RESEARCH PROGRAMS

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Development of High-Performance Concrete Mixtures for Durable Bridge Decks in Montana Using Locally Available Materials

http://www.mdt.mt.gov/research/projects/mat/high_concrete.shtml

Introduction

Concrete bridge decks in Montana are subjected to severe service conditions. Potential deterioration mechanisms include corrosion of the reinforcing steel and scaling of the concrete surface resulting from deicing salt applications, freezing and thawing distress, cracking due to thermal and humidity extremes during and after construction, and materials-related problems. To maximize the useful life of the structures, the concrete used in bridge decks constructed in Montana must be durable and impart durability to the bridge deck structure. The investigation summarized in this document was conducted to determine how best to achieve this objective, through the development of high-performance concrete (HPC) mixtures based on materials available in Montana.

Design and implementation of an HPC for durability poses some specific challenges. Optimizing HPC for durability typically requires the use of supplementary cementitious materials (SCMs) that can both improve workability and beneficially modify the structure of the cementitious paste. Despite these benefits, the number of materials involved increases the complexity of batching, mixing, and placing the final concrete. Also, since some of these supplementary materials are by-products of other industries, their properties can be inherently variable due to the limited production control involved in their "manufacture".

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Therefore, generalizations about the best combination of SCMs cannot be made. Rather, the most effective solution must be uniquely determined based on locally available materials.

What we did

The following essential tasks in the HPC development process were conducted: 1) definition of performance objectives, 2) selection of the locally available raw materials determined to be most likely consistent with the objectives, and 3) evaluation of possible combinations of raw materials.

Performance objectives for durable concrete structures were used to design an experimental program based on standardized tests. The intent of this program was to estimate performance of the concrete relative to the potential deterioration mechanisms. Testing included plastic properties, slump loss, setting characteristics, air-void system parameters, electrical conductivity, strength, chloride diffusion, freezing and thawing resistance, scaling resistance, and drying shrinkage.

The raw materials included aggregates, Type I/II portland cement from Montana, and the following supplementary cementitious materials (SCMs): Class C and Class F fly ashes, ground granulated blast furnace slag (slag), high-reactivity metakaolin, and silica fume. Also examined were blended cements that pre-combined portland cement and SCMs. These blends included a slag blend, a Class C fly ash blend, and a calcined-clay blend. To ensure that the aggregates do not pose a potential limit on the concrete durability, aggregates from four sources throughout the State were evaluated for the potential for developing alkali-silica reaction. The aggregate test program was conducted in parallel to the HPC mixture design investigation.

Three rounds of HPC testing were conducted. The first examined combinations that have historically demonstrated good performance as reported in the literature and based on the experience of the investigators. Since the mixes in the first round that performed best were complex (containing three SCMs), the second round quantified the performance of pre-combined blended cements that enabled similar combinations. The third round examined easy-to-produce mixtures. The first two rounds were conducted using an aggregate from the Yellowstone River Valley (Billings), while the third tested an aggregate source from Western Montana (Missoula).

In evaluating which mixture is the best performer, judgments must be made about the relative importance of desired properties in the actual concrete and about how well the laboratory results from the testing procedures represent the expected in-place concrete behavior. The greatest cause of deterioration in Montana bridge decks is expected to be corrosion of steel initiated by the intrusion of chloride ions from deicers. Therefore, given reasonable or better performance in the other tested properties, the highest emphasis was placed on chloride ponding testing results, since improvements in penetration resistance can be directly measured and will almost certainly translate into more durable structures.

What we found

Based on the 14 mixtures evaluated (Table 1) and for the specific set of raw materials tested, the combinations of SCMs that produced the best overall performance, with emphasis on the chloride penetration resistance, were 5% silica fume alone (mix B), 7% silica fume and 20% slag (mix N), slag-blended cement with 10% Class F fly ash and 5.5% silica fume (mix J), and the calcined clay-blend with 4% silica fume (mix L). Comments about these specific mixtures follow: A silica fume-only mixture may be more difficult to finish and displays somewhat higher shrinkage, and given the limited amount of SCM, this mixture may not have as much alkali-silica reaction (ASR) compensating effect as some of the other mixtures. However, it displayed excellent chloride penetration resistance and would be the simplest of the four options to produce. Prevention of deck cracking is also a potential concern with this mixture. The silica fume and slag combination mixture exhibited well-rounded performance across the test program. This mixture would

Material per cubic yard	Table 1 - Mixture Test Regime as Batched													
	A	B	C	D	E	F	G	H	J	K	L	M	N	O
Cement or blend (lbs.)	562	684	526	526	526	720	649*	649*	575†	629†	654‡	685	526	526
Water (lbs.)	266	266	266	266	266	252	252	252	252	252	252	252	252	252
Fly Ash - Class C (lbs.)	138	0	138	63	0	0	0	0	0	0	0	0	0	125
Fly Ash - Class F (lbs.)	0	0	0	0	54	0	0	0	54	0	0	0	0	0
Silica Fume (lbs.)	0	25	25	25	25	0	38	0	28	38	20	25	35	35
Slag (lbs.)	0	0	0	80	80	0	0	0	0	0	0	0	133	0
HR Metakaolin (lbs.)	0	0	0	0	0	0	0	45	0	0	0	0	0	0
Fine Aggregate (lbs.)	1284	1284	1284	1284	1284	1300	1300	1300	1300	1300	1300	1296	1296	1296
Coarse Aggregate (lbs.)	1572	1572	1572	1572	1572	1593	1593	1593	1593	1593	1593	1573	1573	1573
AEA (fl. oz./cwt.)	2.5	1.8	2.6	2.6	2.2	1.5	1.8	2.9	2.3	2.0	1.8	1.9	2.4	4.2
MRWR (fl. oz./cwt.)	2.4	2.0	2.5	2.5	1.7	4.0	7.0	2.6	2.5	2.6	2.5	2.5	2.5	2.5
HRWR (fl. oz./cwt.)	4.4	4.3	3.7	6.1	7.1	8.0	6.4	11.7	16.3	11.8	17.1	14.1	20.2	18.4

* Class C fly ash
† Slag blended cement
‡ Calcined clay blended cement

be more complex to produce but could be simplified by the use of the slag cement blend, though this blend is produced by an out-of-state supplier. It is likely that the slag blend could easily serve as a replacement for ordinary portland cement in ready-mix producers' silos; however based on price and their other project requirements, it may be difficult to institute. The combination of the slag-blended cement, Class F fly ash, and silica fume also gave excellent performance across all tests, standing out particularly for low drying shrinkage, and would be expected to be the best option to mitigate alkali-silica reactivity. However, the cement blend and fly ash would have to be shipped in from out of state and production would require handling three cementitious materials. Finally, the calcined-clay combination gave excellent performance, including low drying shrinkage, but is a more uncertain option since the materials tested are similar but not exactly the same as would be produced for Montana construction. Also, the material has seen less widespread use and testing than the other SCMs evaluated. The actual availability and cost of the material will depend on demand in Montana and on the transportation costs.

What the researchers recommend

In this test program, concretes produced using the Western Montana aggregate (mainly quartzite and sandstone) demonstrated better performance in terms of strength, resistance to chloride penetration, and scaling resistance than that measured with the Yellowstone River Valley aggregate (mainly basalt and granite). The influence of the raw materials and the importance of testing each mix containing specific materials was clearly demonstrated. In addition, the importance of the character of the paste-aggregate interfacial transition zone for high performance concrete as affected by aggregate type and batching procedures was highlighted.

To ensure the ultimate success of HPC projects in Montana using these mixtures in the future, it would be highly valuable to conduct trial batches using the local production batching procedures and equipment to verify that similar performance can be achieved under the actual job conditions. In addition, the construction demands of HPC beyond typical construction, such as increased curing and quality control, must be considered. This study has provided a solid foundation for constructing highly durable concrete bridge decks in Montana using locally available materials.

For More Details . . .

The research is documented in Report FHWA/MT-05-005/8156-03, *Development of High-Performance Concrete Mixtures for Durable Bridge Decks in Montana Using Locally Available Materials.*

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This research has established a solid base to begin implementing HPC deck mixtures in appropriate areas of the state where batching procedures and deck placement can be monitored for correct application and quality control. Since HPC is a relatively new practice in Montana, working with concrete producers and contractors in the use of these new mix designs will be imperative. The success of implementation will be realizing the same performance in the field as was seen in the laboratory results.

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