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APPLICATION OF FALLING WEIGHT DEFLECTOMETER TO ASSESS ROAD STRUCTURAL CONDITION FOR THAILAND PAVEMENT MANAGEMENT SYSTEM

Dr. Auckpath Sawangsuriya[1*], Teerapat Sirirattanachat[2] ,Danainut Taworn[2] and Suranon Yuayong[2]

[1] Civil Engineer - Expert Level, Bureau of Road Research and Development, Department of Highways, Ministry of Transport, Bangkok, Thailand

[2] Civil Engineer - Practitioner Level, Bureau of Road Research and Development, Department of Highways, Ministry of Transport, Bangkok, Thailand

[*]Corresponding author: sawangsuriya@gmail.com

ABSTRACT

Although road condition data, e.g. visual distress and ride quality, provide a good indication of the overall network-level road condition, it does not give a direct measure of structural integrity and capacity of a road pavement. To address this issue, the road structural condition parameters based on the falling weight deflectometer (FWD) measurements are proposed and implemented in the road deterioration model for Thailand pavement management system (PMS). This paper highlights the practical implication of structural condition parameters suggested in the past publications for road maintenance, rehabilitation, and reconstruction. The preliminary analysis of this study showed that the FWD was the most comprehensive approach for road structural condition assessment and road deterioration model for Thailand pavement performance prediction, which was an integral part of PMS. The Department of Highways, Thailand aims to reduce road deterioration and maintenance cost through using improved PMS which employs the road deterioration model uniquely developed based on Thailand road conditions.

KEYWORDS: road structure, structural condition, pavement performance, falling weight deflectometer, pavement management system

บทคัดย่อ

ข้อมูลสภาพถนน อาทิ สภาพความเสียหายและคุณภาพการขับขี่ สามารถใช้เป็นตัวชี้วัดด้านคุณภาพของโครงข่ายถนนของประเทศได้ แต่ข้อมูลดังกล่าวไม่ได้เป็นตัวชี้วัดความแข็งแรงและความสามารถในการรับน้ำหนักบรรทุกของโครงสร้างถนนโดยตรง เพื่อตอบประเด็นข้อจำกัดดังกล่าว ตัวแปรด้านโครงสร้างถนนทดสอบด้วยเครื่อง Falling Weight Deflectometer (FWD) จึงถูกนำมาใช้พัฒนาแบบจำลองการเสื่อมสภาพถนนสำหรับระบบบริหารจัดการทางหลวงของประเทศไทย บทความวิจัยนี้นำเสนอแนวทางการนำตัวแปรด้านโครงสร้างถนนสำหรับงานบำรุงรักษาและบูรณะปรับปรุงถนน โดยอ้างอิงจากผลงานศึกษาในอดีต ผลการวิเคราะห์ในเบื้องต้นจากการศึกษาครั้งนี้ พบว่าเครื่อง FWD สามารถใช้ประเมินสภาพโครงสร้างถนนและใช้เป็นแนวทางพัฒนาแบบจำลองการเสื่อมสภาพถนนเพื่อทำนายสมรรถนะทางหลวงของประเทศไทยต่อไปได้ ซึ่งเป็นหัวใจสำคัญของระบบบริหารจัดการทาง

หลวงในอนาคต กรมทางหลวงมุ่งหวังที่จะลดความเสียหายและค่าใช้จ่ายในการซ่อมบำรุงทางหลวง โดยอาศัยข้อมูลสภาพถนนจริงและแบบจำลองทำนายสมรรถนะทางหลวงซึ่งเป็นของประเทศไทยเอง ผ่านระบบบริหารจัดการทางหลวงที่ทันสมัย

คำสำคัญ: โครงสร้างถนน, สภาพความแข็งแรง, สมรรถนะของถนน, เครื่องมือวัดการแอ่นตัวแบบตกกระแทก, ระบบบริหารจัดการถนน

1. Introduction

The Department of Highways (DOH), Thailand consumed a lot of resources and efforts to preserve the national road networks each year. A number of preventive measures, extensive maintenance, and preservation alternatives have applied in order to improve the road conditions and to prolong the pavement service life. Most measures provided a temporary improvement of surface conditions, but they did not prevent the problem from reoccurring and did not provide the remedy to any structural deficiency associated with the road pavements. As a result, the overall road condition kept deteriorating due to the structural deficiency, even though road preservations were applied periodically.

A road pavement has generally four major functions: (1) to distribute load from tires to subgrade (e.g. load bearing capacity), (2) to seal roadbed from moisture, (3) to smooth surface for comfortable ride, and (4) to provide friction with tire for safe ride. Road pavement performance, which is usually described as the function of road serviceability to meet the traffic demands and environmental conditions during its service life, is becoming a crucial issue and major concern for the road administrations and agencies to efficiently maintain, rehabilitate, and preserve road networks as well as their assets. The evaluation of road pavement performance (e.g. distress, roughness, friction, and structure) is certainly an integral part of pavement management. A pavement management system (PMS) essentially evaluates various alternatives of pavement maintenance and rehabilitation and their expected impacts on the future performance of pavements as well as the information needed to support the maintenance and rehabilitation operations, prioritization, capital funding requests etc. The prediction of road pavement performance is an integral part of the PMS for estimating preservation and funding requirements for road networks.

Currently, the PMS of Thailand DOH adopts the World Bank's HDM-4 (Highway Design and Maintenance Standards) model known as roughness performance model, which was developed based on data source from somewhere else. Such model cannot be universal and should only be used to predict the future condition of a road section in similar materials, traffic, and environments. Ideally, both road deterioration models and work effects models shall be uniquely developed in Thailand. In other words, the models should be developed in such a way that they are relevant and appropriate to local Thailand conditions e.g. construction, maintenance, materials, traffic, climate etc. In order to understand and predict how roads behaved and deteriorated with various maintenance strategies under the stress of heavy vehicle traffic loads and Thailand weather conditions, long-term pavement performance study shall be locally performed in Thailand's unique combination of weather conditions, heavy vehicle traffic conditions, road behavior over its life-cycle etc. Thailand DOH aims to develop deterministic road deterioration model for Thailand pavement performance prediction and to ensure that the model developed could be implemented by road practitioners.

On-going research is undertaken to investigate the reliability, range, and scope of the road deterioration model for future Thailand PMS. Road structural condition assessment and associated factors are needed to account for local road variability. It is important that road authorities and agencies shall consider the road structural condition and its deterioration for road pavement performance modelling in order to make proper decisions about the type of preservation needed and cost-effective preventive maintenance and to reduce road deterioration and maintenance cost through using improved PMS which employs the road deterioration model uniquely developed based on Thailand road conditions. This paper focuses on the application of the falling weight deflectometer (FWD) to assess road structural condition for Thailand PMS. The structural condition parameters were also proposed as indicators of road structural condition and for road pavement performance modelling as well as the future adoption at the network level.

2. Literature Review

2.1 Falling Weight Deflectometer

Road condition data is generally consisted of the type, amount, and severity of surface distress, structural integrity, ride quality, and skid resistance of the pavement [4]. The road condition assessment is necessary to identify maintenance and rehabilitation requirements, strategies, future road condition, work effects, prioritize work, and optimize maintenance and rehabilitation fund expenditures. As agreed by the participating organizations, one of the key road performance parameters is the structural integrity (i.e., strength and deflection) and its capacity needed to accommodate projected traffic. Deflection measurements have long been used to back calculate the elastic moduli of pavement layers and to evaluate the integrity and capacity of road structural condition. The device that measures deflections and is being adopted by several road authorities and agencies is the falling weight deflectometer (FWD).

The FWD is commonly used in Thailand by the Department of Highways (DOH) and the Department of Rural Roads (DRR) for the structural condition evaluation of a pavement section, where the back calculation of the subgrade and the pavement layer moduli is employed to characterize the structural condition. In particular, the Bureau of Road Research and Development (BRRD), DOH, Thailand, possessed the Dynatest Model 8000 FWD system from Denmark since 2000 as shown in Figure1.

The FWD was used to measure the surface deflections through nine surface sensors (geophones). A deflection bowl was generated by the impulse force, which was created by varying the drop height and weight. The sensors were located at 0, 200, 300, 450, 600, 900, 1200, 1500, and 1800 mm distance from the centre of the loading plate. The load was transmitted to the road pavement through a 300-mm diameter loading plate. The magnitude of load was measured by a load cell. A number of research projects by the BRRD involved the practical implications of the FWD deflection measurements after the construction stage as well as during the in-service stage. Many of them were well-documented in the final report, refereed journal publications, and conference proceedings [2], [3], [8].

Figure 1 Dynatest Model 8000 Falling Weight Deflectometer (FWD) from Denmark.

2.2 Structural Condition Parameters for Road Pavements

In order to estimate the road pavement's structural condition, one needs the existing and the required structural condition. Since the FWD is considered to be the most comprehensive approach currently adopted by Thailand DOH, it is possible to calculate the modulus (E) and structural number (SN) of a road pavement from FWD deflection measurements. By comparing between the existing and the required structural condition parameters (e.g. E and SN), the structural integrity and capacity of the road pavement can be estimated. Two methods of estimating the structural condition parameters are presented as follows:

(1) Modulus Ratio (MR)

$$MR = E_p/E_{req} \tag{1}$$

where

E_p = existing (estimated) pavement modulus of all layers above the subgrade

E_{req} = required pavement modulus of all layers above the subgrade

= $(E_1H_1+E_2H_2+E_3H_3+\dots E_NH_N) / (H_1+H_2+H_3\dots+ H_N)$

E_N = modulus of elasticity of pavement layer N (see Table 1)

H_N = thickness of pavement layer N

and (2) Structural Condition Index (SCI)

$$SCI = SN_{eff}/SN_{req} \tag{2}$$

where

SN_{eff} = existing (effective) structural number (SN)

SN_{req} = required structural number (SN), which can be determined from the following equation [1]:

$$\log(W_{18}) = Z_R \times S_o + 9.36\log(SN_{req}+1) - 0.20 + \frac{\log\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40+\frac{1094}{(SN_{req}+1)^{5.19}}} + 2.32\log(M_R) - 8.07 \quad (3)$$

W_{18} = predicted number of 18-kip equivalent single axle load applications

Z_R = standard normal deviate

S_0 = combined standard error of the traffic prediction and performance prediction

ΔPSI = difference between the initial design serviceability index, p_o, and the design terminal serviceability index

M_R = resilient modulus (psi)

Rohde [6] suggested that the existing (effective) SN can be estimated from the deflection data. The deflection bowl as measured by a peak deflection under FWD load represents a combination of the deflection in the subgrade and the elastic compression of the pavement structure. By comparing the deflection measured at an offset of 1.5 times the pavement thickness with the peak deflection measured under FWD load, one can estimate the amount of deflection that originated within the pavement structure only. If the total pavement thickness and the deflection within the pavement structure are known, the SN_{eff} can be calculated using the following regression equation [6].

$$SN_{eff} = 0.4728\ SIP^{-0.4810}\ H_p^{0.7581} \quad (4)$$

where

SIP = structural index of pavement (microns or 1/1000th of a millimetre)

= $\delta_1 - \delta_{1.5Hp}$

δ_1 = peak deflection measured under a standard 5,000-kg (50 kN) FWD load (microns)

$\delta_{1.5Hp}$ = deflection measured at an offset of 1.5 times of H_p under a standard 5,000-kg (50 kN) FWD load (microns)

H_p = total pavement thickness, e.g. all layer thicknesses above the subgrade (millimetre)

It is noteworthy that the required SN is usually calculated for the estimated traffic (ESALs) of the next 20 years [1]. This is the case when the pavement is newly built. However, for the maintenance of an existing pavement, it is up to the road authorities and agencies to determine the time period for which the accumulated ESALs are to be estimated [9].

3. Methodology

3.1 FWD Measurements

A trial section of road pavement selected for this study was a part of national highway No. 4 from km post 88+570 to 88+745 toward the capital city of Thailand. This section is situated in Potaram district, Rachaburi province. It has a minimum length of 250 m and 3.5 m wide. Its pavement structure consisted of five layers including 200-mm asphalt surfacing, 200-mm crushed rock base, 200-mm lateritic soil subbase, 250-mm selected material, and subgrade. The selected trial section was part of research project under the supervision of BRRD, DOH during 2017-2018. Details are summarized in Sawangsuriya [7]. For the scope of this study, three replicated drops of a 750-kPa target loading stress were applied at each test point. Practically, three magnitudes of load: 40, 53, 70 kN (e.g. 575, 750, 1,000 kPa) were applied on the pavement structure according to the FWD testing method. The mean loading stress of 750 kPa had been adopted by the BRRD, DOH for several years because this typical stress was averaged based on the design standard single axle-load of 100 kN (10 metric tons) from a legal load permit of 25-ton gross weight (e.g. 10-wheel Thai truck). Such a single axle-load generated the dual-wheel load of approximately 50 kN. Therefore, the impact load of 49 and 52.5 kN over a 300-mm diameter metal plate would appreciably produce the contact pressure between 700 kPa and 750 kPa. The FWD test was generally conducted over the wheel paths. Three sets of measured deflection data (e.g. three replicated drops) made at 0, 200, 300, 450, 600, 900, 1200, 1500, and 1800 mm distance from the center of the loading plate were reported herein. After finishing each set, tests were carefully made at identical locations consistently marked on the road surface for two more sets.

The material properties for road structural analysis e.g. modulus of elasticity (E) and Poisson's ratio (ν) along with their layer thicknesses are summarized in Table 1. It should be also noted that E values in Table 1 are referred to typical design values practically adopted by Thailand DOH (denoted as E-local design) and those determined from the FWD backcalculation analysis (denoted as E-backcal). The backcalculation analysis was performed by the ELMOD (Evaluation of Layer Moduli and Overlay Design) software on the basis of the method of equivalent thickness. The deflections measured by the FWD were generally processed through this backcalculation software for computing layer modulus of road pavement. In this process, the deflections were calculated for assumed elastic moduli, compared with the observed deflections, and accordingly the assumed moduli were further adjusted for the next iteration. The iteration continues until the calculated and observed deflections match closely.

Table 1 Material properties for road structural analysis.

Pavement materials	Layer Thickness (mm)	Modulus of elasticity, E-local Design (MPa)	Modulus of elasticity, E-backcal-Culated (MPa)	Poisson's ratio
Asphalt surfacing	200	2,500	1,508	0.35
Crushed rock base	200	350	127	0.35
Lateritic soil subbase	200	150	149	0.35
Selected material	250	100	149	0.35
Subgrade	-	40	98	0.40

3.2 Numerical Analyses

To efficiently estimate the road structural responses under FWD measurements, the numerical methods using the finite-element analysis (FEA), the multi-layer linear-elastic analysis (LEA), and the elastic solutions were performed. Such methods have been widely accepted in most mechanistic design and performance analysis of the road pavements where their structures were assumed to be homogenous, isotropic, linear-elastic, and finite thickness with modulus of elasticity (E) and Poisson's ratio (ν).

In this study, the FEA was performed to examine the road structural responses under the FWD. Although a 3-D model could be essentially implemented in most FEA, it usually required larger computational resource and more complexity in model development. Thus, an axisymmetric model was considered herein. The geometry of FEA model developed in this study was respectively selected to be 12 and 50 times of applied loading radius (a = 150 mm) in width and in height as suggested in Kim [3]. The calculated domain size of FEA model was therefore equal to 12a x 50a (1,800 mm x 7,500 mm). The base of the subgrade was assumed a pinned support (e.g. no horizontal and vertical movement), while the lateral constraint was a roller (e.g. only vertical movement). The applied constant stress of 750 kPa was uniformly distributed over a circular contact area (70,686 mm^2) having radius (a) of 150 mm. A general 4-node isoparametric element for axisymmetric model was selected in the FEA model. Although finer mesh yielded better results, it required longer computational time. In addition to be in consistent with the layer thickness of pavement system in this study, the mesh size of 25 mm @ 8 (= 200 mm) was selected for 200-mm asphalt surfacing, 200-mm crushed rock base, and 200-mm lateritic soil subbase, while the mesh size of 50 mm @ 5 (= 250 mm) was selected for 250-mm selected material and subgrade. The load application, geometry, and boundary conditions of FEA model as suggested in Kim [5]. The road structural responses in terms of deflections were calculated from the FEA.

In companion with the FEA, the LEA was performed to examine the responses of a linear-elastic multi-layered structure. The analysis was based on the assumption that the layered materials were homogenous, isotropic, and linear-elastic. The applied vertical load was uniformly distributed over a circular area. The input parameters for the LEA including material properties, layer thickness, and load geometry were identical to the FEA. The corresponding road structural responses in terms of deflections were calculated from the LEA.

The elastic solutions based on Boussinesq's equations were also used to compare with the FEA and LEA results. The Boussinesq's equations described the relationship between surface deflection and modulus of elasticity in a half space and can be expressed as:

$$E(0) = \frac{2(1-\nu^2)\sigma_0 a}{\delta(0)} \tag{5}$$

$$E(r) = \frac{(1-\nu^2)\sigma_0 a^2}{r\,\delta(r)} \tag{6}$$

where E(0) = modulus of elasticity of an equivalent single layer system, which would give the same deflection at the center of load application (MPa); E(r) = modulus of elasticity of an equivalent single layer system, which would give the same deflection at distance r from the center of load application (MPa); ν = Poisson's ratio; σ_0 = applied stress (MPa); a = radius of loading area (mm); r = distance from the center of load application (mm); $\delta(0)$ = deflection at center of load application (mm); $\delta(r)$ = deflection at distance r from the center of load application (mm). In this study, both E(0) and E(r) were assumed pavement moduli determined from the weighted average of all layers above the subgrade. The deflections were then calculated from Eqs. (5) and (6).

4. Results and Discussion

4.1 Comparison between FWD Measurements and Numerical Analyses

A series of FWD surface deflections along a trial section aforementioned were presented in Table 2. The average FWD surface deflections from three replicated measurements in Table 2 were calculated and compared with numerical analysis (e.g. FEA, LEA, and elastic solutions). An axisymmetric FEA model developed along with the LEA and the closed-form solutions based on the elastic theory was used to estimate the road structural responses under FWD measurements and the comparison between FWD measurements and numerical analysis was made accordingly.

The FEA, LEA, and elastic solutions were calculated based on the assumption that the layered material exhibited linear and elastic. The surface deflections determined from the FEA, LEA, and elastic solutions were compared with the FWD measured data. A plot of surface deflection vs. the offset distance is shown in Figure 2. Both E-local design and E-backcal were also considered in the analysis and were compared in the plot. It was found that both FEA and LEA based on E-local design tended to give larger surface deflections when compared to those based on E-backcal. In a case of the elastic solutions, Boussinesq's equations based on E-local design however gave smaller surface deflections than thosed based on E-backcal. In addition, the comparison results indicated that the surface defections from both FEA and LEA were close to those from the FWD measurements, while the elastic solutions tended to underestimate the surface deflections as illustrated in Figure 2.

4.2 Estimation of Structural Condition Parameters

Figure 3 illustrated the FWD deflection data at the center of load application from a road section of national highway No. 4 from km post 88+570 to 88+745 aforementioned. The measurements were made in the left (L) and right (R) tracks over the wheel paths (about 0.80 m offset from the traffic line) as shown in Figures 3(a) and 3(b), respectively. Four set of data taken in different periods were presented. The corresponding MR and SCI parameters calculated from Eqs. (3) and (4) were plotted against the dates of which the FWD measurements were taken as shown in Figures 4(a) and 4(b), respectively. The structural condition results at this road section indicated that both MR and SCI values were higher than 1.0.

Table 2 FWD surface deflections.

Set No.	Location	Stress (kPa)	Deflection (microns) at offset distance (mm)								
			0	200	300	450	600	900	1200	1500	1800
1	1	756	501.0	395.6	326.9	254.6	192.9	104.0	74.2	55.4	44.9
	2	754	578.3	444.8	363.1	277.1	204.8	108.8	77.8	58.3	46.2
	3	754	519.3	406.0	338.7	264.2	204.5	121.7	78.9	55.8	44.1
	4	755	551.2	440.2	363.8	281.8	215.8	126.6	81.8	59.3	46.9
	5	754	520.1	411.9	335.5	256.6	194.0	114.9	78.0	56.9	44.6
	6	752	587.1	461.4	380.7	293.0	226.9	137.8	91.4	64.8	50.4
	7	754	608.0	478.0	379.4	280.2	205.3	112.6	72.8	54.9	44.7
	8	757	563.5	451.7	373.2	284.7	216.2	127.1	83.5	61.1	48.5
Average #1		**755**	**553.6**	**436.2**	**357.7**	**274.0**	**207.6**	**119.2**	**79.8**	**58.3**	**46.3**
2	1	756	507.1	399.7	329.3	254.7	189.8	103.5	73.3	55.4	43.7
	2	753	578.1	438.0	357.9	270.5	199.6	106.7	75.6	56.5	44.0
	3	756	527.3	415.2	343.1	268.0	205.9	122.9	78.9	57.0	44.4
	4	752	572.9	454.9	376.5	288.9	218.7	127.9	82.6	62.2	47.6
	5	753	528.6	411.8	336.3	254.0	192.2	115.8	79.2	57.4	45.6
	6	753	573.3	455.6	375.1	290.2	225.0	137.8	91.7	64.9	51.4
	7	751	615.8	487.2	384.7	285.1	209.6	118.3	80.2	63.4	53.4
	8	751	581.5	455.8	376.6	286.6	217.3	129.0	85.4	65.8	51.0
Average #2		**753**	**560.6**	**439.8**	**359.9**	**274.8**	**207.3**	**120.2**	**120.2**	**60.3**	**47.6**
3	1	754	514.1	405.5	334.5	256.8	190.2	102.7	73.1	54.8	43.1
	2	755	599.4	455.6	371.0	279.9	205.0	107.2	76.3	56.7	45.3
	3	751	538.3	418.3	346.1	268.3	205.7	122.0	78.4	56.7	44.7
	4	752	568.5	449.6	370.5	281.1	214.2	123.9	80.2	56.8	45.3
	5	753	545.7	411.1	335.1	255.9	193.2	116.8	78.9	57.3	44.8
	6	755	607.3	473.5	388.3	297.3	228.5	138.6	91.9	65.3	50.6
	7	756	615.9	485.2	385.4	284.4	210.3	115.7	75.1	56.4	45.4
	8	749	594.3	465.8	384.6	289.4	219.6	128.5	87.7	66.3	54.0
Average #3		**753**	**572.9**	**445.6**	**364.4**	**276.6**	**208.3**	**119.4**	**80.2**	**58.8**	**46.7**

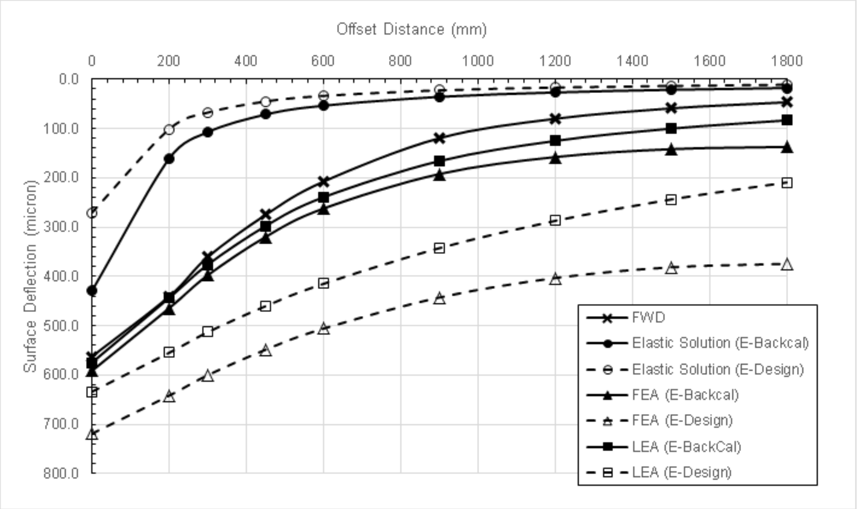
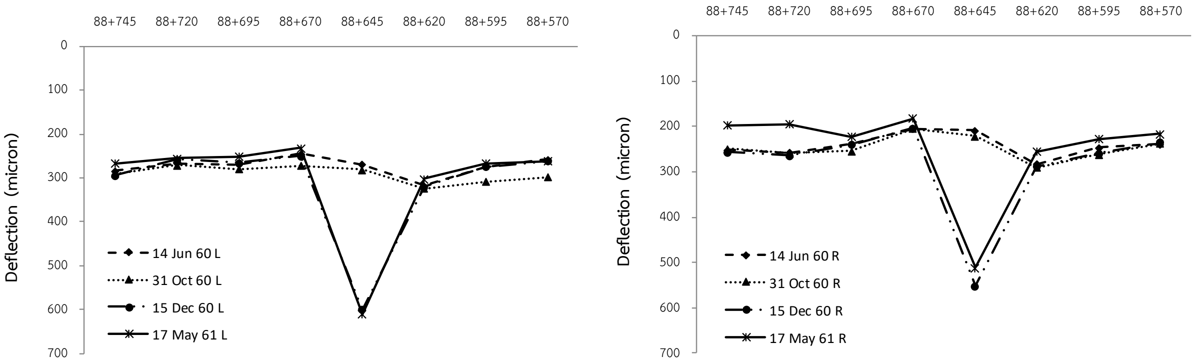


Figure 2 Surface deflections from the FWD, FEA, LEA, and elastic solutions.

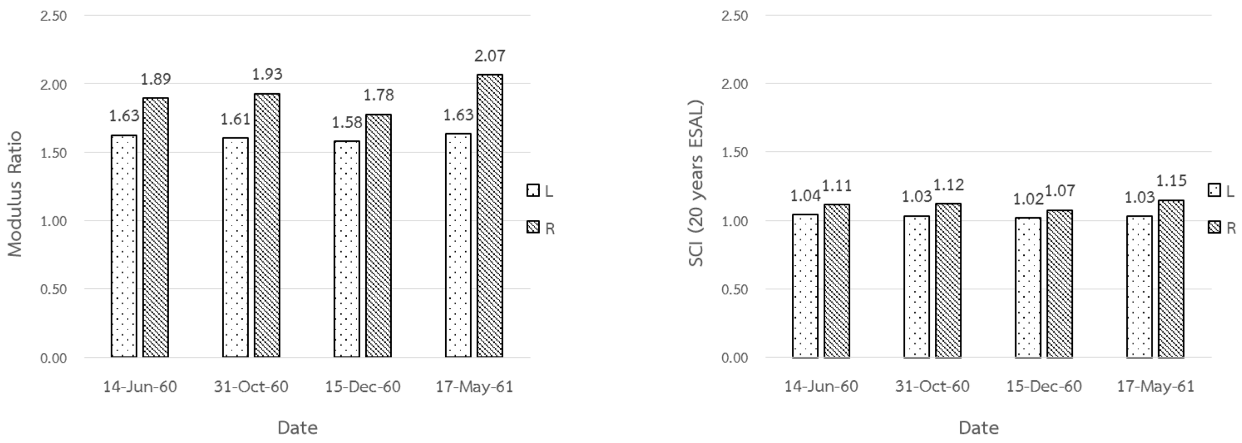


(a) Left track

(b) Right track

Figure 3 FWD deflection data at the center of load application from a road section of national highway No. 4 from km post 88+570 to 88+745, Potaram district, Rachaburi province.

The MR and SCI values equal to or greater than 1.0 suggest that the pavement is in a sound structural condition (e.g. strengthening is not required). However, when the MR and SCI is less than one, rehabilitation work that will strengthen and increase the structural capacity of the pavement should be considered. It should be also noted that variability in road structures can affect the FWD deflection readings for the same section. Consequently, such variability would yield great variability in the estimated E and SN and must be considered in order to minimize its impact when using the parameters MR and SCI. Nevertheless, Thailand DOH can easily implement a comprehensive procedure for the selection of maintenance and rehabilitation projects as part of Thailand PMS.



(a) MR parameter (b) SCI parameter

Figure 4 MR parameter calculated from Eq. (3) and SCI parameter calculated from Eq. (4) at different measurement periods.

Results presented in this paper were collected from a road section as part of preliminary study. The MR and SCI parameters based on the FWD deflection measurements were also carried out with a total of 21 road sections under the traffic loads, local materials, and weather conditions in Thailand. Currently, at least 2-3 periods of FWD measurements were made at the same test points in each section. Results suggested that both parameters were readily indicators of the road structural condition and future adoption at the network level. Even though the road deterioration model development is a time-consuming process involving a trial and error method of problem solving, the model is currently being developed by the BRRD to predict the future condition of a road section under the traffic loads, local materials, and weather conditions in Thailand. The road deterioration model will essentially be used in the future pavement performance prediction as part of Thailand PMS.

5. Conclusions

The concluding remarks can be made as follows:

- Road condition data, e.g. visual distress and ride quality, do not provide a direct measure of structural integrity and capacity of a road pavement. The BRRD, DOH, Thailand attempts to address this issue by introducing the road structural condition parameters based on the FWD measurements. The study focuses on the practical implication of the structural condition parameters suggested in the past publications for road rehabilitation and preservation at the network level.
- A comparison of the surface deflections determined from the numerical analysis e.g. FEA, LEA, and elastic solution with those from the FWD measurements suggested that the FEA and LEA results were close to the FWD deflection measurements, while the elastic solution tended to underestimate the surface deflections.

- A preliminary study of the MR and SCI parameters based on the FWD deflection measurements were also carried out with a total of 21 road sections under the traffic loads, local materials, and weather conditions in Thailand. At least 2-3 periods of FWD measurements were made at the same test points in each section. Results suggested that both parameters were readily indicators of the road structural condition and future adoption at the network level.
- The BRRD aimed to develop deterministic road deterioration model for Thailand pavement performance prediction and to ensure that the model developed could be implemented by road practitioners. The models are currently being developed in such a way that they are relevant and appropriate to local Thailand conditions e.g. construction, maintenance, materials, traffic, climate etc. The model will essentially be used in the future pavement performance prediction as part of Thailand PMS.
- On-going research is undertaken to investigate the reliability, range, and scope of the road deterioration model for future Thailand PMS. Road condition assessment and associated factors are needed to account for local road variability. Moreover, the road authorities and agencies should consider the road structural condition and its deterioration for road pavement performance modelling in order to make proper decisions about the type of preservation needed and cost-effective preventive maintenance.

6. Future Recommendations

The BRRD is in progress of developing the correlation between the structural condition parameters from FWD measurement data and field measurement data from embedded instrumentation as shown in Figure 5. The structural condition parameters from both FWD measurement data are MR and SCI values, while those from field measurement data are the rutting and fatigue ratios which were computed for each of the FWD test points. It should be also noted that the rutting and fatigue ratios are defined as the ratio of number of load repetitions (ESALs) to failure (i.e., from the Asphalt Institute (AI) rutting and fatigue models) and the estimated 20-year ESALs [10]. The MR and SCI values were compared to the rutting and fatigue ratios for the same point.

Figure 5 FWD measurement data and field measurement data from embedded instrumentation.

Over the years, Thailand DOH has been collecting and storing huge FWD data in Thailand PMS. It is anticipating that the advancement of Artificial Intelligence (AI) and deep learning in data processing will definitely improve the efficiency of Thailand PMS. The application of new innovative technology (e.g. drones for mapping) in road condition assessment can help manage road pavement assets. In addition, laser scanning and imaging processing technologies are gaining more interest to the road and transport industry. They are capable of non-contact measurement and non-destructive testing (NDT) of structural and functional monitoring of road surface. Such an emerging technology provides a cost-effective solution in terms of collecting and monitoring network-level road condition as well as asset management activities.

References

[1] AASHTO. *AASHTO guide for design of pavement structures*. AASHTO. Washington, DC, 1993.

[2] Faikratok, T. *Evaluation of structural number for flexible pavement by nondestructive testing*. Report No. RD189. Center for Road Research and Development. Department of Highways. Bangkok, Thailand, 2001.

[3] Fu-Trakul, B., Sanpakitjamnong, W., Srianthumrong, S., Anuvechsirikiat, S., and Silarom, P. *PCC pavement subsealing inspection by GPR and FWD*. Report No. RD211. Center for Road Research and Development. Department of Highways. Bangkok, Thailand, 2004.

[4] Huang, Y.H. *Pavement analysis and design*. 2nd Edition. Pearson Prentice Hall, NJ, 2004.

[5] Kim, M. *Three-dimensional finite element analysis of flexible pavement considering nonlinear pavement foundation behaviour*. Ph.D. Dissertation. University of Illinois at Urbana-Champaign, IL, 2007.

[6] Rohde, G.T. Determining pavement structural number from FWD testing, *Transportation Research Record 1448*. Washington, DC, 1994.

[7] Sawangsuriya, A. Investigation of structural capacity and performance of Department of Highways road pavement. *6th Thai Geotechnical Conference,* 2019. Bangkok, Thailand.

[8] Sawangsuriya, A., Taworn, D., and Yuayong, S. An empirical approach for evaluating highway performance using FWD and LWD. *23rd National Convention on Civil Engineering.* 2018, Nakhon Nayok, Thailand.

[9] Zhang, Z., Manuel, L., Damnjanovic, I., and Li, Z. *Development of a new methodology for characterizing pavement structural condition for network-level applications*. Report No. FHWA/TX/-04/0-4322-1. Centre for Transportation Research. Austin, TX., 2003.

[10] Zhang, Z., Murphy, M.R., and Peddibhotla, S. Implementation study of a structural condition index at the network level. *8th International Conference on Managing Pavement Assets (ICMPA8)*.2011, Santiago, Chile.