Overlay thickness evaluation based on Indonesian manual road design and shell pavement design method

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Abstract. Brebes Regency is one of the areas crossed by the north coast road (Pantura). This road is very important and forms the basis of land transportation traffic on the island of Java. We often encounter traffic jams on this road because it is part of a national road along the northern side of the island of Java. There are several treatments that are usually carried out to repair roads that have been damaged, one of which is the addition of a thick layer or overlay. Therefore, researchers conducted an analysis study of the added layer thickness (overlay) on the road to find out and analyze the results of the 2017 Road Pavement Design Manual overlay method and the Shell Pavment Design Method (SPDM) program method. In this study, the data collected were primary data and secondary data, namely road profiles obtained directly from field observations, average daily traffic data (LHR) and Falling Weight Deflectometer (FWD). The results of the overlay calculation using MDP 2017 obtained an overlay value of 50 mm and the SPDM program was 46 mm. An effective method in terms of data requirements, calculations and time is the SPDM program because when it is used it can be easily and calculated automatically in the program, whereas if you use MDP 2017 the calculations are still manual and the determination of the overlay thickness uses a graphic that accurately adjusts the user's foresight and will affect the results of the overlay calculation.

1 Introduction

Roads, which are the main infrastructure for land transportation, play an important role in supporting the community's economy and connecting one region to another. The construction of these lines must be carried out as well as possible to achieve the desired results in accordance with the plan both in terms of quality and quantity. This is confirmed in the Law of the Republic of Indonesia (RI) No. 38 of 2004, article 1, paragraph 4, concerning roads, which states that roads are land transportation infrastructure which includes all parts of the road, including auxiliary buildings and equipment intended for traffic that is on the surface. land and/or water, as well as above the surface of the water, except for railroads, lorry roads and cable roads [1]. Whereas based on RI Law No. 22 of 2009 concerning traffic and transportation, roads are defined as all parts of the road, including auxiliary buildings and equipment intended for public traffic, which are on the ground surface, above ground level, below ground level and water, as well as above the water level, except for railroads and cable roads.

Brebes Regency is one of the areas crossed by the north coast road (Pantura). This road is very important and forms the basis of land transportation traffic on the island of Java. We often encounter traffic jams on this road because it is part of a national road along the northern side of the island of Java. The length of this road in Brebes Regency is 32.8 km, which passes through several sub-districts, namely Bulakamba, Brebes, Losari, Wanasari and Tanjung sub-districts [2]. Over time, the large number of heavy vehicles and the dense traffic flow on this road causes a decrease in the value of flexible pavement conditions. Roads that are continuously passed by loads with traffic volumes greater than the design load can experience a decrease in road pavement conditions [3]. This can be seen from the condition of the road surface, both functional and structural conditions, which were damaged [4]. As an effort to maintain road quality due to the continuous volume and traffic burden that is greater than the planned load, the Government carries out regular road maintenance. The largest budget for the Directorate General of Highways under the Ministry of Public Works and Public Housing (PUPR) in 2022 allocates IDR 21.79 trillion for road infrastructure as stated in the national news [5]. With the large budget for the maintenance of this road, it is necessary to have an appropriate and economical road maintenance program.

There are several treatments that are usually carried out to repair roads that have been damaged, one of which is by adding thick overlays [6]. This is a pavement layer that is applied over the road pavement construction intended to strengthen the existing structure so that it can withstand the planned traffic load during the design life. With the issuance of the 2017 Road Pavement Design Manual, it is one of the strategies of the Directorate General of Highways in accommodating current road asset performance issues [6]. The 2017 Pavement Design Manual and the Shell Pavement Design Method (SPDM) program are 2 methods for finding very

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different overlay thicknesses where the MDP is more concerned with the influence of vehicles crossing the road, while the SPDM program is more concerned with the road structure.

This research was conducted on Losari National Road (West Java Province Boundary) – Pejagan STA 3+000 – 9+370 which is a national road that connects West Java and Central Java Provinces. To maintain the comfort of users from road damage due to heavy traffic and large vehicles passing on this road, it is necessary to maintain and repair the Losari National Road (West Java Provincial Boundary) - Pejagan, one way is by overlaying it. So in this research apply the 2017 Road Pavement Design Manual (MDP) and the Shell Pavement Design Method (SPDM) Program to determine the thickness of the overlay.

2 Research method

This study uses an analytical descriptive method by providing a description or description of the research object studied through collected data or samples and draws conclusions that apply in general [7]. The type of data applied is primary data in the form of road profiles obtained directly from field observations and secondary data in the form of Deflection Falling Weight Deflectometer (FWD) data and Average Annual Daily Traffic (AADV) data.

2.1 Determining overlays using the Indonesian pavement design manual 2017

The procedure of determining the overlay thicness based on the 2017 Indonesia Road Pavement Design Manual (MDP) are composed of three satge [6].

2.1.1 Calculation the cumulatice equivalent single axle axle

Cumulative Equivalent Single Axle Load (CESAL) or cumulative standard axle load is the cumulative sum of the design traffic axle load on the design lane over the design life, which is described as Equation 1.

$$ESA = \left(\sum LHRxVDF\right)x365xDDxDLxR \quad (1)$$

where

ESA	: Standard axle load
R	: Traffic growth factor
VDF	: Vehicle Damage Factor
DL	: Lane Distribution
DD	: Directional Distribution Factor

2.1.2 Determining overlay thickness based on maximum deflection (D0)

The results of the deflection value use a Falling Weight Deflectometer (FWD) which is calibrated with load and temperature correction factors. After that determine the thickness of the additional layer (overlay) based on the maximum deflection value (D0) that represents the real deflection.

2.1.3 Determining thin overlays and thick overlays based on deflection curvature (CF)

The results of the deflection value use a calibrated FWD tool with load, temperature correction factors, and FWD adjustments to the Benkelman Beam (BB). After that, determine the thickness of the additional layer (overlay) based on the obtained average deflection value (CF).

2.2 Defining an overlay thickness using the shell pavement design method (spdm) program

Operating the SPDM program by opening the SPDM program then selecting the Project option then the New option then the Thickness Design option, then filling in the Climate column with the temperature at the research location using FWD data, filling in the Traffic & Design Life column with processed data such as traffic growth, design life, and load equivalent factor, fill in the Base Layers & Subgrade Strain column with data that has been obtained such as thickness between layers, CBR value of subgrade, Young's modulus of elasticity (stiffness modulus) and Poisson's ratio obtained from the 2017 MDP guidelines, fill in the Asphalt column Mix Composition & Fatique according to the default SPDM program, fill in the Asphalt Stiffness & Layer Thickness column with data that has been obtained such as surface to subbase layer thickness, Young's modulus of elasticity (stiffness modulus) and Poisson's ratio obtained from the 2017 MDP guidelines, after all data is filled in then pressing the result button, after that you will get the thickness of the flexible pavement from the subbase to the surface, therefore to determine the thickness of the overlay from SPDM, the results of the pavement thickness from SPDM will be reduced by the sum of the thicknesses of the subbase and surface before being overlaid [8].

3 Resultas and discussion

3.1 Traffic analysis and calculation

Losari National Road (West Java Provincial Boundary) – Pejagan STA 3,000-9,370 has a traffic growth rate (i) of 4.8% because it is located in the area of Java Island [5] and has a design life (UR) of 10 years [5], then the cumulative traffic growth factor (R) value for the design age is 10.02.

Losari National Road (West Java Province Boundary) – Pejagan STA 3000-9370 has a road with 2 directions and 2 lanes, so the direction distribution factor (DD) is taken as 0.5 and the lane distribution factor (DL) is taken as 0.8 [6]. The results of the recapitulation of the traffic load calculation and the subsequent Comulative Stingle Axle Load are presented in Table 1-2. Based on the CESA4 and CESA5 values that have been obtained, determine the overlay thickness procedure used, CESA4 is used to determine the overlay thickness based on the CF value and maximum deflection (permanent deformation) according to Fig. 1.

Table 1. The traffic plan data and vihicle damage factor.

Vehicle	Type	ADV	VDF 4	VDF 5
Midle bus	5a	336	0.3	0.2
Big Bus	5b	188	1.0	1.0
Double axle truck 4 wheel	6a	1435	0.8	0.8
Double axle truck 6 wheel	6b	1326	0.7	0.7
Triple axle truck	7a	1485	7.6	11.2
Articulated Truck	7b	184	36.9	90.4
Semitrailer	7c	724	13.6	24

Table 2. The caculation of cumulative single axle load (CESA).

Vehicle	CESA 4	CESA 5
Midle bus	147.486,2901	98.324,1934
Big Bus	275.073,6363	275.073,6363
Double axle truck 4 wheel	629.889,3640	419.926,2427
Double axle truck 6 wheel	1.358.102,9214	1.358.102,9214
Triple axle truck	16.513.197,1250	24.335.237,8685
Articulated Truck	9.934.255,1125	
Semitrailer	14.406.835,3865	25.423.827,1527
∑	43.264.839,8360	76.248.070,9357

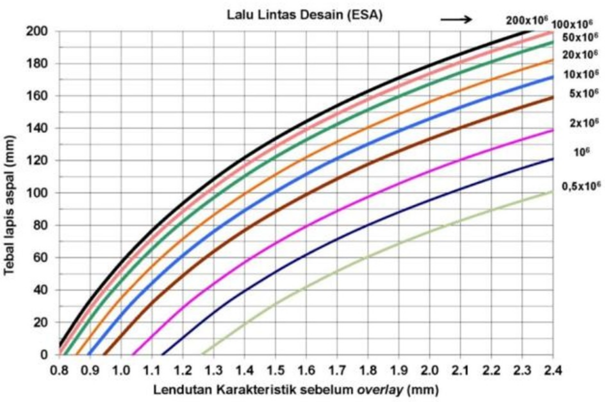

Fig. 1. Overlay design based on maximum deflection value [9].

3.2 The calculation of overlay thickness based on maximum deflection value (D0) and deflection curvature (CF)

The Deflection testing using FWD data was carried out at STA 3000-9370 during the rainy season, then normalized to a standard load factor of 40 kN [3] as in column 6-7 Table 3, there is an asphalt temperature correction factor of 36.4 ^{0}C as in column 2-3 Table 4, and the adjustment factor for the deflection correction from FWD to BB is 1.25 [3] as in column 4 Table 4. Based on the maximum deflection to determine the overlay thickness, Fig. 1 is used with the results of calculating D0 representative and entering the design traffic load (CESA4) and the characteristic deflection values in Fig. 1. Meanwhile, the deflection curves for the overlay thickness are using Fig. 2-3 with the calculation results of the average temperature corrected CF value and entering the design traffic load (CESA5) and the average temperature corrected CF value into Fig. 2-3. The full calculation of representative D_0 and average CF is presented in Table 3-4 respectively.

Table 3. The calculation of deflection and normal derflection.

No.	STA	Load (kN)	D_0 (µm)	D_{200} (µm)	D_0 Normal value (µm)	D_{200} Normal value(µm)
1	3+000	41.09	256.5	204.4	249.70	198.98
2	3+500	40.79	170.6	94.2	167.30	92.38
3	4+000	41.34	221.0	165.4	213.84	160.04
4	4+500	39.64	502.0	259.0	506.56	261.35
5	5+000	40.93	307.6	213.7	300.61	208.84
6	5+500	40.86	587.2	274.0	574.84	268.23
7	6+000	41.3	390.2	110.2	377.92	106.73
8	6+500	41.95	211.8	102.3	201.95	97.54
9	7+000	41.34	807.1	133.6	780.94	129.27
10	7+500	41.78	135.7	71.4	129.92	68.36
11	8+000	41.78	149.6	96.0	143.23	91.91
12	8+500	42.43	90.2	67.1	85.03	63.26
13	9+000	42.73	40.8	30.8	38.19	28.83
14	9+370	40.38	75.3	56.4	74.59	55.87

Table 4. The calculation of curfature derflection (CF).

CF (µm)	D_0 corrected temperature value (µm)	CF corrected temperature value (µm)	D_0 Convertion from FWD to D_0 BB (µm)
50.72	262.18	57.82	327.73
74.92	175.66	85.41	219.58
53.80	224.53	61.33	280.66
245.21	531.89	279.54	664.86
91.77	315.64	104.61	394.55
306.61	603.58	349.53	754.48
271.19	396.81	309.15	496.02
104.41	212.05	114.85	265.07
651.67	819.99	716.84	1024.98
61.56	136.41	67.72	170.52
51.32	150.39	56.45	187.98
21.78	89.29	23.95	111.61
9.36	40.10	10.30	50.13
18.72	78.32	20.59	97.90
Average		161.29	360.43
Deviation Standard			282.63
D_0 representative			722.7619

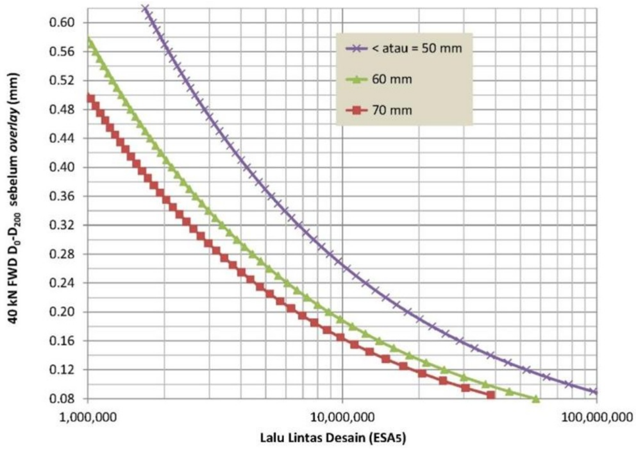

Fig. 2. Thin overlay design based on maximum deflection value [9].

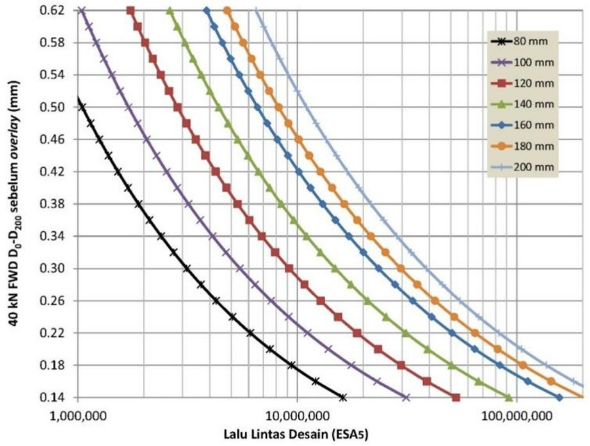

Fig. 3. Overlay design based on deflection curvature value [9].

From the calculation, it is obtained that the average CF = 0.16 is drawn horizontally to the left and the CESA5 value of 76,248,070.94 is drawn a vertical line up, the two lines form a point, based on the deflection curve graph in Fig. 2 and Fig. 3, it is obtained that the overlay thickness is 50 mm (overlay thin) and 140 mm (thick overlay). As for the maximum deflection, it is obtained D0 representative = 0.72 mm pulled vertically upwards to approach the curved line of the CESA4 value of 43,264,839.84, because in Fig. 1 the curve graph of the back deflection of the minimum BB that is 0.8 mm, the overlay thickness based on the maximum deflection is 0 mm. These results can illustrate that the Losari National Road (West Java Provincial Boundary) – Pejagan STA 3+000 – STA 9+370 is still able to withstand permanent deformation but has not been able to withstand fatigue cracking so a thin overlay is needed.

3.3 The calculation of overlay thickness using the shell pavement design method (SPDM) program

Setting up the parameters used in the SPDM program such as air temperature at the research location, traffic growth, the Vehicle Damage Factor obtained from the 2017 MPD results, Sub-base thickness, Young's modulus of elasticity (stiffness modulus), Poisson's ratio, CBR subgrade soil, Asphalt Mix Composition in the form of Volume % of Bitumen, Volume % of Aggregate, and Volume % of Voids, and Thickness from surface to sub-base, then open the SPDM program then click project and select thickness. Fill in the Climate table with available data as shown in Fig. 4.

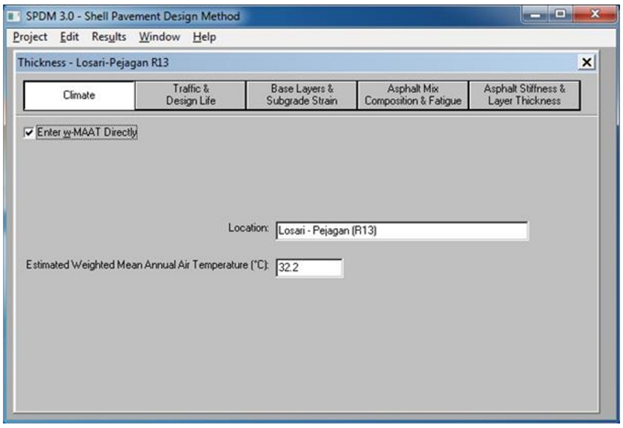

Fig. 4. Fill in the climate data column in SPDM.

After Climate is filled in, the next step is to fill in Traffic & Design Life based on VDF 5 overlay plans that you have. If the data obtained is only LHR data, then you can press the traffic spectrum option and fill in the LHR data in the traffic spectrum option according to the LHR data you have according to Fig. 5.

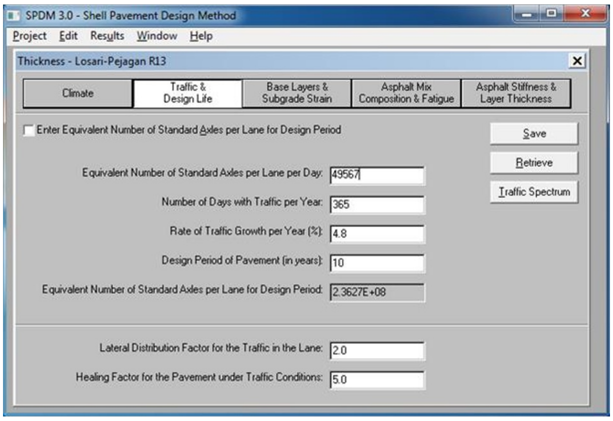

Fig. 5. Fill in the traffic & design life column in SPDM.

After Traffic & Design Life is filled in, the next step is to fill in the Base Layers & Subgrade Strains. For the type of material used in the sub base, use AC Base with a thickness of 210 mm with a typical modulus of 1600 MPa and a Poisson ratio of 0.40. As for the subgrade, it has a typical modulus of 34.72 MPa (FWD data) and a Poisson ratio of 0.45 due to cohesive soil as shown in Fig. 6.

After the Base Layers & Subgrade Strains are filled, the next step is to fill in the Asphalt Mix Composition & Fatique. To fill in the Asphalt Mix Composition & Fatique table, because the required bitumen and void data cannot be obtained, fill in according to the default SPDM program, namely the bitumen volume is 12%, the void volume is 5%, and the rest is aggregate as shown in Fig. 7.

The next step is to fill in Asphalt Stiffness & Layer Thickness. The thickness used is the initial thickness (surface + sub base) of 370 mm with a Poisson ratio of

 https://doi.org/10.1051/e3sconf/202342903011

0.40 and a typical modulus of 1100 MPa as shown in Fig. 8 then press the Result option. The SPDM calculation results can be seen in Fig. 9. From Fig. 9 it can be seen that the SPDM asphalt thickness design results are 0.416 m or 416 mm. These results will be reduced by the thickness of the previous flexible pavement layer of 370 mm, so the overlay thickness obtained from the SPDM program is 46 mm.

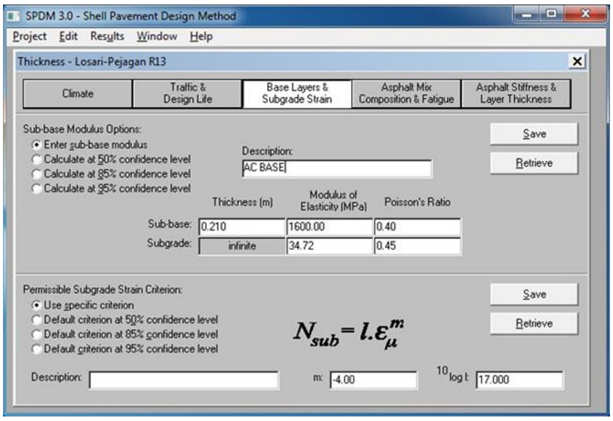

Fig. 6. Fill in the base layers & subgrade strains column in SPDM.

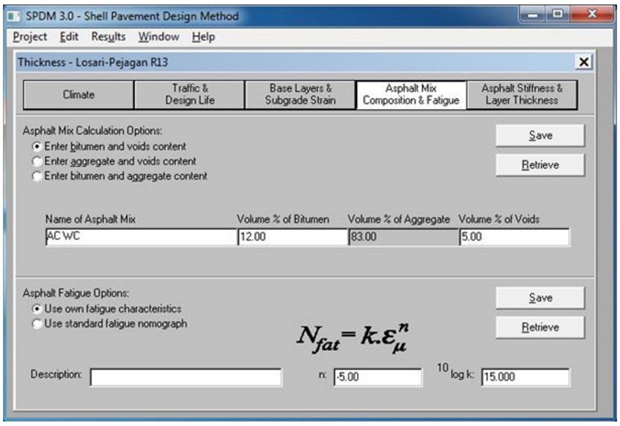

Fig. 7. Fill in the asphalt mix composition & fatique column in SPDM.

3.4 The evaluation of overlay thickness using MDP 2017 and SPDM

3.4.1 The Evaluation of Design Concepts

The design method used in the 2017 MDP method is an empirical mechanistic method that has been widely used in various developing countries. With this method the analysis of pavement structures is carried out using mechanical principles that are used to predict structural performance based on empirical experience. The 2017 MDPJ sharpens the approach in Interim Guidelines No.002/P/BM/2011.

The design method used in the SPDM method itself is a program based on a three-layer structure consisting of an asphalt pavement on a granular material base that is not bound on subgrade. The three-layer structure used as part of the SPDM is considered a linear elastic multi-layer system in which the materials are based on Young's modulus of elasticity (stiffness modulus) and Poisson's ratio. With that data, SPDM can find the required overlay thickness in a road section.

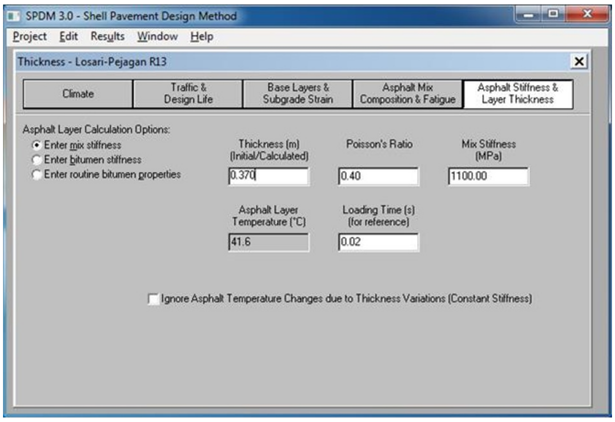

Fig. 8. Fill in the asphalt stiffness & layer thickness column in SPDM.

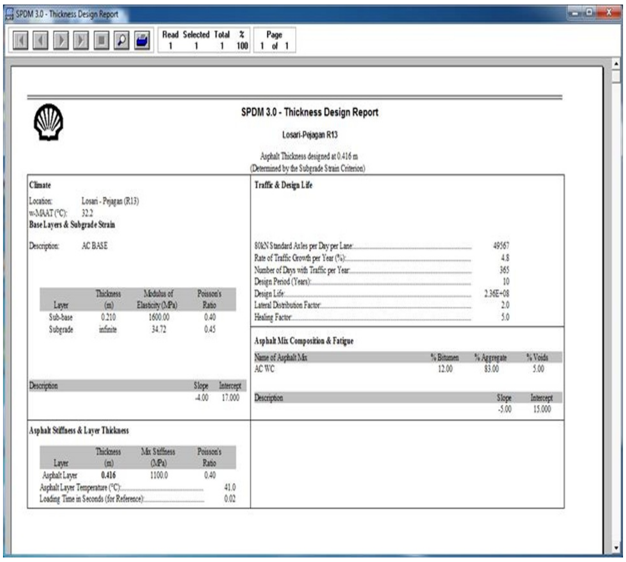

Fig. 9. Fill in the traffic & design life column in SPDM.

3.4.2 The Evaluation of Design Procedures

The procedure for calculating the 2017 MDP method to obtain the overlay thickness based on the maximum deflection is by using the graph provided by the 2017 MDP by entering the CESA4 value and the representative maximum deflection value. The CESA4 value is calculated based on several parameters, namely daily traffic (LHR), design life (UR), traffic growth factor (R), direction and lane distribution factor and also load equivalent factor (VDF). Meanwhile, the maximum deflection value is obtained based on the deflection test using the FWD tool. The results of the deflection test were analyzed based on the uniformity factor, seasonal correction factor, load correction factor, temperature correction factor and FWD to BB adjustment factor. From the results of the correction factor, the maximum deflection value (D0) will be obtained for each station. Then the value is averaged and then the standard deviation value is sought. Furthermore, the magnitude of the representative deflection is adjusted to the function/class of the road being studied. After obtaining the representative deflection value and CESA4 value, the graph on the 2017 MDP can be used to obtain the required overlay thickness.

In the 2017 MDP method there are other parameters, namely in the form of a deflection curve (D0 – D200). Deflection curve analysis (D0 – D200) is required to ensure that the overlay layer is capable of resisting fatigue cracking. The procedure for calculating the overlay thickness based on the deflection curve is basically the same as the procedure for calculating the overlay thickness based on the maximum deflection, except that the calculation of the overlay thickness based on the deflection curve uses the CESA5 value and the average value of the deflection curve (D0 – D200). The MDP 2017 method has taken into account the functional condition of the road in determining the thickness of the added layer for repairing unevenness, this is suitable for use in Indonesia because of road demands that must function optimally, comfortably, safely and smoothly [1].

The procedure for calculating the SPDM program method to obtain the overlay thickness is by calculating the Resilient Modulus of subgrade (subgrade MR), determining the design age, determining the traffic growth factor, calculating the Load Equivalence Factor (VDF), the VDF value is obtained using the 2017 MDP based on Traffic Average Daily (LHR), MR value of subgrade obtained from FWD deflection data which is also obtained from the results of an annual survey conducted by the Team of the Semarang VII National Road Implementation Center. The deflection that reflects the MR value of subgrade is the deflection that is measured far enough from the load center. The calculation of the MR value is carried out at each deflection measurement point to obtain the smallest MR value.

The next procedure is to determine the thickness of the sub-base, the Young's modulus of elasticity, and the Poisson's ratio obtained from the Table of the Modulus Characteristics of the Bonded Material in MPD 2017. For the calculation of the composition of the asphalt mix, follow the default SPDM program. Continue to calculate Asphalt Stiffness & Layer Thickness, enter the thickness value from surface to sub-base, Young's modulus of elasticity, and Poisson's ratio obtained from the Table of Modulus Characteristics of Bonded Materials in MPD 2017 then press the result option to get the overlay thickness calculation results. The calculation results from SPDM will later be reduced by the thickness value from the surface to the sub-base to get the overlay value from the SPDM program.

3.4.3 The Evaluation of Design Results

Based on the analysis of the average deflection curve (D0 – D200) in the 2017 MDP method, an overlay thickness of 50 mm was obtained, while based on the analysis of the maximum deflection, the maximum deflection value was obtained below the existing minimum maximum deflection value, then Losari National Road (Provincial Boundary) West Java) – Pejagan STA 3+000 – STA 9+370 is considered capable of resisting permanent deformation but not yet capable of resisting fatigue cracking so a thin overlay is required. The thin overlay was chosen because the comparison of the results of the SPDM method shows that the thin overlay has similar results to the two methods. This is because the lower the deflection value produced, the better the structural condition of a road segment. So, with a thick overlay design based on a deflection curve value of 50 mm it is considered sufficient to increase the structural value of the pavement, namely in the form of preventing grooves and changes in surface shape on the Losari National Road section (West Java Provincial Boundary) – Pejagan STA 3+000 – STA 9 +370.

In the SPDM program method, the analysis used is all FWD deflection values (d1-d9), in order to obtain the smallest subgrade MR value, namely the deflection measured far enough from the load center. It is this smallest subgrade MR value that will later be used to obtain the subgrade CBR value. Factors that affect the results of the overlay thickness based on the SPDM program method include the carrying capacity of the existing subgrade and the pavement layer above it. Thus, the SPDM program method produces a smaller overlay thickness of 46 mm compared to the 2017 MDP method with an overlay thickness of 50 mm. The difference in the minimum overlay thickness also affects the thickness of the overlay because the SPDM program method has a minimum overlay value starting at 0.0 mm, while MDP 2017 has a minimum overlay value starting at 50 mm. This is why some code fields do not require overlay because they are below the minimum overlay value.

Previous studies regarding the 2017 MDP, the 2017 MDP results are smaller than the 1993 AASHTO method, one of the contributing factors is the difference in design traffic generated by the two methods [10]. The SPDM for design traffic has the same value as MDP 2017. The results from SPDM itself have a variety of values starting from a minimum overlay thickness of 0 cm which is influenced by several parameters, namely subgrade CBR, Young's modulus of elasticity, and Poisson's ratio. The difference in the minimum value of the overlay thickness affects the thickness of the overlay which causes some code fields not to require overlay because it is below the minimum overlay value, while using SPDM you will definitely get an overlay thickness even if the value is below 50 mm. The thickness of the layer used in the SPDM can also be obtained from the previous road pavement planning so this makes it easier to design the road overlay to be reviewed.

3.4.4 The evaluation of Design Cost

Overlay planning in this study in terms of costs based on the data used for each method, MDP 2017 has a higher cost than SPDM, this is because MDP 2017 requires FWD and IRI data for calculations, while SPDM uses FWD data to find CBR values. Replace using Dynamic Cone Penetrometer (DCP) which costs less. Based on ease of access, the MDP 2017 module can be accessed by downloading it on the Bina Marga page, while the SPDM program can be downloaded on the SPDM Software page but can only be accessed on older versions of computers. This research can also get overlay results that are more effective in terms of calculations and time when using the SPDM program, this is because SPDM uses fewer assumptions used in design parameters and has the same parameters as MDP 2017 such as design traffic and subgrade CBR. when using the SPDM operating system you can easily use it and it is calculated automatically in the program, whereas if you use MDP 2017 the calculations are still manual and the determination of the overlay thickness uses graphic images whose accuracy adjusts to the user's foresight.

4 Conclusion

From the results of data analysis carried out on the Losari National Road section (West Java Province Boundary) – Pejagan STA 3+000 – STA 9+370 in Brebes Regency, Central Java, the following conclusions can be drawn:

1. The results of overlay calculations using the 2017 Road Pavement Design Manual (MDP 2017) obtained an overlay thickness of 50 mm and the results of calculations using the Shell Pavement Design Method (SPDM) program obtained an overlay thickness value of 46 mm.
2. The evaluation results of the overlay thickness analysis between the 2017 Road Pavement Design Manual (MDP 2017) and the Shell Pavement Design Method (SPDM) program obtained differences in the thickness of the overlay, including the following:
   a. If reviewing from the design concept, the difference in the results of the overlay thickness is due to differences in the design concept including the parameters used in the calculation of the overlay thickness,
   b. From the results of the design procedures, in MDP 2017 it is only seen from the thickness of the existing surface, while in SPDM the thickness is reviewed from the thickness of the surface to the thickness of the existing Sub Base. In addition, this difference also occurs because the 2017 MDP looks more at the deflection value while the SPDM program looks at the Poisson Ratio and Elasticity Modulus values,
   c. From the thicness of design result, it is found the difference in the minimum overlay thickness affects the overlay thickness which causes some section codes not to require overlay because they are below the minimum overlay value while using SPDM will definitely result in an overlay thickness even if the value is below 5 cm,

d. From the cost consideration of the design result, the thickness of the overlay is more effective in terms of data requirements, calculations and time, namely using the SPDM program because it is user friendly where when using this operating system you can easily use it and it is calculated automatically in the program whereas if you use MDP 2017 the calculations are still manual and determining the thickness of the overlay using a graphic image whose accuracy adjusts the user's foresight and will affect the final result of the overlay thickness.

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