2_ROAD PAVEMENT

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Evaluation of Toll Road Pavement Performance Based on the 2013 Bina Marga Method (Case Study: Serpong-Pondok Aren Toll Road)

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Abstract. Traffic growth due to economic growth in a region, impacted pavement on bearing a heavier load. Faster road pavement damage is one of the consequences of this incident, whereas toll roads are required to provide much better performance. Therefore it is necessary to conduct a study relating to the analysis of the results of road pavement performance as one part of the evaluation of pavement conditions. The purpose of this study is to conduct a pavement evaluation both functionally and structurally based on the 2013 Bina Marga method. The results of this study are expected to provide benefits in developing toll road maintenance policies and plans. The method used in this study is a survey method and descriptive statistical analysis of the data collected. Based on the results of this study, IRI values in each row can be categorized very well. In the last 5 years, only 24 points were found that had IRI values> 4, at STA 5+-500 lane 1 of Pondok Aren-Serpong showed unevenness at the same station for several years. RCI values indicate that pavement is classified as very good and regular. PSI values indicate that the pavement has provided sufficient services. The deflection value is an average of 167.47 micrometers with deflection uniformity of 0.222 so that the pavement is classified as very good. The results of the analysis of the pavement performance evaluation that has been carried out, show that the performance of the pavement, both functional and structural for the road on the Serpong-Pondok Aren toll road is classified as good.

1. Introduction

Along with the growth of traffic every year, traffic loads, even overloading from heavy vehicles, can cause damage to the surface and pavement structure. This is unavoidable and is likely to always happen. Sometimes the pavement conditions get damaged faster and deteriorated, this can reduce the service life that has been set. On the other hand the expectations of users and the government that toll roads must always provide excellent services, including those related to good pavement conditions. A good pavement structure is flat and smooth so that traffic can run smoothly, safely and comfortably [1].

The government and the toll road management have already paid attention to matters relating to the performance of road pavement, starting from routine monitoring of the condition of the pavement visually to using the equipment. The equipment intended is to determine the road flatness and deflection that occurs due to traffic loads. The data obtained from the test results will be used as a reference for monitoring and evaluation activities relating to services provided to toll road users. This information is very important for the Government and the toll road management to draw up maintenance work plans to provide excellent service. Therefore it is necessary to conduct research relating to the analysis of the results of road pavement performance as one part of the evaluation of pavement conditions, both functionally and structurally.

2. Literature review

In general, roads can also be interpreted as a transportation infrastructure that facilitates the smooth movement of goods and/or services from one location to another. Along with the times, the need for a good pavement infrastructure has also increased [2].

2.1. Pavement

Based on his book, Sukirman stated that pavement construction consists of a subgrade layer, a subbase course, a base course, and a surface course [3]. Traffic loads that occur on pavement consist of vertical loads in the form of vehicle loads, a horizontal force from vehicle brakes, and vibrations from vehicle wheels. The forces accepted by the road pavement itself will get smaller and smaller, therefore, the pavement layer must be able to accept all kinds of styles. Pavement can be divided into three, namely flexible pavement using asphalt as a binding, rigid pavement using cement as the binding material, and composite pavement which is a combination of both [4].

2.2. Pavement performance

Pavement performance covers 3 things including security, form and service functions. But in general, the performance of pavement can be determined in 2 ways namely objectively and subjectively [5]. Objectively through parameters such as IRI (International Roughness Index) and subjectively through parameters such as RCI (Road Condition Index) and PSI (Present Serviceability Index).

2.3. Minister Regulations of Public Works

One of the goals of road maintenance and surveillance arrangements is to actualize road services that accordance with the minimum service standards as noted in the Minister Regulations of Public Works of The Republic of Indonesia Number 16 / PRT / M / 2014 concerning toll road minimum service standards [6]. The scope of regulation for road maintenance and surveillance procedures includes supervision including evaluation, reporting on road maintenance activities and planning as well as implementing road maintenance.

According to the Regulation, regarding the minimum service standards for toll roads, toll roads are public roads that are part of the road network system and a national road where users are required to pay[6]. Toll roads must have higher specifications than ordinary roads in terms of both safety and comfort. To provide certainty of services to the toll road user community, a ministerial regulation is made which contains the minimum toll road service standards which include toll road conditions, average travel speed, accessibility, mobility, safety, rescue/rescue units and service assistance, the environment, and rest area. Some references so that toll road conditions always meet the standards are roughness> 0.33mm, IRI ≤4m / km, absence of holes, cracks, and 100% rutting.

2.4. Bina Marga method

Based on the Bina Marga Pavement Design Manual [7], a type of pavement handling method is provided using a trigger value. These trigger values include Benkelman Beam (BB) deflection triggers, Falling Weight Deflectometer (FWD) deflection, International Roughness Index (IRI) triggers. and triggers for pavement conditions.

2.4.1. IRI (International Roughness Index.

IRI is an objective determinant of road pavement performance objectively describing the elongated profile of a road so that it can be seen as the flatness of the road. This parameter was developed by the World Bank in 1980 by calculating the amount of rising and falling of the surface in the direction of the lengthwise profile divided by the distance / overall surface length. IRI can be correlated subjectively in the form of RCI (Road Condition Index) which can show surface conditions and PSI (Present Serviceability Index) related to the level of road service [8].

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2.4.2. RCI (Road Condition Index).

It is a method developed by AASHTO (American Association of State Highway Officials) in 1960 that measures the scale of road comfort and performance using both visual method and the roughometer tool. From this tool, IRI values are obtained which are then correlated through calculations and graphs. In Indonesia, the correlation between the two is as follows:

$$RCI = 10 * Exp\,(-0{,}0501 * IRI^{1{,}220920}) \quad (1)$$

Table 1. RCI value [9].

Pavement Surface Types Visually	Field Condition Visually	RCI Value
A poor drainage dirt road and all types of surfaces that are not maintained at all.	Can't be passed	0 – 2
All types of pavement that have not been maintained for a long time (4 - 5 years or more)	Severely damaged, many holes in the entire surface area.	2 – 3
Old PM (Periodic Maintenance), Old Latasbum, Gravel.	Broken, bumpy, many holes	3 – 4
PM (Periodic Maintenance) after 2 years of use, old Latasbum	A little bit damaged, few holes, uneven surface	4 – 5
New PM (Periodic Maintenance), New Latasbum, Lasbutag after 2 years of use.	Very few holes, the surface is rather uneven	5 – 6
Old Thin Layer of Hot-mix, New Latasbum, New Lasbutag.	Well	6-7
Hotmix after 2 years, thin hotmix over PM	Very good, generally flat	7-8
New Hot-mix, increase by using more than 1 layer.	Very flat and organized	8 – 10

2.4.3. PSI (Present Serviceability Index).

This is a method developed by the AASHTO (American Association of State Highway Officials) that states the rigidity and stiffness of the road surface to the level of service [3]. The correlation of PSI with IRI on the flexible pavement is:

$$PSI = 5 - 0{,}2937X^4 + 1{,}1771X^3 - 1{,}4045X^2 - 1{,}5803X \quad (2)$$

Where:
- X = Log (1+SV)
- SV = *Slope Variance* = 2,2704 IRI^2
- PSI = *Present Serviceability Index*
- IRI = *International Roughness Index*, m/km

Table 2. PSI [3].

Present Serviceability Index (PSI)	Level of Service
4-5	Very Good
3-4	Good
2-3	Fair
1-2	Poor
0-1	Very poor

2.4.4. Falling weight deflectometer.

FWD was first introduced in the United Kingdom in the mid-1980s which is a measurement tool in evaluating the strength of structures by measuring deflection on road pavement [10]:

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$$FK = \frac{S}{d_R}\ x\ 100\% < FK_{Allowable} \tag{3}$$

$$D_V = d_R + 2s\ ;\ for\ toll\ road\ (accuracy\ 98\%) \tag{4}$$

Where:
FK = uniformity factor
S = Standard deviation
d_R = average deflection on a segment
D_V = deflection alternate
$FK_{Allowable}$ = Allowable uniformity factor
= 0-10% very good
= 11-20% good
= 21-30% fair

3. Methodology

The study began with a literature study on pavement performance and the methods used in evaluating the performance of the pavement. Next, problem identification is carried out to find out what things need to be examined in this evaluation. Data collection in the form of secondary data obtained from PT. Bintaro Serpong Damai. The data are in the form of road section data, map of road locations, geometry characteristics, International Roughness Index (IRI) values, and deflection data from the Falling Weight Deflectometer (FWD).

Data processing in this study is divided into 2 stages, namely data processing to determine the functional performance of pavement and data processing to determine the structural performance of the pavement. In evaluating functional pavement performance, the International Roughness Index (IRI) data is processed through the Road Condition Index (RCI) and Present Serviceability Index (PSI) parameters. After the data processing is complete, analysis and discussion of functional road performance are carried out.

In the next step, data processing is carried out based on test data using the Falling Weight Deflectometer (FWD) to analyze structural pavement through deflection data. After processing this data, analysis and discussion of the structural performance of the road are carried out.

The final step in this research is conclusions. The conclusions contain the results of the analysis and answer all the objectives of this study as well as suggestions that contain things not done in this study.

4. Results of the evaluation study and discussion

The length of the Serpong-Pondok Aren toll road is estimated to be 7.25km. It is a 3.5m six-lane two-direction road each with a composite pavement type and began operating on February 2, 1999. Flatness data obtained from this road will be used to determine the level of comfort and function of road services. While deflection data is used to determine the structural performance of the road.

4.1. Geometric data

The geometric data of the Serpong-Pondok Aren toll road section is as follows:
-Status : Toll Road
-Road configuration : Six lanes two directions (6/2D)
-Coordinates : S 06’18’33.71”-E 106’41’10.56”
-Length : 7.25km
-Operating Year : 2 February 1999

4.2. RCI (Road Condition Index) and PSI (Present Serviceability Index)

The Road Condition Index, which functions as a scale of subjective comfort or pavement performance, is obtained from the correlation between IRI and RCI. This research itself uses the correlation between IRI and RCI [7]. Examples of calculations performed on the 1st Row of Pondok Aren-Serpong with an IRI value of 2.92, the Road Condition Index value is obtained as follows:

$$\begin{aligned} RCI &= 10^{*} \text{ Exp } (-0.0501^{*}IRI^{1.220920}) \\ &= 10^{*} \text{ Exp } (-0,.0501^{*}2.92^{1.220920}) \\ &= 8.31 \end{aligned}$$

Based on the Minister Regulations of Public Works No. 13 of 2011, the 2013 lane of Pondok Aren-Serpong is visually very good and orderly. The functional condition of the road analyzed is service function and road surface condition. Analysis of road service functions is done by calculating the PSI value with an example calculation performed on the 1 lane direction of Pondok Aren-Serpong with an RCI value of 8.31 then the PSI is obtained as follows:

$$\begin{aligned} SV &= 2.2704 \ IRI^{2} \\ &= 2.2704\ (2.92^{2}) \\ &= 19.33 \\ X &= \text{Log } (1+19.33) \\ &= 1.31 \\ PSI &= 5 - 0.2937X^{4} + 1.1771X^{3} - 1.4045X^{2} - 1.5803X \\ &= 5 - 0.2937(1.31)^{4} + 1.1771(1.31)^{3} - 1.4045(1.31)^{2} - 1.5803(1.31) \\ &= 2.304 \end{aligned}$$

Based on Table 2, the service function and surface index of this lane is considered sufficient. The results of the RCI and PSI analysis in the 5 years the rest of the data can be seen in Table 3.

Table 3. Road Condition Index and Present Serviceability Index of 2013.

Lane	Direction	Year	RCI	Fields Visual Condition	PSI	Service Function
1	Pondok Aren-Serpong	2013	8.31	Very Good and Even	2.304	Fair
2	Pondok Aren-Serpong		8.35		2.337	
3	Pondok Aren-Serpong		8.38		2.360	
1	Serpong-Pondok Aren		8.30		2.299	
2	Serpong-Pondok Aren		8.40		2.383	
3	Serpong-Pondok Aren		8.45		2.421	
1	Pondok Aren-Serpong	2015	8.67	Very Good and Even	2.636	Fair
2	Pondok Aren-Serpong		8.79		2.767	
3	Pondok Aren-Serpong		8.80		2.776	
1	Serpong-Pondok Aren		8.63		2.591	
2	Serpong-Pondok Aren		8.86		2.839	
3	Serpong-Pondok Aren		8.90		2.894	
1	Pondok Aren-Serpong	2016	8.50	Very Good and Even	2.469	Fair
2	Pondok Aren-Serpong		8.61		2.573	
3	Pondok Aren-Serpong		8.62		2.585	
1	Serpong-Pondok Aren		8.47		2.439	
2	Serpong-Pondok Aren		8.76		2.729	
3	Serpong-Pondok Aren		8.85		2.832	
1	Pondok Aren-Serpong	2017	8.32	Very Good and Even	2.315	Fair
2	Pondok Aren-Serpong		8.43		2.409	
3	Pondok Aren-Serpong		8.41		2.389	
1	Serpong-Pondok Aren		8.32		2.312	
2	Serpong-Pondok Aren		8.29		2.291	
3	Serpong-Pondok Aren		8.35		2.337	
1	Pondok Aren-Serpong	2018	8.54	Very Good and Even	2.505	Fair
2	Pondok Aren-Serpong		8.76		2.725	
3	Pondok Aren-Serpong		8.75		2.714	
1	Serpong-Pondok Aren		8.56		2.521	
2	Serpong-Pondok Aren		8.83		2.804	
3	Serpong-Pondok Aren		8.85		2.828	

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From 5 years of data obtained, it can be seen that overall road conditions are very good and regular with sufficient service functions. Besides good road performance, several points have experienced above-average damage. Among them in 2013 the direction of Pondok Aren-Serpong lane 1 STA 5 + 500 with an IRI value of 4.06 and 3 lanes STA 11 + 700 with an IRI value of 4.41.

In 2016 the direction of Pondok Aren-Serpong, lane 1 STA 5 + 500 with an IRI value of 7.60; STA 5 + 600 with an IRI value of 5.40; STA 5 + 700 with an IRI value of 4.10; STA 6 + 000 with an IRI value of 4.20; lane 2 STA 5 + 500 with an IRI value of 8.10; STA 5 + 600 with an IRI value of 4.40; STA 11 + 900 with an IRI value of 4.10; lane 3 STA 5 + 500 with IRI value of 7.70; STA 12 + 000 with an IRI value of 4.20; STA 12 + 100 with an IRI value of 4.20. Direction Serpong-Pondok Aren lane 1 STA 12 + 200 with IRI 7.50; STA 5 + 800 with an IRI value of 4.30; lane 2 STA 12 + 200 with an IRI value of 8.30.

In 2017 the direction of Pondok Aren-Serpong lane 1 STA 8 + 200 with an IRI value of 4.02; lane 3 STA 7 + 500 with IRI value of 4.22; STA 12 + 600 with an IRI value of 4.11. The direction of Serpong-Pondok Aren lane 1 STA 12 + 700 with IRI value of 4.76; lane 3 STA 9 + 700 with an IRI value of 4.55.

In 2018 the direction of Pondok Aren-Serpong lane 1 STA 5 + 500 with an IRI value of 5.44; STA 5 + 900 with an IRI value of 4.06; STA 12 + 400 with an IRI value of 5.55; STA 12 + 500 with IRI 9.18; STA 12 + 600 with an IRI value of 5.00; lane 3 STA 5 + 500 with IRI value of 4.48; STA 5 + 900 with an IRI value of 4.13. Direction Serpong-Pondok Aren lane 1 STA 9 + 600 with an IRI value of 4.92; STA 6 + 000 with an IRI value of 4.09; lane 2 STA 5 + 600 with an IRI value of 4.28; lane 3 STA 9 + 900 with an IRI value of 4.09; STA 5 + 600 with an IRI value of 4.32.

4.3. FWD (Falling Weight Deflectometer)

The pavement strength test using the Falling Weight Deflectometer (FWD) method produces data as in table 4 below.

Table 4. Falling Weight Deflectometer lane 1.

STA	D1	D2	D3	D4	D5	D6	D7	D8	D9
5.500	115.63	111.07	109.10	104.30	99.23	90.63	80.90	72.67	63.77
5.607	140.90	124.70	120.83	115.07	109.67	99.47	90.10	80.83	71.63
5.700	121.27	109.70	107.17	103.20	98.73	91.70	81.70	73.57	63.87
5.800	125.80	114.10	110.53	105.77	102.03	91.00	83.63	75.30	66.90
5.899	156.67	140.97	136.20	128.87	121.73	108.07	95.30	83.73	72.90
6.002	147.63	135.63	132.87	126.57	119.47	106.60	93.97	81.17	69.27

The data then can be visualized so that the deflection can be seen in Figure 1 below.

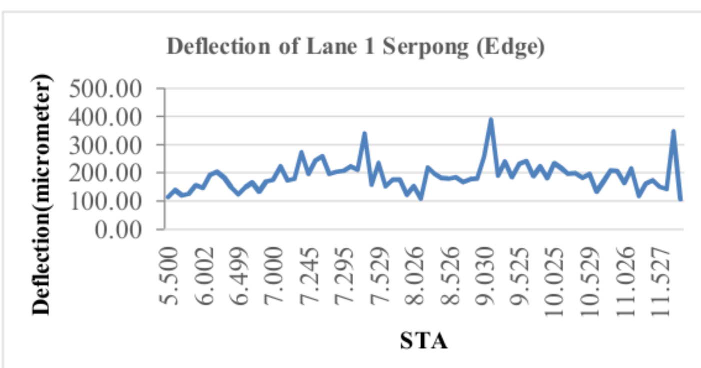

Figure 1. FWD Lane 1 Serpong (Edge).

The picture above is a visualization of deflection that occurs in lane 1 Serpong (edge). The average deflection on this row is 189.82 micrometers. Then, to look for the value of D_V, the calculation is also divided into two parts, namely between the middle and edge. The calculation starts with doing the calculation with the following steps:

Calculation of average FWD Deflection (dr) 1 lane direction Serpong (edge):

$$d_R = \frac{\sum D}{\sum \text{segment}} = \frac{14046,33}{74} = 189.82 \text{ micrometer}$$

Standard deviation of FWD deflection (s) 1-way lane Serpong (edge)::

$$S = \sqrt{\frac{n(\sum d^2) - (\sum d)^2}{n(n-1)}} = 51.64$$

Deflection alternate (D_V) lane 1 Serpong (edge)::

$$D_V = d_R + 2s = 189.82 + (2 \text{ x } 51.64) = 293.10 \text{ micrometer}$$

Uniformity Factor (FK) lane 1 Serpong (edge)

$$FK = \frac{S}{d_R} \text{ x } 100\% < FK_{\text{Allowable}}$$
$$= \frac{51,64}{189.82} \text{ x } 100\% < FK_{\text{Allowable}}$$
$$= 0.27\% \text{ (Very well uniform)}$$

Based on the FWD calculation results contained in table 14, it can be seen that each toll road segment both in the direction of Serpong and Pondok Aren has very good uniformity.

4.3.1 Structural analysis. Based on the results of the structural analysis that has been carried out on the Serpong-Pondok Aren Toll Road along 7.25 km, several conclusions can be drawn including:

- The deflection in lane 1 of Serpong at the edge is 189.82 micrometers and the middle part is 171.81 micrometers with a uniformity factor at the edges of 0.27 and the middle part at 0.27. This shows that the magnitude of deflection that occurs on this pavement is very small, accompanied by a very good uniformity factor.
- The deflection in lane 1 of Jakarta at the edge is 186.11 micrometers and the middle part is 173.02 micrometers with a uniformity factor at the edge of 0.26 and the center at 0.21. This shows that the magnitude of deflection that occurs on this pavement is very small, accompanied by a very good uniformity factor.
- The deflection in lane 2 of Serpong at the edge is 183.95 micrometers and the middle part is 182.10 micrometers with a uniformity factor at the edge of 0.21 and the middle part at 0.27. This shows that the magnitude of deflection that occurs on this pavement is very small, accompanied by a very good uniformity factor.
- The deflection in the 2 lane direction of Jakarta at the edge is 184.00 micrometers and the middle part is 173.27 micrometers with a uniformity factor at the edges of 0.29 and the middle section at 0.19. This shows that the magnitude of deflection that occurs on this pavement is very small, accompanied by a very good uniformity factor.
- The deflection in the 3-way lane Serpong at the edge is 209.96 micrometers and the middle part is 205.12 micrometers with a uniformity factor at the edges of 0.17 and the middle part at 0.15. This shows that the magnitude of deflection that occurs on this pavement is very small, accompanied by a very good uniformity factor.

- The deflection in the 2 lane direction of Jakarta at the edge is 203.34 micrometers and the middle part is 184.62 micrometers with a uniformity factor at the edge of 0.3 and the center at 0.13. This shows that the magnitude of deflection that occurs on this pavement is very small, accompanied by a very good uniformity factor.

It can be seen that the highest average deflection occurs in lane 3. Both from Serpong and Jakarta, both on the edge of the pavement and the middle side of the pavement.

5. Conclusions

Based on the analysis that has been done, several conclusions can be drawn as follows:

- Functional road pavement performance in 5 years data obtained shows that the results of surface conditions are visually very flat and regular with the service function in the sufficient category with a flatness value or IRI of less than 4. This is the result of good maintenance.
- Structural pavement performance at the service life of 20 years shows a very small deflection accompanied by a good deflection uniformity factor. This shows that the service life planned will be achieved alongside with a good road performance.
- Besides good pavement, several points experienced repeated unevenness which is STA 5 + 500 lanes 1 and 3 of Pondok Aren-Serpong.
- The highest unevenness value occurred at STA 12 + 500 in 2018 of Pondok Aren-Serpong with an IRI value of 9.18.

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