3	Natural water content, w_n	%	50,49
4	Water content, *w*	%	54,87
5	Clay content	%	92,93
6	Sand content	%	6,89
7	Bulk density, γ	kN/m^3	16,32
8	Dry density, γ_d	kN/m^3	10,90
9	Undrained shear strength,S_u		
	- Undisturbed	kN/m^2	20,14
	- Remolded	kN/m^2	11,74
10	CBR	%	0,83
11	Soil classification:		
	- AASHTO	-	A-7-6
	- USCS	-	CH

Soil was excavated for thickening slab and also assembled 4 pressure meters on soil surface in deferent location. The 5 cm lean concrete then poured on the soil surface, and continued by conducting CBR test and plate load test after 3 days. The slab and vertical wall barrier reinforcement rebar were assembled and included with setting up strain-gauges. And then concrete was poured for slab and taken slump test, cylindrical concrete specimens, and also concrete pouring on slab specimen mold for flexural tests. Slab was cured by wet carpet and after 28 days of concrete age the loading set up was assembled. Loading test was conducted on the slab for different load positions. Loads were transfer to the slab surface by using circular plate with 30 cm in diameter (the plate represents the single wheel load contact area). Generally, the system were not loaded until failure condition, except reached the early plastic zone. Repetitive loadings were conducted after monotonic loadings had done. Loads were given stage by stage by load increase twice the previous load and unloading to zero loads. Each load repetition was given in 5 repetitions. For all loading points, the load intensity was increased gradually from P = 0, then became P = 5 kN, and continued unloading to zero. Repeat this procedure until 5 repetitions.

Similar procedure was also done for P = 10 kN, 20 kN, 40 kN, 80 kN, and 160 kN respectively. Then all instrumentations were recorded. Aphotograph in testing is presented in Fig. 3.



a). Plan of view



b). Cross section

Figure 2 Schematic Diagram of Full Scale Nailed-slab (Puri, et.al., 2013d)

Figure 3 Loading test on the edge of slab

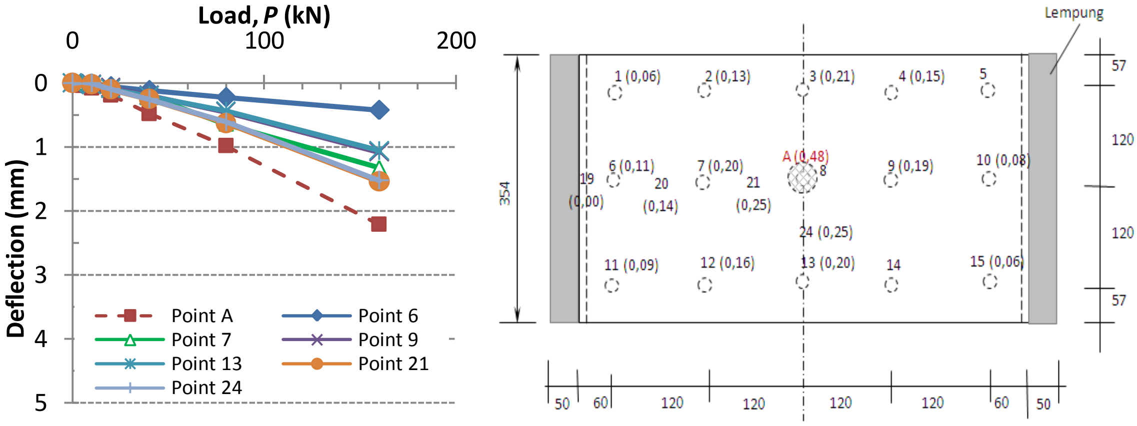
RESULTS AND DISCUSSIONS

Loading Test Results

In this paper, loading test results will be presented for 3 loading positions, i.e. centric load (point A), edge load (point C), and interior load (point D).

Centric loads (point A)

The P-δ relationship for centric load is presented in Fig. 4 (especially for nearest points to the loading point). It can be seen although the load reached 160 kN (±4 x 40 kN design single wheel load), the maximum deflection occurred on the load point was still very small (about 2.21 mm). The linear response is clearly seen at the curve for load smaller than 160 kN, which the load 160 kN is quite enough (reached ±4 x 40 kN design single wheel load). So, deflection due to load P = 40 kN is in linear-elastic zone. Deflection responses for others points are not discussed since they have smaller deflection values. For load 40 kN, deflection on load position was occurred 0.48 mm, then continued with 0.25 mm, 0.25 mm, 0.20 mm, 0.19 mm and 0.20 mm for points 21, 24, 7, 9, and 13 respectively (Fig. 5b). The responses of slab deflections were good agreement with expectation that the deflections decrease by far away from loading position. Deflected bowl approaches symmetrical shape that shown in Fig.5. It indicates that all piles able to response similarly in 3D, and also proved that slab connector can connect piles and slab monolithically.



a) b)

Figure 4 Results for centric load, a) P-δ relationship for 5th repetition, b) Observed deflections at P = 40 kN. Note: distance in cm, deflection in mm (indicated by parenthesis)

Every repetition when the unloading condition (P = 0) was given, the deflection of all points tends to zero again (Fig.6). This indicates that the piles gave good response and all components of structures (including slab, piles, connector slab, and vertical concrete wall barrier) perfectly worked that closed to linear elastic until load 160 kN. Slab deflection for 5th repetition is closely to deflection due to monotonic loading. The deflections for all repetition on all loading intensities were shown insignificant disparity.

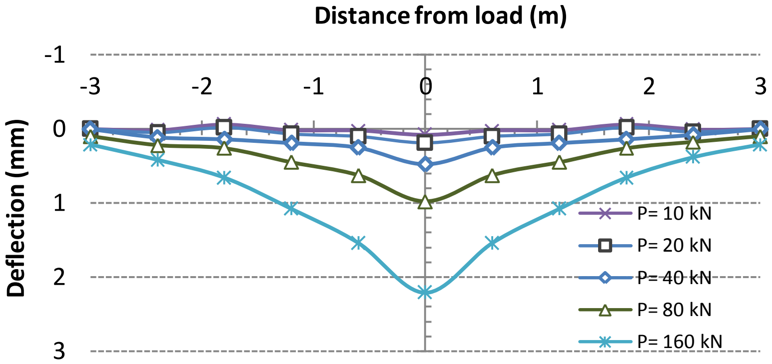


Figure 5 Deflection shape along the slab due to centric load (for 5th repetition)

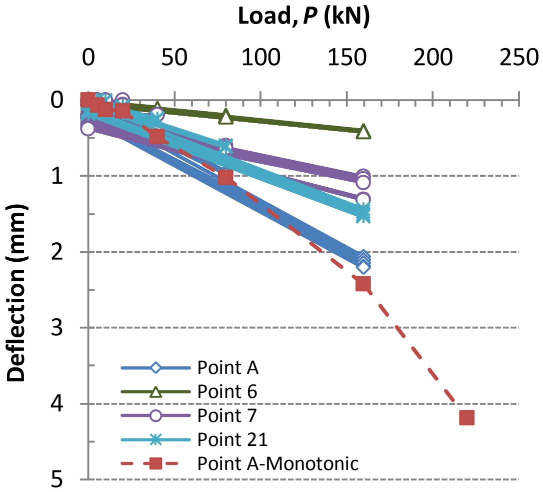
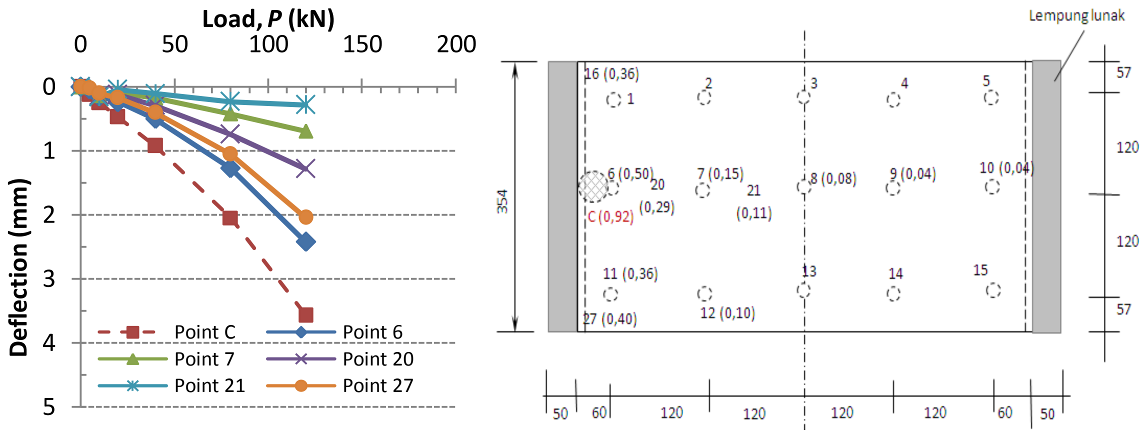


Figure 6 *P-δ* relationships for several points due to centric load. Point A-monotonic is from Puri, et.al. (2013d)

Edge loads (Point C)

P-δ relationship for edge loads is shown in Fig.7a. It can be seen that although the load reached 120 kN (±3x single wheel load), maximum deflection under the load point was still very small (about 3.57 mm). For load 40 kN, deflection on load position was occurred 0.92 mm, then continued with 0.50 mm, 0.36 mm, 0.29 mm, 0.15 mm and 0.11 mm for points 6, 11, 20, 7, and 21 respectively (Fig. 7b). The responses of slab deflections were good agreement with expectation that the deflections decrease by far away from loading position. Deflected bowl approaches a half bowl shape that shown in Fig.8. It indicates that all piles were response in good enough.

Every repetition when the unloading condition (P = 0) was given, the deflection of all points tends to zero again (Fig.9). This indicates that the piles gave good response and all components of structures (including slab, piles, connector slab, and vertical concrete wall barrier) goody worked that closed to linear elastic until load 80 kN. Slab deflection for 5th repetition tends higher than deflection due to monotonic loading. The deflections for all repetition on all loading intensities were shown insignificant disparity.



a) b)

Figure 7 Results for edge load, a) *P*-δ relationship for 5th repetition, b) Observed deflections at P = 40 kN. Note: distance in cm, deflection in mm (indicated by parenthesis)

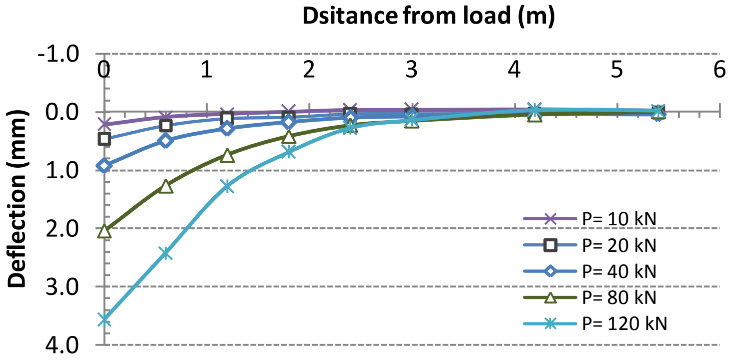


Figure 8 Deflection shape along the slab due to edge load (for 5th repetition)

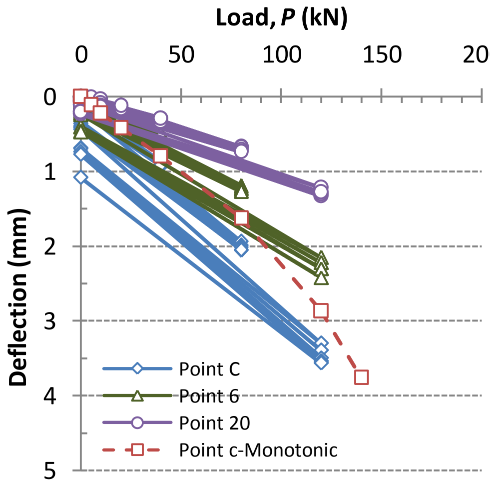
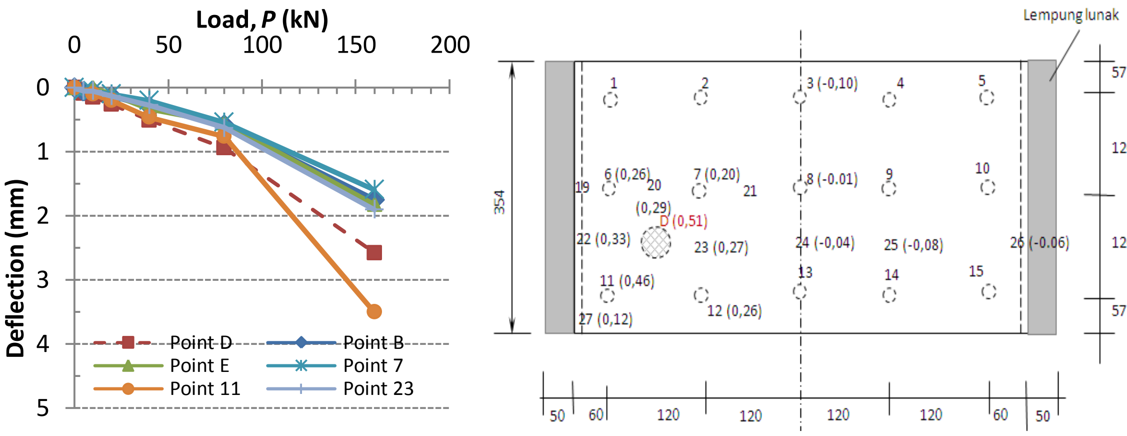


Figure 9 *P*-δ relationships for several points due to edge load. Point C-monotonic is from Puri, et.al. (2013d)

Interior loads

Fig.10shows *P-δ* relationship for interior loads (point D). Unfortunately, deflection of point 6 was not measured correctly. It can be seen although the load reached 160 kN (±4 x 40 kN design single wheel load), the maximum deflection occurred on the load point is still small (about 2.58 mm). For load 40 kN, deflection on load position was occurred 0.51 mm, then continued with 0.29 mm, 0.33 mm, 0.27 mm, 0.26 mm and 0.20 mm for points 20, 22, 23, 6, and 7 respectively (Fig. 10b). The responses of slab deflections were good agreement with expectation that the deflections decrease by far away from loading position. Deflected bowl approaches a symmetrical shapes that shown in Fig.11. It indicates that all piles were response in good enough.



a) b)

Figure 10 Results for interior load, a) *P-δ* relationship for 5th repetition, b) Observed deflections at *P* = 40 kN. Note: distance in cm, deflection in mm (indicated by parenthesis)

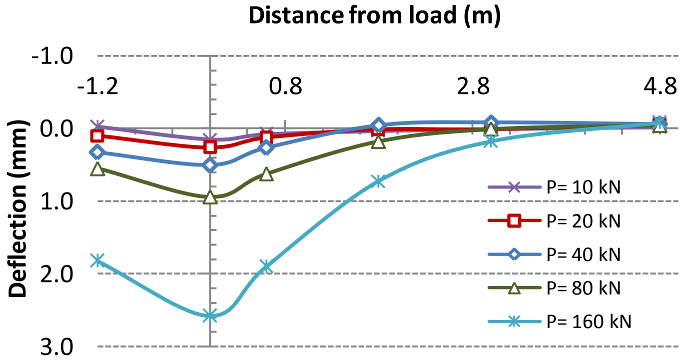


Figure 11 Deflection shape along the slab due to interior load (for 5th repetition)

Every repetition when the unloading condition (*P* = 0) was given, the deflection of all points tends to zero again (Fig.12), except for the points on slab edge (point 11, 22, and 23). But, this phenomenon occurred only for load 160 kN. Similar phenomenon is also detected on monotonic loading where the deflection under unloading after load 160 kN was relatively equal. However, this still indicates that the piles gave good response and all components of structures (including slab, piles, connector slab, and vertical concrete wall barrier) perfectly worked that closed to linear elastic until load 80 kN. Slab deflection for 5th repetition is closely to deflection due to monotonic loading. Generally, deflection on load point tends to smaller than the deflection due to monotonic loadings.

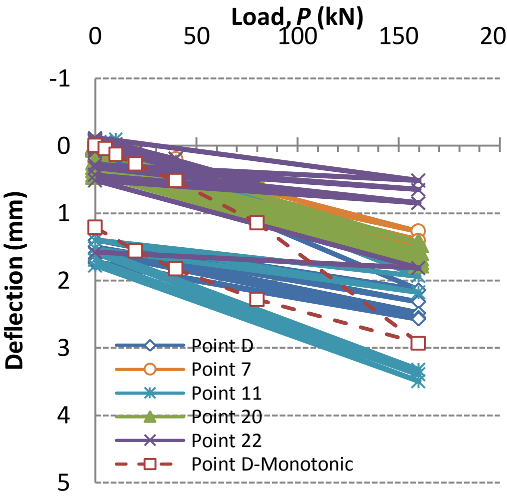


Figure 12 *P*-δ relationships for several points due to interior load. Point D-monotonic is from Puri, et.al. (2013d)

Fig.13 shows the comparison of deflections along the slab between repetitive and monotonic loadings. Different type of loading tends to be insignificant effect to deflection until load 80 kN. Significant effect occurred at load 160 kN for deflection on the slab edge (left edge of slab), where the occurred deflection was higher for monotonic loading. It means the monotonic loading tends to be more dangerous for this case.

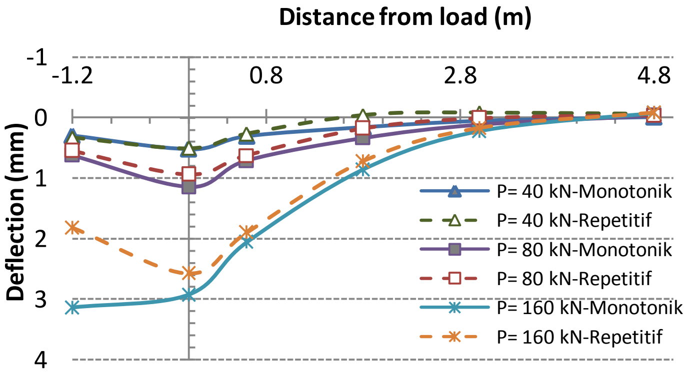


Figure 13 Comparison of deflection due to repetitive and monotonic loadings for interior load

Consideration for Practical Application

Based on results and discussions in the previous sections, there are some important things related to performance of nailed-slab system as follows

1. The short micro piles were well functioned as slab stiffeners. Hence, the thin slab (15 cm thickness) can be performed as thick slab while its self-weight was lower.
2. The higher slab stiffness was caused by installed piles under the slab and able to distribute loads widely. It indicates by there was no negative deflection (uplift). Piles kept the slab keep contact with the soils.

In this study, the tested nailed-slab was 6.00 m × 3.54 m, 0.15 m in slab thickness, and the slab was stiffened by installing15 micro piles underneath. Micro piles dimension was 0.20 m in diameter and 1.50 m in length. The spacing between piles was 1.20 m. 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 was equipped by the vertical concrete wall barrier. But, the results show the performance of this system is promising for application. 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. This system can also be applied for runway, apron, and parking lot.

Nailed-slab can be constructed directly on soft soils. It is necessary to strip the soil surface to avoid organic materials. This system will have higher bearing capacity and stiffness, and also has no problem in consolidation settlement (because there is no embankment on soft soils, smaller slab thickness that reduce self-weight, and generally the loads will be temporary loadings). In case the pavement surface level is customarily constructed higher than soil level to avoid floods, and then the Nailed-slab System can be combined with light in weight embankment materials. The Nailed-slab System can also be combined with necessary soil improvement, because this system is not about soil improvement but rather about the method to gain performance of rigid pavement on soft soils.

Using of short micro piles in the Nailed-slab System will be easier in construction and no need heavy equipment and working platform for heavy equipment passing (consists of 0.35 m thickness of sub base layer and 0.15 m lean concrete). With the result that it will be less in time consuming and relatively inexpensive construction cost.

CONCLUSIONS

Repetitive loading test by variation in loading position on the full scale model of Nailed-slab System was conducted. It can be concluded as follows

1. The tested Nailed-slab system on soft clay showed the smooth deflected bowl. It indicates that the all piles able to give similar responses in 3D. Compression and pull out capacity of piles were mobilized that made the slab keep contact with soil.
1. The short micro piles increased slab stiffness. Piles were well functioned as slab stiffeners.
2. This system had higher bearing capacity (at least 160 kN) and higher vibration resistance where every repetition when the unloading condition (P = 0) was given, the deflection of all points tends to zero again
3. It is concluded that the Nailed-slab system is promising for practical application.

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