Reducing Shrinkage in Concrete Bridge Decks Using Single and Double Ring Test Methods

Proposal

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Problem Statement

The condition of concrete on bridge decks is one of the most costly parts of Wyoming DOTs budget. Currently the cost of maintenance can be problematic. This proposal evaluates critical factors relating to early age shrinkage and proposes combining multiple methods to reduce this factor that contributes to early degradation. While cost effective solutions exist, they are evaluated under laboratory conditions and do not consider the effects of temperature or humidity on curing environments. This project combines testing under laboratory conditions as well as conditions similar to the extremes that exist during field curing.

Background Statement

The concrete surface of bridge decks is one of the most significant costs in maintaining our roads. Current practices and standards fail to properly evaluate the early age shrinkage, which is critical to determine long-term performance. In addition, stronger concretes with higher cement contents are more susceptible to early age shrinkage. Environmental factors such as heat, dry climates, and wind all promote early-age shrinkage. Wyoming has two of these critical factors and bridge deck end restraints naturally induce stresses in fresh concrete; this causes additional internal stresses leading to an increased risk of early cracking. Furthermore, early age cracking substantially decreases service life of concrete because the early-age cracks accelerate damage in bridge decks leading to increased overlays and maintenance costs.

The aim of this proposal is to balance this deficit by creating recommendations using additional remedies to reduce shrinkage and provide a more durable, long-lasting concrete to reduce the required maintenance on bridge decks. Conventional methods of controlling drying shrinkage are material selection, mixture proportioning and effective construction techniques such as using curing compounds and proper construction methods [1]. This proposal addresses four additional methods including adding fibers, shrinkage admixtures, shrinkage compensating cement and internal curing of lightweight aggregate.

Literature Review and Methods to Mitigate Shrinkage Cracking

Presently, there is a lack of agreement on how to measure shrinkage. Part of this is related to the various types of shrinkage: chemical, autogenous, and drying. Some of the different methods used to evaluate restrained shrinkage include free-shrinkage tests (ASTM C157), a shrinkage ring (ASTM C1581), various types of molds with flared ends, bonded overlays, and field test slabs [2]. European work has used a restrained shrinkage specimen with flared end (Figure 1) and this has been adopted by other researchers in the US [3]. Alternatively, a double shrinkage ring has been adopted that permits changes in temperature and humidity levels [4]. Of the different methods, the shrinkage ring specimens are most conducive to laboratory studies because of their smaller size and relatively smaller cost. Furthermore, different temperatures and relative humidity levels can be evaluated using an environmental chamber. The PI and research team have developed one that is currently in use.

The ASTM T334 shrinkage ring method uses an internal steel ring outfitted with strain gages to measure stresses generated during the early ages of concrete. Three inches of concrete are cast around this ring and the external portion is sealed allowing moisture to leave from the top and bottom of the ring. This test method is typically used to evaluate mortar, however, this project would use up to 3/8” aggregate to evaluate the interface between cement paste and coarse aggregate as well as the stiffening effect of the coarse aggregate.

On the other hand, ASTM T363 permits the evaluation of early age behavior subject to both shrinkage and expansion by using Invar, a material with a low thermal expansion. It is combined with chilling and heating mechanisms to better approximate field conditions, in particular in climates with larger thermal swings. Building a system to evaluate this type of conditions is approximately $16,500, while constructing a system to evaluate the flared end method would be approximately $40,000. This proposal compares results of both ring tests and gives more accurate data for local aggregate sources.

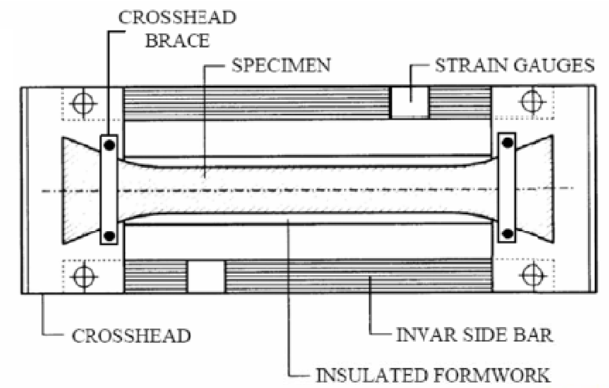

Figure 1: Flared end methods to restrain shrinkage [3].

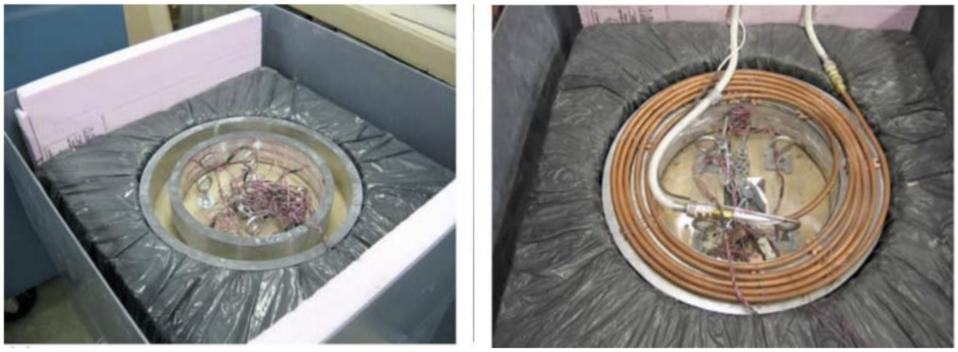

Figure 2: Examples of double-ring shrinkage test method [4].

Another advantage to using the ring is the opportunity to evaluate autogenous shrinkage and effects of early-age moisture loss. As water is lost and shrinkage occurs, internal stresses are generated (Figure 3). When the stresses exceed the tensile strength, the first crack occurs causing a drop in strain and internal stresses. Without mitigation measures, the stresses decrease by roughly 90% as illustrated in Figure 3b. However as fibers are added, cracking width decreases. With sufficient fibers, the stress drop is reduced by only 25%. For example, Shaw and Weiss found that a 0.5% use of steel fibers was effective, however, using smaller ratios such as 0.06% did not reduce shrinkage stress using the ring method [5].

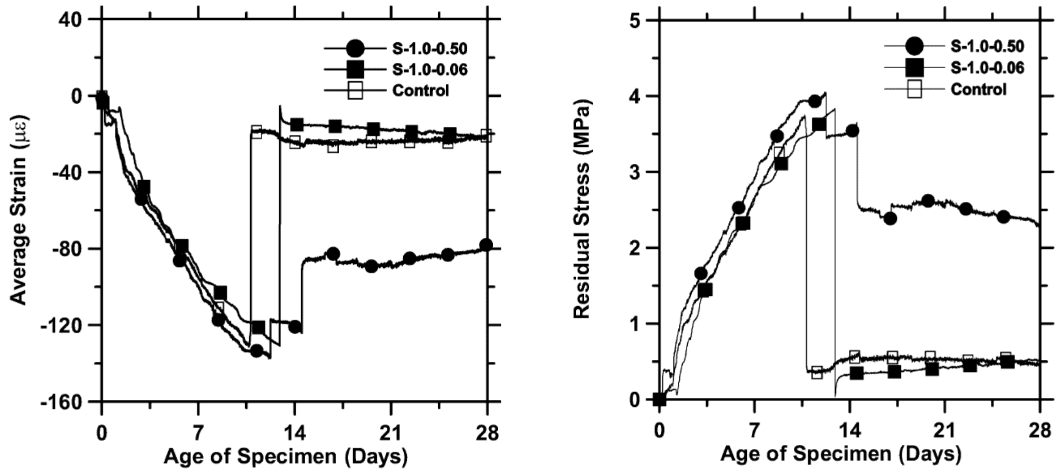

Figure 3. Strain and corresponding residual stresses in shrinkage ring test results. Effective fiber use illustrated by data set with circle markers [5].

Because fibers increase tensile strength, the resistance to cracking also increases with curing time. The type of fibers is also very important; polypropylene fibers have slightly more shrinkage than steel fibers, thus larger volume is required to match the effects of steel fibers [6, 7]. Despite this fact, macro- and micro-polypropylene fibers are proposed to avoid the risk of corrosion with steel fibers. Another benefit to adding fiber is a more distributed cracking pattern [5, 8]. This is helpful because the crack size is smaller and the harmful effects of cracking are reduced.

A second method to reduce cracking is using shrinkage reducing admixtures or expansive cement. This mitigation method delays the occurrence of cracking. By delaying the action, the concrete has more time to gain strength. As reported in other studies, applying multiple mitigation measures is more effective than just a single measure [9]. Testing using a shrinkage ring could be modified to accommodate different construction practices such as covering the concrete or adjusting the relative humidity by placing specimens in an environmental chamber. Such methods will be added to the use of fibers and use of SRAs.

A third method to improve the quality of concrete on bridge decks includes using methods of internal curing to reduce cracking. Concrete will continue to cure if saturated lightweight fine aggregates are used within concrete mixtures. As the effects of drying cause internal shrinkage, the additional water in the fine aggregate is slowly released into the paste. This longer-term method decreases the negative effects of drying and slows down the time to first cracking [10, 11]. Because combined effects will create the most significant effect, the majority of testing is focused on combined solutions that WYDOT can use when specifying concrete design mixtures. The incremental cost of adding SRA and fibers is approximately $25 per cubic yard for each method [12]. Although there is little information available on the cost of internal curing, incrementally it is anticipated to be even less than the previous two methods.

A final method of evaluating shrinkage is using a flared end specimen for restrained shrinkage and this has been standardized by RILEM and is the preferred standard in Europe [1]. This type of test is less conservative than the shrinkage ring because it represents the effect of permitting a length of concrete to shrink with only end restraints rather than being restrained around the entire circumference as occurs with the ring test. Drying can be controlled along the top of the specimen and different sections can be sealed allowing for different curing conditions [13]. This testing would be considered part of Phase II of this project if WYDOT wishes to pursue this option. A relationship between the two methods is lacking in the industry and would provide considerable information to DOT's around the country.

Objectives

The objectives of this proposal are as follows:

1. Evaluate the effects of single methods to mitigate shrinkage;
2. Quantify the beneficial effects of multiple methods to mitigate shrinkage;
3. Propose solutions for WYDOT using standard mix designs for two types of aggregates; and
4. Provide guidance on the use of internal curing for concrete mix designs.

Benefits

As an example of maintenance costs, a single 6,000 ft^2 bridge deck can reach up to $250,000. This considers two rigid overlays and one epoxy overlay with a 10% class II-A and 5% class II-B repairs. These costs do not include the traffic control and safety mobilization that can add another $100,000 to this single hypothetical bridge deck. If overlays can be deferred or eliminated by reducing or eliminating early age shrinkage cracking, this could result in a significant savings for WYDOT.

Statement of Work and Work Plan

This research program focuses on using shrinkage rings to compare and contrast results for selected shrinkage reducing variables. Once data is available for single mitigation strategies, a combination of two or more methods will be proposed to evaluate how much more resilient concrete can become.

Task 1a – Synthesize results of fiber studies using either of these two methods in a form of a database of existing mitigation measures and effectiveness. This data is not readily available in the literature and will provide guidance on what variables need to be evaluated.

Task 1b – Update existing WYDOT testing single ring equipment and perform preliminary testing to evaluate the upper and lower bounds based on results determined for Task 1a.

Task 1c – Construct an AASHTO T363 dual ring system to measure early age shrinkage or expansion based on temperature swings in Wyoming.

Task 2 – Based on results of Task 1b and 1c complete a limited set of single variable studies to quantify the effects of each type of mitigation for two common types of aggregates in Wyoming. One will be a stiffer coarse aggregate such as granite and other will be a limestone because it is relatively softer. Modifying single variables includes: using varying dosages of shrinkage reducing admixture to recommend a minimum dosage; using different ratios of micro- and macro-fibers to decrease early age cracking; blended or expansive cements; and internal curing methods. A minimum of 4 variations for each of the combinations are proposed with an additional 3 for the most promising two methods. Results of this study would be compared to shrinkage limits in high performance concrete [14].

Task 3 – Based on results of Task 2, propose a set of mixtures using multiple variables to reduce shrinkage using both types of shrinkage rings. In conjunction with WYDOT, develop a complete testing matrix of variables for the single-variable portion of this work. Because these methods are most likely to improve concrete, they are the primary focus of this investigation. The most likely combination is internal curing of fine aggregate, fibers and shrinking reducing admixtures. Optimum solutions from Task 2 will be combined to provide the most durable concrete for Wyoming aggregates. A minimum of 4 combinations will be evaluated for determining recommended mixtures for use in bridge decks.

Task 4 – Develop a set of recommendations for WYDOT to require when specifying concrete mixtures for bridge decks. A suite of two to four optimum concrete mixtures will be recommended for each type of aggregates to use in future WYDOT. A second step in Phase I, is creating a set of practices to assist contractors in using internal curing methods to mitigate the effect of drying shrinkage in the state of Wyoming. This will be presented at a Wyoming Concrete Associate gathering to further disseminate the findings in this study.

Phase II

A separate phase II will compare and contrast the best mixtures using the dual shrinkage ring and a larger shrinkage resistant frame. The larger frame would be a joint effort between UW and a collaborator with a laboratory that has an existing frame to evaluate the most promising concrete mixtures.

The final product of Phases I and II will be a relationship between the two most widely used methods in research.

Budget

Based on the above tasks, the anticipated budget is $116,300 with details outlined in

Table 1. An additional 5,000 is required for the materials laboratory to assist with sample collection and delivery bringing the total budget up to $121,300.

Table 1. Proposed budget for this project.

Senior Personnel	Notes	UW request
Tanner	1.5 months of support	$ 14,917
Other Personnel		
MS salary	Three semesters of support	$ 29,818
MS tuition and fees		$ 14,052
Undergraduate assistant	($10/hour x 10 hours/week x 40 weeks)*9%	$ 4,360
Fringe Benefits		
Senior personnel x 36.6%		$ 5,460
Students x 2.4%		$ 1,158
Operating Expenses		
Fabricate equipment	Construct dual ring test with chilling and heating capacity, AASHTO T363	$ 16,500
Fabricate equipment	Fabricate AASHTO T334 test equipment, potentially use WYDOT remnants	$ 6,000
Supplies	Purchase cement and additional materials	$ 3,000
Technical support	Machine shop time - 35 hours at $50 per hour	$ 1,750
Communications	Report publication/printing/editing	$ 2,000
Laboratory fees	Equipment maintenance	$ 1,000
Travel		
Professional travel	Trips to present findings at professional meetings	$ 3,000
Subtotal		$103,014
Indirect Costs		
Direct costs x percentage	20% of costs excluding tuition and fees and equipment	$ 13,292
Total RAC request	WYDOT contribution	**$116,306**

Technology Transfer

Results from this project will be supplied to WYDOT in terms of a final report and recommended concrete mixtures. The PI is willing to attend WYDOT training sessions to educate field engineers on results of this study including internal curing methods.

Implementation and Data Management Plan

A Gantt chart outlining the proposed schedule is presented in

Table 2. Information generated within this project would be stored on a secure server with backup options at 30 day intervals. At the end of the project, data will be supplied to WYDOT or be made available by the PI upon reasonable request for three years following this publication of the final report.

Table 2. Proposed schedule for this project.

AY		2021				2022		
Task / Quarter	4	1	2	3	4	1	2	3
T1a	■	■	■					
T1b			■	■				
T1c			■	■				
T2				■	■	■		
T3						■	■	
T4							■	■

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