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Study and Analysis of Metakaoline in High Performance Concrete

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ABSTRACT

Floating bridge concrete must be watertight, durable, workable, and must have sufficient cohesiveness to prevent segregation in heavily congested deep walls. The mix design must experience minimal creep and shrinkage to reduce prestress losses, and shrinkage cracking. As a result of recent concrete research, new mixes were created incorporating various quantities of fly ash, silica fume, metakaolin, poly-carboxylate ether superplasticizers, and Caltite waterproofing admixture. This research focuses on concrete with a water binder ratio of 0.33 and a slump in the range of 8 to 9 inches. Workability characteristics of the fresh concrete are analyzed and hardened concrete properties tested in this research are compressive strength, chloride ion permeability, and creep and drying shrinkage properties.

It was found that metakaolin was successful in producing mix designs with similar properties as Silica fume modified concrete. Satisfactory strength was achieved through increasing the fly ash and lowering the silica fume contents, though, chloride ion permeability was negatively affected. The removal of silica fume and the inclusion of Caltite decreased the concrete's resistance to chloride ion permeability and produced concrete that failed to attain the required 28-day ultimate compressive strength of 6500 psi.

The second part of this study focuses on developing an experimental setup to evaluate products and construction methods to help prevent water leakage through construction joints in pontoon floating bridges. A pressure system was used to apply significant pressures to concrete test specimens containing a construction joint. Different products and construction methods were used in constructing the joints to determine the most effective methods for preventing water penetration in the field.

The testing results have shown compaction effort is the most important factor in water leakage through a joint. Increased compaction in laboratory specimens leads to less water leakage through construction joints. Product selection was ineffective in preventing water leakage if concrete compaction was inadequate.

INTRODUCTION

BACKGROUND

The State of Washington has been designing and building concrete floating bridges since 1938. The original Lacey V. Murrow floating bridge opened to traffic in 1940, and was considered at that time to be one of the most innovative and controversial bridges in the world (Lwin el al. 1994). Since that time, Washington State has become a worldwide authority in the design and implementation of this practical and economically viable structure. Four floating bridges are currently in service in the state including the new Lacey V. Murrow Bridge, the Evergreen Point Floating Bridge (or the Second Lake Washington Bridge), the Third Lake Washington Bridge, and the Hood Canal Floating Bridge.

PROBLEM STATEMENT

It is the desire of the Washington State Department of Transportation to use a state of the art concrete mix design for the floating pontoon sections of the new Hood Canal Floating Bridge. The LVM mix design has worked well in the past, but there is room for improvements, which are discussed in detail in the forthcoming pages.

Concrete, similar to most construction materials, deforms under constant load sustained for a long period. This deformation is known as creep deflection and must be understood and accounted for in structural design. One main area of impact that creep has within concrete structures, and in particular prestressed concrete structures, is loss of prestressing force due to the shortening of the concrete member.

OBJECTIVES

The overall goals of this research are to improve the concrete mix design currently used in concrete floating bridges and to develop a watertight construction joint for these bridges. The LVM mix design is used as a baseline for the development of new mix designs suitable for use in concrete floating bridges. The intent is to explore new concrete technology and new materials that have emerged since the LVM creation in 1990, and to implement these into LVM alterations. Tests will be performed to determine properties in each mix and the results will be compared to the performance of the LVM. Conclusions will be formulated based on these results.

Some concrete properties are of primary importance in selecting a mix design for use in concrete floating bridges. These properties include fresh concrete workability, creep, shrinkage, compressive strength, and chloride permeability. Creep of concrete will be discussed in detail due to the relatively rare implementation of this test into mix design performance studies.

Research objectives for the study of watertight construction joints include:

- To investigate different alternatives for developing a watertight construction joint suitable for floating bridge pontoons.
- To design a laboratory experiment to simulate water infiltration in concrete pontoon joints under conditions similar to those experienced in the field.
- To recommend guidelines for reducing water penetration through a construction joint to be included in specifications for future floating bridges and other similar projects.

LITERATURE REVIEW

This literature review focuses on the key aspects of concrete mix design development and performance for use in concrete floating bridges. Topics of interest for this research were a previous floating bridge mix design study and mechanisms of concrete creep. Other noted literature included admixture and supplementary cementitious material effects on freshly mixed and hardened concrete properties.

CONCRETE FOR THE LACEY V. MURROW FLOATING BRIDGE

Concrete for the Lacey V. Murrow floating bridge was first developed with water tightness and durability of the concrete as the prime importance. The research committee conducted a concrete mix development program consisting of three phases. The first phase included the investigation of many trial mixes. These mixes were used to verify the resulting concrete properties produced by the inclusion of different supplementary cementitious materials and concrete admixtures.

EXPERIMENTAL METHODS

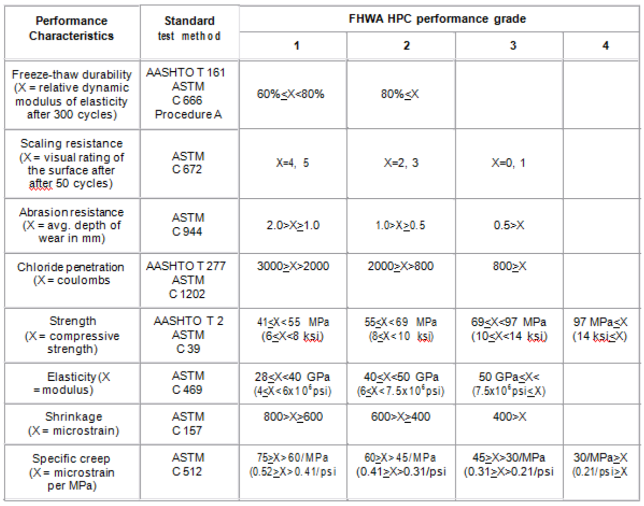
MATERIALS AND MIX DESIGNS

Concrete used in floating bridges must be designed with compressive strength, durability, and long-term properties as the critical factors for successful performance. The LVM mix design, of which the origin was previously described in detail, has these characteristics and was used as the reference mix for use in the development of new mix designs. The LVM concrete is Mix Design number 1 and Mix Design number 5 in this research.

EXPERIMENTAL RESULTS AND ANALYSIS

The Federal Highway Administration provides classifications for high performance concrete (HPC) with different performance characteristics. Grades of HPC are listed from 1 to 4, 1 having the lowest performance in each of the criteria. It should be noted that HPC grade 1 is still a high performance concrete and performs ”better” than normal concrete. The information is shown below in its original format in Table 4.1.

Table 4.1 - HPC Performance Grades (Table 1.2 - Definition of HPC according to Federal Highway Administration, Goodspeed, et al. 1996)



Performance Characteristics	Standard test method	FHWA HPC performance grade			
		1	2	3	4
Freeze-thaw durability (X = relative dynamic modulus of elasticity after 300 cycles)	AASHTO T 161 ASTM C 666 Procedure A	60%≤X<80%	80%≤X		
Scaling resistance (X = visual rating of the surface after after 50 cycles)	ASTM C 672	X=4, 5	X=2, 3	X=0, 1	
Abrasion resistance (X = avg. depth of wear in mm)	ASTM C 944	2.0>X≥1.0	1.0>X≥0.5	0.5>X	
Chloride penetration (X = coulombs	AASHTO T 277 ASTM C 1202	3000≥X>2000	2000≥X>800	800≥X	
Strength (X = compressive strength)	AASHTO T 2 ASTM C 39	41≤X<55 MPa (6≤X<8 ksi)	55≤X<69 MPa (8≤X<10 ksi)	69≤X<97 MPa (10≤X<14 ksi)	97 MPa≤X (14 ksi≤X)
Elasticity (X = modulus)	ASTM C 469	28≤X<40 GPa (4≤X<6x10^{6}psi)	40≤X<50 GPa (6≤X<7.5x10^{6}psi)	50 GPa≤X< (7.5x10^{6}psi≤X)	
Shrinkage (X = microstrain)	ASTM C 157	800>X≥600	600>X≥400	400>X	
Specific creep (X = microstrain per MPa)	ASTM C 512	75≥X>60/MPa (0.52≥X>0.41/psi	60≥X>45/MPa (0.41≥X>0.31/psi	45≥X>30/MPa (0.31≥X>0.21/psi	30/MPa≥X (0.21/psi≥X

CREEP

Measuring deformations to the precision necessary for accurate creep and shrinkage results is an intricate task. The accuracy required by ASTM C512 is one ten-thousandths of an inch. The specimen preparation procedure must be performed with care. Gage points should be perpendicular with the axis of the cylindrical specimen and should be parallel with each other so that the mechanical comparator can be used effectively. Drilling of the holes and gluing the points into the correct position is critical for useful results. If the gage points are not lined up correctly as previously described, accurate measurements can still be collected. To collect strain data, the same person should take all of the measurements and the mechanical comparator must be held at the same orientation with respect to the specimen and gage points each time a reading is taken.

SHRINKAGE

The engineers that designed the Lacey V. Murrow Bridge specifications placed a limit on the maximum allowable shrinkage strains in the pontoons. The length change of hardened concrete, tested according to AASHTO T160 or ASTM C 157, was required to be less than 400 millionths (micro-strain) at 28 days. As was discussed previously, shrinkage strain must be kept to a minimum so that shrinkage cracking does not occur and allow water to penetrate into the pontoon cells.

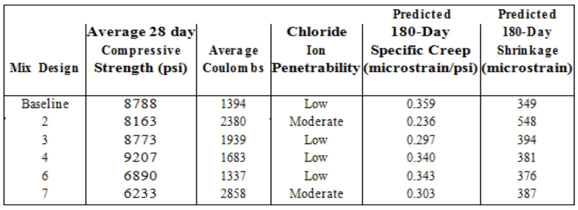
SUMMARY AND CONCLUSIONS

This research provides a comparative study of several concrete mix designs for use in floating bridges for the purpose of improvements in existing practices. The Lacey V. Murrow (LVM) mix design is used as a baseline mix and alterations are made to that design to improved the concrete performance.

The concrete mixes were studied for their fresh and hardened properties including the 28-day compressive strength, chloride ion permeability, creep and shrinkage. For purposes of comparison and determination of a better mix design, it is advantageous to have a reference mix. Results are tabulated in Table 5.1 and should be referred to when reviewing the conclusions reached.

Results of this research reiterates that the LVM mix design is a quality, high performance concrete mix. The LVM has performed well in all the categories tested, and has only slightly been improved in some areas by certain mix alterations. Though the mix design was developed in 1991, it remains a mix that is quite suitable for use in concrete floating bridges. Bridge designers must evaluate the importance of minor improvements in the LVM concrete performance for the benefits in the application.

Table 5.1 – Mix Design Test Results



Mix Design	Average 28 day Compressive Strength (psi)	Average Coulombs	Chloride Ion Penetrability	Predicted 180-Day Specific Creep (microstrain/psi)	Predicted 180-Day Shrinkage (microstrain)
Baseline	8788	1394	Low	0.359	349
2	8163	2380	Moderate	0.236	548
3	8773	1939	Low	0.297	394
4	9207	1683	Low	0.340	381
6	6890	1337	Low	0.343	376
7	6233	2858	Moderate	0.303	387

LITERATURE REVIEW

This literature review focuses on three main topics. The first one is the history of floating bridges with special attention to the Hood Canal Floating Bridge. The second topic is on mix designs used on past floating bridges in the state of Washington. Finally, the third topic is on concrete experiments that addressed leakage tests through cracked concrete elements, waterstop testing and compaction level tests for concrete construction joints.

FLOATING BRIDGE HISTORY

Floating bridges have been an important element of the transportation system for the Puget Sound and Seattle, Washington area for over 60 years. Lwin (1993b) stated that floating bridges have been constructed to cross wide bodies of water where the depth of water is very great or the soil bottom is too soft making conventional bridges too expensive. Lwin et al. (1984) discussed a relative cost analysis performed during the replacement of the west half of the Hood Canal Floating Bridge in the early 1980's. The relative cost of the floating bridge replacement was at least two-and-a-half times less expensive than a conventional fixed bridge. Lwin (1993b) stated that experience has shown prestressed concrete bridges are an economical, durable and low maintenance bridge solution.

TEST RESULTS

MIX CHARACTERISTICS

The characteristics of the mix prepared at Washington State University were described in Table 8.2. All specimens were prepared as closely to the LVM mix design as possible. The amount of water reducer used per mix was slightly modified to create a more workable mix. Concrete compressive strength and slump were determined for six test cylinders made with the given mix. Slump tests and compressive strength tests were not performed for each concrete pour due to the similarity between pours.

EXPERIMENT 1 TEST RESULTS

Four 8x12x16 inch concrete specimens were tested in the first experiment according to methods described in section 8.3. The specimens tested in the first experiment were two controls, one with and one without a construction joint and two waterstops, the MC-2010MN product and the Synko-flex product.

EXPERIMENT 2 TEST RESULTS

As discussed in Chapter 8, the setup of the first experiment was modified to apply a variable air pressure to the system as described in section 8.4. A variable air pressure system was used because the pressure that would cause leakage through the specimens was unknown. Air pressure could be slowly increased until leakage occurred through the joint. The initial water pressure on the system was 16.48psi.

THIRD EXPERIMENT: TEST RESULTS

The three waterstops tested in the third experiment performed very differently. Measurements of waterstop expansion and thickness increases were taken. Waterstops damaged during handling were removed from testing. Testing began with three samples of each waterstop.

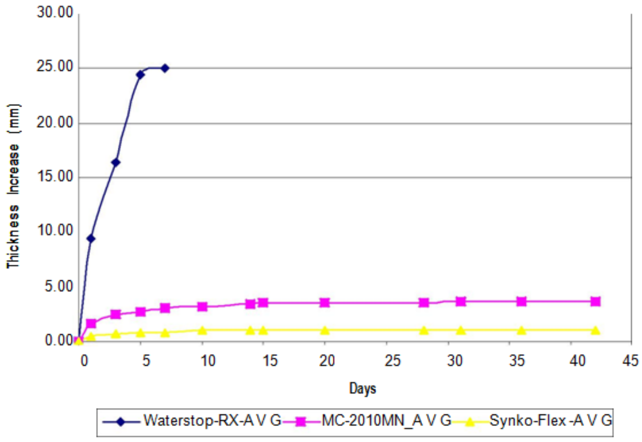


Figure 9.10 - Average thickness increases of waterstop samples in the third experiment.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The main objective of this study was to investigate alternatives for creating a watertight construction joint for inclusion in the specifications for the Hood Canal East Half Replacement Project. Determining the

effectiveness of different products and construction methods at preventing water penetration will give WSDOT a starting point in building better more watertight joints for floating bridges.
The testing methods used in this study did not conform to a standard testing method due to the lack of such methods. The first experiment performed in this study worked correctly but the pressure applied by the system was too low to give any significant experimental results. Consequently, a second experimental procedure was used that applied a variable air pressure to the system. The system of the second experiment did increase the pressure applied to the specimens by over five times the pressure of experiment one but did not provide results for determining one products effectiveness over another at preventing water penetration.

The first two experiments were effective in showing that compaction is the deciding factor in water penetration through the construction joint. The greater the concrete compaction at the joint the less likely it will leak under pressure. Specimens in stages one and two were compacted to a higher level than stage three specimens through the use of a mechanical stinger. There was excellent compaction at the joint and no observed honeycombing in any of the specimens of the first two stages. Stage three specimens were compacted by stick strikes of the slump rod dropped into the freshly poured concrete. The compaction level of stage three specimens was much lower than that of the first two stages. Honeycombing was observed in all specimens and was most severe near the joint. The honeycombing provided openings within the concrete to easily allow passage of water through the joint.

Product selection did not play an important role in preventing or decreasing water leakage through the joint. Poorly compacted specimens leaked immediately regardless of the applied product while all well-compacted specimens remained watertight. Honeycombing of the concrete near the joint signified poor compaction that has a high likelihood of leaking.

Products that should be most effective in helping to prevent water leakage through the joint are those that increase compaction at the joint. The mortar/slurry mixture applied to the first few inches of the joint helped improve compaction of the joint. The stage three specimen built using this construction method was one of only two specimens that did not leak before being placed within the testing setup. The removal of coarse aggregate from the first few inches of the second pour allowed the concrete to compact at a lower compaction effort than would be needed for a similar mix containing coarse aggregate. The mortar/slurry had the added benefit of helping to replace fines lost from segregation of the concrete when placed in a tall wall.

The third experiment was performed to determine the expansion rates of the three waterstops submerged in water. The Waterstop-RX 101TRH and MC-2010MN products saw significant expansion and thickness increases within the first two weeks of testing. The use of these two products in a joint exposed to significant moisture for an extended period of time could cause these products to lose their effectiveness as a water barrier. The Synko-flex waterstop retained its original shape and should not be damaged by extended exposure to significant moisture. The Synko-flex product performed the best of the three waterstops tested in the third experiment but has not been proven to effectively reduce water penetration at the joint; more testing needs to be performed using a compaction level that demonstrates the Synko-Flex products ability to reduce water penetration more effectively than a similar jointed control specimen for a given air pressure.

GENERAL GUIDELINES FOR WATERTIGHT JOINT

The following general guidelines will help improve the resistance to water penetration for a concrete construction joint.

- The top surface of the joint should be compacted to as high a compaction level as can be achieved in the field.

- Repair any honeycombed concrete in the vicinity of the construction joint.
- Use materials and construction methods to construct the joint that improve compaction at the joint such as the mortar/slurry mixture.
- Products such as waterstops and surface coatings may help to decrease water penetration through the joint, but are far less important than good construction practices when building the joint.

RECOMMENDATIONS FOR FURTHER STUDY

Clearly, there is a need for further testing to determine the ability of individual products to prevent or reduce water penetration through a concrete construction joint.

The setup of the second experiment can be used to test these products. The products and testing methods used in this study along with additional products should be tested using the experimental setup of the second experiment with several small modifications.

The minimum compaction needed to prevent water leakage through the construction joint of the control specimen should be determined for the initial 16.48psi system pressure caused by the 4 foot water elevation. This minimum compaction should be used with all specimens to determine the air pressure necessary to cause leakage through the joint. Using this minimum compaction level will allow the most effective products for limiting water penetration to be determined.

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