Design of Concrete Pavement for the Ohio Turnpike's Mainline Pavement Replacement: An Innovative Approach

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Abstract

This paper describes the design of a concrete pavement for a section of the Ohio Turnpike's mainline pavement. This design is a part of the Ohio Turnpike and Infrastructure Commission's ongoing project to replace its existing two lanes of 241.26 miles long mainline pavement in both directions (east and west). The original pavement was built as concrete pavement which was subsequently overlaid with asphalt. Resource International, Inc. used current methods of pavement design, including Mechanistic-Empirical Pavement Design Guide (MEPDG), to design a concrete pavement and a composite pavement for this project. The concrete pavement for this section of the Turnpike was designed as a wide width (14') pavement for the outside lane. This made it possible to build an outside shoulder with Recycled Cement Concrete Aggregates from old pavement and still achieve the benefits of a tied shoulder (decreased slab thickness). The construction of this pavement section (as a composite pavement) was completed in 2011 (WB) and 2012 (EB). Performance data has been collected since its construction. This paper describes the design of the pavement and observations of its performance made so far. The details of testing methods used, analysis performed, and the results are also described in the paper.

Introduction

The Ohio Turnpike and Infrastructure Commission (OTIC), formerly the Ohio Turnpike Commission, initiated a project in 2008 to evaluate, prioritize, design, and ultimately replace the original 241.2 mile-long mainline pavement consisting of two lanes of the eastbound and two lanes of the westbound directions. This pavement was originally built as concrete pavement and was subsequently overlaid with asphalt.

Based on the findings of the master plan, Resource International, Inc. (Rii) was assigned to design a concrete pavement section for the first priority section of a 5-mile length of the Turnpike located between Mile Posts (MP) 95.90 and 101.20. In this connection, Rii designed and proposed three different types of the pavements (flexible, rigid and composite). Based on these recommendations, OTIC decided to build a composite pavement for this section of the Turnpike.

As a part of final recommendations, Rii proposed to build a wide pavement (14' width) for the outside lane. This allowed OTIC to construct the outside shoulder without tying it to the mainline pavement and still achieve the benefits of a tied shoulder. Additionally, it allowed the agency to utilize the old concrete

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aggregates from the existing pavement in a Roller Compacted Concrete (RCC) shoulder.

The construction of this pavement (from MP 95.90 to MP 101.20) in the WB direction was completed in 2011 and the EB direction was completed in 2012. OTIC recommended the use of global chemical stabilization of subgrade soil.

During construction, pavement evaluation was performed using the latest state-of-the-art equipment, such as: Automated Dynamic Cone Penetrometer (ADCP), Light Weight Deflectometer (LWD) and Ground Penetrating Radar (GPR). This equipment was used to assess the quality of construction, including quality of global soil stabilization, Elastic Modulus of each pavement layer, subgrade soil strength and thicknesses of pavement layers. After the completion of construction, as a post construction investigation, additional testing was performed using Falling Weight Deflectometer (FWD) in December of 2011, May 2013, December 2013, and December 2014.

Pavement Design

The Ohio Turnpike was constructed in the 1950s, with such a high quality and workmanship that over half a century of service it has carried millions of vehicles that far exceeded the original design expectations. Recognizing this fact, the OTIC expected that the design of new pavement should provide similar lasting quality; therefore, Rii aimed at a "Zero Maintenance Pavement" for this mainline pavement reconstruction project.

The "Zero Maintenance Pavement" terminology was originally defined by FHWA in 1978 as long lasting pavements that during their service life only exhibit surface distresses with no structural distress. This FHWA report was intended to include all types of pavements, rigid, flexible and composite.

The paper describes the design of a zero maintenance concrete pavement and the observations of its performance after its construction. The OTIC built this section of the Turnpike with a composite pavement.

The design of the pavement section for this mainline pavement was based on the current Ohio DOT and/or AASHTO Design Manuals. The important input parameters for this design were based on the data collected from the Ohio Turnpike's existing pavements. Some of these important parameters are summarized in Table 1.

The design thicknesses of slabs for untied and tied shoulders were **15" and 14" respectively**. This design (tied/widened shoulder) was used to construct a composite pavement with the following layer thicknesses:

1. Asphalt Layer consisting of surface and intermediate layers - 3.25"
2. Reinforced Concrete Slab thickness - 13.0"
3. Aggregate Base - 6.0"
4. Stabilized Subgrade (Lime in WB and Cement in EB) - 16.0"

Table 1. List of Material Properties and Other Parameters Used in the Design of Pavement Section of the Ohio Turnpike (MP 95.90 – 101.20, EB and WB)

Item #	Description	Rigid Pavement
1.	Reliability	95%
2.	Overall Standard Deviation	0.39
3.	Modulus of Rupture of Conc., psi	700 psi
4.	Modulus of Elasticity of Concrete	5×10^6 psi
5.	Load Transfer Factor, J, Concrete Pavement	
	Untied Shoulder	3.2
	Tied or Wide Shoulder	2.7
6.	Drainage Coefficient	1.0
7.	Initial Serviceability	4.2
8.	Terminal Serviceability	2.5
9.	CBR of Natural Subgrade	4
10.	Resilient Modulus of Natural Subgrade, M_R	6,000 psi
11.	Effective Modulus of Subgrade Reaction, k, of 6" Agg. base and Natural Subgrade	108 pci
12.	Elastic Modulus of Aggregate Baser	20,000 psi
13.	Loss of Support, Aggregate Base	1.0
14.	Total 20-year Design Lane Traffic, ESAL	88,473,600

Figure 1 shows the schematic layout of the existing pavement and proposed pavement for this section of the Turnpike.

Design Verification Using MEPDG Analysis

Rii performed the design verification of this pavement. For this purpose, the current version of software, MEPDG, was used. This program uses the parameters of the pavement design that are generally used in current methods of the pavement design (AASHTO/ODOT design methods). The results of the data analysis produces the results in the form of pavement responses which represent the future performance of the pavement for a specified design period (20 years in this case). For the rigid pavements, the performance parameters are as follows:

1. Terminal IRI (in./mile)
2. Transverse Cracking (% slabs cracked)
3. Mean Joint Faulting (in.)

The proposed design was analyzed by the software twice; first by using the original design inputs (AASHTO/ODOT) that were used in the design of the pavement section with no consideration for global chemical stabilization, and second by using the material inputs and parameters that were obtained from the tests performed on the pavement during and after construction. The inputs used in the first analysis are listed in Table 2.

Figure 1. Schematic Layout of the Existing Pavement and Proposed Pavement for the Turnpike Pavement Section between MP 95.90 and MP 101.20

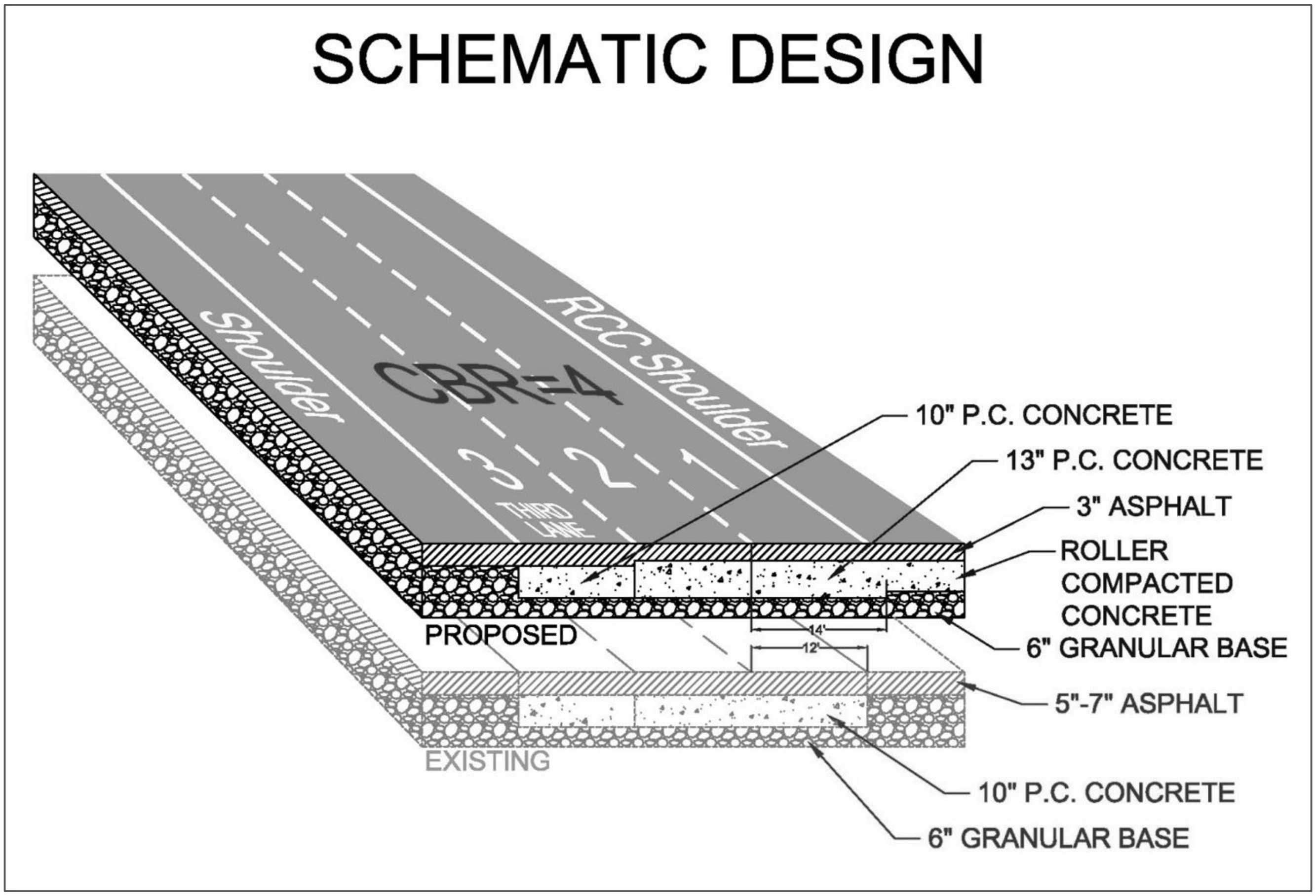

Table 2. List of Material Properties and Other Input Parameters Used in the Design of Typical Pavement Sections of the Ohio Turnpike Using MEPDG Method (MP 95.9 – 101.20, EB and WB)

Design Life: Design Type: Existing Construction: Pavement Construction: Traffic Opening: Climate Data Sources (Lat./Lon):	20 years Jointed Plain Concrete Pavement (JPCP) June 2011 September 2011 41.563, -83.476 (Toledo, Ohio)

Design Structure		
Layer Type	**Material Type**	**Thickness (in.)**
PCC	JPCP	14.0
Non Stabilized	Crushed Stone (1)	6.0
Stabilized Subgrade	A-2-4	16.0
Subgrade	A-7-6 (2)	Semi-infinite
Joint Design:		
Joint Spacing (ft.)	15.0	
Dowel Diameter (in.)	1.50, 1.75	
Slab width (ft.)	14.0 (widened)	

Traffic	
Age (years)	**Heavy Trucks (cumulative)**
2011 (initial)	15,460
2021 (10 years)	29,236,100
2031 (20 years)	63,836,700
Traffic Growth	2% per year (linear)
M_R of subgrade and aggregate Base layers, psi	
Natural Subgrade	6,000
Aggregate Base on Nat. Subg.	20,000

It should be noted here that MEPDG analysis uses the traffic data in a different format than required for the AASHTO/ODOT analysis. AASHTO/ODOT uses the design traffic in terms of total **ESAL** (18,000 lb. **E**quivalent **S**ingle **A**xle **L**oads) for the specified design period (20 years in this case). MEPDG uses the **A**nnual **A**verage **D**aily **T**ruck **T**raffic (**AADTT**) count and the distribution of this traffic among the various truck classification types, as defined by FHWA vehicle classification. Therefore, for this purpose, the Turnpike's traffic data was converted into the FHWA vehicle classification using the traffic counts of the year 2008 and extrapolating the data for the future growth.

The results of the MEPDG analysis are summarized in Table 3. Based on this analysis, it was observed that the pavement, as it was designed by the AASHTO/ODOT method, will not meet the requirements of Mean Joint Faulting if 1.5" Dowel Bars were used. However, if Dowel bars of 1.75" were used, then the design will meet the requirements of all performance parameters.

Table 3. Summary of MEPDG Analysis of Pavement Design Based on Properties of Natural Subgrade

Performance Parameter	Target Value	Predicted Value	Criteria Satisfied?
Dowel Diameter = 1.5”			
Terminal IRI (in./mile)	172.00	151.92	**Fail**
Mean Joint Faulting (in.)	0.12	0.06	**Pass**
JCP Transverse Cracking (% Slabs)	15.00	4.49	**Pass**
Dowel Diameter = 1.75”			
Terminal IRI (in./mile)	172.00	175.48	**Pass**
Mean Joint Faulting (in.)	0.12	0.10	**Pass**
JCP Transverse Cracking (% Slabs)	15.00	4.49	**Pass**

Observations of Pavement Performance after Construction of Pavement Sections (MP 95.90 to MP 101.20)

An FWD was used to collect deflection data for the purpose of evaluating the **future performance** of EB and WB sections.

The first FWD tests on WB pavement were performed soon after its construction in December 2011, and subsequent tests were performed in May 2013, December 2013, and December 2014.

The first FWD tests on EB pavement were performed after its construction in May 2013, and subsequent tests were performed in December 2013 and December 2014.

FWD data collected for these sections and the results of data analysis are summarized below.

Natural Subgrade Layer: Following is a summary of data collected on natural subgrade as of December 2014.

Section ID	Date Tested	Natural Subgrade Layer	
		Avg. CBR	Avg. M_R, psi.
WB	Dec. 2011	13.0	15,500
	May 2013	10.5	12,600
	Dec. 2013	10.0	11,600
	Dec. 2014	7.8	9,400
EB	May 2013	10.0	12,000
	Dec. 2013	8.6	10,300
	Dec. 2014	7.6	9,100

The above data indicates that in-situ M_R is more than the design M_R of 6,000 psi of this pavement. However, a gradual and small drop in the in-situ value of M_R is **noted** from this data, which could be attributed to significant differences in the weather conditions between December 2011 and 2013 and saturation and moisture levels in the pavement layers.

It should also be noted that the FWD tests could not be performed exactly at the same spot each time; therefore, some of the observed variations may be due to the inherent variability in material and pavement layer thicknesses.

Stabilized Subgrade Layer: Following is a summary of data collected on stabilized subgrade as of December 2014:

Section ID	Date Tested	Avg. M_R, psi.
WB	Dec. 2011	27,000
	May 2013	29,300
	Dec. 2013	19,700
	Dec. 2014	29,900
EB	May 2013	37,200
	Dec. 2013	32,200
	Dec. 2014	33,500

While the above data for the WB section indicates that in-situ M_R of the stabilized subgrade layer measured in December 2011 and May 2013 are relatively the same and within the range of laboratory predicted values, there is a measureable drop in M_R from May 2013 to December 2013. This could be either a result of gradual change in M_R with time or due to the harsh winter of 2013.

It should be noted here that the WB section of the Turnpike was stabilized with lime and the EB section was stabilized with cement. This may explain slightly higher values of M_R for the EB section. Also, stabilized subgrade of the EB section did not show any effects of harsh winter of 2013, as was observed for WB section.

Aggregate Base Layer: This layer was designed for M_R of 20,000 psi. Following is a summary of data collected on aggregate base as of December 2014:

Section ID	Date Tested	Avg. M_R, psi.
WB	Dec. 2011	61,200
	May 2013	50,300
	Dec. 2013	29,100
	Dec. 2014	42,700
EB	May 2013	70,000
	Dec. 2013	51,100
	Dec. 2014	51,400

The above data indicates that the M_R of this layer is about 2 to 2.5 times greater than the design value of 20,000 psi, and is consistent with the Moduli values measured in the field during construction for "design verification" purposes using a LWD. The lower measured Moduli in December 2013 could be again associated with the harsh environment and similar to the trend observed for natural subgrade as well as stabilized subgrade.

Cement Concrete Layer: The pavement concrete layer of PCC was designed for elastic modulus, E of $5x10^6$ psi. The back-calculated E values of this layer (from FWD data) are summarized below:

Section ID	Date Tested	Avg. E, psi.
WB	Dec. 2011	5,515,600
	May 2013	5,352,400
	Dec. 2013	4,405,200
	Dec. 2014	7,031,300
EB	May 2013	7,293,200
	Dec. 2013	6,190,600
	Dec. 2014	7,338,000

The above data indicates that the elastic modulus, E, of the concrete pavement layer has remained almost the same between the measurements of December 2011 and May 2013, but has unrealistically decreased between May 2013 and December 2013 for the WB section. This trend is similar to the trend observed for other layers of this pavement, and raises the suspicion that the changes might not be related to "pavement performance".

Further, the elastic modulus, E, for the EB section was slightly higher than the WB section in two measurements performed in May and December 2013. However, the back-calculated E values in December 2014 were similar for both sides (WB and EB). This indicates that the quality of concrete for this pavement is better than it was originally designed.

Asphalt Concrete (AC) Layer: AC layer elastic modulus, E, was back-calculated from FWD data. The results are summarized below:

Date Tested	Temperature, ^{O}F		Avg. E, psi.
	Air	Surface	
Dec. 2011	35.6	55.4	1,422,300
May 2013	71.9	81.1	1,245,800
Dec. 2013	36.0	43.8	2,231,800
Dec. 2014	22.5	47.8	1,178,800
May 2013	82.2	98.9	675,600
Dec. 2013	31.9	43.2	1,065,200
Dec. 2014	34.2	49.4	639,800

This pavement layer is temperature sensitive; therefore it requires temperature corrections to convert the back-calculated E to a standard temperature in order to compare the trend. However, the estimated values listed above indicate that the elastic modulus of this layer is reasonably satisfactory.

In summary, the FWD data collected for this section of the mainline pavement indicates that the Elastic Moduli of all pavement layers, as observed from the last tests, shows a great consistency between December 2011 and December 2014 and the field design verification tests performed during construction in the summer of 2011. The measured moduli of natural subgrade, stabilized subgrade, aggregate base and concrete layers, however, have decreased from May 2013 to December 2013.

Research studies on newly constructed pavements have indicated that immediately after new construction, there is a pore pressure built-up under the pavement due to the moisture vapor travelling from bottom to top layers of the pavement; therefore, this may have contributed to the changes observed from these tests. Future tests on this pavement section will provide additional data to confirm or contradict these statements.

In summary, the FWD data collected for this section of the mainline pavement indicates that the strength of pavement component layers, as observed from the last post-construction tests, shows that natural subgrade, stabilized subgrade and aggregate base layer have moduli 2 to 2.5 times greater than the "design values". The measured moduli values of PCC and Asphalt Concrete (AC) layers also represent high quality construction and some variation due to seasonal effects.

To estimate the effect of global stabilization of subgrade on the future performance of pavement, the results of post-construction testing were used to perform MEPDG analysis of the pavement again. Two scenarios were used for this purpose:

1. Use design parameters obtained from back-calculated values for natural subgrade, stabilized subgrade and aggregate base with Dowel Bar dia. = 1.5" and design life of 20 years.
2. Use the inputs above and check the performance of pavement for 30 years design life.

The following back-calculated values for pavement layers were used in this analysis:

1. Natural Subgrade M_R = 9,000 psi
2. Stabilized Subgrade M_R = 30,000 psi
3. Aggregate Base on Stabilized Subgrade M_R = 40,000 psi

The results of this analysis are summarized in Table 4. Based on this analysis, it was observed that the pavement, as was designed by AASHTO/ODOT method, may not meet the requirements of Mean Joint Faulting if 1.5" Dowel Bars were used, but if the effect of subgrade stabilization is included, the design not only will meet the requirements of a 20-year life, but will exceed it, as indicated by the results of analysis for a design life of 30 years (see Table 4). Figure 2 shows the summary page of the 30-year analysis by MEPDG.

Table 4. Summary of MEPDG Analysis of Pavement Design Based on Properties of Stabilized Subgrade

Performance Parameter	Target Value	Predicted Value	Criteria Satisfied?
Design Life = 20 years			
Terminal IRI (in./mile)	172.00	134.96	**Pass**
Mean Joint Faulting (in.)	0.12	0.08	**Pass**
JCP Transverse Cracking (% Slabs)	15.00	4.77	**Pass**
Design Life = 30 years			
Terminal IRI (in./mile)	172.00	153.56	**Pass**
Mean Joint Faulting (in.)	0.12	0.10	**Pass**
JCP Transverse Cracking (% Slabs)	15.00	5.11	**Pass**

Significance of this Research

A review of the performance prediction generated by the MEPDG analysis indicates that a 30-year design is fully achievable, recognizing that within 15 to 20 years corrective maintenance actions are required.

In addition, the following was observed from the results of data: Localized stabilization of weak subgrade areas has provided a good solution to a better performing pavement in the past, yet it was observed by many highway agencies that this practice caused an unnecessary increase in cost of the construction due to changes in the estimated quantities (of subgrade stabilization) during construction of the project when unidentified areas of weak subgrade were discovered during construction. Therefore, global stabilization of subgrade not only eliminates the uncertainty of under estimated quantities, but improves the quality of the subgrade to the extent that added benefits can be reaped in the form of better compaction of pavement layers built on the stabilized subgrade platform resulting in overall increase in the design life of the pavement.

Conclusions

This paper presents the results of findings which supports the following conclusions:

- Global chemical soil stabilization improves the quality of subgrade and the results of analysis show that pavement designers could consider a “conservative” increase of the design subgrade CBR as a result of global soil stabilization.
- The presence of the stabilized subgrade layer is expected to improve the quality of unbound granular base course in terms of its density and compaction. The results of FWD data analysis also shows an increase in the elastic modulus of the granular base layer by factors of 2 to 3 times for this project.

Figure 2. Summary of 30-Year Analysis Performed by MEPDG

Sandusky MP 95-101 Stab15 30YR

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Design Inputs

Design Life:	30 years	Existing construction:	-	Climate Data Sources (Lat/Lon)	41.563, -83.476
Design Type:	Jointed Plain Concrete Pavement (JPCP)	Pavement construction:	June, 2011		
		Traffic opening:	September, 2011		

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	14.0
NonStabilized	Crushed stone	6.0
Subgrade	A-2-4	16.0
Subgrade	A-7-6	Semi-infinite

Joint Design:	
Joint spacing (ft)	15.0
Dowel diameter (in.)	1.50
Slab width (ft)	14.0 (w)

Traffic

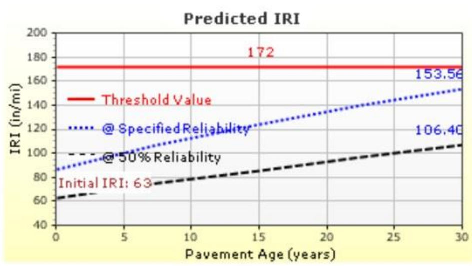
Age (year)	Heavy Trucks (cumulative)
2011 (initial)	15,460
2026 (15 years)	45,865,800
2041 (30 years)	103,802,000

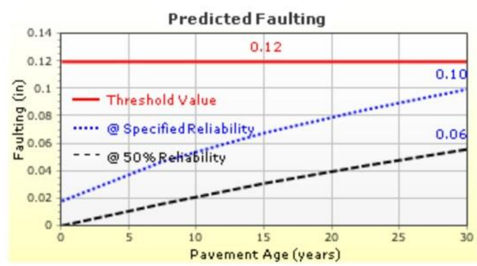
Design Outputs

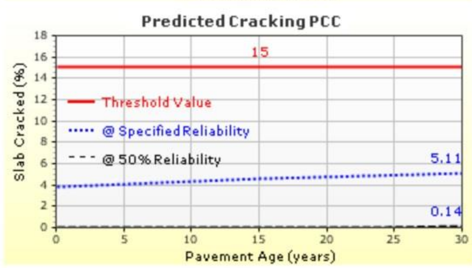
Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	153.56	90.00	96.27	Pass
Mean joint faulting (in.)	0.12	0.10	90.00	96.92	Pass
JPCP transverse cracking (percent slabs)	15.00	5.11	90.00	99.99	Pass

Distress Charts







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