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Project Level Pavement Evaluation Using FWD, GPR, and Video Logging and Its Application in Pavement Rehabilitation in Indiana

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Abstract: Pavement rehabilitation is a major activity for all highway agencies. Accurate and efficient measurement of the rehabilitated pavement performances becomes more and more important in this procedure. In the last 10 years, significant improvements have been made in pavement nondestructive evaluation. NDT (non-destructive testing) has gained popularity because of its advantage in comparison to laboratory testing. Some of these advantages include minimal or no damage to structure, in-situ full-scale testing, relatively low operational cost, and short test duration. The INDOT (Indiana Department of Transportation) has a project level pavement evaluation program that began several years ago. This project level evaluation program employs FWD (falling weight deflectometer), GPR (ground penetration radar) and video logging. The program provides valuable information about pavement performance characteristics and offers useful tools for developing pavement rehabilitation strategies, specifically overlays and pavement underseals. On the other hand, the state of Indiana had rehabilitated its flexible, rigid or composite pavement almost exclusively with asphalt. This AC (asphalt concrete) overlay can improve the condition of existing pavement and extend the service life of the existing pavement structure. This paper thus describes the experiences of pavement overlay with AC thickness design for the INDOT (Indiana State Department of Transportation) using the AASHTO (American Association of State Highway and Transportation Officials) 1993 Guide, the MEPDG (Mechanistic-Empirical Pavement Design Guide). In order to do that, backcalculation program was compared and evaluated to obtain subgrade resilient modulus and *k* value for pavement rehabilitation using FWD data. Video logging provides IRI (international roughness index) and rut depth for existing pavement condition and GPR provides thickness or pavement bonding conditions in pavement. Emphasis is placed on observations and issues encountered using the current AASHTO 1993 Guide and the MEPDG.

Key words: FWD, GPR, video logging, backcalculation, 1993 AASHTO, MEPDG.

1. Introduction

The state of Indiana is a busy Midwest corridor that connects the east and west coasts with a 12,000-mile roadway system consisting of Interstates, U.S. Routes and State Routes in 92 counties. The INDOT (Indiana Department of Transportation) is responsible for maintaining and upgrading this roadway network. ASCE (American Society of Civil Engineers) indicates that 20% of all Indiana's roads are in poor or mediocre conditions, which is better than most of the surrounding States. To effectively maintain and upgrade this roadway network, pavement overlay and underseal are the two effective and efficient methods that improve pavement riding and structural quality. In the pavement project level structural evaluation testing, INDOT uses pavement deflection data as a mechanistic tool for pavement structural evaluation to determine the pavement layer moduli, estimate in-situ pavement structural number, estimate soil support, and estimate pavement structural remaining service life.

Asphalt pavement rehabilitation typically involves milling and resurfacing of the existing asphalt pavement to mitigate the effects of per ride rutting, cracking, and other distresses. Resurfacing thickness may depend on the condition of the existing pavement,

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anticipated future truck traffic, and available funding. Concrete or composite pavement, on the other hand, have quite different characteristics. Specifically, locations and amounts of concrete or composite pavement to be undersealed can be determined from the deflection data. Most of concrete pavement sections from 1960s and 1970s have been rehabilitated to composite pavement by cracked-and-seated, break-and-seated, and rubblization after those pavement sections gradually deteriorated due to development of different types of distresses from traffic and environmental factors. Different pavement thickness profiles can be found even within a one-mile section. Core sampling activity cannot predict pavement thickness variation without pavement construction reports. In the pavement structure itself, if the overlay is being placed for structural improvements, the required overlay thickness depends on both the structural capacity to meet future traffic demands and the structural capacity of existing pavement. HMA (hot mixed asphalt) overlay of conventional asphalt pavement, JPCP (jointed plain concrete pavement) and JRCP (jointed reinforced concrete pavement) is commonly constructed as thin as 50 mm (2 inches) to as thick as 250 mm (10 inches). Typical pavement overlay thicknesses for most highway projects are 70 to 150 mm (3 to 6 inches). To evaluate the pavement response using FWD (falling weight deflectometer) requires fairly accurate pavement thickness from section to section. Decreasing the spacing of core sampling becomes impractical, while incorrect thickness input in pavement evaluation gives inaccurate results.

Another concern for aging composite pavement is voids beneath the JPCP and JRCP. These voids create weak spots in the pavement structure that will increase tensile stress and therefore the possibility of fatigue cracking. Accurately locating the voids underneath the pavement will extend the life of the pavement and provide preventive maintenance to the pavement structure that will prolong the pavement life even longer. With a proper set of threshold values for deflection, the voids can be determined accurately and underseal can be executed effectively.

The process of pavement rehabilitation includes inspection of existing pavements to assess the current surface and structural conditions and involves the following procedures: (1) Prioritization of pavements in need of rehabilitation, which incorporates monitoring activities to assess the functional and structural condition of pavements; (2) Development of feasible rehabilitation strategies; (3) Selection of the most cost-effective rehabilitation strategy given a set of constraints, which may include reduced service life, life-cycle costs, and budgetary constraints; and (4) Adequate measurement of performance of the rehabilitated pavements. Therefore, a successful pavement rehabilitation program requires effective pavement evaluation and analysis prior to planning the rehabilitation activity [1]. Once a project level evaluation has been conducted, the most cost effective and reliable rehabilitation plan can be executed based on a combination of existing pavement condition data, future traffic projections, soil subgrade properties and pavement material properties to ensure a proper rehabilitated pavement design. INDOT has long history using 1993 AASHTO guide for rehabilitation design. The recently introduced MEPDG (mechanistic-empirical pavement design guide) and related software provide alternative for the analysis and performance prediction of overlay thickness for different types of existing pavements. The design thickness comparisons between 1993 AASHTO [2] and MEPDG [3] were conducted for verification purposes.

2. Objectives

The objectives of this research study are as follows:

(1) To investigate the literature for the state of the art in overlay design and nondestructive testing of pavement.

(2) To investigate the feasibility in combining the traditional destructive testing with the nondestructive

testing in the project level testing and provide recommendations for the future testing.

(3) To evaluate the pavement structural parameters, identify the void locations underneath pavement and estimate remaining life based on the data from coring, video logging, GPR (ground penetration radar), and FWD.

(4) To investigate the relationship between backcalculated resilient modulus from FWD and laboratory sample tests, and provide necessary information to the new MEPDG in the state of Indiana.

(5) To present INDOT's experience in overlay thickness design using 1993 AASHTO and MEPDG.

3. FWD Testing Program

The overall objective of the pavement rehabilitation design is to provide a cost-effective solution that addresses deficiencies of pavement under the evaluation and meet departmental imposed constraints such as available funding and constructability. This goal can be achieved only through pavement evaluation to determine the cause and extent of the deterioration. This requires systematic data collection and an analysis of the structural and functional condition of the pavement as well as several other factors. In the state of Indiana, six districts take responsibility to complete routine maintenance of pavement, both functional and structural. In the project level testing, most FWD testing requests focus on overlay design and underseal estimation. FWD testing is also requested for the purpose of selecting economic strategies between reconstruction and overlay. The engineers from the six districts fill out on-line FWD testing requests for the purpose of overlay and underseal.

4. Data Collection

4.1 Visual Condition Survey with Video Logs

Prior to any field data collection, pavement evaluation engineers can conduct a visual inspection of pavement conditions by reviewing the video logs. Currently INDOT uses the PathView video logging program developed by the Pathway Service Inc. PathView provides digital images of roadways and pavement surfaces along with road condition data such as IRI (international roughness index), rutting and PCR (pavement condition rating). Video logs can help engineers to locate areas with pavement distresses, identify distress type, and estimate the severity and extent of the distresses. The information not only allows engineers to set up appropriate field testing plans, but also provides valuable insights information during data analysis.

4.2 Thickness Data Collection from Coring

Analysis of FWD data requires knowledge of pavement structure profile. For some pavement sections, the exact structure is not known; therefore, pavement coring is required. Information from coring samples includes:

(1) Layer materials—hot mixed asphalt, Portland cement concrete, granular and cement treated base, etc.

(2) Layer thickness—Thickness of each pavement structural layer

(3) Layer condition—Stripping HMA layer, deteriorated PCC layer, cracked-and-seated (or break-and-seat) PCC layer, and rubblized pavement layer, etc.

Coring also allows engineers to determine if and where stripping susceptible asphalt layers lie in the pavement section. However, due to its destructive nature, only a limited number of pavement coring should be performed. In our studies, one core per mile was extracted in both directions from the selected roadways. Incomplete pavement structural layer information from the INDOT Districts is resolved with layer thickness estimation using GPR.

4.3 Thickness Data Collection Using GPR

GPR provides a non-destructive method for estimating pavement layer thickness. One of the advantages of GPR lies in its capability in continuously measuring variation of thickness throughout the pavement sections. According to the past experiences of INDOT in the network level testing [1], GPR can provide accurate thickness measurement up to 13 inches for full depth asphalt pavement. However, in composite pavements, the method has difficulties in measuring rubblized JRCP pavement underneath the HMA overlay. This generally agrees with the findings from Willett et al. [4], in which the conclusion was made that the use of GPR for determining asphalt pavement layer thickness appears to be promising while caution is needed for concrete pavement. The combination of the coring and the GPR testing has been used in the pavement evaluation in order to achieve the most accurate results.

4.4 Deflection Data Collection Using FWD

To determine the existing structural capacity of pavement, an in-situ structural condition evaluation must be performed. Knowledge of the pavement structural condition provides valuable information in selecting feasible and efficient pavement rehabilitation and reconstruction alternatives. The pavement structural evaluation can be performed using non-destructive deflection testing and analysis such as FWD.

FWD was used to test driving lanes in both directions of the selected pavement sections in this study. Deflection tests were performed every 100 m along the driving lanes. Based on INDOT previous studies and past experiences, 16 testing locations per mile are the minimum testing frequency to statistically represent a mile in the project level analysis. There are two different project level testing protocols applied in the FWD testing of PCCP and composite pavement, namely underseal and overlay testing protocols. The major difference between the two protocols is the location of the drop load. The underseal protocol calls for loading on the edge of the pavement slab while the overlay protocol calls for loading in the middle of the slab. Three drop load levels were used in both testing protocols. The loads are 7,000 lbs, 9,000 lbs, and 11,000 lbs.

5. FWD Data Processing Procedures

Once pavement condition, materials, layer thickness, and deflection data are collected, the project level data analysis can be performed. The type of data processing depends on:

(1) Pavement type: flexible, rigid, or composite, and

(2) Testing locations: center, joint, or corner location.

FWD testing data are used in conjunction with the pavement distress survey and layer thickness information to determine pavement layer moduli, and other pavement parameters of rigid, flexible, and composite pavements.

For flexible pavements, Effective Structural Number (SN_{eff}), layer moduli and resilient modulus of the subgrade were calculated. For rigid pavements, elastic modulus of the concrete slab, moduli of subbase and subgrade, LTE (load transfer efficiency) at cracks and joints, and presence of voids underneath the concrete slabs were determined. For composite pavements, elastic modulus of the concrete slab, composite resilient modulus of the subgrade, LTE at cracks and joints, and presence of voids underneath the slabs were also determined. In addition, CBR for subgrade and remaining life of pavement in terms of ESALs (equivalent single axle load), were calculated for any pavement type.

5.1 Void Detection and Underseal Estimation Testing and Reporting Procedures

Undersealing provides an economical means of preventive maintenance to prolong the life of the concrete slab. Underseal material, hot asphalt or cement slurry, was pumped from the surface of concrete through pre-drilled holes and flowed under the slab and filled the cavities forming a support underneath the slab. Thus, both pavement deflection and localized stress are reduced. The voids often occurred at the joint and/or the comer of the concrete slabs.

In the underseal testing protocol, the FWD plate was placed on the leave slab about 6 inches from a joint or crack at about every 100 m interval with one sensor behind the loading plate, as shown in Fig. 1. Three load levels were applied in each testing location at 7,000, 9,000, and 11,000 pounds. The FWD center deflection in 9,000 pound and a temperature of 68 °F were used to decide if underseal is necessary for PCC and composite pavement. LTE across a transverse joint or crack can also be determined using this FWD testing protocol. LTE information can be very beneficial in the analysis of a pavement section that is still in fair to good condition that does not need excessive maintenance.

Temperature correction factor used by INDOT is in accordance to the 1993 AASHTO Pavement Design Guide. This temperature correction factor varies greatly with temperature and HMA surface thickness. The correction factor could change from 1.36 to 0.4 within the range of between 30 °F and 120 °F. The uncorrected deflection could affect structure number, thus affect the overlay thickness eventually. In the underseal detection, uncorrected deflection values can be misleading, whether to underseal or not to underseal. Correction factors are based on mean pavement temperature calculated using air and surface data collected during the FWD testing. The software UNDERSEAL developed by INDOT was used in all analysis. Table 1 presents underseal requirement criteria for Interstate (8 mils), US Highways (10 mils) and State Routes (12 mils). For each deflection value exceeding these requirement criteria, underseal is required. Table 2 shows FWD testing protocol sensor arrangement for underseal and overlay testing. The deflections from the first sensor (center plate) and sensor #8 at 48 inches under 9,000 lb are plotted. Sensor #1 is used to determine the underseal criteria while sensor #8 is used to determine the bearing capacity of the subgrade soil in terms of CBR that 2.35 mils is generally correlated to CBR of 3%. The testing location is identified by DMI in meters. If the percentage length of the required underseal is larger than 50%, other pavement rehabilitation strategy such as reconstruction could be considered.

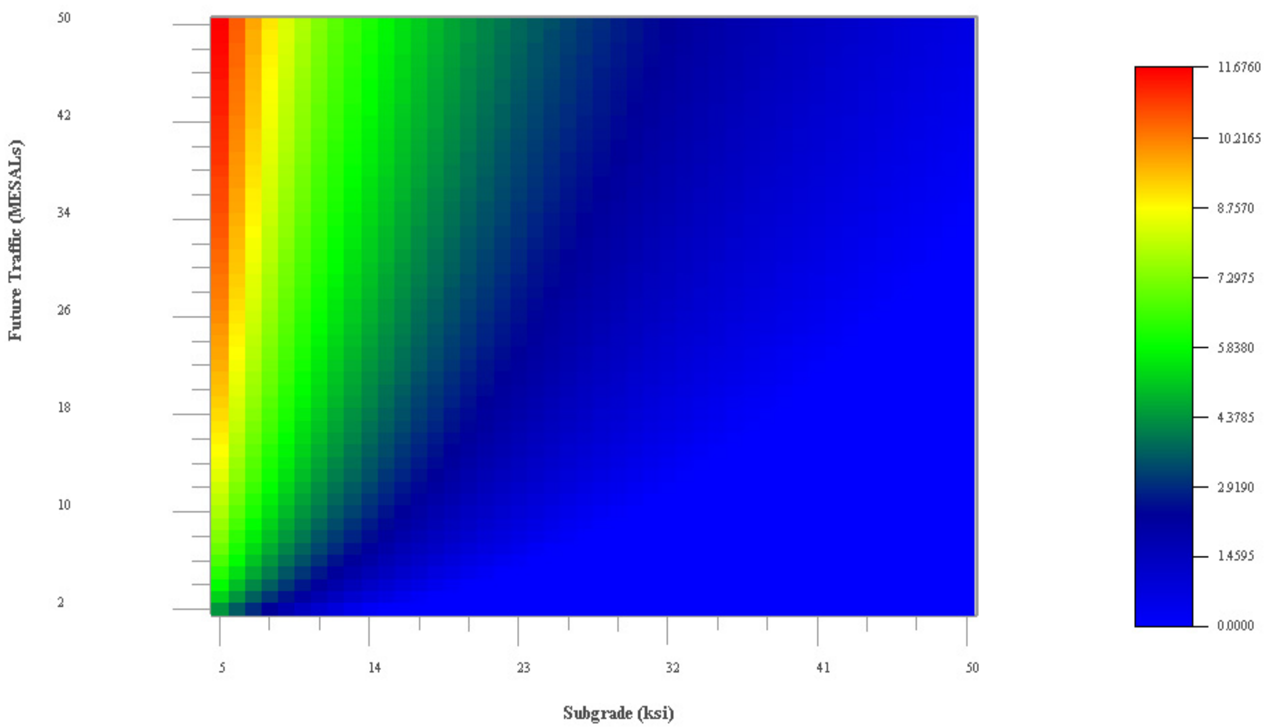

Fig. 1 AC (asphalt concrete) overlay thickness on existing HMA pavement (SN_{eff} = 3).

Table 1 Underseal criteria based on center deflection for a 9,000 pound load at 68 °F.

Condition	Interstates HIghway		State routes		US routes		
ESALs (million)	> 30	10-30	3-10	< 3	10-30	3-10	< 3
Traffic	Heavy traffic	Heavy traffic	Medium traffic	Light traffic	Heavy traffic	Medium traffic	Light traffic
Deflection (mils)	8	8	10	12	8	10	12

Table 2 FWD sensors arrangement for underseal and overlay.

Sensor number	#1	#2	#3	#4	#5	#6	#7	#8	#9
Distance from plate (inches)	0	-12	8	12	18	24	36	48	60

5.2 Overlay Design Testing and Reporting Procedures

Overlay design includes functional overlays and structural overlays. In the state of Indiana, an overlay with thickness greater than 4 inches is considered a structural overlay. The overlay thickness is calculated to increase the pavement structural capacity to carry future traffic. It is, therefore, important to conduct the overly design testing to make the in-service pavement capable to carry the future design traffic to meet the additional design life.

In the overlay testing, the FWD loading plate was placed on the middle of the slab close to the wheel path about every 100 m interval without any sensor behind the loading plate. The temperature corrected FWD center deflection values are used to estimate the remaining ESALs and the back calculated moduli. Once deflection data were collected, backcalculation was performed to determine the layer modulus using the ELMOD 5.0 software developed by Dynatest. The program iterates to achieve a “convergence” solution between the measured deflection basin and a calculated deflection basin based on the backcalculated layer moduli. The backcalculated moduli are used to evaluate individual pavement layer structural condition. The backcalculated layer moduli help the pavement engineers to identify the pavement layers structural deficiencies. The deficiencies in a pavement can be in the HMA surface layer, PCC layer, untreated subbase, or in the subgrade. This pavement structural information provides critical information to the pavement rehabilitation strategy.

The layer moduli vary from station to station. The variation can come from temperature, soil properties, and construction layer thicknesses. Layer moduli provide engineers quick review of the structure capacity of the pavement sections under evaluation. In this case, the modulus of the HMA layer is low compared to the normal value, which is in the range of 300 ksi to 500 ksi. Therefore, the HMA materials have deteriorated to the point that a “mill-and-fill” rehabilitation or structural overlay option is required. Underneath the HMA layer, the modulus of the PCC slab is about 1,000 ksi. This might indicate that the PCC slab underneath is badly deteriorated by D-Cracking or that the past rehabilitation option had been cracked-and-seated.

If the overall modulus of this PCC slab is lower than 500 ksi, rubblization or crack might have already been conducted in the past rehabilitation activity. The underseal treatment is not recommended for this road section. When the backcalculated subgrade modulus from ELMOD 5.0 cannot be used directly as a design modulus, the adjustment factor has to be made. The 1993 AASHTO procedure was developed to estimate the subgrade modulus from the FWD test data. FORTRAN program is employed to calculate the overlay thickness iterative using AASHTO formulation.

6. Pavement Overlay Using 1993 AASHTO

The overlay of pavement is used to correct surface deficiencies and improve structural capacity. The 1993 AASHTO Guide for Design of Pavement Structures outlines procedures for determining the overlay thickness for all types of pavements. For asphalt pavement, AASHTO considers a two-layer pavement structure: one constructed material layer and subgrade layer. The effective structural number (SN_{eff}) for flexible pavements, based on non-destructive deflection measurements, is often obtained using a FWD. The NDT (non-destructive testing) method for determining SN_{eff} follows the assumption that the structural capacity of the pavement is a function of its total thickness and overall stiffness. The relationship between SN_{eff}, thickness, and stiffness is as follows:

$$SN_{eff} = 0.0045 D \sqrt[3]{E_p} \qquad (5)$$

where:

SN_{eff} = effective structural number

D = total thickness of all pavement layers above the subgrade (inches)

E_p = effective modulus of pavement layers above the subgrade (psi).

The SN_f value is determined by using several pieces of information. These items include: the effective design subgrade resilient modulus, design PSI (present serviceability index) loss, overlay design reliability (R), and the overall standard deviation (S_o) for flexible pavement. The overlay thickness (D_{ol}) is determined by taking the difference between the SN_f and SN_{eff} values and dividing this quantity by the layer coefficient for new asphalt pavement ($D_{ol} = (SN_f - SN_{eff})/a_{ol}$).

On the other hand, there are another two main types of existing pavement for Indiana highway. One is bare concrete (PCC) and another one is composite pavement (AC/PCC). AC is used as overlay material for both cases since it is less expensive than concrete overlay. Concrete pavement and composite use provide modulus of subgrade reaction (k value), which is backcalculated from FWD data using recommendations by 1993 AASHTO.

6.1 Input: Overlay Asphalt Pavements

The total change in serviceability indexes (ΔPSI) from the construction to the end of the pavement design life is set to 2 with p_o = 4.5 and p_t = 2.5. The overall standard deviation (S_o) is taken as 0.35. HMA layer coefficient a_1 = 0.34 (INDOT specification).

6.2 Input: Overlay Rigid Pavements

The total change in serviceability indexes (ΔPSI) from the construction to the end of the pavement design life is set to 2 with p_o = 4.5 and p_t = 2.5. The overall standard deviation (S_o) is taken as 0.35. The modulus of rupture S_c' is 650 psi. The drainage coefficient (Cd) is taken as 1.0. The load transfer coefficient (J) is set to 3.2. The subgrade reaction k is set from 50 psi/in to 500 psi/in. The modulus of slab E_c is 4.0×10^6 psi. Concrete is assumed to be 9 and 11 inches. The reliability factors used are 98% (interstate routes), 95% (urban arterials), and 90% (other routes) for Indiana pavements.

6.3 Input: Overlay Composite Pavements

The AC surface needs to be milled prior to overlay to remove ruts. The thickness of AC to be milled is set to 1.5 inches. The traffic levels, which are expressed by ESAL (equivalent single axle load), are considered from 3 million to 50 million. For composite pavement, there are already 4 and 6 inches thick AC over both 9-inch and 11-inch PCC. The reliability factors used are 98% (interstate routes), 95% (urban arterials), and 90% (other routes) for Indiana pavements.

7. Results and Discussions

Fig. 1 shows HMA overlay thickness on existing pavement with subgrade resilient modulus ranging from 5 ksi to 50 ksi with the assumption of existing structure number SN_{eff} = 3. It is found that the foundation of a pavement, the subgrade, plays a critical role in asphalt pavement design and structural performance. Thus, knowledge of the properties of subgrade material is very important when structurally evaluating the asphalt pavement. With the assumption of subgrade 5 ksi or under, asphalt overlay can be 12 inches if traffic reaches 50 million ESALs, on the other hand, the subgrade stiffness of 20 ksi only requires as low as 4 inches overlay. Thus, the chemical treatment of subgrade will be cost-efficient when building asphalt pavement. Secondly, traffic estimations are second important factors in success of pavement design. Estimated future traffic from 2 MESALs to 50 MESALs can substantially increase the thickness. The weaker the subgrade is, the more influence on overlay thickness. As expect, mechanistic model of asphalt pavement depends on multi-layer system jointly support loading.

Figs. 2 and 3 illustrate the overlay thicknesses with different combination of existing pavement thicknesses for bare concrete pavement, and composite pavement, respectively. Three reliability levels are considered in pavement design. One surface in the figures denotes one reliability level. It is obvious that the overlay thicknesses increase with increasing reliability factor. It can be seen that the overlay thicknesses increase significantly with increasing ESALs. The future ESAL is a key factor for computing overlay thickness comparing to subgrade reaction. When *k*-value decreases, the overlay thicknesses increase slightly. Take 9-inch bare concrete pavement for example, when the *k*-value increases 10 times, from 50 psi to 500 psi, the maximum overlay thickness decreases from 9.9 to 8.3 inches, which means only 17% drop. It concluded that subgrade stiffness is not as important as expected in concrete pavement. The method to try to improve stiffness to reduce the design overlay may not be cost efficient.

The summary of overlay thickness for both existing bare concrete pavement and composite pavement is listed in Tables 3 and 4, on which typical Indiana existing pavement is used with a relative weak subgrade reaction stiffness (k = 50 pci). For existing 9-inch and 11-inch bare concrete pavement, the maximum thicknesses of overlay can be as high as 9.9 and 7.0 inches with 98% reliability level, respectively. It shows that thickness of existing PCC pavement would also affect the overlay thickness significantly. Same trends are also observed in the composite concrete pavement in Table 4. The overlay thicknesses for composite pavement are smaller than those for bare concrete pavement with same PCC thickness. That is due to the existing overlay of AC on the top of PCC. For composite pavement with 4- and 6-inch AC over the 9-inch PCC, the maximum overlay thicknesses are 7.6 and 6.1 inches, respectively. When PCC layer is 11 inches thick, the maximum thicknesses of overlay are 4.5 and 2.8 inches with 4- and 6-inch AC on the top, respectively. It can be seen that for composite pavement herein, functional overlays are sufficient when future design ESALs are lower than 30 million.

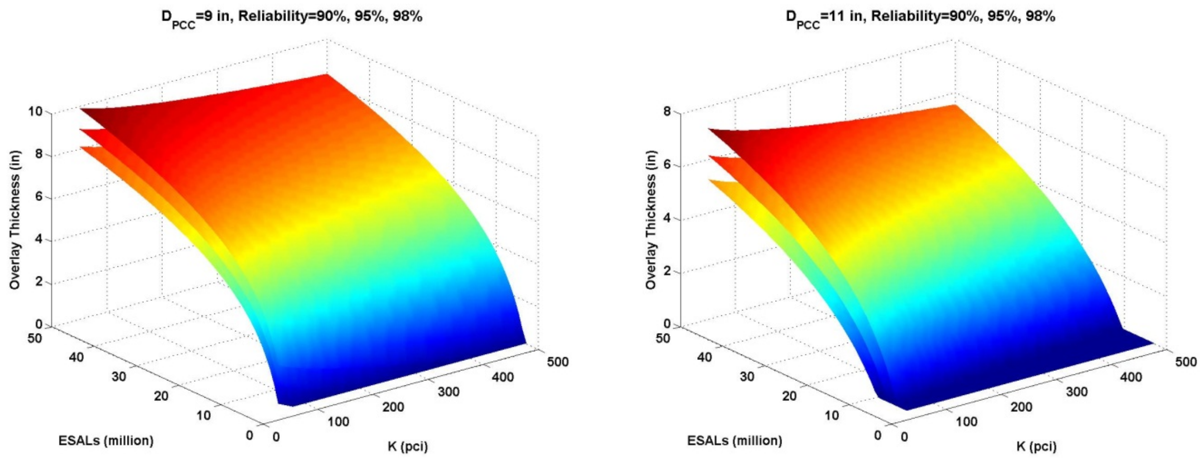

Fig. 2 AC overlay of existing PCCP.

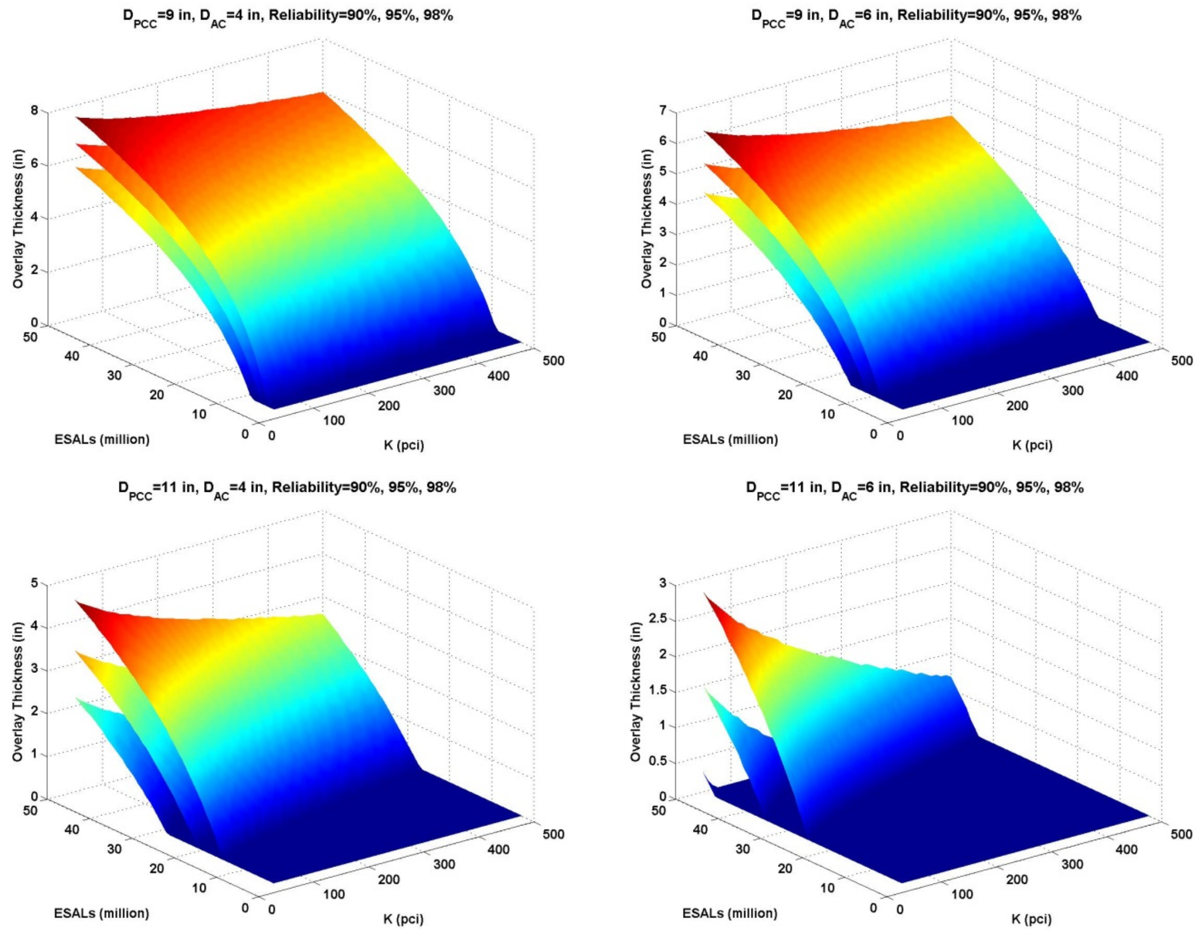

Fig. 3 AC overlay of AC/PCCP.

Table 3 Overlay thickness (in.) for bare concrete pavement (*k*-value is 50 psi).

Existing PCC thickness (in.)	Reliability factor	ESALs (million)			
		3	10	30	50
9	90%	0.3	3.8	6.7	8.1
	95%	1.2	4.6	7.5	8.9
	98%	2.1	5.5	8.4	9.9
11	90%	0.0	0.1	3.6	5.2
	95%	0.0	1.1	4.6	6.1
	98%	0.0	2.1	5.6	7.2

Table 4 Overlay thickness (in.) for composite concrete pavement (*k*-value is 50 psi).

Slab thickness (in.)	Reliability factor	ESALs (million)			
		3	10	30	50
$D_{PCC} = 9$ $D_{AC} = 4$	90%	0.0	0.6	4.1	5.7
	95%	0.0	1.6	5.0	6.6
	98%	0.0	2.6	6.0	7.6
$D_{PCC} = 9$ $D_{AC} = 6$	90%	0.0	0.0	2.4	4.1
	95%	0.0	0.0	3.4	5.1
	98%	0.0	0.7	4.5	6.1

Table 4 to be continued

D_{PCC} = 11 D_{AC} = 4	90%	0.0	0.0	0.3	2.2
	95%	0.0	0.0	1.4	3.2
	98%	0.0	0.0	2.6	4.5
D_{PCC} = 11 D_{AC} = 6	90%	0.0	0.0	0.0	0.3
	95%	0.0	0.0	0.0	1.5
	98%	0.0	0.0	0.7	2.8

8. Overlay Design Using MEPDG

The mechanistic-empirical approach uses both mathematical models and experimental results to estimate the future pavement distress under a defined pavement condition of climate, traffic patterns, materials and structure. The M-E Design Guide is accompanied with software that enables the design of both new and rehabilitated sections of flexible and rigid pavements. The work described herein is an example using the 1993 AASHTO and M-E Design Guide. Three levels are provided for the design inputs in our implementation plan recommended by NCHRRP:

Level 3 represents the lowest level of the hierarchy system and provides the lowest level of accuracy. The inputs consist of default or user-selected values obtained from national and regional experiences such as LTTP sites. This level will typically be used for non-critical projects, such as low-volume roads. Level 2 represents a higher level in the hierarchy system and provides more accuracy than Level 3. Design inputs are based on limited laboratory test data and/or default predictive equations. This level is expected to be used on pavement design projects of higher significance. Many design projects fall under this classification in INDOT. Level 1 represents the highest level in the hierarchy system and provides the highest level of accuracy. Design inputs are generally site specific and are determined from material testing and/or in-situ measurement. It is expected that this level will be used for projects of high economic impact, such as very high volume roads and/or major interstates, for forensic investigations, or for research purposes.

The MEPDG requires three categories of input data: traffic, climate and pavement structure. This analysis used the typical axle load spectra created by prior INDOT studies of WIM station data [5]. It includes traffic volume adjustment factors, vehicle class 15 distribution and axle load distribution factors. The Annual Average Daily Truck 16 Traffic (AADTT), traffic growth rates were obtained from INDOT traffic data. To match the format of the design catalog and compare MEPDG design with the AASHTO results, these detailed traffic data were converted to ESALs over the entire design life by using a fixed ESAL number for each truck type from AASHTO (1993 AASHTO). The default climate data of weather stations located in Indiana State have proved acceptable for use with the MEPDG. The detailed material properties and structural information were obtained from INDOT original design files, material tests [6].

The traffic in MEPDG was used as input traffic values for the AASHTO 1993 Guide in an effort to check design thicknesses for reasonableness. There are three sections that will be considered in the following analysis: US-421, SR-25, and US-231. These pavements have been designed in accordance with MEPDG and 1993 AASHTO under Chapter 52 of the Indian Design Manual for specific project condition with 9-year design life.

The section of US-421 existing pavement is a composite pavement of 7 in. HMA over 7 in. PCC. The existing pavement has medium severity reflective transverse crack, wheel path cracks, and age related cracks. The US-421 recommended treatment will be: (1) F ollow FWD testing recommendations and underseal sections recommended by Table 1; (2) Remove the existing asphalt pavement up to top of the concrete at high distress locations and patch with HMA; (3) Mill the existing pavement 1.0 in. Overlay 1.5 in.

Table 5 Comparisons overlay thickness using MEPDG and 1993 AASHTO.

Design method		AASHTO 1993			MEPDG		
Pavement section	Overlay type	ESALs	Reliability (%)	Overlay thickness (in.)	AADTT	Reliability (%)	Overlay thickness (in.)
SR-25 RP 39 to RP 50	HMA over Composite pavement	6.0	95	1.5	1500 (1% GF)	95	1.5
SR-421 RP 106 to RP111	HMA over Composite pavement	2.0	95	1.5	500 (1% GF)	95	1.5
US-231 RP 150 to RP158	HMA over asphalt pavement	1.8	95	1.0	400 (1% GF)	95	1.5

GF: annual growth factor.

HMA with 9.5 mm aggregate. The section of SR-25 existing pavement is a composite pavement of 8 in. HMA over 7 in. PCC. Pavement rutting is 0.06 in. and IRI is 88 in./mile in 2010. The existing pavement is still in fair condition with minor distresses including longitudinal and transverse cracks. There are also several small pavement structures that need to be repaired or replaced. The purpose of this project is to extend the service life of pavement. The proposed treatment is: (1) Follow FWD testing recommendations and underseal sections recommended by Table 1; (2) Pavement with structural deficiencies required overlay with full-depth patch; (3) Restoration transverse and reflect cracks and other distresses; (4) Mill the existing pavement 1.0 in. and overlay 1.5 in. HMA with 9.5 mm aggregate.

The section of US-231 existing asphalt pavement has 5 in. HMA on 7 in. crush stone base. The existing pavement has transverse cracking of moderate extent and severity. The center line longitudinal joint has moderate cracking. There is also extensive wheel path cracking of moderate severity due to a pavement longitudinal joint when the roadway was widened. Rutting is 0.20 in. and IRI is 101 in./mile in 2012. FWD testing was performed and backcalculted subgrade modulus are used as inputs for overlay design. The treatment will be restoration transverse cracks and other distresses, full depth patch in high severity fatigue areas. Mill the existing pavement 1.0 in. overlay 1.5 in. HMA with 9.5 mm aggregate.

Table 5 only lists overlay design thickness in which functional overlay is required in all these sections. It shows that MEPDG provided comparable thickness to the 1993 AASHTO in these three sections. It may be due to the facts that existing pavements have already good structure capacity in general and with such low volume traffic.

9. Conclusions

Nondestructive testing has become an integral part for pavement structural evaluation and selection of pavement rehabilitation strategies at project level pavement evaluation in Indiana. Experience in pavement evaluation using with FWD, GPR, and video logging at project level can improve significantly the efficiency and accuracy of the testing results. Therefore, a systematic approach in determining a pavement rehabilitation strategy can be supported by implementing this project level evaluation. In addition, As INDOT moves the empirical design procedures towards the implementation of the M-E Design Guide, the need has risen for a more accurate and efficient evaluation of the incorporated design procedures and consideration of practical steps necessary for its proper implementation. The following recommendations are made as following:

(1) GPR estimates thickness of concrete pavements, HMA layer of flexible pavement, and HMA layer of composite pavements accurately. But thickness underneath these layers is not as accurate as it should

be, therefore, limited amount of core sampling is still needed. Destructive testing can be used to supplement the NDT to provide the necessary project level information needed for pavement evaluation to achieve more accurate results.

(2) Accurate back-calculation of pavement layer properties depends on the accuracy of the layer thickness. Incorrect assumptions regarding the thickness of each pavement layer can result in inefficient pavement rehabilitation strategy. Unnecessary cost and shortened pavement life can be the result of incorrect conclusions regarding pavement layer thickness.

(3) Temperature correction in FWD deflection testing is very important in the asphalt surface pavement and should be taken into consideration in the pavement deflection analysis. Temperature correction in FWD testing affects the locations of underseal requirement and overlay design substantially.

(4) Overlay thickness depends on all factors such as the pavement type, traffic, and environment, material, construction. Unlike concrete and composite pavement, asphalt pavement structural responses (stresses, strains, and deflections) are highly dependent on the subgrade support compared to JPCP and composite pavement.

(5) MEPDG provided comparable thickness to the 1993 AASHTO, however, it provides more valuable information to predict pavement performances so that designer can be well prepared for future treatment. On the other hand, 1993 AASHO can provide simple inputs for engineering practices because of simple inputs.

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