Towards Developing a Mechanistic Design Procedure for Pervious Concrete Pavements

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Introduction

Background

Pervious concrete (PC) is a special class of concrete with about 15 to 30 percent volume of interconnected voids to allow runoff to infiltrate into underlayers. A successful PC pavement provides the support to withstand the applied traffic load and provide rapid infiltration of stormwater to the underlying drainage system. The growing use of PC nationwide raised the need for the development of a structural design procedure that can serve the designers, practitioners, transportation agencies and other users of this type of pavements. In this project, we took the preparatory steps towards developing a mechanistic design procedure to select the required layer thicknesses for PC pavements for various material properties and traffic loads. American Concrete Institute (ACI)'s Committee 522 is in the process of updating the current version of the ACI 522 document. The findings of this project will be an integral addition to the updated document on the layer thickness design side.

Project Overview

In order to develop a mechanistic design methodology for PC pavements, the structural behavior of PC needs to be investigated. In this project, the in-situ structural evaluation of PC pavements is combined with an extensive experimental mechanical material characterization as well as flexural fatigue testing. The end result is to set forth a layer thickness database for PC pavements with different structural features to serve different levels of traffic loads. To incorporate a wide selection of commonly used PC mixtures, the study parameters include two different aggregate types and two cement contents. To incorporate the effect of field installation in terms of compaction level, the specimens from each mixture are cast in three levels of target porosity. Additionally, sufficient specimens are cast to allow for fatigue testing at three ratios of the applied cyclic stress to the flexural strength (SR.) This report presents the current status of the project tasks and the remaining research work and their expected completion dates.

Laboratory Test Program

Mixture Designs

After collection of mixture designs from several PC producers across Washington State and batching several trial mixtures in the laboratory, the mixture designs for this study were selected as shown in Table 1. The trial mixtures of PC proved that the crushed basalt aggregates (maximum size 3/8") does not produce 20% hardened porosity due to the aggregate angularity. Thus, Pea gravel aggregates (also with maximum size of 3/8") were used, which successfully produced PC specimens with 20% and below porosities. The water-to-cement ratio (w/c) was fixed to 0.34 for all mixtures, which is a common w/c used for PC. Two cement content levels were used in the two types of mixture designs, 480 and 520 lb, to achieve a full spectrum of strength levels. For each SR, and cement content specimens were cast at three target porosity levels: 20, 25 and 30 percent. For each mixture design and porosity level, three 4×4×14 inch PC beams and four 6×12 inch (diameter by height) cylinders were casted for flexural and compression strength test, respectively. The number of cast specimens for each mixture design was 63 beams and 12 cylinders. The total number of specimens used in this project was 150. Fig.1 illustrate the testing program and specimen categories.

Table 1: Mixture designs used in the study.

Mixture Design 1 Cement content level: 480 lb		Mixture Design 2 Cement content level: 520 lb	
Mixture design for 25 and 30% porosity level using crushed Basalt			
Aggregates lb/yd^3	2,700	Aggregates lb/yd^3	2,700
Cement lb/yd^3	480	Cement lb/yd^3	520
Water lb/yd^3	163	Water lb/yd^3	177
VMAR oz/yd^3	39	VMAR oz/yd^3	39
Recover oz/yd^3	38	Recover oz/yd^3	38
Mixture design for 20% and below porosity level using Pea gravel			
Aggregates lb/yd^3	2,765	Aggregates lb/yd^3	2,765
Cement lb/yd^3	480	Cement lb/yd^3	520
Water lb/yd^3	163	Water lb/yd^3	177
Delvo oz/yd^3	52	Delvo oz/yd^3	52

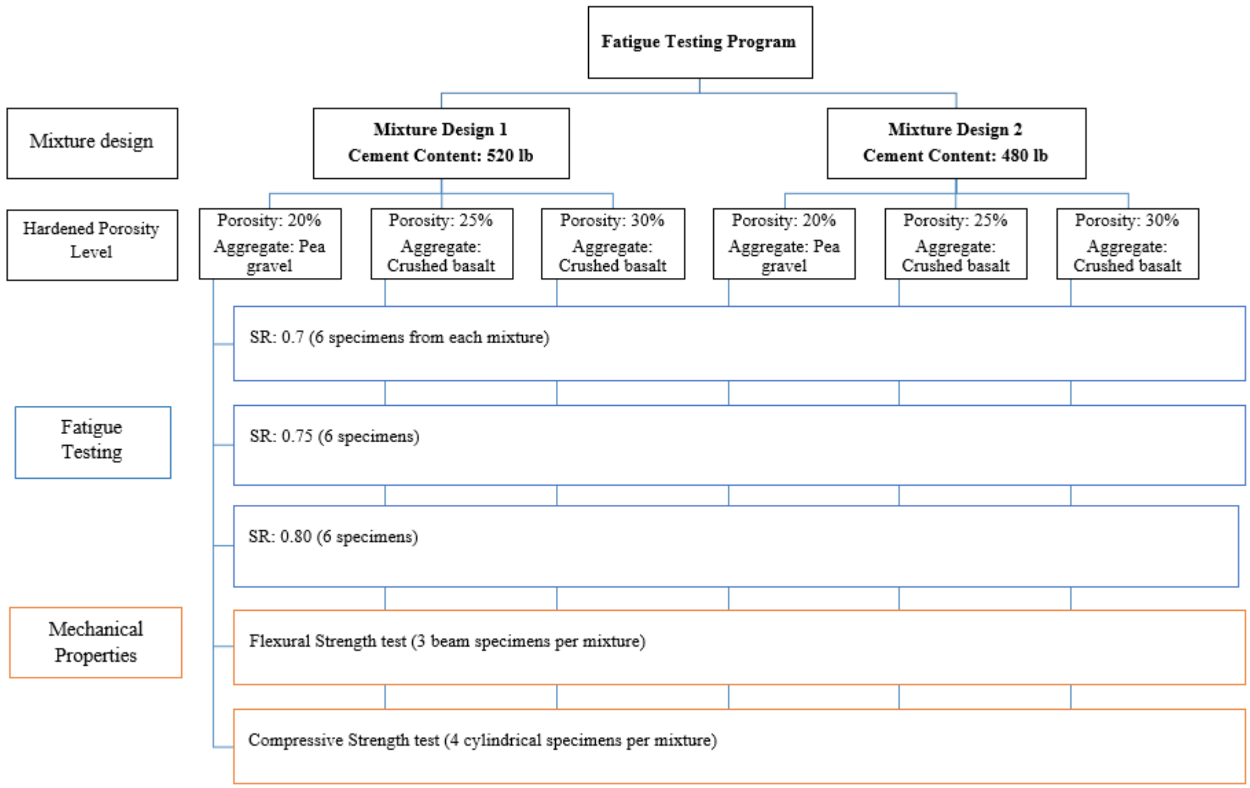

Fig. 1 Laboratory Test Program for Fatigue Model Development

Fatigue Tests

In this study, PC specimens are subjected to fatigue load at three proposed SR: 0.7, 0.75 and 0.8. To select the fatigue test frequency, previous researchers developed a relationship that correlates the vehicle speed with frequency. Commonly, PC is used in parking lots and driveways as well as low-traffic streets, where the speed limit is typically 10-30 mph which corresponds to 0.5 Hz. Therefore, the fatigue test frequency was kept constant at 0.5 Hz.

Currently, trial fatigue tests are conducted on PC specimens to identify suitable and feasible SRs. The preliminary results showed that fatigue tests with SR less than 0.75 are time consuming and unrealistic considering the project timeline. Specimens tested under fatigue load with SR less than 0.75 exceeded 500,000 cycles without any signs of failure and therefore the tests were terminated. However, trial fatigue tests with SRs ranging between 0.75~0.85 yielded timely results. Fig. 2 illustrate the test results for one porosity level specimens, where the logarithm of the number of cycles for each specimen is plotted against the corresponding SR. Moreover, Fig.3 shows beam failure after conducting a flexural fatigue test and

Fig. 2 Beam failure after cyclic flexural fatigue loading

Fatigue tests are conducted on PC specimens after 60 days from casting to ensure that the majority of the strength is gained and the properties remain fairly stable. Even though, a companion beam specimen is tested in flexure prior to each fatigue testing to establish the most representative SR for the beam on the test day. Fatigue tests on all the specimens are anticipated to be completed by the end of December 2017. Fatigue models will be developed, based on the experimental data, and will be compared to the existing models in the literature, which are typically for traditional Portland cement concrete.

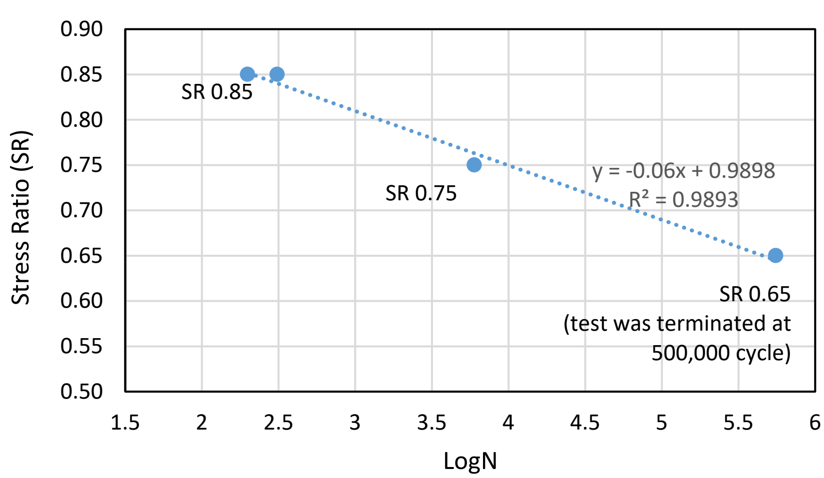

Fig. 3 Stress ratio vs Log of the number of cycles for specimens with 30% porosity and 480lb cement content

Mechanical Test Results

Currently, all the specimens are cast, cured, and tested for hardened porosity. The resulted porosities were close to the targeted porosity levels. Table 2 presents the flexural and compressive strength tests conducted at 28-days as well as the average measured porosities of the tested specimens. The 28-day flexural and compressive strength tests for mixture design 2 and 20% targeted porosity are expected to be completed in October 2017.

Table 2: Average 28-day Mechanical Properties

Mixture Design (Cement Content)	Targeted Porosity (%)	Flexural Strength		Compressive Strength	
		Strength (psi)	Measured Hardened Porosity (%)	Strength (psi)	Measured Hardened Porosity (%)
1	20	320	24	2,004	17.3
	25	348	24.9	1,335	24.7
	30	262	30.25	1,110	28.8
2	20	Test scheduled in October 2017	21.7	Test scheduled in October 2017	19.8
	25	279	25.7	816	29.4
	30	203	34.7	588	34

Field Test Program

Lightweight Deflectometer (LWD) test was used to investigate the in-situ structural properties of PC pavements (Fig.4). The results of LWD test were used to backcalculate the PC pavement moduli using the AREA method. Since this method is developed for traditional PCC pavements and for Falling Weight Deflectometer (FWD) test, finite element modeling was used to validate the results. The moduli from LWD test results were used in a fatigue model that was developed for conventional PCC to create a thickness design table for PC pavements. The results of the field testing were submitted to the Transportation Research Board (TRB). Please refer to the paper for more information on the results of the field experiments[1]. In the upcoming months and as the PC fatigue model becomes available in this project, the thickness database for PC with various materials properties and traffic volumes will be updated.

Fig. 4 LWD testing conducted on PC pavement

Project Outcomes and Impacts

The research work conducted in this project have the following impacts:

- Research results regarding pavement layer thickness deign was summarized in the form of a journal paper and was submitted on 7/29/2017 to the 2018 Transportation Research Board (TRB) annual meeting for presentation and publication. The paper was accepted for presentation and publication and the project findings will be presented at the annual meeting in Washington DC in January 2018.
- A presentation is scheduled in the Research in Progress Part 2 Session of the ACI fall convention in Anaheim, CA in October 2017.
- We plan to submit a journal paper on the developed fatigue model for the ACI Materials Journal (Expected in April, 2018).
- The final report to the CRC is expected to be ready in March 2018.
- We plan to present a webinar through the International Society for Concrete Pavements to highlight some of the findings of the project in spring 2018.

The finding of the project as summarized in the above two papers and the final report are anticipated to be directly incorporated in ACI 522 document.

[1] Othman, A, and S., Nassiri. Initial Steps towards the Mechanistic Design of Pervious Concrete Pavements, 2018 Transportation Research Board, accepted, 2017.