Executive Summary Research Readiness Level Assessment and Technology Transfer

Evaluation of Reducing Cement Content in NDOT Class R Combined Aggregate Gradations

Research Objectives

- Evaluated the current NDOT class R combined aggregate gradation and proportioning, and identified critical sieve sizes that drive the aggregate particle distribution for good workability based on concrete performance;
- Evaluated how does NDOT class R combined aggregate gradation fit in the "Tarantula Curve" and any further optimization to be achieved; and
- Evaluated the feasibility of producing concrete mixes with reduced cement content (5.5-, 5.0- and 4.5-sacks) with current (or modified) class R combined aggregate gradation.

Research Benefits

Developed a concrete mix design with an optimum combined aggregate gradation that is more cost effective comparing to the current mixes.

The study provided NDOT and contractors with recommendations:

- Ensured workability and constructability so that the mixes can be easily used in engineering application, and appropriate mechanical properties and durability characteristics meet NDOT specifications.
- The optimum gradation of aggregate allowed the maximum use of local aggregates and reduced costs by virtue of the lower cement usage. The reduced cement content also enhanced air entrainment system and reduced shrinkage, so achieved a durable design.

Background

This research project aimed to achieve a cement reduction on Nebraska slip-form pavement concrete through aggregate particle packing optimization. A literature review was conducted to examine different aggregate optimization tools, quality control tests, and historical data of Nebraska Department of Transportation (NDOT) pavement mixtures. It was found that the Modified Toufar Model has good potential in optimizing particle packing and predicting packing degrees. The combined aggregate void content test was found to be useful to experimentally justify optimized aggregate gradations. The Box Test with a modified index and image analysis tool for surface void estimation was used to evaluate the effect of cement reduction and optimized aggregate gradation on pavement concrete workability.

Conclusion

Based on the results from the theoretical and experimental study of aggregate packing and the performance of pavement concrete prepared with the standard and optimized aggregate gradations and the reduced cement contents, the following conclusions can be drawn:

- The modified Toufar Model was an effective tool for pavement concrete mix design. By incorporating the packing degree of aggregates, the model accounts for the gradation as well as the shape and texture characteristics.
- Results from the theoretical aggregate particle packing analysis based on the Modified Toufar Model matched well with the experimental results when the vibration plus pressure procedure was used.
- The Box test with the modified index provided a reliable and more objective evaluation of the fresh pavement concrete performance. However, the results in this study implied that the VKelly test does not fit well to evaluate the performance of pavement concrete when coarse aggregate content is low.
- When the optimum aggregate gradation is used, cement content was effectively reduced by up to 1.0 sack (94 lb/yd^3) without compromising the fresh properties, mechanical properties, and permeability.
- The results of free and restrained shrinkage indicated that shrinkage and cracking potential can be reduced when the concrete mixture is more optimized. Freeze/thaw resistance was improved although it is not significant.
- A mix design procedure considering both the theoretical and experimental void contents and the minimum paste-to-aggregates volume ratio ($P_e\%/V_{B\_agg}\%$) was used to reach better design concrete mixtures in a more optimal manner.

Principal Investigators

Jiong Hu (P.I.) and Yong-Rak Kim (Co P.I.)
University of Nebraska

Lead TAC Member

Wally Heyen, PCC Engineer

Executive Summary Research Readiness Level Assessment and Technology Transfer

Interested in finding out more?

Final report is available at:
NDOT Research Website

NDOT Recommendations Based Off of Research Project

The Department has made changes to the specifications based on the completion of this research. The contractor now has the option to use the Tarantula Curve to optimize the aggregate in the mix design. If the contractor shows they can meet the Departments other criteria prior to the beginning of the project, the contractor can reduce the cement content by a half a sack of cement.

- *As provided by Wally Heyen, Lead TAC Member*

Technology Transfer

Conference Presentation

- M. Mamirov, S. Gholami, J. Hu, Y. Kim, "Sustainable Pavement Concrete and Pavement Patching Materials through Aggregate Gradation Optimization and Reduced Cement Content", International Airfield and Highway Pavements Conference, Chicago, Illinois, July 21-24, 2019.
- M. Mamirov, J. Hu, and Y. Kim, "Optimization of Pavement Concrete based on Theoretical and Experimental Particle Packing Methods and Pavement Workability Tests", Nebraska Concrete Pavement Association Annual Workshop, Lincoln, NE, January 22, 2019.
- M. Mamirov, J. Hu, and Y. Kim, Optimization of Pavement Concrete based on Theoretical and Experimental Particle Packing Methods and Pavement Workability Tests, Transportation Research Board Meeting, Washington DC, January 13–17, 2019.

Research Readiness Level (RRL) Assessment

RRL 4

Level 4: Implementation

Research/Technology refined and adopted by the Department. Benefits of the implementation will be evaluated for a time frame of 5 years.

This brief summarizes Project SPR-P1 (18) M069
"Evaluation of Reducing Cement Content in NDOR Class R Combined Aggregate"
Nebraska Department of Transportation Research Program