

Evaluation of the Structural Condition of Composite Pavement



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Abstract One of the road tolls at the borderline of Jakarta, the capital of Indonesia, i.e., Tangerang-Merak toll road, was found in a damaged condition in several locations. The toll's pavement structure comprises an asphalt layer (blacktopping) over a concrete slab (or a composite structure). An evaluation is required to find out the last condition of the pavement to propose the remedy for the problem. An eight-step evaluation was conducted systematically in this study, and the 1993 AASHTO method was the method used to analyze the results. The first step was to conduct traffic analysis by calculating ADT from toll gate transaction data validated with CCTV data, while vehicle axle loads were measured by static load surveys to calculate the vehicle equivalent factor. Another analysis of the pavement's structural condition was conducted using backcalculation analysis using FWD deflection data to produce the moduli of subgrade reaction and the elastic modulus of the concrete pavement. The analysis showed that several locations of the toll road suffered a medium to severe deterioration as indicated by high deflection values. This fact was also supported by the findings that the pavement system's remaining life is 22% on average. Two recommendations were made by implementing 7.12 in. or 18 cm overlay thickness on the in-service pavement for road segments with good prediction of moduli, and 2 in. or 5 cm repairing treatment to strengthen the existing pavement may be considered as planned stage of construction for the rest. Before the overlay and treatments were conducted, various repairs were taken place on the damaged spots along the road segment.

Keywords AASHTO 1993 · Evaluation of structural conditions · Composite pavement structure · Deflection

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1 Introduction

A toll road is a national-level road that requires strict technical requirements and has to meet the aspects of safety, security, comfort, and smoothness of traffic. The toll road is planned to be able to serve long-distance traffic flows with high mobility. According to the Toll Road Regulatory Agency (BPJT), the aim of toll road construction is to smoothen traffic in developed areas and improve goods and services distribution services to support economic growth and alleviate the burden on Government funds through the participation of road users. Therefore, a toll road must have a solid pavement structure and minimal damage during its service life. A toll road maintenance program is one program that should be carried out periodically to ensure the pavement is always at its high performance.

One of the toll roads with the highest traffic load at the borderline of Jakarta, the capital of Indonesia, is Tangerang-Merak toll road. At present, the surface of pavement of this toll road, a composite pavement structure or asphalt concrete (AC) over jointed plain concrete pavement (JPCP), is in damaged condition due to high traffic loads, so it can affect vehicles' travel time and increase the number of accidents. Evaluating the existing pavement condition is the first and critical process to develop a road pavement rehabilitation plan. A comprehensive evaluation of pavement conditions will provide critical input into pavement rehabilitation design. Therefore, research is needed to evaluate the pavement's structural conditions, and it was expected to end up with proposed possible solutions to the problems encountered to enable the road serving traffic loads up to the planned service life. Especially for toll roads with the rigid pavement that have been overlaid with asphalt pavement (blacktopping) or AC/JPCP, there were not many studies that explain how to evaluate this pavement's structural conditions [1].

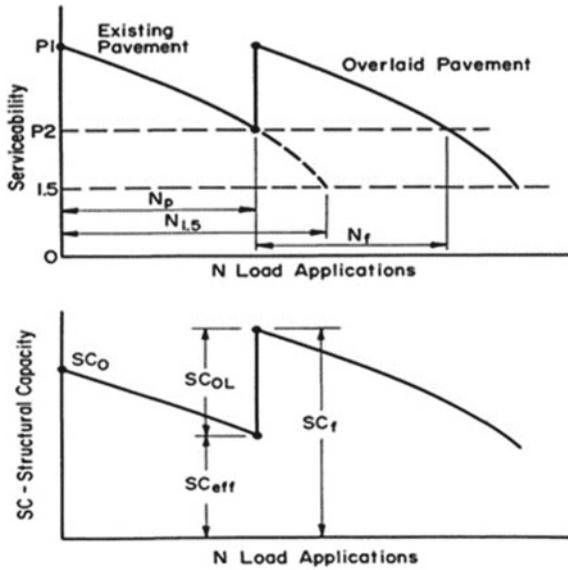
2 Structural Condition of Road Pavement

According to AASHTO [2], the evaluation of the structural and functional condition of road pavement is the information about the performance of pavement structures against traffic loads and environmental conditions. The pavement's structural condition will experience a decrease in performance due to the repetition of traffic loads, inadequate drainage systems, high rain intensity, changes in temperature, unstable subgrade conditions, and poor performance of maintenance works.

An overlay is designed to be applied over the entire surface of the existing pavement to increase the structural or functional capacity significantly. An overlay is used when restoration techniques are no longer adequate or cost-effective but necessary before reconstruction is required.

AASHTO [2] illustrates reduced service levels and structural capacity and the contribution of overlay to return the service level to approaching the previous level (Fig. 1). When newly built, the pavement structural capacity is denoted as SC_0 (or

Fig. 1 Illustration of the structural capacity of road pavement and the contribution of overlay to improve the reduced service level of existing pavement [2]



initial service capacity for flexible pavement) or D (or initial slab thickness for rigid pavement) with service level P_1 . The structural capacity can be expressed as the equivalent slab thickness (D) as for composite pavements. Over time and loading (N_p), the service level will decrease to P_2 , and structural capacity is reduced to SC_{eff} (or D_{eff}). The overlay is carried out to increase the structural capacity (SC_{ol}) to withstand the predicted traffic load during the design period with the required structural capacity (SC_f).

Several measurements or surveys are needed to evaluate in-service pavement’s structural capacity, such as deflection measurement [3, 4] and road condition survey. A backcalculation procedure is carried out to determine the layer moduli [5], which, together with the service load prediction (N_f), is used to calculate the required slab thickness (D_f).

Besides, a road condition survey is performed to check whether there are deteriorations in the existing pavement. The presence of damages could reduce the existing structural capacity (D_{eff}). The difference between D_f and D_{eff} is the additional capacity in terms of overlay to maintain or increase the structural capacity of the composite structure.

3 Results and Discussions

The structural evaluation procedure in this study was conducted on a composite pavement structure, i.e., AC overlay over the AC/JPCP layers, which can be described in 8 steps: (a) existing pavement structure overview; (b) traffic analysis; (c) road

condition survey; (d) deflection testing; (e) coring and material testing; (f) determination of required pavement thickness (D_f); (g) determination of effective pavement thickness (D_{eff}); and (h) determination of thickness overlay (D_{ol}). Some steps were described in details in the following sections.

3.1 Existing Pavement Structure Overview

The toll road evaluated in this study is Tangerang–Merak toll road at 32.100–36.300 km heading to Tangerang with a total length of 4.2 km (see Fig. 2). The structure of the road consists of five layers as follows.

1. Asphalt mixture wearing course (AC-WC) layer as blacktopping with a thickness of 10 cm. The thickness came from two times overlay works of 5 cm each on the top of concrete pavement. AC-WC is a dense-graded asphalt mixture with 12.5 mm-maximum size aggregate. This mixture was designed using Marshall Method and produced an optimum asphalt content of 5.85% which determined as the asphalt content required to meet the specification of Asphalt Concrete Wearing Course (AC-WC) in General specification of Ministry of Public Works, Republic of Indonesia [6].

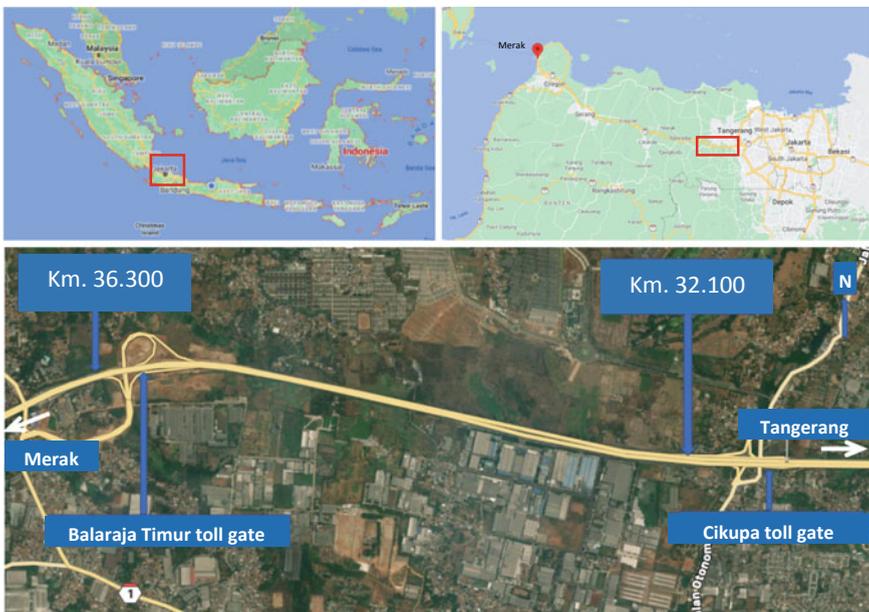


Fig. 2 Location of road segment evaluated

2. Concrete pavement surface without reinforcement or Jointed Plain Concrete Pavement (JPCP), with a thickness of 29 cm and a quality of the concrete f_c 37.35 MPa.
3. A 10-cm lean concrete and the quality of concrete f_c 10.4 MPa.
4. Class A granular base layer with a thickness of 25 cm has a CBR design value of 90%.
5. The subgrade on the existing pavement layer has a CBR design value of 6%, the maximum dry density 2.315 g/cm³ and the optimum water content is 6%.

The rigid pavement of the road was firstly constructed in 1990, and two asphalt-mixture overlays were conducted in 2005 and 2007. During this period, no detail historical data regarding the condition of the pavement was found.

3.2 Traffic Load Analysis

Using traffic data in terms of the number of vehicles per day in 2019 in the direction of Tangerang, the cumulative prediction of 18-kip ESAL (Equivalent Standard Axle Load) in the design lane during the predicted service life (N_d) is shown in Table 1.

This calculation used the value of the DL (Design Lane) value equals 0.65 (because it consists of 3 lanes per direction), the service life of 5 years, and a growth factor of 6%. The Vehicle Damage Factor (VDF) formula was used to calculate the equivalency factor based on the static scale survey conducted by the Directorate General of Highway, Ministry of Public Works and Housing.

Table 1 Traffic load analysis (heading to Tangerang)

Group	Vehicle/day	VDF	ESAL in 2019	Cum. ESAL up to 2024
I (Non Bus)	33,063	0.0024	18,826	105,069
I (Small bus)	265	1.8252	114,753	640,445
I (Large bus)	911	3.7796	816,903	4,559,209
II	8713	2.5030	5,236,114	29,223,231
III	3210	16.0490	16,587,421	92,575,905
IV	1173	6.4680	2,318,760	12,941,213
V	1005	16.2430	3,940,346	21,991,432
Total			29,033,124	162,036,505

3.3 Calculation of Asphalt Concrete and Slab Modulus Using Backcalculation Procedure

The method of backcalculation procedure used in this research was the closed-form method. This approach could provide a unique solution by solving the equations. The accurateness of the results produced by the closed-form method can outperform of that produced by iterative or database backcalculation methods [7]. This procedure is used by AASHTO Guide for rehabilitation design of existing AC/PCC structure [2], by adopting AREA method [8] in determining the layer moduli, as shown in Eqs. 1–10. All the variables in the equations were expressed in English units. The conversion to Metrics unit may be possible to be applied once the modulus values were obtained.

Deflection measurements using FWD and temperature measurements were carried out at each point in the evaluated locations. Temperature, together with some properties of the asphalt mixture, was used to calculate the elastic modulus of the mix (E_{AC}) (in psi) using Eq. (1).

$$\begin{aligned} \log(E_{AC}) = & 5.553833 + 0.028829 \left(\frac{P_{200}}{F^{0.17033}} \right) - 0.33476 V_v + 0.070377 \eta_{70F, 10^6} \\ & + 0.000005 t_p^{(1.3+0.49825 \log(F))} P_{AC}^{0.5} + \frac{0.00189}{F^{1.1}} t_p^{(1.3+0.49825 \log(F))} P_{AC}^{0.5} \\ & + 0.931757 \left(\frac{1}{F^{0.02774}} \right) \end{aligned} \quad (1)$$

in which: P_{200} is percentage of aggregate that passes through sieve # 200; F is load frequency (Hz); V_v is air voids (%); $\eta_{70^\circ F, 10^6}$ is absolute viscosity at 70° F, 10⁶ poise; P_{AC} is asphalt content (%); and t_p is AC mix temperature (°F).

Using typical values for the several parameters: $F = 18$ Hz at duration 25–30 ms, $P_{200} = 4\%$, $V_v = 5\%$, $\eta_{70F, 10^6} = 2$ poise, $P_{AC} = 5\%$, Eq. (1) can be simplified as follows.

$$\log(E_{AC}) = 6.451235 - 0.000164671 t_p^{1.9254} \quad (2)$$

Deflections from four FWD sensors were selected for backcalculation analysis using the 1993 AAHTO method to obtain the concrete pavement layer's elastic modulus, as follows.

$$d_{0compress} = -0.0000328 + 121.5006 \left(\frac{D_{AC}}{E_{AC}} \right)^{1.0798} \quad (3)$$

$$d_{0JPCP} = d_0 - d_{0compress} \quad (4)$$

$$AREA_{JPCP} = 6 \left[1 + 2 \left(\frac{d_{12}}{d_{0JPCP}} \right) + 2 \left(\frac{d_{24}}{d_{0JPCP}} \right) + \left(\frac{d_{36}}{d_{0JPCP}} \right) \right] \quad (5)$$

$$\lambda_k = \left[\frac{\ln \left(\frac{36 - AREA_{JPCP}}{1812.279133} \right)}{-2.559340} \right]^{4.387009} \quad (6)$$

$$k_d = \left(\frac{P}{8d_{0JPCP}\lambda_k^2} \right) \left\{ 1 + \left(\frac{1}{2\pi} \right) \times \left[\ln \left(\frac{a}{2\lambda_k} \right) + \gamma - 1.25 \right] \left(\frac{a}{\lambda_k} \right)^2 \right\} \quad (7)$$

$$k_s = 0.5k_d \quad (8)$$

$$E_{JPCP} = \frac{\lambda_k^4 [12(1 - \mu_{JPCP}^2)k]}{D_{JPCP}^3} \quad (9)$$

$$S_c = 43, 5 \left(\frac{E_{JPCP}}{10^6} \right) + 488, 5 \quad (10)$$

where: $d_{compress}$ is a deflection that occurs due to pressure in the AC layer in the middle of the slab (mils); d_{AC} is layer thickness of asphalt layer (in.); $d_0, d_{12}, d_{24}, d_{36}$ are deflection at a distance 0, 12, 24, 36 in., respectively from the load (mils); λ_k is the radius of the relative stiffness of slab to subgrade (in.); γ is Euler constant; k_d and k_s is effective dynamic- and static-k value (pci), respectively; E_{JPCP} is slab elastic modulus (psi); S_c is the modulus of rupture (psi).

The calculation of the asphalt, slab, and subgrade moduli at each point evaluated are tabulated in Table 2. The grey-shaded parts of the table indicated that it not possible to calculate the moduli due to the *AREA* values greater than 36 (see Eq. 6).

The lack of providing satisfactory results for all segments showed that the AASHTO procedure has a limitation in practice. This could be contributed using four or more deflections in *AREA* method to predict the moduli, i.e., the cumulative deviations or errors between the corresponding measured and calculated deflections will increase when unusual pattern of the deflections is found. Therefore, Fwa and Setiadji [9] proposed the use of any two-deflection combination to overcome this problem and to produce better prediction of the moduli. The use of only two deflections in the backcalculation procedure will minimize the cumulative errors between the measured and calculated deflections.

In Table 2, the static *k-value*, which is medium to high, means that the subgrade bearing capacity is quite good. There is a low *E* value due to the low pavement-structure carrying capacity indicated by large deflection measured.

Table 2 Calculation of asphalt, slab, and subgrade moduli

Km	D_{AC} (in.)	D_{JPCP} (in.)	t_p (° F)	E_{AC} (psi)	$d_{compress}$ (mils)	D_0 (in.)	D_{0JPCP} (in.)	D_{12} (in.)	D_{24} (in.)	D_{36} (in.)	AREA	λ_k (in.)	k_d (pci)	k_s (pci)	E_{JPCP} (psi)	S_c (psi)
32.175	3.937	9.055	108.20	123,501.15	1.66	1.73	0.10	1.30	1.10	1.00	529.90					
32.425	3.937	9.055	101.20	180,280.54	1.09	3.06	2.00	1.40	1.00	0.90	22.92	17.77	1729.73	864.86	2724.09	607.00
32.600	3.937	9.055	124.20	47,662.67	4.71	10.69	6.00	6.50	4.40	3.20	31.09	39.36	120.04	60.02	4552.57	686.54
32.825	3.937	9.055	109.27	116,355.62	1.78	3.14	1.40	1.00	0.70	0.70	24.78	20.32	1931.49	965.75	5204.27	714.89
33.150	3.937	9.055	109.27	116,355.62	1.78	1.93	0.20	1.10	1.00	0.90	205.31					
33.250	3.937	9.055	105.22	145,475.50	1.39	2.30	0.90	1.60	1.60	1.50	57.81					
33.375	3.937	9.055	105.37	144,353.74	1.40	6.05	4.60	2.20	2.00	1.60	18.92	13.92	1170.26	585.13	693.548	518.67
33.600	3.937	9.055	103.09	163,196.78	1.22	1.94	0.70	1.20	1.20	1.10	55.57					
33.775	3.937	9.055	106.81	133,419.65	1.53	2.35	0.80	1.60	1.40	1.30	58.35					
34.025	3.937	9.055	106.81	133,419.65	1.53	4.23	2.70	2.10	1.60	1.40	25.54	21.57	867.21	433.60	2968.05	617.62
34.200	3.937	9.055	106.81	133,419.65	1.53	2.23	0.70	1.40	1.30	1.10	61.91					
34.425	3.937	9.055	103.81	157,036.91	1.28	2.97	1.70	1.50	1.30	1.10	30.10	34.27	557.37	278.69	6057.19	751.99
34.650	3.937	9.055	112.07	99,195.76	2.12	1.40	-0.70	0.90	0.90	0.80	-31.50					
34.800	3.937	9.055	99.81	193,852.31	1.01	2.44	1.40	1.30	1.10	0.90	29.93	33.52	690.03	345.02	6868.67	787.29
35.025	3.937	9.055	99.81	193,852.31	1.01	2.19	1.20	0.90	0.90	0.80	28.07	27.14	1261.44	630.72	5391.04	723.01
35.200	3.937	9.055	99.81	193,852.31	1.01	2.70	1.70	1.50	1.30	1.10	29.62	32.24	629.05	314.53	5358.83	721.61
35.425	3.937	9.055	108.71	120,034.28	1.72	1.73	0.00	1.10	0.90	0.70	2865.5					
35.575	3.937	9.055	108.71	120,034.28	1.72	1.78	0.10	1.00	0.90	0.80	433.45					
35.850	3.937	9.055	105.37	144,353.74	1.40	1.61	0.20	1.40	1.20	1.00	186.13					
36.250	3.937	9.055	99.81	193,852.31	1.01	2.22	1.20	1.00	0.90	0.80	28.75	29.16	1068.72	534.36	6089.90	753.41

3.4 Calculation of Overlay Thickness (D_{OL})

The overlay thickness was calculated as a deviation between effective- and required-slab thickness, D_{eff} and D_f , respectively. The required slab thicknesses (D_f) were determined using nomograph in the AASTHO method [2]. Several parameters were determined based on field justification: overall standard deviation (S_o) = 0.39 1; reliability (R) = 0.96; drainage coefficient (C_d) = 0.8; load transfer (J) = 2.5; initial serviceability (p_o) = 4.5; terminal serviceability = 2.5; while effective static k -value, slab elastic modulus and modulus of rupture were obtained from Table 2, and the proposed traffic volume was as calculated in Table 1.

On the other hand, the effective-slab thickness (D_{eff}) was determined using Eq. (11) as follows.

$$D_{eff} = (D_{JPCP} \times F_{jc} \times F_{dur}) + \left[\left(\frac{D_{AC}}{2} \right) F_{AC} \right] \quad (11)$$

in which: F_{jc} is joint and cracks adjustment factor; F_{dur} is durability adjustment factor; F_{AC} is AC quality adjustment factor.

Some adjustments were made for the parameters to calculate D_{eff} , i.e., F_{jc} was in between 0.90 and 0.95 (depends on the number of deterioration), while F_{dur} and F_{AC} were selected to equal 0.96 to indicate minor PCC and AC distresses, respectively.

Finally, the overlay thickness (D_{ol}) was calculated using the following equations.

$$D_{ol} = A(D_f - D_{eff}) \quad (12)$$

$$A = 2.2233 + 0.0099(D_f - D_{eff})^2 - 0.1534(D_f - D_{eff}) \quad (13)$$

Another interesting parameter that could be calculated besides the overlay thickness is the remaining life (RL) of the pavement structure. According to AASHTO [2], the remaining life can be determined as a ratio of total traffic to date (N_p) to total traffic to pavement failure ($N_{1.5}$) (in ESAL) as follows.

$$RL = 100[1 - (N_p/N_{1.5})] \quad (14)$$

N_p can be obtained from Table 1, while $N_{1.5}$ was determined using nomograph in the AASHTO method [2] with $p_t = 1.5$.

As mentioned previously, not all thicknesses at points evaluated can be determined due to there were no moduli resulted from the calculation as the effect of large AREA values, as shown in Table 2. After carefully examining the calculation, only ten thicknesses can be produced, as depicted in Table 3.

Table 3 shows that the average remaining life of the pavement of Tangerang-Merak toll road (heading to Tangerang) is 26%, although the pavement surface visually may not show severe damage. An overlay of 7.12 in. or 18 cm (maximum thickness in Table 3) will be applied to the toll road segment STA 32 + 425 to STA 36 + 250.

Table 3 Calculation of overlay thickness and remaining life

Km	Effective pavement thickness				D_f (in.)	Overlay thick		Remaining Life		
	F_{jc}	F_{dur}	F_{AC}	D_{eff} (in.)		A	D_{OL} (in.)	$N_{1,5}$ (ESAL)	N_p (ESAL)	RL (%)
32.425	0.90	0.96	0.96	11.75	15.53	1.79	6.75	40.563.280	29.033.124	28
32.600	0.95	0.96	0.96	12.30	16.33	1.77	7.12	35.656.937	29.033.124	19
32.825	0.90	0.96	0.96	11.75	14.66	1.86	5.41	41.770.119	29.033.124	30
33.375	0.95	0.96	0.96	12.30	15.71	1.82	6.19	40.174.614	29.033.124	28
34.025	0.95	0.96	0.96	12.30	16.04	1.79	6.68	39.010.255	29.033.124	26
34.425	0.94	0.96	0.96	12.19	15.13	1.86	5.45	39.328.606	29.033.124	26
34.800	0.90	0.96	0.96	11.75	14.73	1.85	5.52	39.251.934	29.033.124	26
35.025	0.90	0.96	0.96	11.75	14.90	1.84	5.79	38.222.538	29.033.124	24
35.200	0.95	0.96	0.96	12.30	15.32	1.85	5.79	40.014.391	29.033.124	27
36.250	0.9	0.96	0.96	11.75	14.77	1.85	5.58	39.675.227	29.033.124	27

Before the overlay is applied, the damage that occurred has to be repaired first by proposing different treatments, as shown in Table 4. The treatments selected were those recommended based on the solutions in AASHTO Guide [2] for rehabilitation methods other than overlay.

In the case of the overlay thickness and remaining life cannot be evaluated (as showed by grey-shaded parts in Table 2), a treatment for repairing the damage should be applied and a minimum thickness of 2 in. or 5 cm for strengthening of existing pavement structure may be considered as a planned stage of the construction. The development of a closed-form backcalculation algorithm for composite pavement requires a lot of work due to different fundamental concept of two systems, i.e.,

Table 4 Proposed treatment on the damage before overlying the road

Km	Type of distress	Proposed treatment
32.425	Raveling	Patching
	Potholes	Shallow patching
32.600	Upheaval at patching	Re-patching
32.825	Depression at patching	Re-patching
33.375	Depression at patching	Re-patching
34.025	Upheaval at patching	Re-patching
34.425	Upheaval at patching	Re-patching
34.800	Transversal cracking	Grouting
35.025	Raveling	Patching
	Block cracking	Shallow patching
35.200	Upheaval	Patching
36.250	Block cracking	Shallow patching

flexible and rigid pavements. The use of iterative best-fit trial and error backcalculation method by simulating the pavement structures into three layers (AC, PCC and subgrade) could be one proposed solution in practice [10], although the use of the method in evaluating the composite structure need a careful consideration.

4 Conclusions

This paper evaluated composite pavements' functional and structural conditions on the Tangerang-Merak toll road, especially at 32.100–36.300 km. Based on the road condition survey results, several damages were found on the pavement surface along the section evaluated. The study indicated high deflection values produced by FWD, which led to the summary that the pavement was in medium to severely damage at several locations. It was also supported by the remaining life analysis, which showed a relatively low bearing capacity on those points. A calculation was conducting using AASHTO 1993 method and proposed two recommendations, that is, an overlay thickness of 7.12 in. or 18 cm to be implemented for the road sections with good prediction of moduli using backcalculation analysis, and a minimum thickness of 2 in. or 5 cm of repairing treatment to strengthen the existing pavement may be considered as planned stage of construction for the rest. All treatments and overlay were carried out after the damages in the sections were repaired first.

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