Hawaii Transportation Department High Performance Bridge Deck Mix

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ABSTRACT

This paper presents the description of the North-South Road grade separation structure. The emphasis will be placed on the novel deck topping concrete design mix, which limited bleeding, plastic shrinkage, drying shrinkage, creep and fatigue. The topping concrete was made with Type I/II cement, 3F Basalt rock, sand from British Columbia, and Dune sand. The concrete sand is manufactured from basalt rocks. The water cement ratio was 0.37. The following admixtures were employed 1) water reducer-Type A,B&D 2) High Range Water Reducer-Type A&F 3) Hydration Stabilizer-Type B&D 4) Viscosity Modifying Admixture-Type S 5) Shrinkage Reducing Admixture-(SRA) 6) Synthetic Air Entrainer-Miracon. Miracon is more stable than typical surfactant AEA's, because it is formulated with polymers that are chemically inert. Fibers were employed to help in plastic shrinkage and fatigue. Visible deck cracks have not been observed to date (October 2009).

Keywords: high performance bridge deck concrete

INTRODUCTION

The North-South Road project is a limited access 2.2-mile principal arterial highway that would connect Interstate Route H-1 Freeway to the proposed Kapolei Parkway. The project is located in the District of Ewa, Island of Oahu, and State of Hawaii. The North-South Road is perpendicular to the Interstate Route H-1 Freeway. At the intersection, it was necessary to build a grade separation structure above the North-South Road and parallel to the H-1 Freeway. The H-1 Freeway is the principal arterial highway connecting West Oahu to Honolulu. This paper presents the description of the grade separation structure. The emphasis will be placed on the novel deck topping concrete design mix, which limited bleeding, plastic shrinkage, drying shrinkage and creep. The bleeding increases permeability, reduces abrasion resistance, and forms microscopic voids under the deck reinforcing. Traffic vibration induces cracks from the voids along the reinforcing. The cracking is increased as the concrete loses its strength from fatigue caused by traffic vibration.

GRADE SEPARATION STRUCTURE

Two grade separation structures were built. One structure carried the westbound traffic and the second structure carried the eastbound traffic. Each structure width is 56 feet, with three 12 feet traffic lanes, and two 10 feet shoulders. The bridge span is 165 feet. The spliced girders consisted of three pre-tensioned girder segments that were 40 feet, 80 feet and 40 feet, in length. The girders were spliced at the site and post-tensioned. These 66-inch girders were modified Washington State Department of Transportation (WF74PTG) spliced girders that was fabricated in Tacoma, Washington and barged to Hawaii.
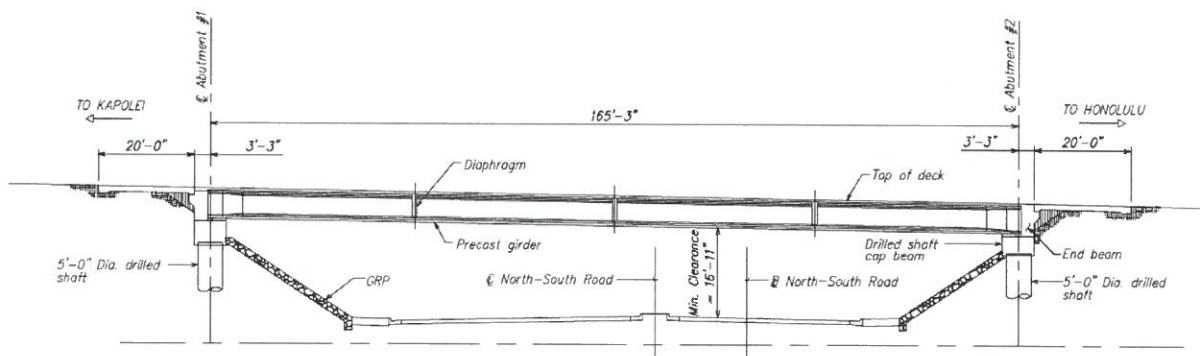
Eight girders were spaced in the 56 feet width. The bridge deck consisted of a 3-1/2 inch deep precast plank spanning 7 feet-six inches with a 5-inch topping. The super-structure was supported by four, 5 feet diameter drill shafts at each abutment. The grade separation structure was designed as an integral abutment bridge with no joints.

DECK CONCRETE MIX DESIGN

The deck concrete mix design was designed with the view of minimizing concrete cracking. The deck concrete mix was used for the precast planks and deck topping. Bleeding results in fine

aggregates migrating to the top and weakening the concrete of the wearing surface. The migration of the fine aggregates leaves a void under the topping reinforcing. Creep and shrinkage give large tensile strains in the deck. Fatigue is speculated as the major cause of deck concrete spall in Hawaii. A secondary objective was to limit the effects of creep and shrinkage and to limit the effects of concrete fatigue in the deck.

The concrete mix was made with Type I/II cement, 3F Basalt rock, Sand from British Columbia, and Dune Sand. The concrete sand is manufactured from Basalt rock. The specification for the deck topping concrete requires a 28 day compressive strength of 6,000-psi. A 0.37 water-cement ratio was required to achieve the desired compressive strength. The following admixtures were utilized to achieve a workable concrete that would not bleed and have low shrinkage and creep. The admixtures were 1) water reducer-Type A,B&D 2) High Range Water Reducer-Type A&F 3) Hydration Stabilizer-Type B&D 4) Viscosity Modifying Admixture-Type S 5) Shrinkage Reducing Admixture-(SRA) 6) Synthetic Air Entrainer-Miracon. Miracon is more stable than typical surfactant AEA's because it is formulated with polymers that are chemically inert.

The materials and proportions of the concrete were selected based on providing a mix that had less shrinkage than existing deck mixes. Tests were conducted locally and at a certified national testing lab to confirm locally testing results.

Cement	752 lb/cu yd
British Columbia Sand	1292
3F Basalt Rock	1547
3/8" Basalt	120
Water	280
Total	3991 lb/cu yd

To achieve the desired reduction in plastic shrinkage and fatigue qualities, macro-fibers and micro-fibers were employed. Macro-fibers typically refer to fibers which have a diameter larger than the cement grains. Micro-fibers typically refer to fibers which have a diameter smaller than the cement grains. Both micro- and macro-fibers were polyprylene.

CONCRETE TESTING

Construction Technology Laboratories, Skokie, Illinois was employed to conduct the concrete testing. The Hawaiian cement, aggregates and sand were shipped to Skokie to fabricate the test specimen. The admixtures were shipped directly from vendors.

Compressive Strength Test

ASTM C 39, "Test Method for Compressive Strength of Cylindrical Concrete Specimens," was followed to fabricate 4-inch diameter and 8-inch long specimen. Three cylinders each were tested at age 3-day, 7-day and 28-day. The average compressive strength for each age was 6460-psi, 8390-psi, and 9630-psi. The 6000-psi specification compressive strength at 28-day was met.

Flexural Strength of Concrete Beam Specimens

ASTM C 78, "Flexural Strength of Concrete Beam Specimens," was followed to fabricate 6 x 6 x 18 inch beam specimens. Three specimens were tested in flexure with third point loading. The

failure stress was 974-psi, 1025-psi, and 960-psi. The average flexural strength is 986-psi. The results from the flexural strength tests were used to determine the loads for the fatigue tests.

Fatigue Tests

Three specimens for each stress level were tested in fatigue. The cycles to failure in the table represents the average of three tests. The concrete age at the time of testing is 28-day. The specimens were cured at 73.4$\pm$3 ^{o}F, 100% RH. The specimen geometry was identical to that of the flexural strength tests.

Stress Level	Cycles to Failure
60%	457,916
65%	315,141
70%	150,134
75%	8,846
80%	3,576
85%	1,544
90%	219

The failed specimens were inspected at the failure surface to determine the mode of failure of the fibers. Fracture of fibers was not observed.

Bleeding

ASTM C 232, "Standard Test Methods for Bleeding of Concrete," was followed to determine the tendency of the mix to bleed. Method A, sample consolidated by tamping, was used to evaluate bleeding. A cylindrical container approximately ½ ft^3 capacities was used to house the concrete.

Readings of the bleed water were taken at intervals specified by the standard. The design mix showed minimal tendency to bleed.

Bond Strength

ASTM C 234-91, "Standard Test Method for Comparing Concretes on the Basis of Bond Developed with Reinforcing Steel," was followed to evaluate bond strength. Three beam
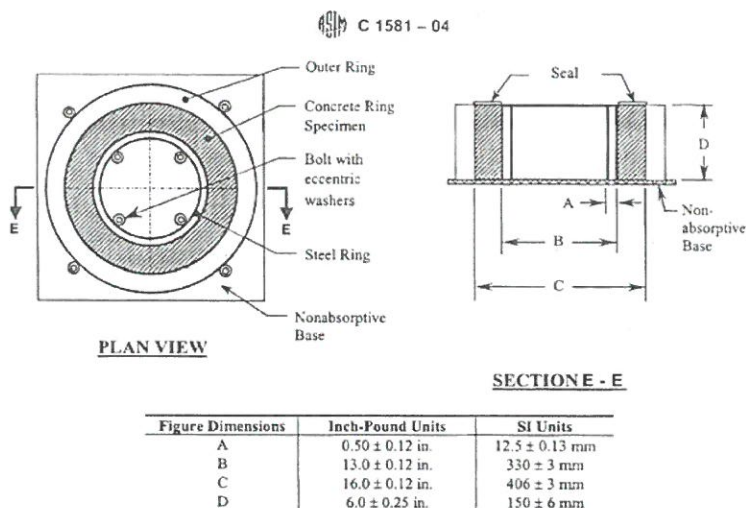
Specimen	Pullout Load, lbf	Bond Stress, psi	Slip at Failure, inch
C-Bot Bar	42021	2972	-0.188
C-Top Bar	37170	2629	-0.118
B-Bot Bar	41663	2946	-0.178
B-Top Bar	38452	2719	-0.128
A-Bot Bar	36978	2615	-0.108
A-Top Bar	34012	2405	-0.055

specimens were fabricated with one top bar and one bottom bar. The concrete compressive strength was 9630-psi. The above table summarizes the test results. There is no statistical difference between top bars and bottom bars. This result confirms the observation that there is no bleeding in this mix design.

Creep and Shrinkage

The evaluation of concrete creep and shrinkage was undertaken by ASTM C 512,"Standard Test Method for Creep of Concrete in Compression," and ASTM C 1581-04, "Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage." The creep tests were conducted by CMT Engineering Laboratories, North South Lake, Utah. Six-inch diameter concrete cylinders were the test specimen. A vibrating wire strain gage was placed along the axis of the cylinder. Two sets of cylinders were required. One set without axial loads and a second set under constant axial load. This combination made it possible to determine creep and shrinkage.

The test for concrete under restrained shrinkage is conducted by fabricating a concrete pipe section exterior and concentric to a steel pipe. The outer diameter of the concrete section is 16 inches. The concrete inner diameter is 13 inches. The concrete pipe is cast against a steel pipe. The top and bottom planar surfaces are sealed to prevent concrete moisture from escaping to the atmosphere. Electrical strain gages are placed circumferentially around the steel ring. The circumferential strain of the steel ring is monitored for the duration of the test. As the concrete pipe shrinks, it compresses the steel ring. The steel ring strain is recorded for the duration of the test, or until the specimen cracks. The concrete of the ring test has no embedded gages. The concrete cylinder test has an embedded vibrating wire strain gage. The ring test is superior to the cylinder test because the concrete in the ring test is free of embedded gages.

Figure Dimensions	Inch-Pound Units	SI Units
A	0.50 ± 0.12 in.	12.5 ± 0.13 mm
B	13.0 ± 0.12 in.	330 ± 3 mm
C	16.0 ± 0.12 in.	406 ± 3 mm
D	6.0 ± 0.25 in.	150 ± 6 mm

Three ring specimens were cast and were tested. The primary purpose of the ring test is to determine concrete cracking potential. The time when cracking occurred was 34.0, 38.4 and 36.9 days with steel ring strains of -92, -72, and -73 micro-in/in. For typical concrete mixes, cracking occurs in seven days. The test results show that the presented concrete mix is superior in resisting cracking caused by shrinkage. A finite element model was constructed to estimate the concrete circumferential tensile strains corresponding to the measured steel compressive strains. For the concrete an elastic modulus of 5,000-ksi and a Poisson ratio of 0.21 were assumed. The

calculated concrete tensile strains from the measured compressive steel ring strains were 196, 154, and 156 micro-in/in. The corresponding concrete tensile stress is 980-psi, 770-psi and 780-psi. Using the ACI formula for modulus of rupture and a compressive strength of 9630-psi, the modulus of rupture is 736-psi. The finite element results compare favorably with the ring test results.

At 36 days, the concrete cylinder data gives a shrinkage strain value of 102 micro-in/in. The volume to surface area for the cylinder is 1.5-inch. For the ring, the volume to surface area is 1.36-inch. There is more surface area per unit volume for the cylinder than the ring so it is expected to have larger shrinkage. The measurements and the computer model verify this expectation.

The cylinder shrinkage strains have been taken for a year, and at one year, the shrinkage is equal to 531 micro-in/in. At the same time, the creep coefficient is 1.5.

ABRASION RESISTANCE

ASTM C 779, "Standard Test Method for Abrasion Resistance of Horizontal Concrete Surfaces, Procedure A- Revolving Disks," was employed to evaluate abrasion resistance of the concrete deck mix. The depth of wear is reported at 2, 5, 15, 30, 60 minutes after abrasion. The concrete samples are 12 in. x 12 in. by 3 in. thick.

FIG. 1 Revolving Disks Abrasion Test Machine
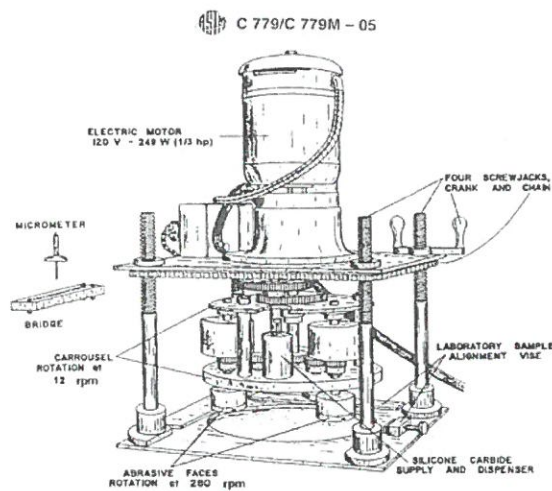
The revolving disks abrasion test machine was used to evaluate concrete surface abrasion. The resulting test data is presented in the table below. This test method is not intended to provide a quantitative measurement of the length of service that may be expected from a given concrete surface, but used to evaluate the effects of concrete materials and curing or finishing procedure on the abrasion resistance of concrete.

Test Results
Depth of Wear, in.

Sample ID	0 minutes	2 minutes	5 minutes	15 minutes	30 minutes	60 min
A	0.000	0.004	0.007	0.017	0.026	0.038
B	0.000	0.008	0.012	0.020	0.027	0.039
C	0.000	0.007	0.013	0.023	0.030	0.041
Ave	0.000	0.006	0.011	0.020	0.028	0.039
A			0.000	0.010	0.020	0.031
B	Per ASTM C 779*		0.000	0.008	0.014	0.026
C			0.000	0.010	0.018	0.028
Ave			0.000	0.009	0.017	0.029

*Per ASTM C 779, initial measurement taken after 5 minutes of abrasion

CONCLUSIONS

A very workable, easy to finish, concrete mix was achieved. At the time of casting the deck surface showed no signs of bleeding. Plastic shrinkage cracks were not observed. The laboratory testing showed a minimum amount of drying and autogenous shrinkage. The SRA was effective in also reducing the amount of creep. The laboratory testing showed a concrete with minimum amount of abrasion and good bond between the concrete and reinforcing steel. The grade separation structure has been open to traffic for a period of six months and to date (October 2009) there are no visible cracks in the deck.

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