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IMPACT OF CONCRETE MATERIAL INPUTS ON PERFORMANCE OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

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Continuously reinforced concrete pavement (CRCP) is increasingly being used in the United States based on its longer service life with minimal maintenance. CRCP provides excellent performance for heavily loaded traffic volume, if designed and constructed properly. The performance of CRCP is evaluated based on punch-outs and pavement roughness according to the Pavement ME (mechanistic-empirical) Design procedure which is the state-of-the-art pavement design tool. Design of CRCP is dependent on various factors including traffic, climate, material inputs and pavement geometry. This study focuses on evaluating the effects of concrete mechanical and thermal properties and traffic volume on CRCP performance. CRCP design simulations were conducted using Pavement ME Design software version 2.3 to evaluate the effects of material input data on CRCP performance and it was observed that there is significant difference between the performance predictions with time series data in comparison to the default data. The impact of material inputs is more significant on punch-outs distress as compared to the pavement roughness. This necessitates the importance of lab tested material inputs for accurate design of CRCP. The impact of traffic volume on CRCP performance was also evaluated and it was found that with increase in traffic volume, the pavement distresses increases and the performance decreases.

Keywords: Punch outs, Pavement roughness, Mechanistic, Elastic modulus, Coefficient of thermal expansion, Modulus of rupture.

1 INTRODUCTION

Continuously reinforced concrete pavement (CRCP) has the potential to provide a long-term solution of highway needs with zero-maintenance. This type of pavement can be used in heavily trafficked areas and in challenging environmental conditions. As for any other pavement, accurate design and quality construction practices are necessary to ensure desired performance. CRCP has no constructed transverse, contraction or expansion, joints except at bridges or at pavement ends (Plei and Tayabji 2012). Longitudinal steel reinforcement is used to keep the transverse cracks closely spaced and reduce the amount of opening at the cracks. CRCP usually has longitudinal reinforcing steel percentages in the range of 0.65 percent to 0.85 percent. The transverse steel bars are used to support the longitudinal reinforcement and keep them in place. The bond area between the concrete and the bars is also critical and Federal Highway Administration (FHWA) recommends at a minimum of 0.030 square inch per cubic inch of concrete (FHWA 1990). A well-performing CRCP can be identified by a reasonably regular transverse cracking pattern with desirable crack spacing of two feet to eight feet that in turn keeps the cracks tight and provides a high level of load transfer across the cracks. With the advancement in pavement design and performance analysis procedures and the advent of Pavement Mechanistic-Empirical (ME) Design software, the importance of concrete material inputs came to the fore front. Prior research has proved that concrete mechanical and thermal properties including compressive strength, elastic modulus, modulus of rupture (MOR) and coefficient of thermal expansion (CTE) has a direct impact on design and performance of rigid pavements (Sabih and Tarefder 2016). The design methodology of Pavement ME Design is coded into a software program that calculates all the necessary mechanistic responses of the trial design structure required for performance predictions, computes damage and other associated parameters and finally predicts performance in terms of pavement distresses over the design life (Rao 2004). This design procedure takes in to account various design factors including concrete material inputs, traffic, climate and etcetera. In terms of material properties, the design procedure uses 3 input levels with level-1 or time series data being the most accurate one.

Although, there has been numerous studies on effects of material inputs on pavement performance of jointed plain concrete pavements but very few studies are available for CRCP. This study focuses on the significance of concrete material inputs and traffic volume on the design and performance of CRCP and for this purpose simulations are conducted in Pavement ME Design version 2.3 and the results are analyzed to compare the effects of material properties on CRCP design.

2 NOTATIONS

The notations/abbreviations used in this study are presented in Table 1.

Table 1. Notations and abbreviations.

Symbol/Abbreviation	Description
CRCP	Continuously reinforced concrete pavement is a type of rigid pavements
Pavement ME	Latest pavement design tool being used in United States based on mechanistic-empirical principles
CTE	Concrete material property related to thermal expansion
MOR	Concrete strength property related to flexure
Elastic modulus	Concrete mechanical property related to stiffness
CA-ID	Concrete mixture designation based on coarse aggregate type
IRI	International roughness index measured in in/mile
ESAL	Equivalent single axle load based on traffic
AADTT	Average annual daily truck traffic
psi	Pounds per square inch (load per area)

3 METHODOLOGY

Six concrete paving mixes (designated as CA-ID-1 to CA-ID-6) were used for this study and time series data was generated for compressive strength, elastic modulus and modulus of rupture (MOR) by laboratory testing. Coefficient of thermal expansion (CTE) testing was also conducted for all the mixes at the age of 28 days according to AASHTO T-336 (2011) test protocol. The sensitivity analysis of various material and traffic inputs on the performance of CRCP was performed by conducting the simulations in Pavement ME design software version 2.3. The major design inputs are shown in Table 2. The performance parameters including punch-outs and IRI were analyzed with respect to the variability of different inputs.

Table 2. CRCP design parameters for simulation work.

Parameter	Value
Design Life	30 years
Design Thickness	10 in.
Shoulders	Tied PCC Shoulders
Steel Reinforcement (%)	0.72
Steel Bar Diameter	3/4 in. (#6 bar)
Steel Depth	3.5 in.
Initial IRI	63 in/mile
Threshold IRI	172 in/mile
Threshold Punch-outs	10 per mile
Reliability	90%
Modulus of Rupture of Concrete	As per CA-ID
Elastic Modulus of Concrete (28 days)	As per CA-ID
Poisson's Ratio	0.2
Climate Station	Albuquerque, New Mexico
AADTT	4000
Traffic ESALS	$30x10^6$
Base Course Thickness	6 in.
Base Course Resilient Modulus	40,000 psi

4 IMPACT OF INPUT LEVELS ON CRCP PERFORMANCE

Pavement ME design has 3 levels of inputs which the designer can use, based on the available data and accuracy required. Level-1 has the highest level of accuracy with all the tested data for the specific project including CTE, MOR, and elastic modulus. While level-3 has the lowest level of accuracy in the design by using the default values of CTE and using compressive strength parameter at 28 days (AASHTO 2015).

The simulations were conducted in pavement ME design for all the paving mixes (CA-ID-1 to CA-ID-6) to contrast the impact of level 1 and level-3 inputs on CRCP performance. The lab tested data for concrete mechanical properties including MOR and elastic modulus and CTE were used for level-1 design simulations while, for level-3 design, default CTE value and compressive strength at the age of 28 days were used. CRCP thickness was 10 in and other design parameters were kept constant (as per Table 1) to compare the effects of input levels.

4.1 Effects on Pavement Roughness

The comparison for terminal values of transverse cracking for CA-ID-1 to CA-ID-6 is presented in Figure 1, which shows that there is significant variation in IRI values between the results of level 1 and level 3 inputs for all the mixes. The variation in IRI with input levels ranges from 1 to 66.7 in/mile which is highly significant. With these results, it is evident that the CRCP must be designed with the accurately tested level-1 inputs for the paving mix to be used so that the designed pavement can last for the entire service life. The ME default CTE data and level-3 inputs will not produce accurate design for these paving mixes.

4.2 Effects on Punch Outs

The comparative summary for CRCP punch outs for impact of material input levels is presented in Figure 2. It is evident that there is a significant impact on punch outs between the two material input levels. The difference in terminal punch out values ranges between 15.1 to 32.8 per mile.

This shows the importance of using accurate concrete material inputs to be used for CRCP design.

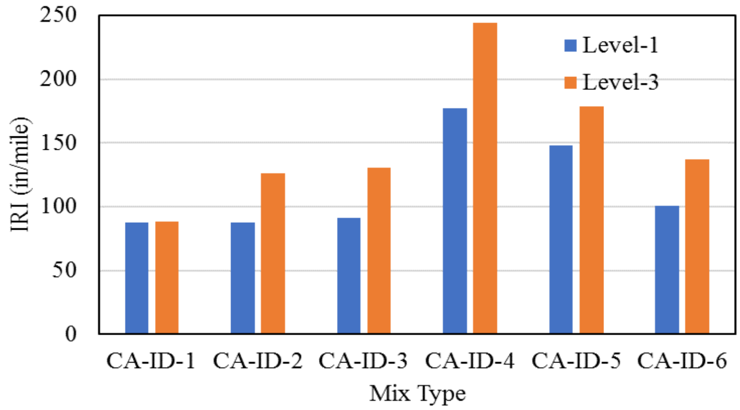

Figure 1. Impact of Input Levels on IRI.

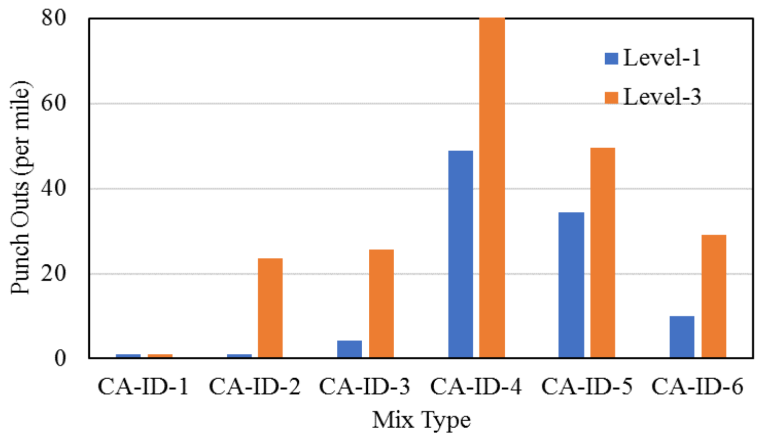

Figure 2. Impact of Input Levels on CRCP Punch Outs.

4.3 Percent Change in CRCP Performance with Level-1 & Level-3 Inputs

The simulation results were analyzed to compare the percentage change in performance parameters including IRI and punch outs with level-1 and level-3 inputs. The results are presented in Figure 3. The results show that the %age change in IRI ranges from 1 to 43.8% while the percentage change in punch outs ranges from 1 to 95.8%. It indicates that the impact of material input levels is more significant on the CRCP punch outs then the pavement roughness. The CRCP designed with level-3 material inputs may be under-designed or over-designed and to obtain accurate CRCP design, level-1 material inputs should be used.

5 EFFECTS OF TRAFFIC VOLUME ON CRCP PERFORMANCE

The effects of traffic volume on CRCP performance were evaluated by conducting simulations with level-1 inputs for all paving mixes with varying traffic volumes ranging from AADTT of 2000 to 9000 (14.9 to 67.2 million ESALs). The slab thickness was kept constant at 10 in. and other design factors were kept constant as shown in Table 1. The analysis of results shows similar trend for all paving mixes and the results for CA-ID-3 are presented in succeeding paras.

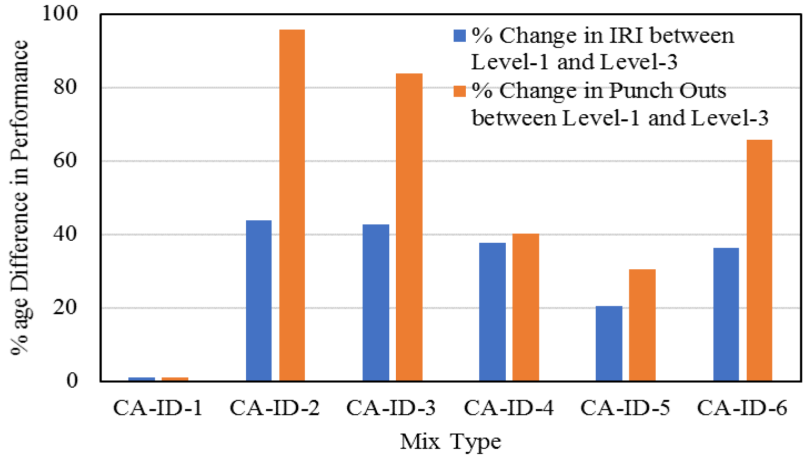

Figure 3. Percent Change in CRCP Performance between Level-1 and Level-3 Inputs.

5.1 Comparison of Effects of Traffic Volume for CA-ID-3

The comparison of the effects of traffic volume on punch outs and IRI are shown in Figures 4 and 5 for CA-ID-3. The results show that the traffic volume has a significant impact on both the performance parameters. As the traffic volume increases, the performance of CRCP decreases with increase in IRI and punch outs. With these results, it is evident that CRCP design be performed with the specific traffic volume for any specific project.

Percentage increase in CRCP distresses was determined for every 1000 increase in AADTT to evaluate the impact of traffic volume on pavement performance. The results show that the traffic volume has a more significant impact on punch outs with a % increase of 8.9 to 88.6% with increased traffic volume whereas the increase in IRI is in the range of 2.2 to 9.6%.

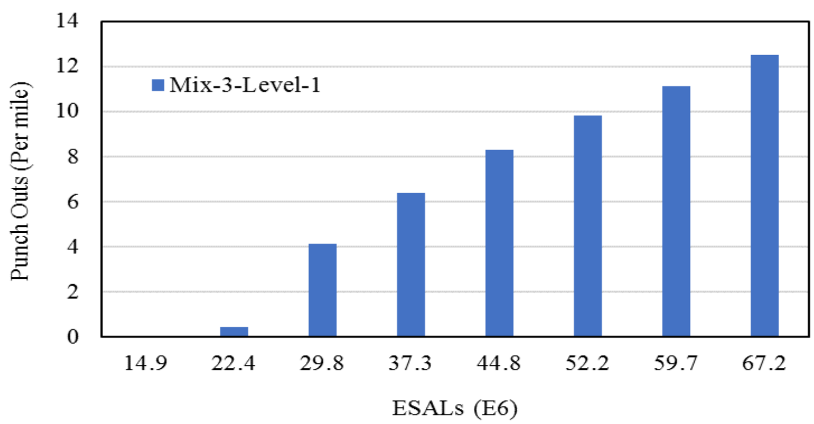

Figure 4. Impact of Traffic Volume on Punch Outs for CA-ID-3.

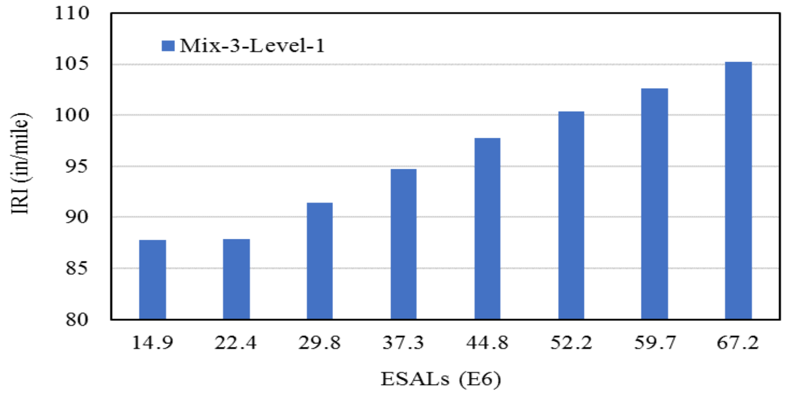

Figure 5. Impact of Traffic Volume on IRI for CA-ID-3.

6 CONCLUSIONS

The analysis of the simulation results of this study dictates that there is significant difference between the predicted performance of CRCP designed with time series data of concrete material inputs and the default material inputs. Both performance parameters including punch-outs and pavement roughness are affected but punch-outs is the most significant with a percent change of up to 95.8% between the two input levels. This necessitates the importance of using time series data of concrete material inputs in design of CRCP. Similarly, the effects of traffic volume on the performance of designed CRCP shows that there is significant impact of traffic volume on pavement performance, thus CRCP should be designed with accurately anticipated traffic volume. Finally, it can be concluded that using time series data for concrete material properties and actual traffic volume will result in accurate CRCP design which can last for the designed service life.

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