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The Influence of Temperature Variations on Rigid Pavement Concrete Slabs

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ABSTRACT This research aims to assess the effect of temperature gradient developed within the concrete slab of rigid pavement, and to investigate its impact when incorporated with the traffic load, and the heat transfer pattern. The rigid pavement model considers an isotropic, uniform, and linear-elastic schemes to simulate the material properties. A numerical analysis approach was employed using Abaqus software incorporated with the 3D Solid model. The traffic loads were obtained from the field surveys, while the temperature of the slabs was measured directly on the site. The dimension of the rigid panel is 2.75 m in width, 5 m long, slab thickness of 25 cm, and concrete specification of 41.33 MPa. The results showed that the temperature gradient produced a significant impact on stress development within the concrete slab of rigid pavement. It was observed that the temperature gradient during the daytime generated higher stress than at night, with a value reaching the MOR (Modulus of Rupture). The exposure of the rigid pavement to 500C tends to produce a principle slab stress of 2.395 MPa, while 1.31 MPa was developed due to the traffic load. When the two factors were combined, the concrete slab acquired a maximum principle stress of 3.322 MPa, which is close to the MOR of 83.34% f_a. These results showed that the pavement is capable of withstanding stress from temperature gradient and traffic load as indicated by the ratio of less than one (1). However, this ratio is high for fatigue failure mitigation purposes, and this reduces the quality of life of the rigid pavement.

KEYWORDS Temperature Gradient; Rigid Pavement; Traffic Load; Numerical Analysis; Concrete Slab

1 INTRODUCTION

The geographical location of Indonesia along the equator confers a tropical climate experience characterized by high temperatures and distinct dry and rainy seasons. The dry season, which is typically marked by moderate heat and dampness, contrasts with the rainy period, during which cold temperatures and high humidity prevail. The varying weather conditions significantly affect the durability of the road network infrastructure in the country. The pavement structures are expected to support the load confer by both external and internal factors. In essence, the road should be able to continuously provide a strong and durable surface layer to ensure high comfort and safety during its period of service. Considering the risk of increasing potential deterioration due to environmental conditions, the road design should also consider the influence of temperature, which has not been investigated. Therefore, a study on the influence of temperature on the stress-strain relationship of the concrete slab pavement is necessary. This involves a numerical analysis on the effect of temperature on the concrete pavement slab on one of the streets in the rural area region. The street has two roads of traffic line, and the concrete panel of the slab is 2.75 meters wide, 5 meters long, and a thickness of 25 centimeters. The dimensions of the concrete slab which tend to be smaller in width than in general are the differences. The rule of thumb is that the ratio of panel length to width should not exceed 1.5. This value is recommended in the Guidelines for Construction of Concrete Floors and Slabs, ACI 302.1R-15, in Section 2.3.2 on contraction joints. Panels with excessive length-to-width ratios tend to crack at the center or at some other location between joints.

Hilyanto and Setiawan (2013) conducted a research on the structural reaction of concrete slab as rigid pavement on subgrade using the finite element method with Plaxis 3D software. The model used is a concrete slab of 6x3 m with thickness variations of 15, 25, and 35 cm, while the quality varies from (f'_c) 20, 25, and 30 MPa. The findings obtained include 1) the loading position which confered large influence on the developed stresses on the concrete slab. 2) The variation in concrete quality which produced different deflection values. 3) The difference in slab thickness yielded a significant difference in stress development and the total soil density in the underneath pavement.

The research carried out by Cui et al. (2022) assessed the thermal stress response of rigid pavements that have bottom voids with polymer grout fillers in the time domain, and the design traffic load was employed. A finite element method with a 3-dimensional approach with the help of Abaqus was also used. The results showed that thermal stress at the corner of the plate has a higher influence on the critical slab stress than other locations. The research also compared the condition of rigid pavement plates before and after going through the polymer grouting repair stage. The findings indicated that the critical tensile stress at the corner of the plate under the vehicle and the thermal load is significantly reduced. The analysis also showed that after 3 years, the stability of the new polymer worked.

Setiawan (2020) conducted research on the influence of temperature differences and the quality of the subgrade on stresses and deflections in rigid pavements. Analysis and visualization of rigid pavement mechanical behavior, such as stress and deflection were performed using the KENPAVE program with variations in temperature and quality of soil parameters. It was found that the subgrade modulus and higher temperature cause intense stress on rigid pavements. The quality of the subgrade was not significantly affected by the curling. Contrarily, curling is greatly dependent on temperature differences. The varied soil quality impacts indicated that a higher subgrade modulus causes smaller deflections, but still has a more significant curve that shifts toward the center of the plate. In addition to the temperature parameters faced by rigid pavement, the load of passing vehicles also needs to be considered. The previous research has not included the load factor of the vehicle that should be conveyed.

MacKiewicz (2014) conducted a study to determine the stress distribution around the dowel rods obtained from the differences in thermal gradients in Poland. Thermal stresses were analyzed concerning different diameters of dowel rods. It was found that the application of a small-diameter dowel increases the pressure around the material. Moreover, the calculations that have been carried out showed that large tensile stresses are concentrated on the concrete slab on both sides of the dowel with a small diameter.

The research conducted by Qin and Hiller (2011) investigated the temperature and thermal stress due to the influence of solar absorption on Jointed Plain Concrete Pavement (JPCP). The study emphasized on the temperature distribution pattern through the thickness of the rigid concrete slab using a one-dimensional heat transfer model. Deterministic and probabilistic methods are used to input the solar radiation parameters. The observation of solar radiation over a certain period is identified as a deterministic method. The estimated solar variation is based on the value of random normal distribution between the highest and lowest radiation. A negative gradient is induced when the weather shifts from a sunny to a cloudy day, and positive when it is otherwise. Previous analysis showed that cloudy weather affects the temperature under the concrete slab. This occurs because the bottom of the concrete slab stores a lot of negative energy. It is observed that the thermal stress that occurs above the concrete slab on the top surface is ±0.3 MPa, while ±0.1 MPa is evident at the bottom. Considering that Indonesia is a country with quite extreme temperatures, the influence of weather conditions innegligible. Given the existing regulations such as the Federal Aviation Administration (FAA) Advisory Circular No. AC 150/5320-6C Airport Pavement Design and Evaluation, Portland Cement Association (PCA), Load Classification Number (LCN), American Association of State Highway and Transport Officials (AASHTO) 1993, Federal Highway Administration (FHWA), and Construction Pavement Design Manual Bina Marga 2017 which has included the influence of temperature in the design, but has not been used optimally. Therefore, this research focused on modeling with rigid pavement types using the 3-Dimensional Finite Element Method with Abaqus software.

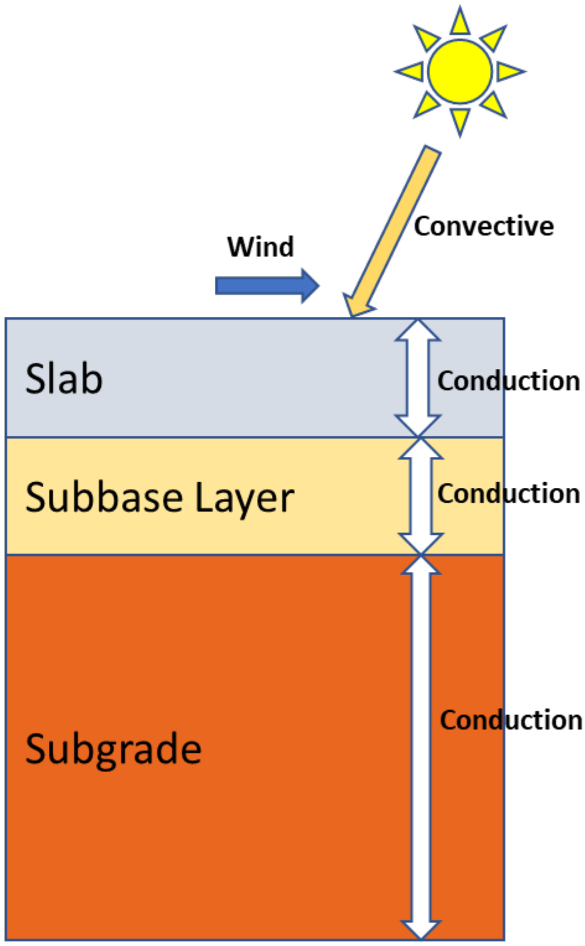


Figure 1 The illustration of heat transfer scheme (Qin and Hiller, 2011)

2 THERMAL PARAMETER

Analyzing thermal influence on the rigid pavement is closely related to the convection process. The convection process begins with the presence of Heat Flux on a continuum surface. According to Huang et al. (2017), Heat Flux is the rate of energy transfer through a surface. The unit of heat level is measured in joules per second or watts. The Heat Flux is the heat rate per unit area with units of watt m^{-2}, and the measurement is carried out by evaluating the temperature difference through a material whose heat conductivity value is known.

According to Huang et al. (2017) convective heat transfer occurs between the moving wind stream and the top surface of the concrete slab when the temperature is different. The degree of coldness and hotness in the fluid region above the plate varies from T_s at the surface and T_a from the ambient air temperature. The heat convection calculation on the pavement surface is as follows:

$$q_c = h_c\left(T_s - T_a\right) \tag{1}$$

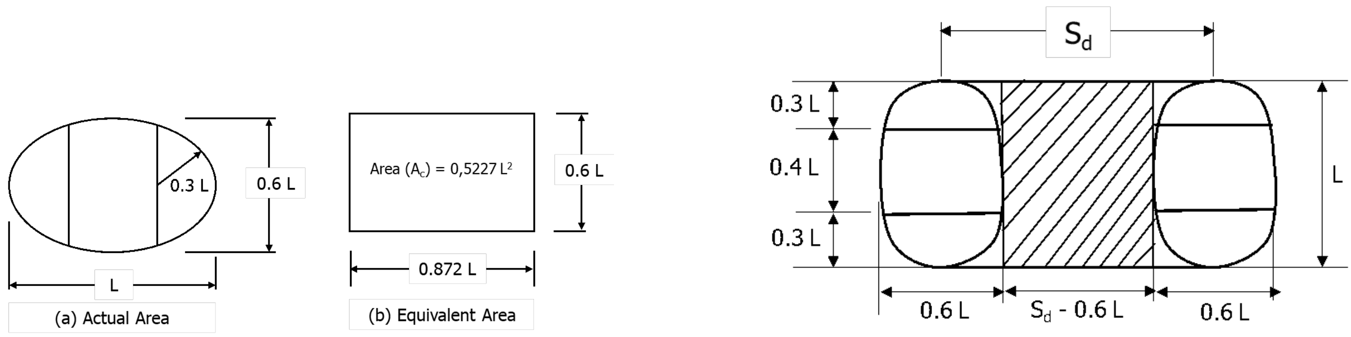
where q_c is the convective heat flux (W m^{-2}), Ts is the temperature of the surface (°C), T_a is the ambient temperature (°C), and h_c is the coefficient of the convection (W m^{-2}°C^{-1}). The coefficient of the convective heat transfer, wind speed, and plate surface roughness was suggested to be calculated by the empirical formula.

3 VEHICLE LOAD

According to the Manual (2017), axle load is the wheel pressure from one axis of the vehicle evenly distributed. The heaviest axle load is the sum of the vehicle wheel pressure against the pavement. The analysis of the structural behavior patterns of class III or primary collector, or district roads was determined. According to the Regulation of the Minister of Public Works and Public Housing of Indonesia, Regulation of the Minister of Public Works and Public Housing Number 05/PRT/M/2018 concerning Determination of Road Classes Based on Traffic Function and Intensity, with Class III Roads identified as the heaviest axis load and dimensions of vehicles. This implies that the road is subjected to vehicles with a width not exceeding 2,100 m, a length of 9,000 m, a height of 3,500 m, and MST of 8 tons. After establishing the axis load to be used, the next step is to determine the size of the contact area. The contact pressure determines the value of the area. According to (Huang, 2004), for low-pressure tires, the contact pressure should be greater than that of the tire. This is due to the pressure on the tire wall and the total vertical force should be equal to that of the contact. In pavement design, the contact force is generally assumed to be equal to the tire pressure. Assuming length (L) and width (0.6L) are given, then the area of contact pressure (A_c) is calculated as (Huang, 2004):

$$A_c = \pi\left(0.3L\right)^2 + \left(0.4L\right)\left(0.6L\right) = \left(0.5227L\right)^2 \tag{2}$$

The PCA method (1984) in Huang (2004) is currently based on a finite element procedure, and the area of a rectangle is assumed to be 0.8712L long and 0.6L wide, which have the same area of 0.5227 L^2.



(a) single-wheel conversion (b) Double wheel

Figure 2 The dimensions of vehicle contact pressure

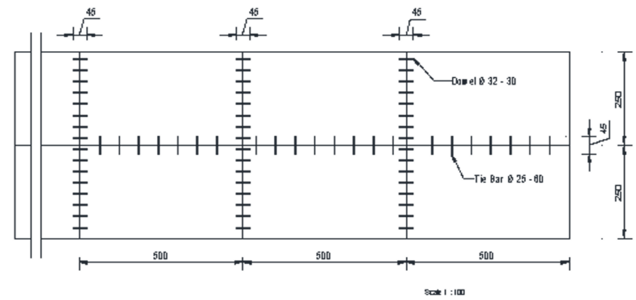


Figure 3 The geometry of the rigid pavement section at Sleman District, Yogyakarta (Scale 1:100)

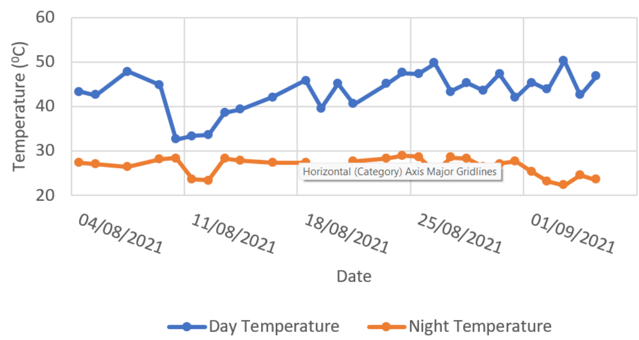


Figure 4 Temperature measurement data

4 RESEARCH METHODS

The assay commenced by conducting a literature study from various references, then proceed with rigid pavement modeling using the software. The analysis of the modeling that has been made should be compared with the applicable standards. The parts of the model consist of six panels of concrete slabs connected with dowels and tie bars (Figure 3). The slab was laid on top of a lean concrete layer of 10 cm thickness. Below the lean concrete layer is sub-based and then the subgrade layer of 6% of CBR value. This layer was according to the design specification issued by the transportation regulation of Sleman District, Yogyakarta, Indonesia.

This research considered three variations of temperature which include 50°C, 45°C, and 40°C by the day, while at night is 25°C, 28°C, and 30°C. These temperature data were measured on-site at the top of a concrete slab of rigid pavement, at various times between August-September 2021, at Sleman, Yogyakarta. The temperature was measured using a calibrated thermogenic, and the result is presented in Figure 4.

An analysis of the effect of linear temperature variation was conducted. This enables the temperature difference on the upper and lower surfaces of the rigid pavement concrete slab to be the same. The temperature difference between the surfaces is also known as the temperature gradient or thermal gradient. The value of the temperature difference in the concrete slab used the approach proposed by Huang (2004) and Khan et al. (2014). The result showed a positive and negative gradient of 0.66°C cm^{-1} and -0.33°C cm^{-1}, respectively.

The structural design of the pavement was developed on the basis of finite element model. The core process of the finite element method is to divide a complex problem into smaller parts from which simpler solutions are easily obtained. Element is an arrangement of matter that has a relatively regular shape and has certain properties depending on the physical form and the constituent material. A structure has an elastic modulus (E), shear modulus (G), cross-sectional area (A), length (L), and inertia (I) (Suhendro, 2000), each of these parts is created in 3D Solid elements. Three-dimensional (3-Dimensional (3D) Solid) elements are the most common because all field variables

(a) Hexahedral elements (b) Tetrahedral elements (Suhendro, 2000)

Figure 5 Solid 3D elements

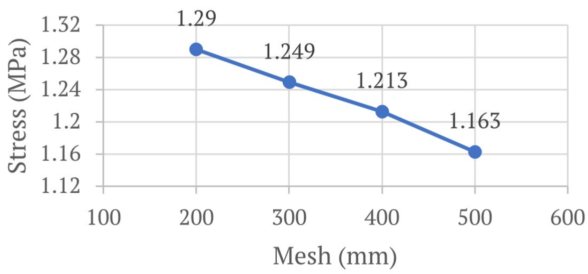


Figure 6 Convergence test on the Rigid Pavement Models

depend on x, y, and z as shown in Figure 5 (Suhendro, 2000).

The Abaqus model was used to develop the structural design of the rigid pavement. In general, Abaqus simulate the engineering behavior of structure, based on the finite element method, which solve problems ranging from relatively simple linear analysis to complex nonlinear simulations, and it models the 3D Solid elements satisfactorily. Solid 3D elements that should be used in this rigid pavement modeling are hexahedral and tetrahedral elements.

Generally, the stress due to temperature is calculated using the following equation by Westergaard (1927), but in this research, the thermal properties/parameters of rigid pavement were included into the modeling system. The thermal parameters considered are conductivity, coefficient of expansion, and specific heat of each material or layers (Table 1). The loading that should be applied in the modeling is service load compounded with the use of isotropic, uniform, and linear-elastic materials.

The modeling was initiated carrying out a convergence test to verify the accuracy, and 25 cm mesh parts were used in El-nakib (2007) research. This implies that parts of rigid pavement modeling were divided into dimensions of 25 cm long and 25 cm wide. The convergence test in Figure 6 showed that the model has sufficient accuracy to be used in numerical analysis.

The next step is identifying structural parts, material properties, form schemes, analysis phases, interactions components, supported loads, and boundary conditions. The data collected contains the dimensions of parts and material properties. The possible interactions among the rigid pavement layers were determined based on assumption of the previous research. Some of the assumption are as follows: 1) The interactions among layers being used in the modeling are surface-to-surface contact (El-nakib, 2007). The analytical step that should be used in the modeling is the couple-temp displacement. 2) The temperature load should be applied only to the rigid pavement concrete slab. The temperature used is obtained from the top and bottom of the plate based on the thermal gradient value. 3) In the Boundary Conditions, the entire system is allowed to deform along the vertical direction except for the sub-surface soil, which is prevented from moving. 4) All subgrade planes are prevented to deform along the horizontal direction (because of their symmetry and infinite domain). 5) The two concrete slabs are prevented from deforming in the horizontal direction, except along the plane of symmetry (cutting plane) (El-nakib, 2007). The assumption for the boundary condition by El-nakib (2007) is shown in Figure 7. The subgrade modeling used 3D Solid with hinge on the underlying surface. This is based on Boussinesq theory (Bowles, 1997). Where at a certain depth, the subgrade is assumed to receive a small stress and tends to be under 5%, in order for the base subsoil surface to adopt the hinges (El-nakib, 2007). This is calculated using the influence

Table 1. Parameters of the pavement and underlying layers

Materials	Parameters	Value	Unit	Reference
Concrete	Compressive Strength (f'c)	41.33	MPa	DPUPKP Kabupaten Sleman, 2021
	Modulus of Rupture	3.985882	MPa	*SNI 2847* (2019)
	Elasticity Modulus	30215.55	MPa	*SNI 2847* (2019)
	Poisson Ratio	0.25		Tyau (2009)
	Density	2.4x10-9	Ton mm^{-3}	Tyau (2009)
	Conductivity (k	1.4	mW mm^{-1}°C^{-1}	Prawesti (2018)
	Specific Heat (Cp)	8.8x108	mJ ton^{-1}°C^{-1}	Prawesti (2018)
	Coefficient of Thermal Expansion (α)	1.2x10-5	°C	Prawesti (2018)
Dowel	Elasticity Modulus	200000	MPa	Tyau (2009)
	Poisson Ratio	0.3		Tyau (2009)
	Density	7.85	Ton mm^{-3}	Tyau (2009)
	Conductivity (k)	45.3	mW mm^{-1}°C^{-1}	Prawesti (2018)
	Specific Heat (Cp)	5.02x108	mJ ton^{-1}°C^{-1}	Prawesti (2018)
Lean Concrete	Compressive Strength (f'c)	10	MPa	DPUPKP Kabupaten Sleman, 2021
	Elasticity Modulus	14862.71	MPa	*SNI 2847* (2019)
	Poisson Ratio	0.25		Tyau (2009)
	Density	2.4x10-9	Ton mm^{-3}	Tyau (2009)
	Conductivity (k)	1.4	mW mm^{-1}°C^{-1}	Prawesti (2018)
	Specific Heat (Cp)	8.8x108	mJ ton^{-1}°C^{-1}	Prawesti (2018)
Subgrade	CBR	6	%	
	Elasticity Modulus	0.04	MPa	NAASRA 1987 chart on Aulia (2015)
	Poisson Ratio	0.3		Bowles (1997)
	Density	1.78x10-9	Ton mm^{-3}	Saffar et al. (2021)
	Conductivity (k	1.675	mW mm^{-1}°C^{-1}	Prawesti (2018)
	Specific Heat (Cp)	1.381x10-9	mJ ton^{-1}°C^{-1}	Prawesti (2018)

value derived from the Boussinesq theory. When the load used is 8 tons, or 506.54 kN m^{-2}, when converted into the dimensions of the vehicle wheel treads, then the subgrade layer tends to receive a maximum stress of 8.104 kN m^{-2}. From the results of these calculations, the lower surface of the subgrade is modeled as a hinge. The assumption for the boundary condition is shown in Figure 8.

The model consists of six-panel of concrete slabs each has dimension of the width of 2.75 m, length of 5.0 m, and thickness of 0.25 m. The slab is resting on a sub-base layer of lean concrete with 0.10 m thickness. The pavement structure is supported by a subgrade of 3.00 m depth, and a 3-D model with dimensions of 5.50 m long, 15.0 m width, and 3.35 m depth. In accordance with El-nakib (2007), FEM meshing is used to make the existing elements uniform in the horizontal direction. The uniform length of the elements in the vertical direction for the concrete slab layer and sub-base is chosen based on the sub-grade depth which has a greater value. In order to minimize the total number of elements in the system, the subgrade discretization in the vertical direction is generated in a biased manner (Figure 9).

5 RESULTS

5.1 Temperature Variations Analysis

Rigid pavement modeling was used to analyze the effects that occurred due to the position of vehicle loads and temperature variations. Figure 10 shows an increase in stress that is directly proportional to the increase in temperature above

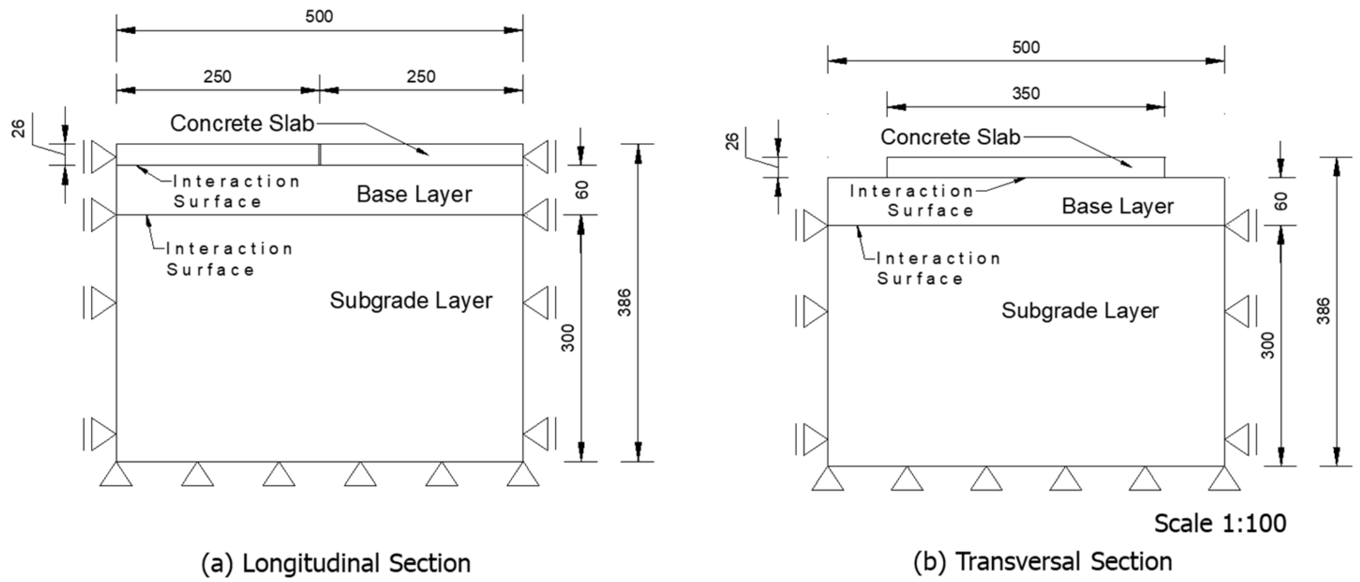


Figure 7 The boundary conditions of the rigid pavement (El-nakib, 2007)

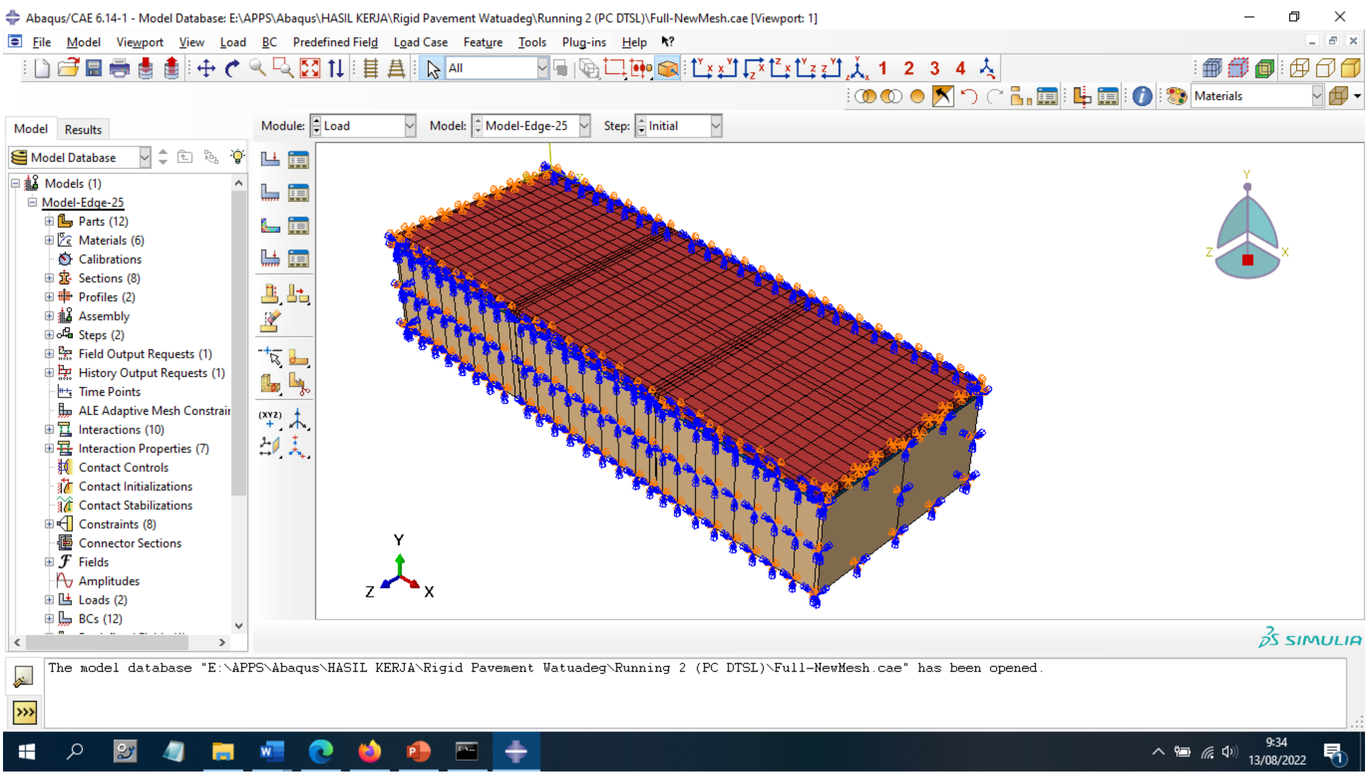
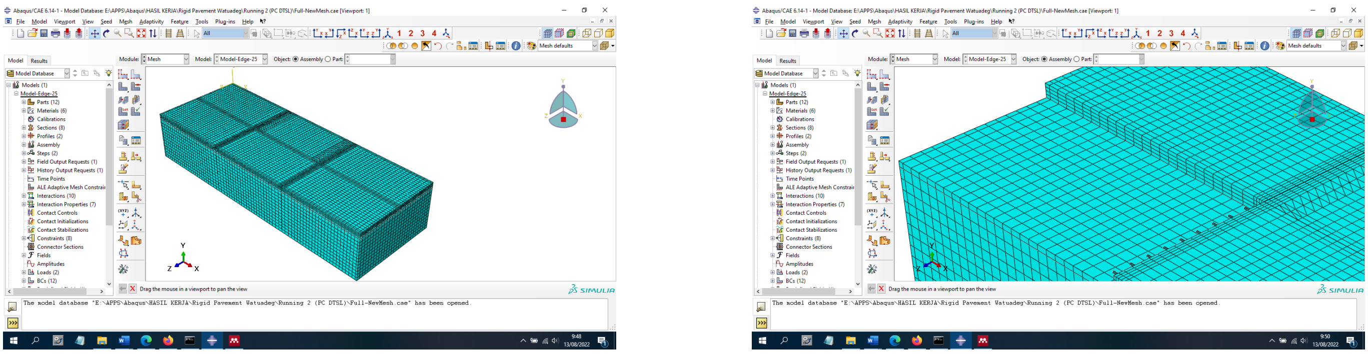


Figure 8 The boundary conditions of the rigid pavement

Table 2. Stress due to temperature variations in rigid pavement

Top Surface (°C)	Bottom Surface (°C)		S_{xx} (MPa)	Syy (MPa)	S_{zz} (MPa)	S_{xy} (MPa)	S_{xz} (MPa)	S_{yz} (MPa)
50	33.5	Max	2.329	2.395	2.04	2.3	2.802	2.515
		Min	-3.167	-2.52	-2.389	2.254	-1.608	-2.543
45	28.5	Max	2.245	2.295	1.711	1.433	1.107	2.213
		Min	-2.922	-2.103	-0.952	-1.41	-1.109	-2.213
40	23.5	Max	2.23	2.278	1.707	1.503	1.329	2.207
		Min	-2.879	-0.691	-0.935	-1.532	1.33	-2.277
30	38.25	Max	1.871	2.202	1.7	1.665	1.305	1.07
		Min	-2.17	-1.816	-1.112	-1.694	-1.295	-1.84
28	36.25	Max	1.586	2.02	1.782	1.894	1.097	1.921
		Min	-1.602	-1.753	-1.297	-1.91	-1.087	-1.878
25	33.25	Max	1.135	2.022	1.881	2.005	0.831	1.924
		Min	-1.67	-1.914	-1.398	-2.003	-0.86	-1.923



(a) Global view of mesh

(b) Mesh between slab, sub-base, and subgrade

Figure 9 Geometry mesh 3D model FEM

the surface of the rigid concrete slab. The result from the numerical analysis shows the similar pattern of stress—temperature effect as conducted by Qin and Hiller (2011) and Kumar, Sood and Bose (2004).

From Table 2, it is observed that the maximum principle or tensile stress occurs when the temperature of the pavement surface reaches 50°C, which is approximately 2.77 MPa in the S_{yy} direction. When the maximum stress is compared with the modulus of Rupture (MOR) of 3.9858 MPa, it was found to be below value (69.49%). Although the stress result from numerical analysis is still lower to that of the allowable value, however it was found to be significant (above 50%). The results indicate the significant effect of performance on the stress-strain behavior. The analysis show that the rigid pavement with dimensions that have a ratio of more than 1.5 between the length and width (ACI 302.1R-15) has a similar effect with the study of Qin and Hiller (2011) and Mohamed and Will (2004). The stress pattern resulting from the analysis of temperature variations shows that the tensile and compressive stresses, as well as principle and shear forces, increase with temperature on the top surface of the concrete slab. This pattern is shown in Figure 10, which represents the normal stress in the form of tensile force, which tends to increase with temperature. It is observed that there is a difference in stress caused by temperature variations on the upper surface of the concrete slab, which is distinct from previous research. This study used the temperature variations in Sleman, Yogyakarta, Indonesia, while Europe was used in previous research. This finding is also in line with the research conducted by Qin and Hiller (2011) and Mohamed and Will (2004), which showed that the stress increases with rise in the temperature of the top surface of rigid pave-

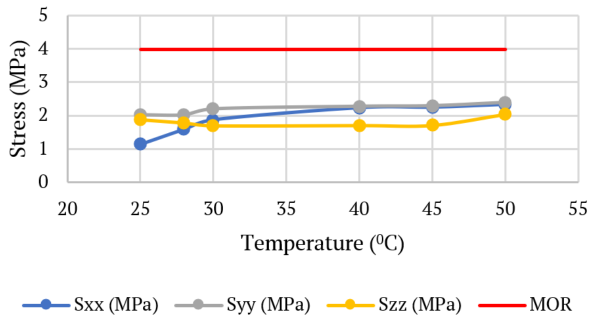


Figure 10 Stress on the influence of temperature on the rigid pavement concrete slab

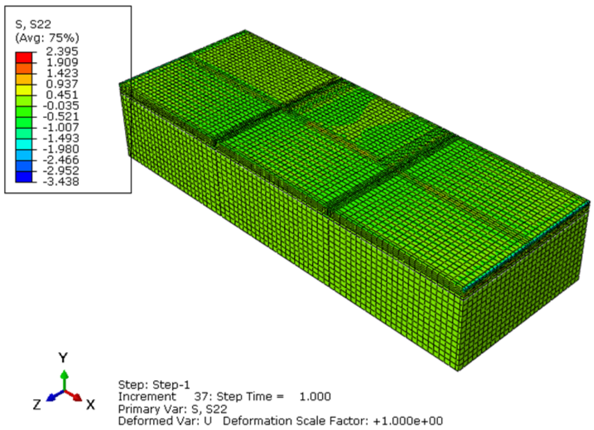
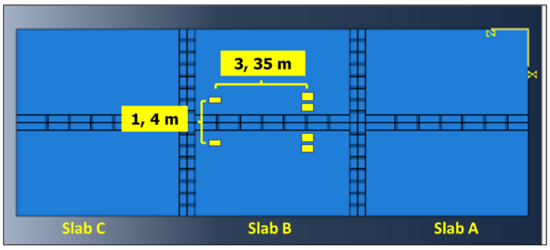
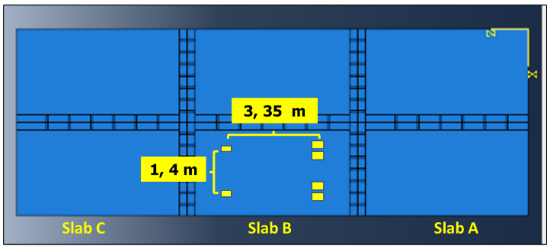


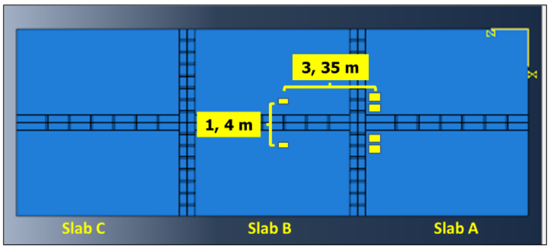
Figure 11 Stress (S_{yy}) Contour in Rigid Pavement due to Temperature Load (50°C)



(a) Edge Loading



(b) Interior Loading



(c) Corner Loading

Figure 12 Vehicle load positions

ment. There is a high expectation that this increased level of stress affects the fatigue resistance Qin and Hiller (2011). According to Qin and Hiller (2011), with an increased fatigue value that is directly proportional to the rise in temperature, this value tends to reduce the quality of life of the pavement that has previously been determined.

5.2 Vehicle Load Analysis

The Rigid pavement was also modeled to account for the influence of traffic design load of 0.37 MPa for the front wheels and 0.15 MPa for the rear. The pressure from the passing vehicle is used as a reference to determine the wheel treading on the surface of the rigid concrete slab. The dimensions for 1 tread that were used include 0.29 meters long and 0.2 meters wide for the front tire, as well as 0.37 meters long and 0.575 meters wide (two wheels) for the rear. The design load was positioned at three different locations, namely interior, edge and corner. An analysis of a load of vehicles that should pass over the pavement is carried out to determine the reaction of the pavement. This is because the main function of the pavement is to support the load that transit and to protect the subgrade. Moreover, this analysis is carried out to determine the stress of the rigid pavement in supporting the service loads that have been determined in the planning phase. This is because, in the existing planning documents, there is no stress

Table 3. Stress due to load position variations in rigid pavement

Load Position		Sxx (MPa)	Syy (MPa)	Szz (MPa)	Sxy (MPa)	Sxz (MPa)	Syz (MPa)
Interior	Max	0.382	0.155	0.431	0.609	0.185	0.372
	Min	-0.692	-1.273	-0.518	-0.247	-0.112	-0.339
Edge	Max	1.310	0.520	0.759	0.387	0.837	0.543
	Min	-1.157	-0.641	-0.928	-0.409	-0.437	-0.230
Corner	Max	0.352	0.152	0.386	0.397	0.344	0.396
	Min	-0.823	-1.772	-0.969	-0.278	0.145	-0.404

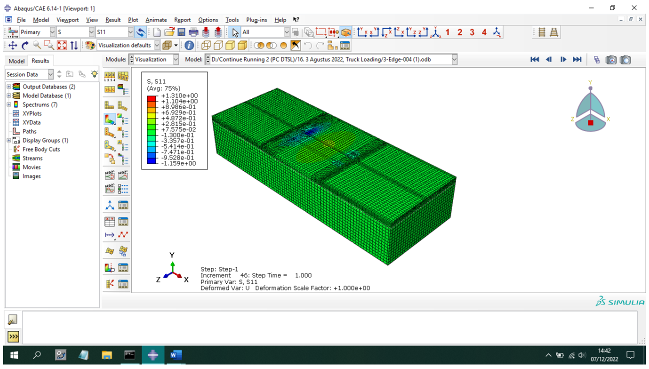


Figure 13 Stress (S_{yy}) Contour in Rigid Pavement due to Vehicle Load (50°C)

reaction due to loads, one of which is from vehicles. Table 3 shows the variation of stress which is influenced by the loading position. The pattern obtained from the modeling shows similarity with the research carried out by El-nakib (2007). Despite the similarity, this model has differences in the working vehicle load and the size of the rigid pavement concrete slab panels.

The maximum principal stress which is tension due to load position variations from Table 3 occurs when the pavement surface is loaded at edge position that yield stress of 1.31 MPa in the S_{xx} direction. This value is well below the modulus of rupture (MOR) of 3.9858 MPa, about 32.86% of the allowable stress. This findings confirm with the result of previous research conducted by Zdiri et al. (2009) and El-nakib (2007). The traffic load that is loaded at the corner and interior positions on the pavement tend to have lower stresses than those at the edge. As known, for the edge load condition, the major tensile stresses are in the upper part of the slab and at the edge of the circular load area. This is because, with the application of the load, a "cantilever" type mechanism is developed for the slab, which naturally generates greater stresses in the upper part of the beam and near the constraint.

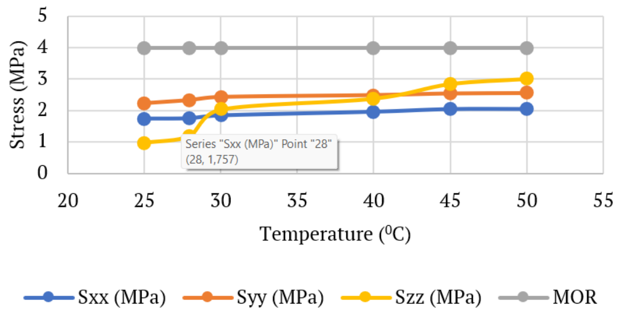


Figure 14 Stress due to temperature variations and interior load position

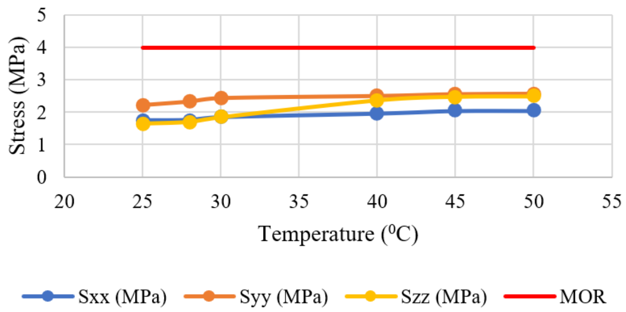


Figure 15 Stress due to temperature variations and corner load position

5.3 The Combinations of Temperature Variations and Vehicle Load Analysis

The rigid pavement was modeled to account for the design traffic load and the temperature variations due to the surrounding environment. This modeling aims to establish the behavior pattern of the structure under real shape in the field. Table 3 shows the variation of stress which is influenced by the loading position. Moreover, the pattern of stress increase is influenced by the existing high temperature. This pattern is similar to that of the research conducted by Cui et al. (2022) and El-nakib (2007).

From Figure 10, 11, and 12, it is observed that the

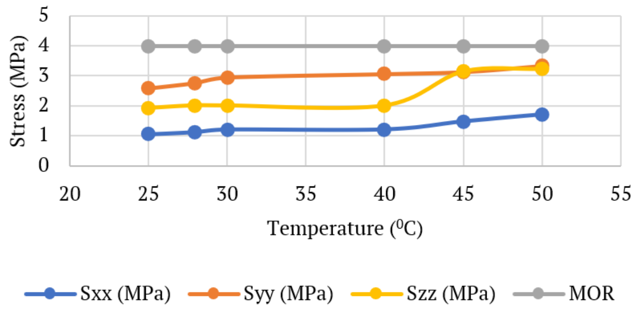


Figure 16 Stress due to temperature variations and edge load position

maximum stress occurs when the temperature of the pavement surface reaches up to 50°C and in the same time when traffic load was in the edge position. The highest result is the combined load between the top surface temperature of the concrete slab of 50°C and the vehicle load in the edge position. The analysis is based on load combinations in the form of vehicle load positions (interior, corner, and edge) as well as the effect of temperature variations. The vehicle load that has the highest stress in the previous research is found to be the edge, followed by the corner and interior. Several studies also emphasize that, the increase in stress is directly proportional to temperature, with the highest value of 50 °C. The load combination analysis showed that the highest stress is at 50°C top surface temperature with the position on the edge. Meanwhile, the lowest stress is at 25°C top surface temperature of the concrete slab with interior load. The maximum principal stress occurs in Syy direction of 3.322 MPa, which is still below the modulus of rupture (MOR) of 3.9858 MPa, about 83.34%. Although this value is still lower than the allowable estimate, but the ratio is higher than the proportional stress for concrete which is about 45% of the f'_c. This value is obtained from a single workload, whereas in reality, it is from a repeated traffic operation, causing the pavement structure to experience fatigue. It is necessary to carry out further research on the fatigue value due to the combination of loads from temperature and vehicle operations to determine the number of repetitive tasks supported by the pavement. There is a great consideration that high level of stress affect the fatigue resistance (Qin and Hiller, 2011). Qin and Hiller (2011) stated that increase fatigue is directly proportional to temperature, as well as reducing the quality of life of the pavement.

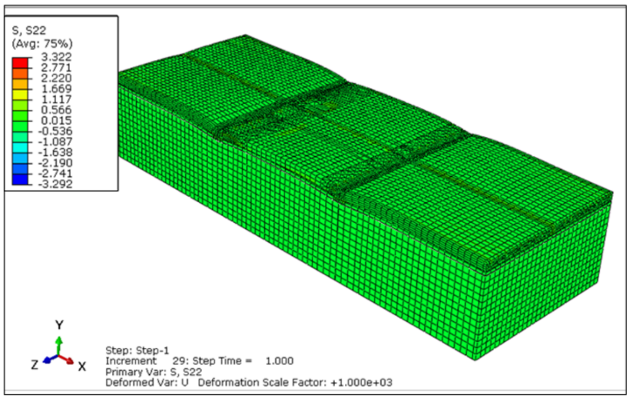


Figure 17 Stress (S_{yy}) contour in Rigid Pavement due to combination load (Edge Load + 50°C)

6 CONCLUSION

The objective of this research is to investigate the reaction of rigid pavement concrete slabs to various existing factors, including vehicle loads and temperature variations. These factors are combined in the FEM analysis which showed that the maximum tensile stress that occurs in the concrete slab is 3.322 MPa at the edge of the pavement, and the effect of the surface temperature is 50°C. The maximum principle or tensile stress does not exceed the modulus of rupture value of 3.9858 MPa, about 83.34%. The results showed that the temperature gradient during the day produces a higher stress than at night, and the value is close to the MOR. Therefore, it is stated that an increase in temperature triggers the stress level of the rigid concrete pavement slab and vice versa. The thermal gradient used tends to determine the value of the stress generated.

Based on the assumptions from previous research, the high stress ratio produced an increased fatigue value, which tends to reduce the pavement's quality of life, and further research is needed to prove this hypothesis. Based on the FEM model analysis, it is recommended that heavy vehicles with a maximum axle load of 8 tonnes should avoid transiting across the rigid pavements during the day in hot weather conditions, to avoid excessive stress and displacement.

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