Comparison Analysis of Flexible Pavement Thickness between Indonesian Pt T-01-2002-B and MDP 2017 Methods using Finite Element Analysis

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Abstract:- Indonesia has regulations and guidelines for designing pavement structures modified by several developed countries. One of the pavement methods used in Indonesia is the Pt T-01-2002-B method derived from AASHTO 1993. However, today Indonesia has an update on the pavement method used, namely the Pavement Design Manual 2017 method sourced from AASHTO and AUSTROAD. The purpose of this study is to determine the results of comparing the thickness of flexible pavement between the Pt T-01-2002-B and MDP 2017 methods by varying the CBR value and traffic load. Then analyze the results of thick planning using Finite Element Analysis modeling in the ANSYS program which aims to determine the value of stress that occurs in the subgrade. From the results of the research conducted, it was found that the variation of CBR value > 1.5% overall pavement thickness produced using the Pt T-01-2002-B method was thicker than MDP 2017 method. However, at CBR 1.5%, the MDP 2017 method produces a much thicker pavement than the Pt T-01-2002-B method. The large difference in pavement thickness between the two methods is due to differences in design parameters and the selection of pavement materials. Based on the stress results, the Pt T-01-2002-B method is considered more conservative than the MDP 2017 method. However, in soil conditions with CBR values below 2.5%, the MDP 2017 method is considered more conservative.

***Keywords**:- Flexible pavement; Pt T-01-2002-B; MDP 2017; odemark method; finite element analysis; stress.*

I. INTRODUCTION

One way to be able to improve or build highway construction, namely by planning or designing the thickness of the road flexible pavement by understanding and using several methods. The correct use of the method will ensure the strength of the highway. Transportation is one of the land transportation infrastructures that have an important role in economic growth, socio-culture, tourism regional development, and defense and security to support national development, so the importance of road pavement is increasingly clear [6].

In Indonesia, one of the methods used in designing pavement thickness is the Pt T-01-2002-B method which originated from AASHTO 1993 and was modified according to the conditions of various factors in Indonesia. Along with the times, Indonesia has an updated pavement design method that is currently used, namely the Manual Desain Perkerasan Jalan (MDP) 2017 method. This method is a modification of AASHTO and AUSTROAD regulations.

Although there are updates to the pavement design methods, these methods still have some disadvantages and advantages so some of the old pavement guidelines are still used today. In the Pt T-01-2002-B method, some design parameters do not have clear written reference parameters for designing pavement thickness. Meanwhile, MDP 2017 has parameters that have been designed by the design chart [1].

In the MDP 2017 guidelines [3] [4], the design of pavement thickness based on the ESA value of rank 4 should be used based on Pt T-01-2002-B guidelines [2]. In addition, if subsurface drainage cannot be provided in the MDP 2017 guidelines, the thickness of the aggregate foundation layer must be adjusted by using the drainage coefficient (m) value according to Pt T-01-2002-B. Then in a special case where there are many design variables and it is difficult to accommodate all of them using a design chart, the reconstruction design solution for heavy traffic must be determined using the mechanistic design procedure, namely the Pt T-01-2002-B method.

Based on the above, the old method can still be used to provide a comparison of design results. Therefore, this research will compare the design of flexible pavement thickness between the Pt T-01-2002-B method and the MDP 2017 method which aims to provide a comparison of design results and find out which method is considered more conservative in pavement design.

II. LITERATURE REVIEW

A. Finite Element Method

The principle of the Finite Element Method (Finite Element Analysis) is to divide the problem domain, be it the spatial domain or the time domain, into smaller subdomains or elements. The core process of the Finite Element Method is to divide a complex problem into smaller parts or elements from which simpler solutions can be easily derived. The solution of each element when combined will be the overall problem solution [7]. The principle of this method can be seen in Figure 1.

ISSN No:-2456-2165

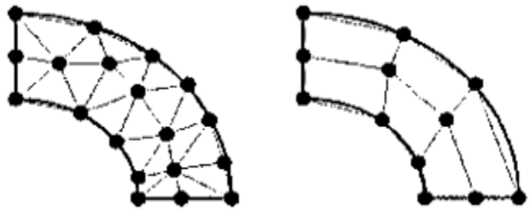

Fig. 1: Principle of finite element method

The number of equations to be solved is usually very large, so obtaining a solution without using a computer is almost impossible. Therefore, the use of computer software will be very useful in modeling FEA [11].

One of the software that can make FEA modeling is ANSYS. ANSYS is a software program that can model finite elements to solve problems related to mechanics, including static, dynamic, structural analysis (both linear and nonlinear), heat transfer problems, fluid problems, and also problems related to acoustics and electro magnetics [8].

B. Odemark Method

Odemark introduced a method, also known as the Method of Equivalent Stiffness (MET), to transfer a multi-layer system into a single-layer semi-half-space. This method converts each layer with different materials into one layer with the same material value as the subgrade. The principle of the Odemark method can be seen in Figure 2.

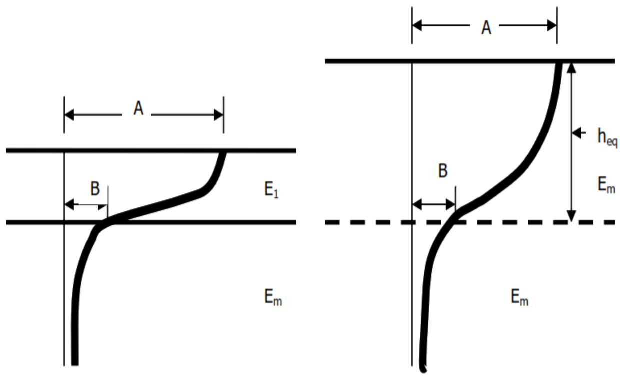

Fig. 2: Principle of odemark method equivalence theory

Based on Figure 2 to be able to calculate the stress in such a two-layer system, Odemark's equivalence theory is helpful. The idea behind Odemark's theory is that the vertical stress at the interface between the top layer with stiffness E_1 and thickness h_1 and the half-space with stiffness E_m is equal to the stress at the equivalent depth h_{eq} with stiffness E_m. The figure on the left shows the vertical stress distribution in a two-layer system. On the right side, the equivalent h_{eq} shows the same vertical stress result (B) at the interface between the top layer and the half-space below [9].

The use of this method has been proven in the research of Prakoso (2017) [10] which shows that by using the half-space system, the result of the stress that occurs in the soil will be the same value when using a multi-layer system. Odemark's equation to calculate the equivalent thickness is as follows:

$$h_{eq} = h_i \times \sqrt[3]{\frac{E_i \times (1-\mu_s^2)}{E_s \times (1-\mu_i^2)}} \qquad (1)$$

Where: h_{eq} is equivalent thickness (mm), h_i is pavement thickness (mm), E_i is modulus elasticity of layer i (MPa), μ_i is Poisson ratio of layer i, E_s is modulus elasticity of subgrade (MPa), μ_s is Poisson ratio of subgrade.

C. Heukelom & Klomp Equation

The distributed stresses from the traffic load and superstructure part should be reduced to the subgrade layer under the limit of its bearing capacity. The criteria in the static design are mainly taken at the maximum stress or strain at the soil's surface to guarantee a certain safe limit against disproportionate plastic deformation and settlement after cyclic loading during the service. According to Prakoso (2017) [10] to calculate the allowable stress can use the Heukelom & Klomp equation as follows.

$$\sigma_{allow} = \frac{0.006E_{dyn}}{1+0.7\log(N)} \qquad (2)$$

This equation suggests the allowable stress limit (σ_{allow}) of the substructure layer considering only the material dynamic modulus value (E_{dyn}) and the number of load cycles (N).

III. RESEARCH METHODS

In this study, a comparison of flexible pavement thickness design between Pt T-01-2002-B and MDP 2017 methods will be conducted by varying the CBR value and traffic load. The CBR value in this study is determined as 1.5%, 2.5%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, 10%, 11%, and 12%. For traffic load values in this study, 1,000,000 ESAL, 5,000,000 ESAL, and 10,000,000 ESAL were determined. From the results of the pavement thickness design, the equivalent thickness can then be calculated using the Odemark method for further analysis in FEA (Finite Element Analysis) modeling in the ANSYS STUDENT 2022 R2 program which aims to determine the stress value on the subgrade. From the stress results, it will be known whether the designed pavement thickness meets the permissible stress using the Heukelom & Klomp equation. Then the correlation relationship between the Pt T-01-2002-B and MDP 2017 methods can be made based on the results of the design thickness and stress values.

IV. RESULTS AND DISCUSSION

A. Comparison of Equivalent Thickness Results Between Pt T-01-2002-B and MDP 2017 Methods

Figure 3, Figure 4, and Figure 5 are the results of the comparison of equivalent pavement thickness between Pt T-01-2002-B and MDP 2017 methods at each traffic load design. From these results, the graphs for traffic loads of 1,000,000 ESAL, 5,000,000 ESAL, and 10,000,000 ESAL all three show the same results where the smaller the CBR value, the greater the need for pavement thickness and the other way round. Then the soil with a good CBR value

ISSN No:-2456-2165

accompanied by an increase in traffic load does not have a significant effect on the addition of pavement thickness. While the soil with a low CBR value, the increase in traffic load will greatly affect the increase in pavement thickness. The three figures clearly show the difference in thickness between the two methods where the results of pavement thickness for the Pt T-01-2002-B method as a whole look thicker than the MDP 2017 method. However, in the design with a CBR value of 1.5%, there is a very significant difference in pavement thickness between the two methods, where instead the MDP 2017 method produces a much thicker pavement than the Pt T-01-2002-B method.

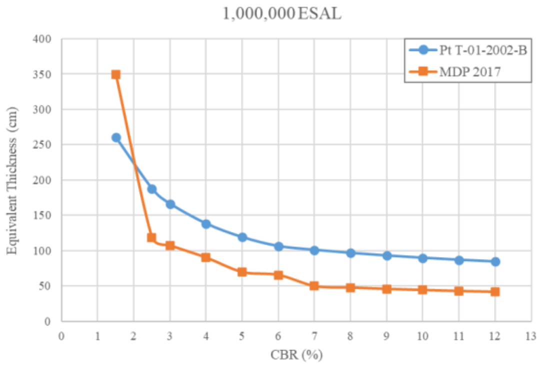

Fig. 3: Comparison results of equivalent thickness at 1,000,000 ESAL

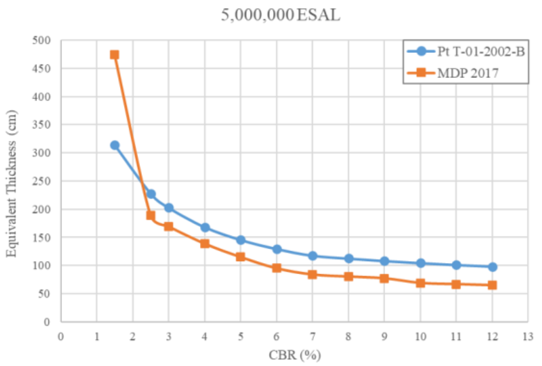

Fig. 4: Comparison results of equivalent thickness at 5,000,000 ESAL

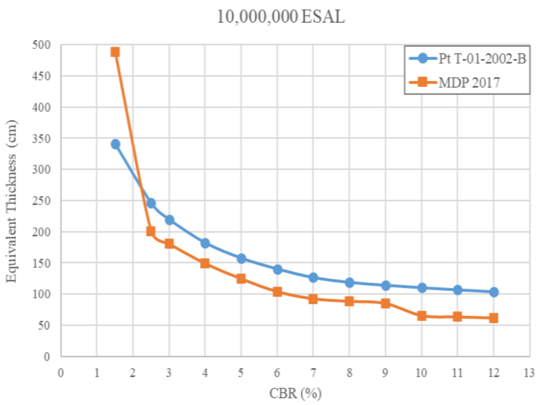

Fig. 5: Comparison results of equivalent thickness at 10,000,000 ESAL

The difference is because according to the MDP 2017 method design guidelines for soils with a CBR value < 6% require improvement of the subgrade or the addition of a support layer that aims to have a bearing capacity equivalent to a CBR value of 6% or reach the minimum requirements. Meanwhile, the Pt T-01-2002-B method itself has not set a formula for improving the subgrade or adding a support layer. As for other parameters that affect the difference in pavement thickness in the two methods, among others, due to differences in the minimum thickness limits of the two methods, besides that in the MDP 2017 method guidelines where the types of materials used such as modulus and Poisson ratio values have been determined in the table, while the Pt T-01-2002-B guidelines can design the type of pavement material planned.

The results of the designed pavement thickness with a CBR value ≥ 6% in both Pt T-01-2002-B and MDP 2017 methods do not show any significant changes in pavement thickness. However, the increase in pavement thickness begins to occur when the CBR value is below 6%. So it can be said that 6% CBR is the CBR value needed to reach the point where the pavement thickness meets the minimum requirements.

According to Eisenmann (2004) [5], the AASHTO correlation equation between maintenance cost and pavement quality is based on road construction testing where the quality of the track geometry (Q_g) and the stress at the base of the track (P_z) can be expressed in a power function relationship: $Q_g = (P_z)^m$. In which m can be of 3 to 4 power degrees. Prakoso (2017) [10] also mentioned that the increase in thickness at the SN value is due to the variation of the repetition limit of the soil pressure and soil bearing capacity which is close to the nonlinear power function. Based on these two studies, the graphs of the equivalent thickness correlation relationship between the Pt T-01-2002-B and MDP 2017 methods depicted in Figure 6, Figure 7, and Figure 8 show similar results where the shape of the curve is similar to a power function. This indicates that the working system that occurs in soft soil conditions is neither linear nor exponential but rather power which means that the increase in value that occurs will be very significant, in this case, the thickness of the pavement.

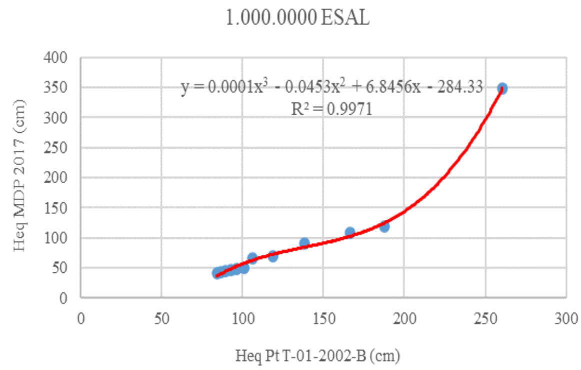

Fig. 6: Correlation of equivalent thickness at 1,000,000 ESAL

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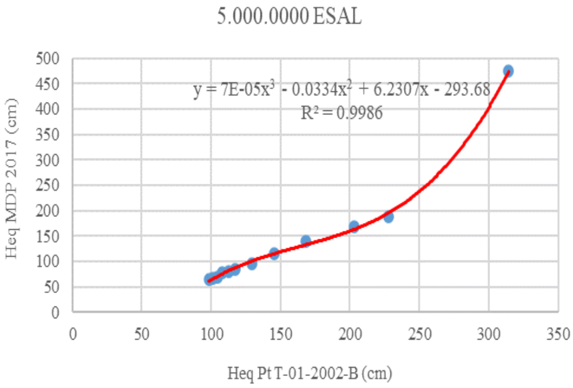


Fig. 7: Correlation of equivalent thickness at 5,000,000 ESAL

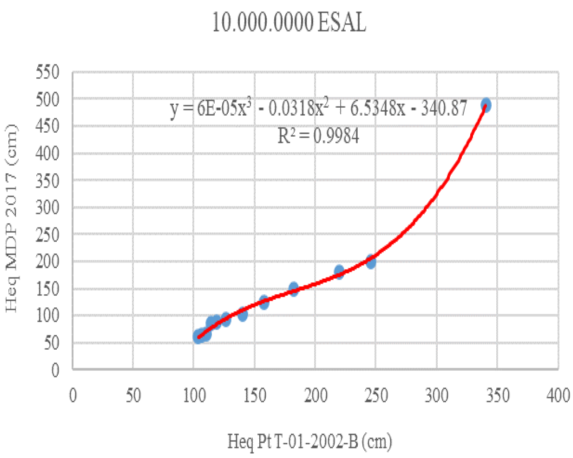


Fig. 8: Correlation of equivalent thickness at 10,000,000 ESAL

The correlation of equivalent thickness obtained between the Pt T-01-2002-B and MDP 2017 methods, which are at a traffic load of 1,000,000 ESAL, the regression equation $y = 0.0001x^3 - 0.0453x^2 + 6.8456x - 284.33$ with a coefficient of determination (R^2) = 0.9971. At a traffic load of 5,000,000 ESAL, the regression equation $y = 7E\text{-}05x^3 - 0.0334x^2 + 6.2307x - 293.68$ with a coefficient of determination (R^2) = 0.9986. And at a traffic load of 10,000,000 ESAL, the regression equation $y = 6E\text{-}05x^3 - 0.0318x^2 + 6.5348x - 340.87$ with a coefficient of determination (R^2) = 0.9984.

B. FEA Modeling Results in ANSYS Program

Based on the results of the equivalent thickness in the Pt-T-01-2002-B and MDP 2017 methods, further analysis is carried out using the ANSYS STUDENT 2022 R2 program. The data to be entered in the ANSYS program are modulus of elasticity, Poisson ratio, and equivalent thickness. Where the thickness analyzed is only one layer or a single layer. The results will be obtained in the form of stress values that occur in the subgrade. Figure 9 and Figure 10 are examples of analysis results from FEA modeling for an equivalent thickness is 416 cm with CBR data is 12%, subgrade modulus is 120 MPa, and Poisson ratio is 0.45.

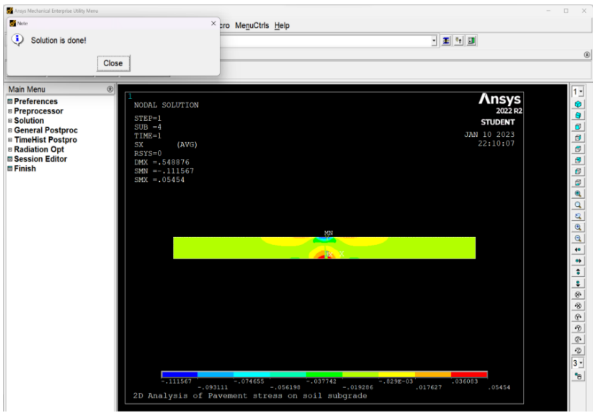
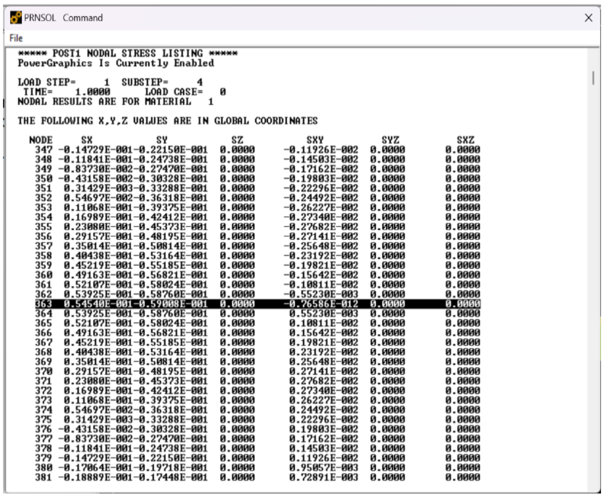


Fig. 9: FEA modeling output results in the ANSYS program



PRNSOL Command

File

***** POST1 NODAL STRESS LISTING *****
PowerGraphics Is Currently Enabled

LOAD STEP= 1 SUBSTEP= 4
TIME= 1.0000 LOAD CASE= 0
NODAL RESULTS ARE FOR MATERIAL 1

THE FOLLOWING X,Y,Z VALUES ARE IN GLOBAL COORDINATES

NODE	SX	SY	SZ	SXY	SYZ	SXZ
347	-0.14729E-001	-0.22150E-001	0.0000	-0.11926E-002	0.0000	0.0000
348	-0.11841E-001	-0.24738E-001	0.0000	-0.14503E-002	0.0000	0.0000
349	-0.83730E-002	-0.27470E-001	0.0000	-0.17162E-002	0.0000	0.0000
350	-0.43158E-002	-0.30328E-001	0.0000	-0.19803E-002	0.0000	0.0000
351	0.31429E-003	-0.33288E-001	0.0000	-0.22296E-002	0.0000	0.0000
352	0.54697E-002	-0.36318E-001	0.0000	-0.24492E-002	0.0000	0.0000
353	0.11068E-001	-0.39375E-001	0.0000	-0.26227E-002	0.0000	0.0000
354	0.16989E-001	-0.42412E-001	0.0000	-0.27340E-002	0.0000	0.0000
355	0.23080E-001	-0.45373E-001	0.0000	-0.27682E-002	0.0000	0.0000
356	0.29157E-001	-0.48195E-001	0.0000	-0.27141E-002	0.0000	0.0000
357	0.35014E-001	-0.50814E-001	0.0000	-0.25648E-002	0.0000	0.0000
358	0.40438E-001	-0.53164E-001	0.0000	-0.23192E-002	0.0000	0.0000
359	0.45219E-001	-0.55185E-001	0.0000	-0.19821E-002	0.0000	0.0000
360	0.49163E-001	-0.56821E-001	0.0000	-0.15642E-002	0.0000	0.0000
361	0.52107E-001	-0.58024E-001	0.0000	-0.10811E-002	0.0000	0.0000
362	0.53925E-001	-0.58760E-001	0.0000	-0.55230E-003	0.0000	0.0000
363	0.54540E-001	-0.59008E-001	0.0000	-0.76586E-012	0.0000	0.0000
364	0.53925E-001	-0.58760E-001	0.0000	0.55230E-003	0.0000	0.0000
365	0.52107E-001	-0.58024E-001	0.0000	0.10811E-002	0.0000	0.0000
366	0.49163E-001	-0.56821E-001	0.0000	0.15642E-002	0.0000	0.0000
367	0.45219E-001	-0.55185E-001	0.0000	0.19821E-002	0.0000	0.0000
368	0.40438E-001	-0.53164E-001	0.0000	0.23192E-002	0.0000	0.0000
369	0.35014E-001	-0.50814E-001	0.0000	0.25648E-002	0.0000	0.0000
370	0.29157E-001	-0.48195E-001	0.0000	0.27141E-002	0.0000	0.0000
371	0.23080E-001	-0.45373E-001	0.0000	0.27682E-002	0.0000	0.0000
372	0.16989E-001	-0.42412E-001	0.0000	0.27340E-002	0.0000	0.0000
373	0.11068E-001	-0.39375E-001	0.0000	0.26227E-002	0.0000	0.0000
374	0.54697E-002	-0.36318E-001	0.0000	0.24492E-002	0.0000	0.0000
375	0.31429E-003	-0.33288E-001	0.0000	0.22296E-002	0.0000	0.0000
376	-0.43158E-002	-0.30328E-001	0.0000	0.19803E-002	0.0000	0.0000
377	-0.83730E-002	-0.27470E-001	0.0000	0.17162E-002	0.0000	0.0000
378	-0.11841E-001	-0.24738E-001	0.0000	0.14503E-002	0.0000	0.0000
379	-0.14729E-001	-0.22150E-001	0.0000	0.11926E-002	0.0000	0.0000
380	-0.17064E-001	-0.19718E-001	0.0000	0.95057E-003	0.0000	0.0000
381	-0.18889E-001	-0.17448E-001	0.0000	0.72891E-003	0.0000	0.0000

Fig. 10: FEA modeling output results: Stress value on subgrade

C. Comparison of Stress Values between Pt T-01-2002-B and MDP 2017 Methods

Based on the output results of FEA modeling in the ANSYS STUDENT 2022 R2 program, the stress values for each pavement design method are obtained. In Figure 11, Figure 12, and Figure 13, we can see the comparison graph of stress values between the Pt T-01-2002-B and MDP 2017 methods.

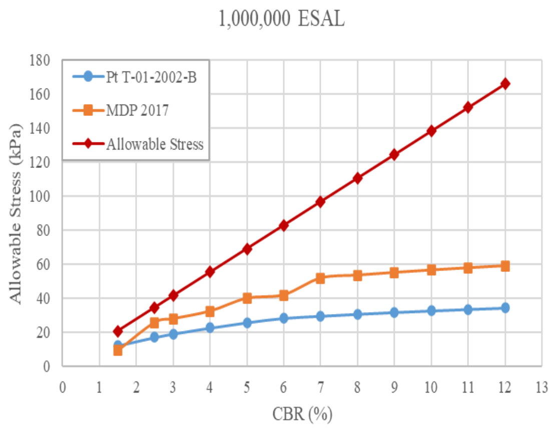


Fig. 11: Comparison results of stress values at 1,000,000 ESAL

ISSN No:-2456-2165

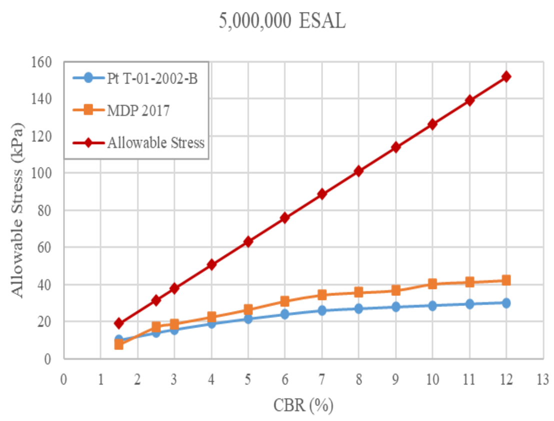


Fig. 12: Comparison results of stress values at 5,000,000 ESAL

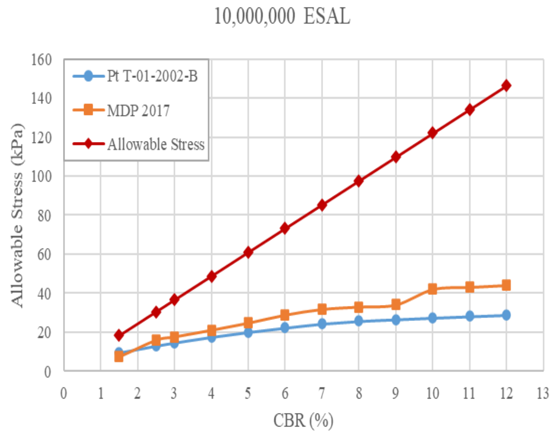


Fig. 13: Comparison results of stress values at 10,000,000 ESAL

The graphs for traffic loads at 1,000,000 ESAL, 5,000,000 ESAL, and 10,000,000 ESAL all show the same results where the higher the traffic load, the smaller the stress that occurs on the subgrade. In addition, the greater the CBR value, the higher the stress that tends to occur. It is because the low CBR value requires a very thick pavement layer so that the stress on the subgrade will be lower. However, as the CBR value increases, the allowable stress will also increase. It is shown from the three graphs above that the stress results between the two design methods are still below the allowable stress.

Overall, it is clear that the MDP 2017 method shows greater stress values than the Pt T-01-2002-B method. However, in the condition of CBR 1.5% or soft soil, the Pt T-01-2002-B method shows higher stress results than the MDP 2017 method. Conversely, using the MDP 2017 method, the stress results for each variation of the traffic plan show lower values than the Pt T-01-2002-B method. So it can be said that in soft soil conditions, the MDP 2017 method is more conservative than the Pt T-01-2002-B method.

Figure 14, Figure 15, and Figure 16 show the correlation of stress values obtained between the Pt T-01-2002-B and MDP 2017 methods, which are at a traffic load of 1,000,000 ESAL, the regression equation y = 2.189x - 15.29 with a coefficient of determination (R^2) = 0.979. At a traffic load of 5,000,000 ESAL, the regression equation y = 1.655x - 8.215 with a coefficient of determination (R^2) = 0.992. And at a traffic load of 10,000,000 ESAL, the regression equation y = 1.748x - 8.946 with a coefficient of determination (R^2) = 0.961.

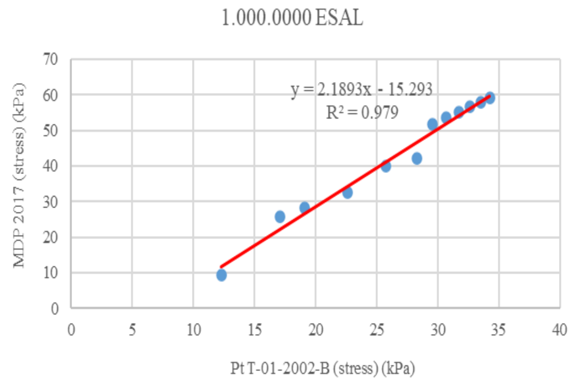


Fig. 14: Correlation of stress values at 1,000,000 ESAL

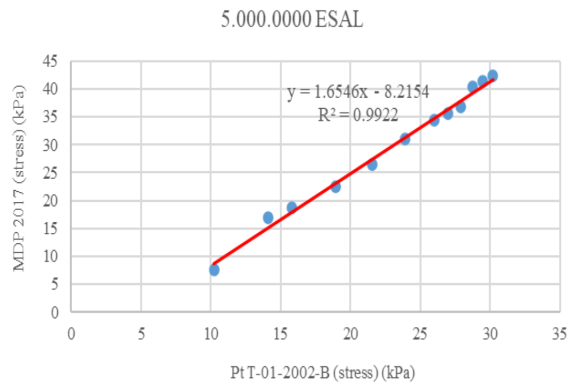


Fig. 15: Correlation of stress values at 5,000,000 ESAL

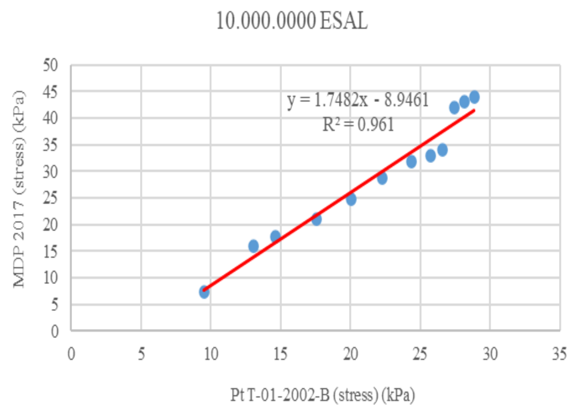


Fig. 16: Correlation of stress values at 10,000,000 ESAL

V. CONCLUSION

The large difference in pavement thickness between Pt T-01-2002-B and MDP 2017 methods is due to differences in design parameters and the selection of pavement materials. The MDP 2017 guidelines for soils with a CBR value less than 6% require improvement of the subgrade or the addition of a support layer that aims to have a bearing capacity equivalent to a CBR value of 6% or reach the minimum requirements, while the Pt T-01-2002-B method itself has not set a formula for improving the subgrade. Then

ISSN No:-2456-2165

in the MDP 2017 guidelines where the types of materials used such as modulus values and Poisson ratio have been determined in the table, while the Pt T-01-2002-B guidelines can design the type of pavement material planned so that to find the efficiency of materials, the Pt T-01-2002-B guidelines are suitable for use.

The correlation of equivalent thickness obtained between the Pt T-01-2002-B and MDP 2017 methods, which are at a traffic load of 1,000,000 ESAL, $y = 0.0001x^3 - 0.0453x^2 + 6.8456x - 284.33$ with $R^2 = 0.9971$. At a traffic load of 5,000,000 ESAL, $y = 7E\text{-}05x^3 - 0.0334x^2 + 6.2307x - 293.68$ with $R^2 = 0.9986$. And at a traffic load of 10,000,000 ESAL, $y = 6E\text{-}05x^3 - 0.0318x^2 + 6.5348x - 340.87$ with $R^2 = 0.9984$.

The correlation of stress values obtained between the Pt T-01-2002-B and MDP 2017 methods, which are at a traffic load of 1,000,000 ESAL, $y = 2.189x - 15.29$ with $R^2 = 0.979$. At a traffic load of 5,000,000 ESAL, $y = 1.655x - 8.215$ with $R^2 = 0.992$. And at a traffic load of 10,000,000 ESAL, $y = 1.748x - 8.946$ with $R^2 = 0.961$.

Based on the stress results obtained in both design methods using FEA modeling, it can be concluded that overall the design using the Pt T-01-2002-B method is considered more conservative than MDP 2017 method. However, in specific conditions where the soil with a CBR value below 2.5%, the design using the MDP 2017 method is considered more conservative than the Pt T-01-2002-B method.

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