Date Submitted: February 2018

A Simple and Nondestructive Evaluation Method to Achieve High-Quality Pervious Concrete Pavement Installations

Funding Area: Research

Organization:

WASHINGTON STATE UNIVERSITY

Applicant:
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Amount of funding requested: $54,940

Duration of project: 24 months

Brief description of project:
In the absence of a standard quality-control method for compaction of pervious concrete pavements (PCP), frequent subpar installations negatively impact the market and limit PCP usage. In this project, we will conduct field testing of PCPs and laboratory testing of collected specimens to identify a nondestructive, simple, and reliable in-situ test to control the quality of PCP jobs by lightweight deflectometer testing. The results of field testing will be extended beyond quality-control purposes to obtain in-situ infiltration rates to estimate the required compaction efforts for future projects and also to estimate structural properties for layer thickness design.

Anticipated outcomes:
Once completed, we have developed a reliable quality-control test protocol to improve durability of PCP. We will aim for a method that is applicable to fresh PCP so that immediate corrective actions can be applied. Guidance from an advisory board of producers and installers will help us develop a test procedure that is implementable by industry. The proposal is strongly supported by a wide network of representatives from PCP associations and technical committees which will help us disseminate and standardize the developed method. In the end, we foresee that providing a method to ensure quality and durability will increase PCP usage by state highway agencies, private owners, and municipalities.
2. **Statement of purpose**

**Problem statement**
 Structural (and hydraulic) performance of pervious concrete pavements (PCP) are crucially dependent on proper compaction achieved by expert workmanship, yet no implementable method exists to assess the density of installed pavements. The lack of proper scrutiny in quality-control has resulted in subpar installations across the country, which negatively impacted the market of this class of concrete. Fresh density according to ASTM C1688 provides a judgment of the mixture density; however, the test method does not represent the roller compaction method applied on the pavement. Further, cores can be extracted to assess hardened density (ASTM C1754), but coring is destructive and can be performed after seven days, which is late for corrective actions. Ready-mix concrete producers and pervious concrete installers will benefit from a quality assessment method that is low-cost, portable, and easily performed at the site.

**Summary of our efforts**
 To address compaction issues in PCP, we used light-weight deflectometer (LWD) testing, which is traditionally used to gage the level of compaction in unbound layers (Fig. 1). Our early research shows that using LWD, soft and dense spots in PCP may be identified. The test is nondestructive and quick: drop weights are released on the pavement surface and the deflections are recorded by three geophones on the surface, which are used to backcalculate elastic moduli of the slab and the underlayers.

Using financial support by the American Concrete Institute (ACI)’s Concrete Research Council in 2015, we were able to test fourteen PCP installations across WA State, which is a highly active state in using pervious concrete. The tested pavements varied in age from 1-5 years old. We extended the ACI project to pavement layer thickness design based on the LWD layers’ moduli using additional funding by Washington Department of Transportation (WSDOT).

The findings from these initial research studies were presented at ACI’s 522 committee meeting in Fall 2017 and were received enthusiastically by the members (please see support letters provided by installers, producers, committee chair, and WSDOT.) With additional funding from RMC, we will continue to evaluate the method by testing more sections, if possible, extend testing to fresh PCP for immediate corrective actions, develop formulas to predict required compaction efforts for future jobs, develop a quality-control test procedure on 7-day age, and develop correlations with laboratory properties to limit the need for coring and laboratory testing, and help with structural layer thickness design. We will also continue to evaluate the method by
using parallel validation tools such as falling-weight deflectometer (FWD) provided by WSDOT. Upon completion, we will have a ready-to-implement quality-control method to improve quality of PCP to improve their quality, durability, and usage.

**Proposed goals and objectives**
The overall goal of the study is to set forth a simple and rapid, yet robust test method to estimate the appropriate compaction level prior to placement, and also judge the level of compaction achieved after placement. To achieve this final goal, the following hierarchical objectives will be pursued:

1. Further evaluate the effectiveness of LWD for quality-control by testing a wide range of pervious concrete installations both in freshly installed state and on 7-day age,
2. Confirm the validity of the moduli by comparison with other methods such as FWD,
3. Assess the sensitivity of LWD testing to identify soft spots that need further compaction to reduce job site variability,
4. Develop correlations between LWD- moduli and laboratory-established properties of cores such as hardened density, compressive strength, Cantabro, and modulus to reduce coring and laboratory testing,
5. Establish correlations to identify clogging issues and predict infiltration rate of installed pervious concrete based on LWD testing,
6. Identify correlations between the LWD results and the distribution of density across the depth of the slab especially for slabs greater than 8-inch,
7. Develop formulas to predict the required compactive efforts pre-installation and gage the level of compaction efforts post-installation.

**Anticipated outcomes and benefits for the concrete industry**
The lack of proper scrutiny in quality-control has resulted in many not-so-perfect installations across the country. This shortcoming has left many concrete producers reluctant to participate in pervious concrete projects. Furthermore, negative reputation has left stakeholders hesitant in selecting this pavement type for their projects. With stringent quality-control methods, pervious concrete pavement can reach its potential in transforming cities for cooler, and greener environments, which means increasing the market for the concrete industry, including producers and installers.
3. Methodology

Conceptual framework

The LWD test is conducted by dropping specific weights on the pavement surface and measuring the pavement response in terms of deflections. The surface deflection measurements of concrete pavement layers resulted from the applied load are used in the backcalculation of elastic modulus and foundation’s k-value using AREA method. AREA method relays on Westergaard’s theory where the pervious concrete slab is assumed to be supported by a dense liquid or elastic solid foundation with linear springs (Fig. 2). After applying the load during the LWD test, the deflection sensors spaced at 12 and 24 inches from the center of LWD loading plate are used to capture the pavement deflection. The normalized area of the deflection basin induced by the applied load on the pavement surface is obtained and used to calculate the pavement’s dynamic elastic modulus and k-value.

Fig. 2. Schematic representation of the concept of backcalculation of rigid pavement supported by elastic solid foundation with linear springs

In a previous research at WSU, the LWD test was applied on PCP in different locations in Washington State with various layer thicknesses. The results showed that LWD was able to deflect a wide range of pervious concrete slab thicknesses (Fig. 3). Furthermore, the AREA method was applied using the LWD deflection results to backcalculate the elastic modulus and k-value of the tested pervious concrete pavements. Backcalculation results showed that elastic modulus increased with increasing AREA while k-value decreased with increasing AREA (Fig. 4 and 5).
Fig. 3. LWD deflection results for various pervious concrete slab thicknesses. D0, D12 and D24 are the deflections captured by sensors located at 0, 12 and 24 inches from the center of LWD loading plate.

Fig. 4. Relationship between AREA and backcalculated elastic modulus $E$ of pervious concrete slabs.

$y = 25.637e^{-0.262x}$

$R^2 = 0.61$

$y = 78648e^{0.1194x}$

$R^2 = 0.318$
Fig. 5. Relationship between AREA and backcalculated k-value of pervious concrete slabs.

The results shown above are promising but show scatter per slab thickness. We need to conduct testing of several more PCPs within each thickness group to identify the sources of variability, find relationships with fresh and in-situ density, strength of cores, and in-situ infiltration, also confirm the validity of the moduli values based on parallel methods FWD.

**Proposed methodology**

WSU is in a prime geographic location in terms of high pervious concrete usage in nearby cities such as Puyallup, Tacoma, Seattle, Portland, Eugene, and Vancouver among others. All these cities are within driving distances from WSU campus in Pullman, allowing for ample testing and data location opportunities across the northwest area. On-site testing is anticipated to encompass the following:

At the site:

1. Conduct LWD testing on the PCP test panel installed prior to the main job installation, core out samples for strength, air voids, and infiltration testing,

2. Conduct LWD tests behind the paving crew on freshly placed slabs at 10-ft intervals, if not too disturbing to the fresh PCP,

3. Run fresh density test, and cast specimens for laboratory testing from multiple truck loads,

4. Return to the tested sites on between 7-90-day age for repeat-LWD testing and companion FWD testing of hardened pervious concrete pavements,

5. Conduct infiltration tests at LWD test locations, collect core samples for further testing,

In the laboratory (testing and analysis):
6. Use the load-deflection data from LWD and FWD to backcalculate slab's modulus and the foundation's k-value,

7. Conduct laboratory testing of cast samples and cores in Cantabro, hardened density and porosity, infiltration, compressive strength, and Cantabro,

8. Develop correlations between moduli/deflection and various parameters for quality control as discussed in the objectives section,

9. Analyze the results from LWD and FWD and identify strengths and limitations of LWD, develop models to estimate the required level of compaction pre-installation, and judge the compaction quality post-installation,

10. Develop a quality-control protocol and report to RMC.

### Schedule of activities

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<tr>
<th>Activity/Quarter &amp; Year</th>
<th>Sum 2018</th>
<th>Fall 2018</th>
<th>Spg 2019</th>
<th>Sum 2019</th>
<th>Fall 2019</th>
<th>Spg 2020</th>
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<td>Field testing (Tasks 1-3)</td>
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<td>Laboratory testing and analysis (Tasks 4-8)</td>
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<td>Meeting with advisory board</td>
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<td>Develop quality-control protocol (Tasks 9-10)</td>
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<td>Final report to RMC (Task 10)</td>
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### Proposed allocation of staff, consultants, collaborating organizations, and other human resources

Dr. Somayeh Nassiri, Assistant Professor at WSU will serve as the PI and will supervise and guide the technical and administration work in the project. One graduate student and one hourly undergraduate student will conduct the testing and analysis in this project. An industry advisory board will be formed to serve as independent evaluators and technical consultants to the project.

### 4. Deliverable Product and Dissemination Plan

#### Targeted audience

The audience of this research is the concrete industry including concrete producers and concrete pavers. Also, the audience extends to project owners such as municipalities, departments of transportation and private project owners. To make sure the findings of the project will reach the target audience several platforms will be used.
**Dissemination**

Findings will be presented at the ACI Committee 522 meeting in 2019 and 2020. Papers will be submitted to the ACI Materials journal and for presentation at the TRB. Also, based on the results of this study, we will work with ASTM subcommittee C09.49 on pervious concrete to develop a standard for quality-control of pervious concrete using the LWD. We will also make sure the findings are disseminated to the National Ready-Mix Concrete Association, National Pervious Concrete Paving Association, and the Puget Sound Concrete Specification Council. Also, we will plan to present the project findings at one of the National Concrete Consortium (NC2) meetings.

**5. Replicability or Application in Association Community**

A practical and standardized protocol will be developed to be used by industry for quality control testing in the field. The protocol will be shared with the advisory board for technical review and editing.

**6. Evaluation**

An industry advisory board will be formed to include several independent evaluators and technical consultants for the project. The advisory board will include Mr. Andrew Marks from the Puget Sound Concrete Specification Council, Mr. Scott Erickson from the National Pervious Concrete Paving Association, Dr. Sadaf Khosravifar from Dynatest, and Mr. Mark Russel from WSDOT.

Quarterly conference calls will be held with the research team and the advisory board to brief the board on the research progress, identity upcoming projects for testing, and collect expert's technical advice on the different aspects of the research. The goal is to ultimately develop a protocol that is implementable by practitioners.

**7. Qualifications**

**Relevant skills**

Dr. Somayeh Nassiri is an Assistant Professor at WSU. She has been heavily involved in pervious concrete research over the last three years. She has served as the principal investigator for many pervious concrete research projects funded by ACI, WSDOT, CESTiCC, PacTrans, and the Boeing Company. She is the author of several research reports and journal publication on this topic. Relying on her background in concrete pavements and research experience in pervious concrete and her experienced team of graduate students, she is prime position for a successful execution of the plan.

**Relevant background**

Dr. Nassiri has led several research projects to investigate the structural performance and material properties of pervious concrete. Various funding organizations include Boeing, WSDOT, and ACI concrete research council. She was also a co-PI on a team led by Applied Pavement Technology on a project funded
by ACRP on the application of pervious concrete at airports. Over the past three years, she has co-authored with her team of graduate students several peer-reviewed journal publications as well as technical reports. Six example journal publications related to pervious concrete are listed below:


**Brief description of applicant organization**

Washington State University is a public research university in Pullman, Washington. The Department of Civil and Environmental Engineering at WSU offers courses leading to the degrees of Bachelor of Science (B.S.) in Civil Engineering, Master of Science (M.S.) in Civil Engineering, M.S. in Environmental Engineering, and Doctor of Philosophy (Ph.D.) in Civil Engineering. Approximately 120 seniors graduate with a B.S. degree each year. Approximately 80 graduate students are in residence, typically one-third of these are Ph.D. candidates and the remainder are pursuing M.S. degrees. Our students consistently perform above the state and national passing rates on the national Fundamentals of Engineering (FE) Exam. Our graduates are actively sought by industry, consulting firms and government employers.

**8. Budget**

**Expenses**

1. **Personnel**
   $25,912 is requested to provide 12 months of support for a 25% FTE PhD student for each year of the project. This includes salary, health insurance, and benefits at 1.5 percent. $997 is requested to support an undergraduate employee at $12.00 hour for 10 hours per week for 4 weeks per year.

2. **Travel**
   $9,000 is requested for travel during the project. This requested amount will be used to travel (mostly drive) to job sites for in-situ testing and sample collection.

3. **Communications**
   Telephone (including conference calls)
Fax  
Postage and handling  
No budget is requested for the above items.

4. Printing/copying  
5. Production of materials  
6. Other Direct Expenses (please specify)  
No budget is requested for items 4-6.

7. Other  
Washington State University’s federally approved indirect cost rate of 53% is applied to the total direct costs and equals $19,032 for this project.

**APPLICANT MATCHING SUPPORT (PLEASE DESCRIBE)**

**Applicant’s direct financial support:**  
This application is not supported by any matching funds in cash, however the proposed project is formed based on the foundational knowledge created through the following projects conducted by Dr. Nassiri.

- “Towards Mechanistic Design of Pervious Concrete Pavements” sponsor: $50,000 by ACI CRC, 2015  
- “Preliminary Study towards Development of Acceptance Specification for Pervious Concrete” $35,000 by WSDOT, 2016 and 2017,  
- “Recycled Carbon Fiber Composite (CCFCM) for Reinforcing Pervious Pavements” more than $500,000 by the Boeing Company, 2015-2018  

**Applicant’s in-kind support**  
WSDOT will provide $22,500 in-kind matching support for this proposal. Please refer to the support letter provided below. The description of the support is provided in the support letter provided by WSDOT.
December 7, 2017

Executive Director
RMC Research & Educational Foundation
900 Spring Street
Silver Spring, MD 20910

RE: Letter in Support of Washington State University’s Proposal

Dear Ms. Julie Garbini,

This letter is to express my full support to the research proposal submitted to RMC Research & Education Foundation by Dr. Somayeh Nassiri from Washington State University (WSU). The title of the proposal is “A simple and nondestructive evaluation method to achieve high-quality pervious concrete pavement installations.”

Over the last two years, Washington State Department of Transportation (WSDOT) has sponsored Dr. Nassiri’s research on pervious concrete with $35,000 cash support. To my understanding, this proposal builds on the preliminary findings in the past projects and will continue the research to develop quality control methods for pervious concrete. We will support the proposed research by $20,000 in-kind support in testing. The support will be in the form of conducting falling-weight deflectometer testing of pervious concrete pavements for validation of the tests conducted in the proposed research.

Furthermore, Mr. Mark Russel, WSDOT State Pavement Design Engineer, will serve on the project's advisory board and will participate in quarterly conference calls. The anticipated allocated time for the technical consult is about 20 hours and is estimated at $2,500. Therefore, the total in-kind support from WSDOT in support of this proposal is $22,500.

Sincerely,

Jeff S. Uhlmeyer, P.E.
WSDOT State Pavement Engineer

JSU:jsu
Executive Director  
RMC Research & Education Foundation  
900 Spring Street  
Silver Spring, MD 20910  

RE: Letter in support of Washington State university’s pervious concrete testing proposal.

Dear Ms. Julie Garbini,

Dr. Somayeh Nassiri of Washington State University (WSU) is requesting financial support from the RMC Research & Education Foundation. The title of her proposal is “Simple and nondestructive evaluation methods to achieve high-quality pervious concrete pavement installations.”

I work with pervious concrete pavement designers, suppliers and installers in the USA and around the world. Recent improvements in pervious concrete; dramatically more user-friendly mixes, better installation tools and simple and effective testing methods increase reliability and acceptance. The proposed WSU research works to develop a simple solution to verifying another needed test to monitor and protect the quality of installations.

ASTM has created good tests for checking unit weight and permeability. But current compaction test methods (coring) takes a minimum of 7 days to sample and extra days to test. By the time results are available, the job may already be done. A quick compaction test would help installers catch and correct mistakes rather than litigate mistakes after the fact. If we can prevent costly mistakes, hopefully we can convince ready mix producers burned by past pervious jobs, to reconsider and start using pervious concrete again. Currently many producers actively avoid pervious concrete. That makes it more expensive and more difficult for us to promote pervious concrete to specifiers.

As I understand it, the proposed work by Dr. Nassiri will focus on developing solutions that will be extremely beneficial to our industry. I will support the proposed research by serving on the industry advisory board and will also assist with the dissemination of the research findings through the National Pervious Concrete Paving Association. I highly recommend this proposal for funding by the RMC.

Sincerely,

Scott Erickson  
NRMCA Pervious Craftsman  
Nation Pervious Concrete Pavement Association President  
ACI 522 Committee member  
Evolution Pervious Resources, Principal
December 15, 2017

Ms. Julie Garbini
Executive Director
RMC Research & Education Foundation
Executive Director 900 Spring Street
Silver Spring, MD 20910

RE: Letter in support of Washington State University research proposal

Dear Ms. Garbini:

I am writing to fully endorse and support the research proposal of Dr. Somayeh Nassiri from Washington State University to the RMC Research & Education Foundation. The proposal is titled “A simple and nondestructive evaluation method to achieve high-quality pervious concrete pavement installations.”

This research proposal involves developing solutions that are significantly needed to increase the quality and workmanship at pervious concrete job sites. The absence of adequate quality control measures and the lack of skilled workmanship has resulted in a negative reputation for pervious concrete. Consequently, consultants are reluctant to specify pervious concrete and Ready Mix operations are hesitant to produce it. To this extent, it has been difficult to promote pervious concrete as a pavement material in Iowa in recent years.

The proposed research work by Dr. Nassiri will address the current issues with installation of pervious concrete by developing solutions and quality control measures. I highly recommend RMC fund this proposal.

Sincerely,
Respectfully,

[Signature]

Steven L. Mallicoat, P.E.
Director of Engineering and Education
Iowa Ready Mixed Concrete Association
12-19-2017

Executive Director
RMC Research & Education Foundation
900 Spring Street
Silver Spring, MD 20910

RE: letter in support of Washington State university’s proposal

Dear Ms. Julie Garbini,

I am writing to express my full support to the research proposal submitted to RMC Research & Education Foundation by Dr. Somayeh Nassiri from Washington State University (WSU). The title of the proposal is “A simple and nondestructive evaluation method to achieve high-quality pervious concrete pavement installations.”

Pervious concrete pavement offers many environmental advantages such as stormwater management and pollutants removal. However, there are issues related to the installation of pervious concrete such as the absence of quality control methods and poor workmanship. The proposed research by Dr. Nassiri will develop an in situ quality control test to monitor and improve the quality of pervious concrete installation. The proposed research will provide a solution for the critical issues with the installation of pervious concrete and will be highly beneficial for concrete industry.

I will support the proposed research by serving on the industry advisory board and by promoting the research finding through the National Pervious Concrete Paving Association. I highly support and recommend this proposal for funding by the RMC.

Sincerely,

Keith Muhich
QC Manager
Miles Sand & Gravel
December 19, 2017

Executive Director
RMC Research & Education Foundation
900 Spring Street
Silver Spring, MD 20910

Reg: Support letter for the proposal from Dr. Somayeh Nassiri of Washington State University to RMC Research and Education Foundation

Dear Ms. Garbin,

I am pleased to endorse and support the research proposal by Dr. Somayeh Nassiri from Washington State University to the RMC Research and Education Foundation. The proposal is titled “A simple and nondestructive evaluation method to achieve high-quality pervious concrete pavement installations.” This proposal involves developing solutions that are immediately needed to increase the quality of workmanship at pervious concrete job sites. The absence of adequate quality control measures and the lack of skilled workmanship has resulted in low-quality pervious concrete pavements in different parts of the country. The proposed research work by Dr. Nassiri will address the current issues with installation of pervious concrete by developing solutions and quality control measures.

ACI committee 522 will help with dissemination of the project findings by providing opportunities for Dr. Nassiri to present the research findings at the committee meetings and sessions and through other platforms available to her as a committee member.

Please do not hesitate to contact me if you have questions.

Sincerely,

Narayanan Neithalath,
Chair, ACI Committee 522

Email: Narayanan_Neithalath@asu.edu

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Narayanan Neithalath, Ph.D
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Senior Sustainability Scientist, Global Institute of Sustainability
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http://faculty.engineering.asu.edu/neithalath
Hi, Julie,

I am writing to express my support of the research proposal by Dr. Somayeh Nassiri from Washington State university to the RMC Research & Education Foundation. The proposal is titled “Simple and nondestructive evaluation methods to achieve high-quality pervious concrete pavement installations.”

As you know, we are still in the technology development phase for pervious concrete. The benefits are well known, and by now, fairly widely accepted. Pervious concrete is gaining popularity as a Stormwater management system, and is being used in the NW for arterial streets, truck terminals, fire stations, and for other heavy traffic applications. There have been some anecdotal observations indicating variability in performance of pervious concrete surfaces based on installation methods, and there is need to quantify both how to measure the effectiveness of construction methods, as well as the relative success of specific construction methods and equipment in addition to refining mixtures, proportions and constituents. I have talked at some length with Somayeh, and I like her approach to this set of issues. I believe her research could be quite helpful in moving the state of the art forward to the benefit of our industry. I urge you to give strong consideration to funding her research proposal from Washington State University.

My support to the proposed research will be through serving on the industry advisory board to help identify projects for testing and steering the research towards implementation in practice. I support and recommend this proposal for funding by the RMC.

Thanks again, Julie,

Andrew E. Marks, PE
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