MPC-564
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Project Title:
Quantifying the Range of Variability in the Flexural Strength of Fiber Reinforced Concrete using Monte Carlo Simulation

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Research Needs:
Fiber reinforced concrete (FRC) is sometimes used in transportation infrastructures due to its superior crack resistance, among other advantages, compared to conventional concrete. However, since its first use, many laboratory studies have shown erratic results in flexural strength among replicate specimens (Chao et al., 2011). As a result, repeatability of results was very challenging.

The high variability in the FRC testing results was mentioned in ACI 544.2R-89 report titled “Measurement of Properties of Fiber-Reinforced Concrete” (ACI, 1989). A very recent study sponsored by SDDOT and MPC titled “Fiber-Reinforced Concrete for Structure Components” also showed similar results to previous studies in terms of extreme variabilities in flexural strength results among replicate specimens (Ghadban et al., 2018). A previous study conducted by Armelin and Banthia attempted to predict this variability but only considered compressive strength and pullout force-versus-slip relationships as inputs for the model. Additionally, during each run, they used the same fiber orientation for every fiber which is not representative of actual FRC members. Their study also lacked sufficient data and did not produce any algorithm that could be used by designers to predict this variability (Armelin & Banthia, 1997). To the best knowledge of the research team, there has been no previous studies sufficiently tackling this issue.

Given this issue, it would be very difficult for design engineers to make reliable claims about the performance of a certain FRC element in the field. Consequently, there is a compelling need to mitigate this issue by either eliminating this variability or quantifying it statistically. The research team believes this problem is inherent in FRC and, therefore, is impossible to eliminate. However, the range of variability is believed to be possible to quantify statistically.

Research Objectives:
This project has the following objectives:

- Statistically quantifying the range of variability in the flexural strength of FRC using Monte Carlo Simulation.
- Experimentally validating the obtained range of variability by conducting flexural tests.

The goal of this project is to provide a better tool for FRC designers to be able to make more robust claims about the performance of any FRC element in transportation infrastructures. The aforementioned objectives are designed to achieve this goal.

Research Methods:
This project will have the following two main research methods necessary to achieve the aforementioned objectives:

Monte Carlo Simulation: In order to attain a statistically reliable range of variability of flexural strength of FRC, hundreds if not thousands of data points need to be collected. It is virtually impossible to experimentally obtain this amount of data points due to budget and time constraints that are usually associated with structural testing studies. Alternatively, Monte Carlo Simulation can be used to obtain tens of thousands if not hundreds of thousands of data points. It is a very powerful tool designed to tackle problems that have some kind of inherent randomness in them. In the case of this study, while the distribution of the fibers can be reasonably assumed to be uniform, the research team believes the cause of the variability in experimental results is the randomness of the orientation of the fibers. Monte Carlo Simulation works by creating a simple theoretical relation between the random parameters and the experimental output then running numerous virtual experiments. In each virtual experiment, random values are assigned to the random parameters and the output is calculated through the simple theoretical relation. The data are then analyzed using statistical methods. In this study, the random parameters will be the orientations of fibers and the theoretical relation will be derived using Euler–Bernoulli beam theory.

Experimental Validation: After the range of variability in the flexural strength of FRC is quantified by statistically analyzing the results obtained from Monte Carlo Simulation, validation will be carried out by conducting flexural tests and confirming that the obtained experimental results lie in the range of variability. A total of 8 concrete mixes will be tested. These mixes will have randomly selected fiber types, fiber dosages, and other concrete properties in order to examine the power of the developed tool for a wide range of mixes. Ranges of variability associated with several confidence levels will be tested.

Expected Outcomes:
This project is expected to produce an algorithm capable of quantifying the range of variability in the flexural strength of FRC given the properties of concrete and fibers along with the confidence level. This will aid transportation engineers in better understanding the performance of FRC structural elements which in turn helps in designing FRC elements that can perform as expected.

Relevance to Strategic Goals:
The anticipated products are related to the following strategic goals: Safety and Economic Competiveness. Due to the variability in the flexural strength of FRC, it is very possible to either underdesign or overdesign an FRC element. Consequently, this could result in safety issues associated with underdesigning or economic issues associated with overdesigning. By quantifying the variability in the flexural strength of FRC, it would be easier to provide more economic and safe designs.

Educational Benefits:
Project findings can be integrated in engineering courses, such as an Advanced Concrete Design course and a Monte Carlo Methods course.

Technology Transfer:
Project findings will be transferred to transportation engineers by sharing findings with DOTs and other transportation agencies. The research team expects local and regional transportation agencies to capitalize on findings and recommendations and efficiently use the developed algorithm to provide better designs of FRC elements. Moreover, all findings will be disseminated through publication in technical journals and conference proceedings. Technology transfer activities will also be reported in the Program Progress Performance Reports (PPPR).

Work Plan:
Task 1: Literature review of the state of the art on the variability of flexural strength of FRC
Task 2: Development of the theoretical relation between the fibers' orientations and the flexural strength of FRC
Task 3: Developing the Monte Carlo Simulation algorithm and performing virtual experiments
Task 4: Statistical data analysis
Task 5: Experimental validation of the power of the algorithm in predicting the range of variability in flexural strength of FRC
Task 6: Final report

Task 1: Conduct a comprehensive literature review on the variability of flexural strength of FRC. This task is expected to be done by the end of the 1st month.

Task 2: Develop a simplified theoretical relation between the random parameters (i.e. fibers' orientations) and the desired output (i.e. flexural strength). Euler–Bernoulli beam theory along with elementary reinforced concrete design theory will be utilized to fulfill this task. This task is expected to be done by the end of the 3th month.

Task 3: Visual Basic for Applications (VBA) will be used to write a Monte Carlo Simulation algorithm and perform virtual experiments. This task is expected to be done by the end of the 4th month.

Task 4: Analyze all data obtained from Task 3 using statistical analysis to examine the range of variability in flexural strength of FRC and its relation to the confidence level. This task is expected to be done by the end of the 5th month.

Task 5: Validate the predicted ranges of variability obtained in Task 4 by testing them on experimental data obtained at South Dakota State University labs. This task is expected to be done by the end of the 6th month.

Task 6: Prepare a final report summarizing the research findings, conclusions, and recommendations. This task is expected to be done by the end of the 7th month.

Project Cost:

Total Project Costs:	$49,741
MPC Funds Requested:	$24,017
Matching Funds:	$25,724
Source of Matching Funds:	South Dakota State University

Project Duration: 7 months

References:

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Chao, S., Cho, J., Karki, N. B., Sahoo, D. R., & Yazdani, N. (2011). FRC Performance Comparison: Uniaxial Direct Tensile Test, Third-Point Bending, and Round Panel Test. Tech. No. SP-276-5. Texas Department of Transportation.

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