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FATIGUE LIFE ANALYSIS OF RIGID PAVEMENT STRUCTURE WITH PERVIOUS CONCRETE BASE LAYER USING 2D FINITE ELEMENT METHOD

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ABSTRACT: In Indonesia, most of the rigid pavement generally use to carry heavy traffic. The combination of trapped infiltration water and repeated traffic loading will generate void between the base layer surface and surface layer base (erosion). Erosion phenomenon could lead to the loss of foundation support, short-term service life issue. Base layer with drainage type like pervious concrete could be useful to tackle those problems. KENSLABS program which is based on the finite element method has been widely used to analyze the pavement response. Some advanced parameters are varied in the simulation to analyze their impact against fatigue life through the mechanistic approach. It was found that the thickness ratio between the surface layer and the base layer can influence the rigid pavement fatigue life. The slab thickness should also be limited when pervious concrete is used as a base layer with an unbonded condition. Pervious concrete with the bonded interface has a longer fatigue life than lean concrete with the bonded interface. The difference among the advanced property values from base layer material and the thickness ratio between the surface layer and the base layer plays an important role in fatigue life value as well. Either in unbonded condition or in bonded condition, fixed base layer with a minimum thickness is more recommended when pervious concrete is used as a base layer because it requires thinner total slab thickness. In sum, pervious concrete could be recommended as an alternative base layer to replace lean concrete.

Keywords: Fatigue life, Rigid pavement, Pervious concrete, Base layer, KENSLABS

1. INTRODUCTION

Erosion phenomenon could lead to the loss of foundation support, pavement premature distress and short-term service life issue [1]. The increase in traffic load will aim to the use of denser, more robust and anti-erosion base material as well. However, the foundation material that contains a large fine creates a base layer with low permeability and slow water movement. The combination of trapped infiltration water which infiltrating through cracks, joints, and gaps alongside the edge of rigid pavement and repeated traffic loading will generate void between base layer surface and surface layer base (erosion).

In Indonesia, most of the rigid pavement generally use to carry heavy traffic. Survey results related to rigid pavement distress collected from several toll roads and highways in Indonesia showed that pumping, faulting, and longitudinal cracking distress are very plentiful. These shorts of distress generally happen due to loss of foundation support, poor drainage and erosion problem in base layer [2].

Base layer with drainage type like pervious concrete could help to handle those problems. Structural and drainage ability possessed by pervious concrete could replace the function both lean concrete and aggregate base A at the same time because its basic properties stayed above the minimum limit required by Specification [3-4]. Pervious concrete advanced properties that designed using continuously graded aggregate show that this concrete has been successfully fulfilling the minimum requirement for rigid pavement base layer [5]. These advanced properties can be utilized to make a pavement model that could describe pavement service life against traffic loads.

A mechanistic model is modeling that considering pavement response through stress and deflection which occur on pavement structure caused by traffic load. Finite element model has been widely used in the engineering field because of its accurate result [6]. KENSLABS program which is based on finite element method has been widely used to create a numerical model through a mechanistic approach on rigid pavement concrete plate [7-9], Previous studies report that the finite element model shows almost the same result with field measurements [10-12].

The aim of this study is to analyze the impact of pervious concrete application against rigid pavement fatigue life through the mechanistic approach. The Fatigue life will be estimated through pavement response, which represented by tensile stress at the bottom of the slab due to traffic loading. Finite element method is selected as a tool to create the rigid pavement structure model. Pervious concrete advanced property values obtained from laboratory test are used as an input parameter for base layer properties in the mechanistic model.

2. RESEARCH METHODOLOGY

The rigid pavement structure mechanistic model is made using KENSLABS program. Two types of interface, i.e. unbonded and bonded condition, is used in this study because the debonding conditions between layers in multilayer concrete pavement have a significant effect on pavement responses [13]. Every interface has three variations depending on the type of material which is used in each layer (see Table 1 and Table 2). Two layering thickness variations are used as a comparison. In variation 1-6, the surface layer thickness is controlled and the base layer thickness is fixed. In variation 7-12, the surface layer thickness is fixed and the base layer thickness is controlled. Both of fixed values for the surface and base layer are taken from the Guidance [14].

Table 1 List of model variation and interface condition

Model Variation	Interface Layer-1 and Layer-2	Layering Thickness Variation
Var-1	Unbonded	Layer-1 controlled and Layer 2 fixed with a minimum base layer thickness
Var-2		
Var-3	Bonded	
Var-4		
Var-5	Unbonded	Layer-1 fixed with minimum surface layer thickness and Layer 2 controlled
Var-6		
Var-7	Bonded	
Var-8		

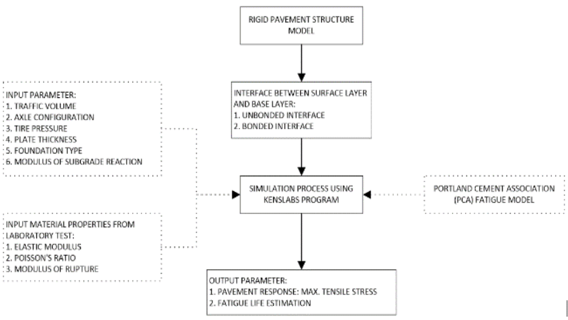

Fig.1 Research methodology outline

The Input parameter used in the model is divided into traffic parameter and performance parameter of concrete material. The traffic parameter consists of traffic volume and tire pressure obtained from the field survey, whereas the performance parameter of concrete material is taken from the laboratory test result. The output parameter of the simulation is shown in the form of pavement response through maximum tensile stress. Portland Cement Association (PCA) fatigue model which is automatically installed in KENSLABS program is used to estimate the pavement fatigue life. The research methodology in this study could be seen in Fig. 1.

Table 2 List of model variation and a layering system

Model Variation	Layering System		
	Layer-1	Layer-2	Layer-3
Var-1 & Var-5	cement concrete	lean concrete	subgrade
Var-2 & Var-6	cement concrete	pervious concrete	subgrade
Var-3 & Var-7	cement concrete	lean concrete	subgrade
Var-4 & Var-8	cement concrete	pervious concrete	subgrade

2.1 Finite Element Model

Finite element model is made in slab shape with 4.5 m x 3.6 m size. This size is a standard dimension for rigid pavement slab in Indonesia required by the Guidance [14]. The plate is divided into finite element mesh which is shown in Fig. 2. KENSLABS program has an advantage if symmetry with respect to one or both axes exists, only one-half or one-quarter of the slab system need to be considered [2]. This feature can save a great deal of computer time and storage.

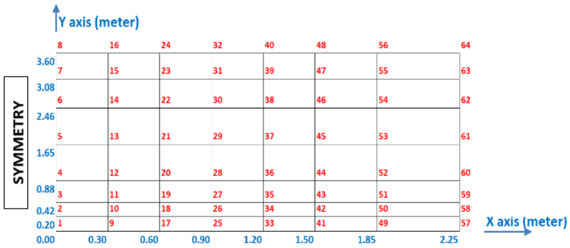

Fig.2 2-D finite element layout model for damage analysis in KENSLABS

Liquid foundation is chosen in this study because rigid pavement design procedure in the Guidance [14] still use CBR and modulus of subgrade reaction to reflect the soil characteristic. The liquid foundation is also called a Winkler foundation, with the force-deflection relationship characterized by an elastic spring. The term "liquid" does not mean that the foundation is a liquid with no shear strength but simply implies that the deformation of the foundation under a slab is similar to that of water under a boat. Nevertheless, the liquid foundation also has a weakness. Unlike the solid foundation, liquid foundation cannot distribute the shear force from one element to the other adjacent element so that the deflection at any nodal point depends only on the force at the node itself (see Fig. 3). Thus, the tensile stress obtained from liquid foundation commonly higher than tensile stress obtained from a solid foundation.

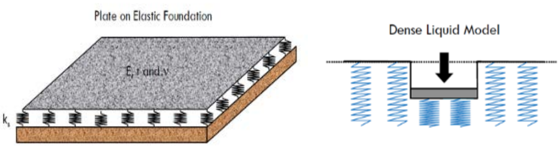

Fig.3 Liquid foundation illustration

The fatigue equations used in this analysis are based on the Portland Cement Association (PCA):

$$\frac{\sigma}{S_c} \ge 0.55 : \log N_f = 11.737 - 12.077\left(\frac{\sigma}{S_c}\right) \quad (1)$$

$$0.45 < \frac{\sigma}{S_c} < 0.55 : \log N_f = \left(\frac{4.2577}{\sigma/S_c - 0.4325}\right)^{3.268} \quad (2)$$

$$\frac{\sigma}{S_c} \le 0.45 : \log N_f = \infty \quad (3)$$

where σ is tensile stress caused by the load (MPa), S_c is the modulus of rupture from concrete material (MPa), N_f is a number of fatigue repetition.

The accumulation of fatigue damage can be expressed as a summation of damage ratios, defined as the ratio between the predicted and allowable number of load repetitions. However, instead of relating to tensile strain, the allowable number of load repetitions is related to the stress ratio, which is the ratio between the flexural stress and the modulus of rupture. The same probability concept used to define percent area cracked can be used to define percent of slabs cracked. After the allowable number of repetitions is determined, the damage ratio can be used to compute the design life. Because only the fatigue cracking is involved, the cracking index (CI), which is the same as the damage ratio is used for describing rigid pavement's fatigue life.

2.2 Input Parameter

Traffic volume which used in fatigue life analysis is taken from traffic survey on the northern coast segment - slow lane Pamanukan direction [15]. The traffic data consists of several classes of vehicle, but the only heavy vehicle used in the analysis (see Table 3 and Table 4). Every single axle load was set in a 12-ton standard load required by Manual [16]. The contact area for each tire imprint is set on ± 41,200 mm^2 [17] so that the tire pressure for each tire will be 728 kPa.

The fatigue of concrete can cause both transverse cracking, which initiates at the pavement edge midway between transverse joints, and longitudinal cracking, which initiates in the wheel-paths at transverse joints, usually at the wheel-path nearest the slab centerline. Fig. 4 shows the most critical loading and stress locations to be considered for fatigue analysis [2]. Transverse cracking is caused by the mid-slab edge loading, and longitudinal cracking is caused by the joint loading.

Table 3 Traffic volume for fatigue analysis

Veh. class	Veh. type	Axle configuration	ADT (vehicle/day)
5B	Bus	1.2	560
6B	Truck	1.2	878
7A	Truck	1.22	1,476
7B	Truck	1.22-2.2	972
7C-1	Trailer	1.2.22	829
7C-2	Trailer	1.2.222	103
7C-3	Trailer	1.22.222	159

Table 4 List of axle number, axle load and tire number for fatigue analysis

Axle type	Axle number (rep/day)	Axle load (ton)	Tire number
Single-axle	4,314[a]	12	4
Tandem-axle	3,436[a]	24	8
Tridem-axle	262[a]	36	16

[a] value has not been multiplied by 0.34 (EDR for tied concrete shoulder)

The lateral distribution of traffic means that wheel loads are not applied at the same location, so only a fraction of the load repetitions need to be considered for fatigue damage. National Cooperative Highway Research Program [18] suggests the use of an equivalent damage ratio (EDR), for each critical loading position. EDR is the ratio of the traffic applied at a critical location that will produce the same accumulated fatigue damage as the total traffic distributed over all locations. It is demonstrated in NCHRP that an EDR of 0.12 to 0.34 can be used for the mid-slab edge loading with tied concrete shoulders.

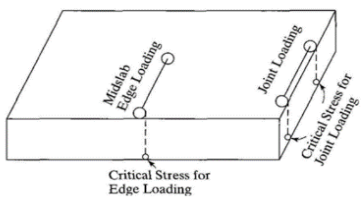

Fig.4 Critical loading and stress locations for fatigue analysis

In this simulation, the subgrade layer is assumed in good condition with CBR value > 5% [14] and class A aggregate granular layer is assumed with minimum CBR value 90% [19]. The stiffness value from the liquid foundation can be obtained through its modulus of subgrade reaction value. This value can be converted from CBR value using a graphic from the Guidance [14] (see Fig. 5).

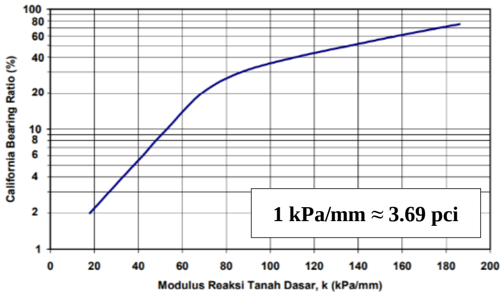

Fig.5 Relationship between CBR value and modulus of subgrade reaction

Properties of foundation can be varied with the season so that a Foundation Seasonal Adjustment Factor (FSAF) is needed to describe the properties of the foundation in each season. The modulus of subgrade reaction of a liquid foundation is multiplied by this factor to simulate the seasonal change in the stiffness of foundation. Because the subgrade in this analysis is assumed in good condition, the FSAF value is set at 1.

Table 5 List of pervious concrete structural properties that used as the input parameter

Type of mix	Elastic modulus (MPa)	Poisson's ratio	Modulus of rupture (MPa)
Mix A	16,964	0.16	2.5
Mix B	16,570	0.22	2.4
Mix C	19,639	0.30	2.8
Mix D	18,950	0.20	2.8
Mix E	22,092	0.24	2.5
Average	18,843	0.22	2.6

Pervious concrete advanced properties that used as input parameter are taken from laboratory experimental test result [5]. Those properties consist of elastic modulus, Poisson's ratio and modulus of rupture. Both elastic modulus and poisson's ratio are obtained from the elastic modulus test in accordance with ASTM C-469. Modulus of rupture is obtained from the flexural strength test in accordance with ASTM C-78. All of them has been surpassed the minimum requirements for rigid pavement base layer required by Specification [19-20]. The average value from five different mixtures composition is applied in the simulation (see Table 5) to represent pervious concrete performance.

Beside pervious concrete, cement concrete and lean concrete are also included as a surface layer (layer-1) and the base layer (layer-2) in model variation. Some of the minimum advanced properties values from cement concrete and lean concrete for rigid pavement are listed in Table 6.

Table 6 List of cement concrete and lean concrete minimum properties values based on Specification

Material properties	Cement concrete	Lean concrete
Modulus of rupture (MPa)	4.7	2.1
Elastic modulus (MPa)	30,000	13,300
Poisson's ratio	0.15	0.15

3. RESULTS AND DISCUSSION

The output parameter from KENSLABS simulation consists of maximum tensile stress at the bottom of the base layer and pavement cracking index.

3.1 Fixed Base layer with Minimum Thickness

In the first layering system variation, the base layer thickness is set in a fixed condition, i.e. 10 cm, and surface layer thickness is controlled. 10 cm is a minimum thickness value for the base layer required by the Guidance [14]. All of the simulation results show that the surface layer produces a higher thickness value compared to the base layer. The surface thickness is varied from 12.5 cm to 42.0 cm. Fig. 6 illustrates the relationship between total thickness and maximum tensile stress at the bottom of the slab using first layering system variation, whereas the relationship between total thickness and fatigue life using first layering system variation is illustrated in Fig. 7. Total slab thickness is a combined thickness of cement concrete slab thickness and pervious concrete slab thickness. Maximum tensile stress at the bottom of the base layer is the highest tensile stress that happened at the bottom of the pervious concrete slab / lean concrete slab (base layer). Its value is obtained from the KENSLABS simulation output. Fatigue life predicts the maximum life that possessed by both slabs (surface layer and base layer) when fatigue load from the vehicle is applied. Its value is also obtained from the KENSLABS simulation output.

Two types of concrete material with different thickness and advanced property values could produce bigger tensile stress when the surface layer and base layer work as a composite structure. Bonded interface produced higher tensile stress at the bottom of the base layer compared to the unbonded interface. According to var-3 and var-4 in Fig. 6, tensile stress values from lean concrete ranged from 1.83 MPa to 0.35 MPa and tensile stress values from pervious concrete ranged from 2.07 MPa to 0.42 MPa. In addition, all of the thickness ratios between the surface layer and the base layer is valued more than 1.0.

The slab thickness should be limited when pervious concrete is used as a base layer with an unbonded condition. When the interface is set in unbonded condition, thinner total thickness might cause the difference of tensile stress between pervious concrete and lean concrete with granular layer rises gradually. Based on var-1 and var-2 in Fig. 6, the difference in tensile stress is big enough when the total thickness is set in the smallest value. However, this difference drops gradually when the total thickness is increased. This situation shows that pervious concrete base layer with unbonded condition tends to be more sensitive in a specific thickness.

Under unbonded and bonded conditions, concrete material with bigger advanced properties could produce higher tensile stress. Looking at var-2 and var-4 in Fig. 6, pervious concrete tends to produce higher tensile stress compared to lean concrete when applied to the unbonded and bonded interface. Tensile stress values from unbonded interface ranged from 1.99 MPa to 0.10 MPa and tensile stress values from bonded interface ranged from 2.07 MPa to 0.42 MPa. This condition happened because most of the structural property values owned by pervious concrete are higher than lean concrete.

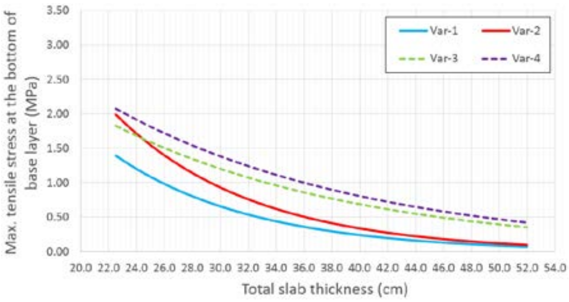

Fig.6 Relationship between total slab thickness and maximum tensile stress at the bottom of the slab using the first layering system variation

On specific thickness, pervious concrete with unbonded interface could produce higher tensile stress at the bottom of the slab compared to lean concrete with the bonded interface. As can be seen in var-2 and var-3 in Fig. 6, maximum tensile stress values owned by pervious concrete is higher than lean concrete with granular layer until their total thickness reaches 24.0 cm. When the total thickness values are set above 24.0 cm, the condition becomes reverse. This condition might be caused by the presence of horizontal stress that appears on the interface due to each slab which works individually. Nevertheless, the horizontal stress does not always increase the tensile stress, especially when the total slab thickness is thicker and the thickness ratio between the surface layer and the base layer is valued more than 1.0.

Indirectly, the bonded interface could increase fatigue life significantly. Compared to the unbonded interface, the bonded interface also requires a thinner total thickness to achieve the specific fatigue life value. According to var-3 and var-4 in Fig. 7, lean concrete only needs about 33.40 cm to reach 20 years of fatigue life and pervious concrete only needs about 32.85 cm to reach 20 years of fatigue life. The presence of horizontal stress tends to fade away due to the stickiness which appears on the interface during the bonded condition.

On specific total thickness, pervious concrete with the bonded interface has a longer fatigue life compared to lean concrete with the bonded interface. Based on var-3 and var-4 in Fig. 7, pervious concrete with a total thickness of 33.0 cm has a fatigue life about 26 years, whereas lean concrete with a total thickness of 33.0 cm has a fatigue life only about 10 years. This condition shows that higher structural properties value from single base layer material could produce bigger fatigue life range. Concrete material with higher advanced properties also has higher elastic modulus value and modulus of rupture value which can increase the material ability to endurance against flexural fatigue load.

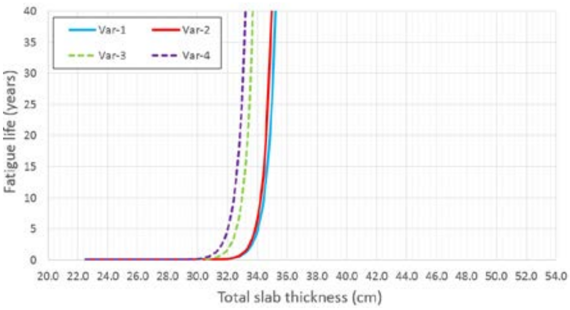

Fig.7 Relationship between total slab thickness and fatigue life using the first layering system variation

The identical fatigue life might be achieved if the difference among the advanced property values from base layer material is not too far and the thickness ratio between the surface layer and the base layer is valued more than 1.0. In addition, a more practical range of thickness in the fixed base layer is maximum 35 cm. When the interface is set in unbonded condition, both of pervious concrete and lean concrete produce almost similar slab thickness. Looking at var-1 and var-3 in Fig. 7, lean concrete requires about 35.25 cm to reach 40 years of fatigue life and pervious concrete requires about 35.00 cm to reach 40 years of fatigue life. Although both them almost have some similarities on their advanced property values, pervious concrete has an advantage in flowing water through its voids. Therefore, pervious concrete with fixed base layer could be recommended as an alternative bonded and unbonded base layer to replace lean concrete.

3.2 Fixed Surface Layer with Minimum Thickness

In the second layering system variation, the surface layer thickness is set in a fixed condition, i.e. 15 cm, and the base layer thickness is controlled. 15 cm is a minimum thickness value for the surface layer required by the Guidance [10]. Most of the simulation results showed that the base layer produces a higher thickness value compared to the surface layer. The base thickness is varied from 7.5 cm to 37.0 cm. Fig. 8 illustrates the relationship between total thickness and maximum tensile stress at the bottom of the slab using second layering system variation, whereas the relationship between total thickness and fatigue life using second layering system variation is illustrated in Fig. 9.

Two types of concrete material with different thickness and advanced property values could produce bigger tensile stress when the surface layer and base layer work individually. Unbonded interface produced higher tensile stress at the bottom of the base layer compared to the bonded interface. According to var-5 and var-6 in Fig. 8, tensile stress values from lean concrete ranged from 2.48 MPa to 0.97 MPa and tensile stress values from pervious concrete ranged from 3.11 MPa to 1.04 MPa. In addition, some of the thickness ratios between the surface layer and the base layer is valued less than 1.0.

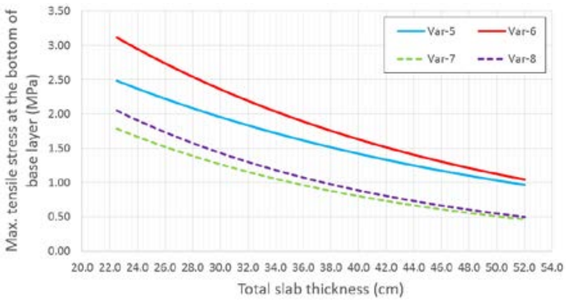

Fig.8 Relationship between total slab thickness and maximum tensile stress at the bottom of the slab using second layering system variation

The slab thickness should be limited when pervious concrete is used as a base layer with an unbonded condition. When the interface is set in unbonded condition, thinner total thickness might cause the difference of tensile stress between pervious concrete and lean concrete with granular layer rises gradually. Based on var-5 and var-6 in Fig. 8, the difference in tensile stress is big enough when the total thickness is set in the smallest value. However, this difference drops gradually when the total thickness is increased. This situation shows that pervious concrete base layer with unbonded condition tends to be more sensitive in a specific thickness.

Under unbonded and bonded conditions, concrete material with bigger advanced properties could produce higher tensile stress. Looking at var-6 and var-8 in Fig. 8, pervious concrete tends to produce higher tensile stress compared to lean concrete when applied to the unbonded and bonded interface. Tensile stress values from unbonded interface ranged from 3.11 MPa to 1.04 MPa and tensile stress values from bonded interface ranged from 2.05 MPa to 0.50 MPa. This condition happened because most of the structural property values owned by pervious concrete are higher than lean concrete.

Indirectly, the bonded interface could increase fatigue life significantly. Compared to the unbonded interface, the bonded interface only requires a thinner total thickness to achieve the specific fatigue life value. According to var-7 and var-8 in Fig. 9, lean concrete only needs about 36.20 cm to reach 40 years of fatigue life but pervious concrete only needs about 34.15 cm to reach 40 years of fatigue life. The presence of horizontal stress tends to fade away due to the stickiness which appears on the interface during the bonded condition.

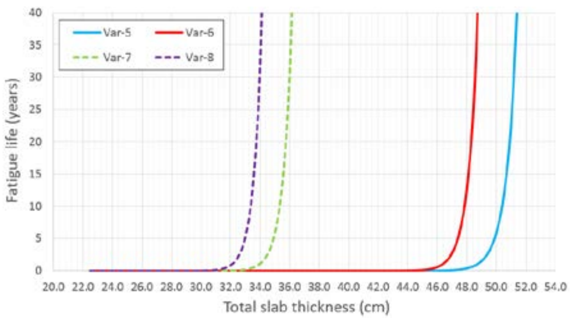

Fig.9 Relationship between total slab thickness and fatigue life using second layering system variation

On specific total thickness, pervious concrete with the bonded interface has a longer fatigue life compared to lean concrete with the bonded interface. Based on var-7 and var-8 in Fig. 9, pervious concrete with a total thickness of 34.0 cm has a fatigue life about 31 years, whereas lean concrete with a total thickness of 34.0 cm has a fatigue life only about 1.0 years. This condition shows that higher structural properties value from single base layer material could produce bigger fatigue life range. Concrete material with higher advanced properties also has higher elastic modulus value and modulus of rupture value which can increase the material ability to endurance against flexural fatigue load.

The different fatigue life might happen if the difference among the advanced property values from base layer material is not too far and the thickness ratio between the surface layer and the base layer is valued less than 1.0. When the interface is set in unbonded condition, pervious concrete required thinner total thickness compared to lean concrete without granular. Looking at var-5 and var-6 in Fig. 9, lean concrete requires about 50.9 cm to reach 20 years of fatigue life and pervious concrete requires about 48.3 cm to reach 20 years of fatigue life. Therefore, pervious concrete with fixed surface layer could also be recommended as an alternative bonded and unbonded base layer to replace lean concrete.

3.3 Comparison between Fixed Base Layer and Fixed Surface Layer

Based on simulation results, both of fixed base layer and fixed surface layer have some similar results. The slab thickness should be limited when pervious concrete is used as a base layer with an unbonded condition. Under unbonded and bonded conditions, concrete material with bigger advanced properties could produce higher tensile stress. Indirectly, the bonded interface could increase fatigue life significantly. Pervious concrete with a bonded interface had a longer fatigue life compared to lean concrete with the bonded interface.

Nevertheless, both of them also have several different results. Two types of concrete material with different thickness and advanced property values could produce bigger tensile stress when the surface layer and base layer work as a composite structure or individually. On the specific total thickness, pervious concrete with unbonded or bonded interface could produce higher tensile stress at the bottom of the slab compared to lean concrete with the bonded or unbonded interface. The identical fatigue life might be achieved if the difference among the advanced property values from base layer material is not too far and the thickness ratio between the surface layer and the base layer is valued more than 1.0. On the other hand, the different fatigue life might happen if the difference among the advanced property values from base layer material is not too far and the thickness ratio between the surface layer and the base layer is valued more than 1.0 or less than 1.0.

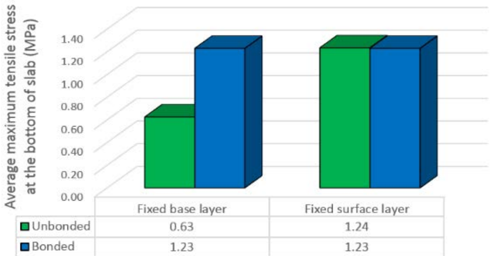

Fig.10 Summary of simulation results for average maximum tensile stress using pervious concrete as rigid pavement base layer

Either in a fixed surface layer condition or a fixed base layer condition, pervious concrete with bonded interface could produce a close maximum tensile stress value almost in every total thickness value. On the total thickness of 36.0 cm, both conditions produce a tensile stress value, respectively 1.07 MPa (var-3 in Fig 6) and 1.00 MPa (var-7 in Fig. 8). This situation might also bring benefit while using pervious concrete as a bonded base layer. If the traffic load is similar and non-structural property like permeability is more considered then fixed surface layer condition with bonded interface could be chosen. If the traffic load is similar and structural property like flexural strength is more considered then fixed base layer condition with bonded interface could be chosen. In the fixed surface layer condition, the pervious concrete layer (base layer) tends to be thicker than the cement concrete layer (surface layer). In the fixed base layer, the pervious concrete layer (base layer) tends to be thinner than the cement concrete layer (surface layer).

When pervious concrete is used as an unbonded base layer, the fixed base layer with a minimum thickness is more recommended better than the fixed surface layer with minimum thickness because it is less sensitive against maximum tensile stress at the bottom of the slab and requires thinner maximum total slab thickness. According to Fig. 10 and Fig. 11, the fixed base layer requires thinner total thickness, i.e. 35.00 cm, for serving the traffic load until 40 years from now. In addition, it also produces lower average maximum tensile stress, i.e. 0.63 MPa, compared to fixed surface layer during those serving time.

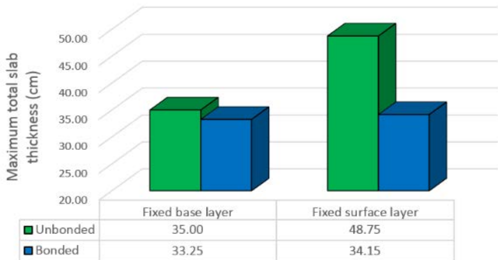

Fig.11 Summary of simulation results for maximum total slab thickness using pervious concrete as a rigid pavement base layer

When pervious concrete is used as a bonded base layer, the fixed base layer with a minimum thickness is more recommended better than the fixed surface layer with minimum thickness because it requires thinner total slab thickness. Looking at Fig. 10 and Fig. 11, both of fixed base layer and fixed surface layer produce almost an equal average maximum tensile stress, i.e. $\pm$ 1.23 MPa, for serving the traffic load until 40 years from now. However, the fixed base layer requires a bit thinner maximum total slab thickness, i.e. 33.25 cm, compared to the fixed surface layer during those serving time.

4. CONCLUSION

Based on the analysis results, several conclusions could be drawn from this study:

1. Pervious concrete with the bonded interface has a longer fatigue life than lean concrete with the bonded interface.
2. The difference among the advanced property values from base layer material and the thickness ratio between the surface layer and the base layer plays an important role in fatigue life value.
3. Either in unbonded condition or in bonded condition, the fixed base layer with a minimum thickness is more recommended when pervious concrete is used as a base layer because it requires thinner total slab thickness.
4. Pervious concrete could be recommended as an alternative base layer to replace lean concrete.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Kozeliski F.A., Permeable Bases Help Solve Pavement Drainage Problems, the Aberdeen Group, 1992, In press.

[2] Huang Y.H., Pavement Analysis and Design 2nd Edition, Upper Saddle River: Pearson Education, Inc., 2004, pp. 380-585.

[3] Care F.R.A.M., Subagio B.S. and Rahman H., Porous Concrete Basic Property Criteria as Rigid Pavement Base Layer in Indonesia, Conference proceedings, in Proc. 3rd Int. Conf. on Sustainable Infrastructure and Built Environment (SIBE), 2018, Vol. 147, pp. 1-16.

[4] Care F.R.A.M., Subagio B.S., Rahman H. and Yamin R.A., Porous Concrete Basic Property Criteria as Rigid Pavement Base Layer Adjusting Field Gradation, Conference proceedings, in Proc. 2nd Int. Conf. on Conference for Civil Engineering Research Networks (ConCERN-2), 2019, Vol. 270, pp. 1-8.

[5] Care F.R.A.M., Subagio B.S., Rahman H. and Yamin R.A., Advanced Properties of Continuously Graded Pervious Concrete for Rigid Pavement Base Layer, International Journal of Engineering and Technology Innovation, IJETI, Vol. 9, No. 2, 2019, pp. 91-107.

[6] Frydrysek K., Janco R. and Gondek H., Solution of Beams, Frames and 3D Structures on Elastic Foundation Using FEM, International Journal of Mechanics, Vol. 7, 2013, pp. 363-369.

[7] Saini P., Analysis of Rigid Pavement Using KENSLABS, M.Tech. Dissertation, National Institute of Technology Kurukshetra, India, 2014, pp. 44-45.

[8] Chegenizadeh A., Keramatikerman M. and Nikraz H., A Study on Numerical Modelling of Rigid Pavement: Temperature and Thickness Effect, International Journal of Civil and Environmental Engineering, IJCEE, Vol. 10, No. 2, 2016, pp. 265-269.

[9] Taghavi Ghalesari A., Chang-Albitres C.M., Sustainable Design of Rigid Pavements Using a Hybrid GP and OLS Method, Geo-Congress, Philadelphia, PA, ASCE GSP 310, 2019, pp. 317-325.

[10] Huang Y.H., Wang S.T., Finite-Element Analysis of Rigid Pavements with Partial Subgrade Contact, Transportation Research Record 485, 1974, pp. 39-54.

[11] Darter M.I., Barenberg E.J., Design of Zero-Maintenance Plain Jointed Concrete Pavement, Report no. FHWA-RD-77-111, Vol .1, 1977.

[12] Chou Y.T., Huang Y.H., A Computer Program for Slabs with Discontinuities on Layered Elastic Solids. Conference Proceedings, in Proc. 2nd Int. Conf. on Concrete Pavement Design, 1981, pp. 78-85.

[13] Parjoko Y.H., Sensitivity Analysis of Concrete Performance Using Finite Element Approach, Journal of the Civil Engineering Forum, JCEF, Vol. XXI, No. 1, 2012, pp. 1171-1182.

[14] Cement Concrete Pavement Design Guidance, Pd T-14-2003, Department of Regional Settlement and Infrastructure, 2003, pp. 9-32.

[15] Care F.R.A.M., Functional and Structural Evaluation of Flexible Pavement Using Nondestructive Method, M.Sc. Thesis, Bandung Institute of Technology, Indonesia, 2012, p. 34.

[16] Manual of Road Pavement, No. 04/SE/Db/2017, Ministry of Public Works and Housing Directorate General of Highways, 2017, p. 4-4.

[17] Fernando E.G., Musani D., Park D.W. and Liu W., Evaluation of Effects of Tire Size and Inflation Pressure on Tire Contact Stresses and Pavement Response, FHWA Technical Report, Texas Transportation Institute, 2006, pp. 46-47.

[18] NCHRP, Calibrated Mechanistic Structural Analysis Procedures for Pavement, NCHRP 1-26, Vol. 1-2, Final Report, the University of Illinois at Urbana-Champaign, 1990.

[19] General Specification 2018 for Bridge and Road Construction Works, Directorate General of Highways Ministry of Public Works, 2018, p. 5-22.

[20] Manual of Hydraulic for Road and Bridge Works: Book 2 Hydraulic Design, No: 01-2/BM/2005, Directorate General of Highways Department of Public Works, 2005, p. 96.