FINITE ELEMENT ANALYSIS OF RIGID PAVEMENT OVER IMPROVED SUBGRADE USING NANOMATERIAL IN KARAWANG REGENCY, INDONESIA

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ABSTRACT

In this paper, the influence of improved subgrade condition of rigid pavements using nanomaterials using Finite Element Method will be discussed. The soil used as subgrade is obtained from National North Coast Road Corridor in Karawang Regency, Indonesia and categorized as soft clay or CH. Soft soil is a type of soil with low bearing capacity and high compressibility. This causes problems on rigid pavements; one example is cracks due to settlements of subgrade. Soft subgrade needs to be improved so that the rigid pavement will not deteriorate during design life. This study aims to analyze the displacement of rigid pavement over subgrade layer before and after soil improvement with the addition of 4% Nano Lime and 4% Nano Silica. The rigid pavement analysis was modeled in the form of a slab with a size of 4 x 6 meters and uses different thickness variations, namely 15, 20, 25, and 30 cm with concrete quality 20 MPa and 30 MPa. The vehicle load is modeled as a static concentrated load or assumed to be at rest, parked, and the speed is below 5 km/hour. The result of the analysis shows the largest total displacement of rigid pavement occurs before soil improvement and edge loading with a displacement value of -7.353 mm. Meanwhile, the displacement of rigid pavement after soil improvement using nanomaterials with the same concrete quality and thickness, shows a reduced displacement of -2.320 mm (a 216.94% reduction). The addition of 4% Nano Lime and 4% Nano Silica in soft subgrade can reduce the total displacement. The thicker the rigid pavement and the higher the quality of the concrete, can also reduce the total displacement that occurs. In addition, the location of the loading also has an influence on the total displacement.

Keywords: Nanomaterial; Finite element method; Soil improvement; Rigid pavement; Soft soil

1. INTRODUCTION

Indonesia has a wide distribution of soft soil, 20 million hectares of land in Indonesia is soft clay soil and peat soil [1]–[5]. Soft soil has low bearing capacity, low permeability, low shear strength value, relatively large compression in a long time, and large shrinkage properties [6]–[11]. The North Coast of Java Island is one area that is dominated by soft soil according to Indonesian Soft Soil Distribution Map. Soil in the North Coast of West Java Province especially in Lemah Abang District are classified as CH soil (Clay High) or clay with high plasticity because it has a liquid limit value of 65.35% and a soil plasticity index value of 35.45%.

Clay soil with high plasticity is not suitable if infrastructure is built on it, one of which is a rigid pavement structure. Soft soil as subgrade on rigid pavement, needs to be improved so that the rigid pavement structure is not damaged or deteriorated during design life [12]. One of the soil improvement efforts is by modifying the soft soil by the addition of nano-lime and nano-silica materials [13]–[17]. The use of nanomaterials in soil improvement is done by changing the atomic structure of the molecule which is added by external factors of nanoparticles [18]. From previous research, the most effective ratio of addition of nano lime and nano silica to reduce the value of soil plasticity index is the addition of 4% nano lime + 4% nano silica.

In this study, an analysis of the rigid pavement structure will be carried out on subgrade before and after soil improvement with an addition of 4% nano lime + 4% nano silica to the soft subgrade. The analysis and simulation were carried out by finite element model using ETABS 2016. The finite element method or FEM is considered the best numerical analysis technique that can provide approximate solutions to construction problems [19].

2. METHOD

The analytical method used is simulation using finite element method by the help of ETABS 2016 to obtain the displacement values at center and edge loading of rigid pavements. The rigid pavement modeled is a plate with a size of 4 x 6 meters. The rigid pavement thickness uses different thickness variations, namely 15, 20, 25, and 30 cm with concrete quality 20 MPa and 30 MPa. The subgrade reaction modulus value (Ks) or spring constants used refers to the CBR value of the soil before and after improvement. The loading used is the heaviest axle load of 10 tons with a full load condition of 42 tons on the 1.2 axis configuration. Vehicle loads are modeled as static concentrated loads or are assumed to be at rest, parked, and at speeds below 5 km per hour (traffic jam condition), and do not pay attention to wear and tear of pavement surface. The output of the analysis is the value of displacement of rigid pavement over subgrade layer before and after soil improvement with different variations of thickness and quality of concrete.

3. RESULTS AND DISCUSSIONS

3.1 Model

The loading used is the heaviest axle load of 10 tons with a full load condition of 42 tons and are modeled as static concentrated loads. Vehicle loads are placed in the middle and edges of rigid pavements. The load modeling at the center of the rigid pavement is presented in Figure 1a and the load modeling at the edge of the rigid pavement is presented in Figure 1b.

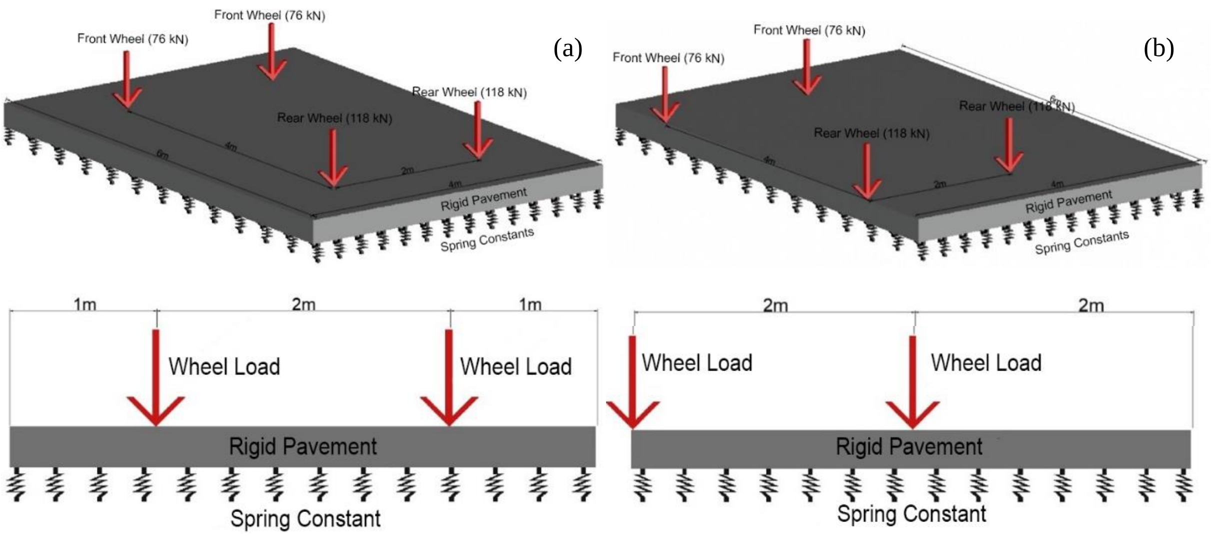

Figure 1. Load model in the (a) middle and (b) edge of pavement slab

The CBR value of the subgrade layer before improvement was 6.50% in the unsoaked condition and 0.70% in the soaked condition. After soil improvement with the addition of 4% nano lime + 4% nano silica, the CBR value of the subgrade were increased to 12.30% in the unsoaked condition and 8.20% in the soaked condition. The CBR value of soft subgrade have very significant increase up to 89.23% in unsoaked and 1071.43% in soaked subgrade condition. The subgrade reaction modulus (Ks) as the spring constant is the ratio/comparison between the soil pressure at a certain point and the resulting displacement [20]. The subgrade was modeled as a spring constant (spring support) in the analysis using ETABS 2016. The spring constant values obtained are presented in Table 1.

Table 1. Spring constants according to CBR value of subgrade

Subgrade condition		CBR (%)	Ks (kPa/mm)
Before soil improvement	Unsoaked	6.50	42
	Soaked	0.70	10
After soil improvement	Unsoaked	12.30	56
	Soaked	8.20	48

3.2 Displacement of Pavement in Unimproved Subgrade

Based on Guidelines for Determination of Pavement Conditions Index (IKP) Number Pd 01-2016-B, the severity of damage to rigid pavement can be categorized based on the displacement that occurs [21]. The severity of the rigid pavement is presented in Table 2. The rigid pavement modeled is a plate with a size of 4 x 6 meters and the load placement influence will be evaluated in the transverse and longitudinal of rigid pavement. The results of the displacement analysis on the rigid pavement structure above the subgrade layer before the improvement of the unsoaked and soaked condition are presented in Table 3. Figure 2 and Figure 3 shows the displacement in subgrade of rigid pavement in transverse direction over unimproved subgrade under middle and edge load. The influence of load placement in longitudinal direction of unimproved subgrade can be seen in Figure 4.

Table 2. Degree of severity of rigid pavement displacement [21]

Degree of severity	Displacement
Low (L)	> 3 mm and < 10 mm
Medium (M)	> 10 mm and < 20 mm
High (H)	> 20 mm

Table 3. Rigid pavement displacement over unimproved subgrade layer

Pavement Thickness (cm)	Concrete Compressive Strength (MPa)	Displacement (mm) Unsoaked subgrade		Soaked subgrade	
		Middle Load	Edge Load	Middle Load	Edge Load
15	20 (K250)	-1.087	-2.554	-3.427	-7.353
	30 (K350)	-1.038	-2.436	-3.421	-7.079
20	20	-0.909	-2.063	-3.420	-6.608
	30	-0.877	-1.976	-3.409	-6.492
25	20	-0.840	-1.793	-3.404	-6.254
	30	-0.810	-1.728	-3.364	-6.140
30	20	-0.800	-1.659	-3.290	-6.017
	30	-0.784	-1.633	-3.317	-5.920

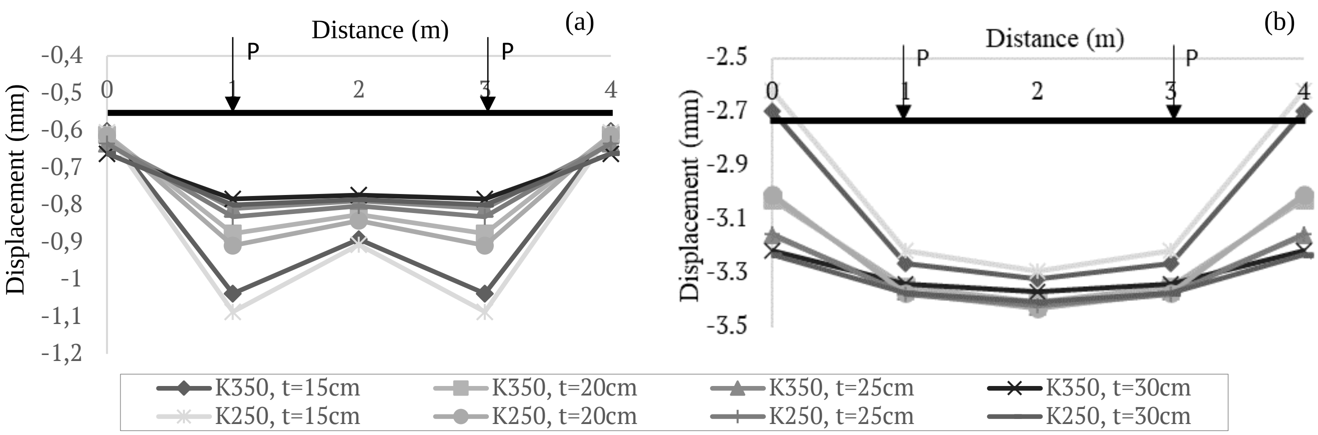

Figure 2. Cross section of pavement displacement under middle load over unimproved (a) unsoaked subgrade condition and (b) soaked subgrade condition

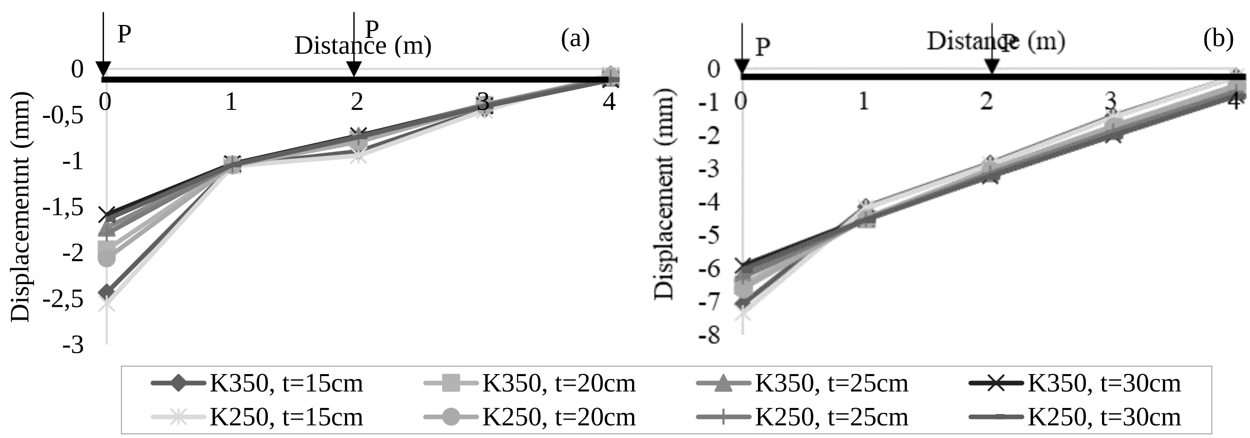

Figure 3. Cross section of pavement displacement under edge load over unimproved (a) unsoaked subgrade condition and (b) soaked subgrade condition.

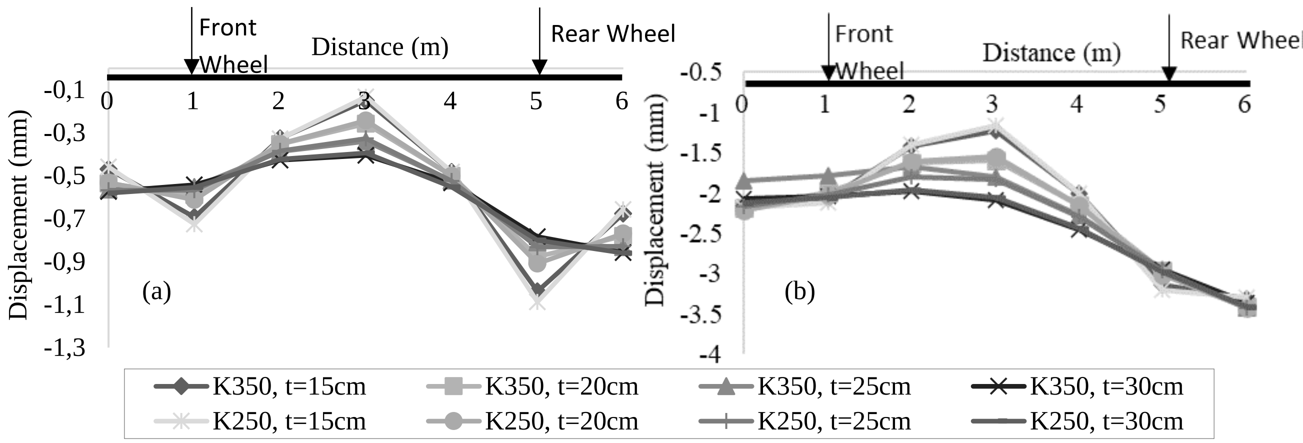

Figure 4. Long profile of pavement displacement under edge load over unimproved (a) unsoaked subgrade condition and (b) soaked subgrade condition.

Based on the result of analysis of unimproved subgrade condition, the largest total displacement of rigid pavement on the subgrade layer of the unsoaked condition is -2.554 mm with 15 cm thick 20 MPa rigid pavement under edge load. Meanwhile, largest total displacement of rigid pavement in the soaked subgrade condition is -7.353 mm with 15 cm thick pavement 20 MPa concrete quality under edge load. This shows that the rigid pavement with the type of damage to the separation of panels (divided slab) is low level of severity (L) before soil improvement.

3.3 Displacement of Pavement in Improved Subgrade using Nanomaterials

The results of the displacement analysis on the rigid pavement structure above the subgrade after soil improvement by the addition of 4% nano lime + 4% nano silica to the soft subgrade the unsoaked and soaked condition are presented in Table 4. Figure 5 and Figure 6 shows the displacement in subgrade of rigid pavement in transverse direction over improved subgrade using nanomaterials under middle and edge load. The influence of load placement in longitudinal direction of improved subgrade can be seen in Figure 7.

Table 4. Rigid pavement displacement over improved subgrade layer

Pavement Thickness (cm)	Concrete Compressive Strength (MPa)	Displacement (mm)			
		Unsoaked subgrade		Soaked subgrade	
		Middle Load	Edge Load	Middle Load	Edge Load
15	20 (K250)	-0.885	-2.076	-0.988	-2.320
	30 (K350)	-0.843	-1.981	-0.942	-2.213
20	20	-0.729	-1.671	-0.820	-1.870
	30	-0.701	-1.579	-0.789	-1.789
25	20	-0.656	-1.438	-0.744	-1.618
	30	-0.637	-1.382	-0.723	-1.557
30	20	-0.624	-1.300	-0.712	-1.470
	30	-0.609	-1.257	-0.697	-1.423

With the addition of nanomaterials (4% nano lime and 4% nano silica) to the soft clay subgrade layer, the CBR values in the unsoaked and soaked conditions significantly increased by 89.23% (from 6.5% to 12.3%) and 1071.43% (from 0.7 % to 8.2%). The largest maximum displacement of rigid pavement on the subgrade after improvement of the unsoaked condition is located at 15 cm thick pavement, 20 MPa, at the edge load with a displacement reduce to -2,076 mm from -2.554 mm (decreased 23.03%) of unimproved subgrade. The largest maximum displacement of rigid pavement in the subgrade after soaked condition improvement is located at 15 cm thick pavement, 20 MPa, at the edge load with a displacement significantly reduced to -2,320 mm from -7.353 mm (decreased 216.94%). This shows that the rigid pavement over improved s with the type of damage to the separation of panels (divided slab) resulting in safe level of severity.

Based on the results of the analysis, the thickness of the pavement and the quality of the concrete affect the value of the displacement that occurs. The location of the loading has an influence on the displacement that occurs. The thicker the rigid pavement and the higher the quality of the concrete, it can reduce the displacement that occurs because the stiffness of the concrete is higher. In addition, the addition of 4% nano lime + 4% nano silica on soft soil can reduce the displacement that occurs.

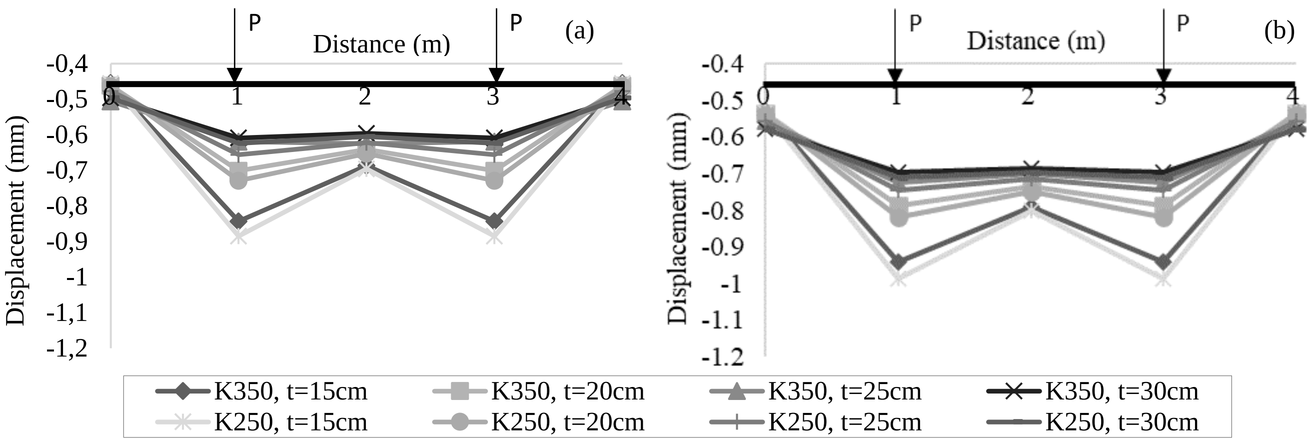

Figure 5. Cross section of pavement displacement under middle load over improved (a) unsoaked subgrade condition and (b) soaked subgrade condition.

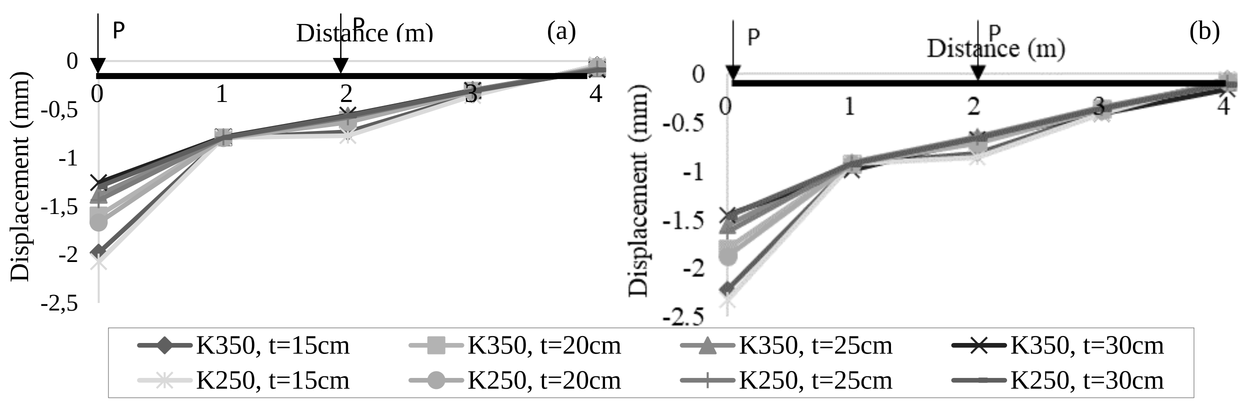

Figure 6. Cross section of pavement displacement under edge load over improved (a) unsoaked subgrade condition and (b) soaked subgrade condition.

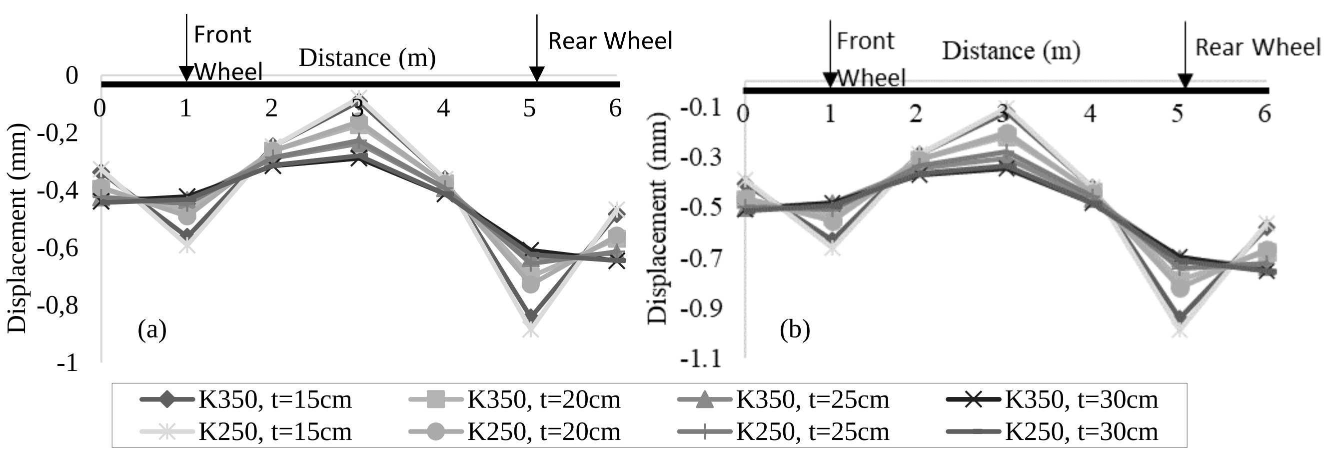

Figure 7. Long profile of pavement displacement under edge load over improved (a) unsoaked subgrade condition and (b) soaked subgrade condition.

4. CONCLUSION

Based on the analysis, it can be concluded that the use of 4% nano lime and 4% nano silica as addition to modified soft subgrade can increase the unsoaked and soaked CBR value of soil up to 89.23% (from 6.5% to 8.2%) and 1071.43% (from 0.7% to 8.2%) respectively. The use of nanomaterials to improve soft subgrade can significantly reduce the displacement of rigid pavement subgrade by 23.03% (from -2.554 mm of unimproved subgrade to -2.076 mm) in unsoaked condition and 216.94% on soaked condition (from -7.353 mm of unimproved subgrade to -2.320 mm).

The thickness of the pavement and the quality of the concrete can also affect the displacement of rigid pavement subgrade layer. The location of the loading has an influence on the displacement that occurs. The thicker the rigid pavement and the higher the quality of the concrete, it can reduce the displacement that occurs because the stiffness of the concrete is higher.

ACKNOWLEDGMENTS

We sincerely thank P3M Politeknik Negeri Bandung, for funding this research, and Civil Engineering Department Politeknik Negeri Bandung which provides facilities for this research.

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