Bridge Views

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HPC for the North-South Road Grade Separation Structure, Hawaii

Harold Hamada, KSF, Inc.

HPC was used in the spliced beams and deck.

The North-South Road Project, in the District of Ewa on the Island of Oahu, HI, involves the construction of a limited access, 2.2-mile (3.5-km) long principal arterial highway that connects Interstate Route H-1 to the proposed Kapolei Parkway. A grade separation structure was required to connect the North-South Road to the H-1 Freeway. The H-1 Freeway is the principal arterial highway connecting West Oahu to Honolulu.

The grade separation structure consists of two separate parallel bridges that span 165 ft (50.3 m). Each bridge is 56 ft (17.1 m) wide, with three 12-ft (3.7-m) wide traffic lanes and two 10-ft (3.1-m) wide shoulders. Eight precast, spliced girders are used in the 56 ft (17.1 m) width. The bridge deck consists of precast reinforced concrete planks and a cast-in-place (CIP) topping. Four, 5-ft (1.5-m) diameter drilled shafts support each abutment. The grade separation structure is an integral abutment bridge with no joints.

Spliced Girders

The girder cross section is a 66-in. (1.68-m) deep modified Washington WF74PTG girder. The precaster fabricated 80- and 40-ft (24- and 12-m) long girder segments in Tacoma, WA, loaded the segments on barges, and shipped them to Hawaii. The specifications required a compressive strength of 10,000 psi (69 MPa) at 28 days. The average compressive strength was 12,120 psi (83.5 MPa) with a standard deviation of 1286 psi (8.37 MPa). The concrete was steam cured at a temperature of 140 to 160°F (60 to 70°C) until the concrete achieved a compressive strength of 5000 psi (34 MPa) before release of the prestressing strands. During the steam curing operation, a maturity meter was used to estimate the concrete compressive strength.

The contractor spliced the 40-, 80-, and 40-ft (12-, 24-, and 12-m) long segments in the field to achieve the desired 165 ft (50.3 m) span. Concrete for the splice had a specified compressive strength of 9000 psi (62 MPa) at 28 days and a specified slump of 7 ± 2 in. (178 ± 50 mm). The concrete contained a water reducer, high-range water-reducer, viscosity modifying admixture, and a corrosion inhibitor. The post-tensioning operation commenced after the splice concrete reached a compressive strength of 8000 psi (55 MPa).

Bridge Deck

The bridge deck comprised 3-1/2-in. (90-mm) thick precast reinforced concrete planks spanning 7 ft 6 in. (2.3 m) with a 5-in. (125-mm) thick CIP composite topping. The topping concrete materials and proportions were selected to minimize drying shrinkage, enhance fatigue endurance, minimize bleeding, and reduce plastic shrinkage compared to previous deck mixes. A shrinkage-reducing admixture (SRA) was used to reduce drying shrinkage. Polypropylene macro-fibers were used to increase the fatigue endurance limit and toughness. Polypropylene micro-fibers were used to limit plastic shrinkage cracking. A synthetic air-entraining admixture (AEA) was used to improve the workability of the concrete. A synthetic admixture is more stable than typical surfactant AEAs because of the chemically inert polymers. In addition to the SRA and AEA, a water reducer, high-range water reducer, hydration stabilizer, and a viscosity modifying admixture were included in the concrete mix. No supplemental cementitious materials were used. During the deck casting operation, balling or clumping of the fibers, bleeding, and plastic shrinkage cracks were not observed. The deck received a 7-day continuous wet cure. The 3-1/2-in. (90-mm) thick precast reinforced concrete planks were 3 ft 11 in. (1.19 m) wide by 7 ft 11 in. (2.41 m) long and made with 6000 psi (41 MPa) compressive strength concrete. The concrete mix for the planks was similar to the mix for the CIP topping, but without the SRA and fibers. The contractor removed the precast planks from the forms 24 hours after casting when the concrete compressive strength ranged from 2500 to 3200 psi (14 to 22 MPa).

The grade separation structure was opened to traffic in January 2009 and to date no drying shrinkage cracks have been observed. The grade separation structure is functioning as designed.

Further Information

For further information about this project, please contact the author at haroldh@ksfinc.us.

(articles continue on next page)

Concrete Materials

Property	Precast Segments	CIP Splice	Precast Planks	CIP Deck
Specified Compressive Strength at 28 days, psi	10,000	9000	6000	6000
Water-Cementitious Materials Ratio	0.27	0.33	0.33	0.33
Cement Type	III	I/II	I/II	I/II
Fine Aggregate Source	Tacoma Quarry	British Columbia	British Columbia	British Columbia
Course Aggregate Source	Tacoma Quarry	Kapaa Quarry 3 F Basalt(1)	Kapaa Quarry 3 F Basalt(1)	Kapaa Quarry 3 F Basalt(1)

1. 3 F is equivalent to No. 67 per ASTM C33.

HPC Precast Panels Provide Accelerated Construction of 24th Street Bridge

Ahmad Abu-Hawash, Iowa Department of Transportation and Hussein Khalil, HDR Inc.

24th Street Bridge, Council Bluffs, IA. Photo: Keith Philpott

The Council Bluffs Interstate System project affects 11 interstate-to-local road interchanges as well as three interstate-to-interstate interchanges along an 18-mile (29 km) stretch of I-80 and I-29 in Council Bluffs, IA—a corridor that is carrying more than double its originally intended traffic capacity. The first segment scheduled for construction was the 24th Street interchange, an important arterial serving several major attractions and businesses.

For the project to be successful, it was essential to maintain three lanes of traffic throughout construction of the new interchange. Consequently, each half of the bridge was replaced in separate phases. It also was determined that traffic restrictions should be limited to a single construction season (April through October) as opposed to the two seasons it typically would take to complete a project of this scope. As a result, maintaining traffic flow and the accelerated construction schedule became the driving forces in the bridge's design.

HPC Precast Panels Prevail

Because of the need to construct the bridge quickly and avoid closures to the interstate highway below, the design team selected full-depth, full-width precast deck panels in lieu of a traditional cast-in-place concrete deck. Each panel was 10 ft x 52 ft 4 in. x 8 in. (3.05 m x 16.0 m x 200 mm) and transversely pretensioned with twenty 0.5-in. (13-mm) diameter low relaxation strands initially tensioned to 31 kips (138 kN) each. Twenty-three flat polyethylene ducts were embedded near the top of each panel for longitudinal post-tensioning after erection.

The panels were placed in two primary phases of 35 panels each, with a cast-in-place longitudinal closure joint between each half. A 2-in. (50-mm) thick low slump, high density concrete overlay riding surface provided an additional layer of corrosion protection and provided the final profile. This project was the first Iowa Department of Transportation (IaDOT) project to use high performance concrete (HPC) in the western part of Iowa. Due to material suitability, use of HPC in western Iowa had been at an impasse.

Methods to level the panels and form the slab build-up below the deck panels were left to the contractor; however, the plans included optional details that could be used by the contractor to aid in setting the panels to the correct elevations. The contractor elected to level the panels with leveling bolts and to form the slab build-up using lumber power nailed to the bottom of the deck. The transverse joints were filled with conventional high-strength, non-shrink grout.

A female-to-female transverse joint between panels eliminated the need for match-casting and reduced the risk of damaging panel edges during erection and post-tensioning. Experiences on other projects showed this type of joint tended to perform better than other joint types, especially where longitudinal post-tensioning had been utilized. Details of the transverse joint and a plan view layout are provided in the reference below.

The longitudinal post-tensioning consisted of four 0.6-in. (15.2-mm) diameter strands in each of the 23 ducts. Each strand was initially tensioned to 41 kips (182 kN). Longitudinal post-tensioning force was applied after the grout in the transverse joints had attained the required strength of 6000 psi (41 MPa). The amount of post-tensioning force was computed in order to eliminate any tension in areas where auxiliary reinforcement was not provided. Tension in the panels was caused by the composite dead load, live load, and impact in the negative moment region near the pier. This criterion controlled the post-tensioning design at the transverse joints between the panels. After post-tensioning, the deck panels were made composite with the steel girders using steel studs installed through pockets in the panels.

Analysis to determine the needed amount of post-tensioning showed that both the age and concrete strength of the panel at the time of post-tensioning have a significant effect on the amount of losses. For example, a 6000 psi (41 MPa) strength panel would be required to be 100 days old before the post-tensioning force could be transferred to the concrete, while a 12,000 psi (83 MPa) panel would need to be 28 days old before post-tensioning. With an October letting date and an expected erection of the panels in June, this would require an accelerated winter fabrication schedule and storage of the panels—resulting in an economic disadvantage to the project. To avoid this situation and to provide as much flexibility as possible during construction, the precasting contractor was given the option of designing a concrete mix that would yield the required design strength while accommodating the construction contractor's accelerated schedule and minimizing fabrication costs. This resulted in a specified compressive strength of 11,000 psi (76 MPa) for post-tensioning at 28 days, 10,000 psi (69 MPa) at 40 days, 9000 psi (62 MPa) at 70 days, or 8000 psi (55 MPa) at 100 days. The contractor selected a target strength of 9500 psi (66 MPa). The panel ages ranged from 30 to 75 days for Phase 1 and 60 to 100 days for Phase 2. All panels in Phase 2 were erected in less than 1 day.

The concrete for the deck panels was specified to have a target rapid chloride permeability of 1500 coulombs at 28 days. The test specimens were wet cured at 73°F (23°C) until age 7 days followed by water curing at 100°F (38°C) for 21 days. The concrete mix design contained 865 lb/yd3 (513 kg/m3) of cementitious materials consisting of 65% portland cement, 20% Grade 120 ground granulated blast-furnace slag, and 15% Class C fly ash at a water-cementitious materials ratio of 0.28. The panels were steam cured after removal from the formwork and achieved concrete compressive strengths ranging from 9140 to 12,470 psi (63.0 to 86.0 MPa). The average strengths were 11,490 and 10,160 psi (72.2 to 70.1 MPa) for Phases 1 and 2, respectively. This project was partially built with funding from the FHWA Highways for LIFE (HfL) initiative and the Innovative Bridge Research and Construction (IBRC) program. The project was substantially completed in 179 days.

Summary

The design incorporated details from past projects, as well as the latest in research in the areas of deck panels. Coordination among the designer, the owner, local contractors, and fabricators was key to developing an economical design that could be constructed under an accelerated timeframe, while minimizing disruption to the traveling public and enhancing safety during and after construction. To date, no reflective cracking in the overlay above the joints has been observed.

Acknowledgements

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Further Information

For further information about this project, please contact the second author at hussein.khalil@hdrinc.com. or see the following reference.

Reference

Abu-Hawash, A., Khalil, H., Schwarz, P., Phares, B., and McDonald, N., "Accelerated Construction and Innovations, The 24th Street Bridge," Proceedings, The National Bridge Conference, Bridges for Life, October 4-7, 2008, Orlando, FL, Precast/Prestressed Concrete Institute, Chicago, IL, Compact Disc, 2008.

High strength lightweight concrete was specified for the Route 33 Bridge over the Mattaponi River, VA.

Specifying High Strength Lightweight Concrete for Bridges

Reid W. Castrodale and Kenneth S. Harmon, Carolina Stalite Company

High strength lightweight concrete (HSLWC) is gaining wider use for bridges, especially in pretensioned girders. HSLWC offers the structural advantage of longer spans, reduced cost of girder transportation, and reduced cost of the entire structure because the superstructure weighs less. An example is the bridge shown in the photo, which carries Route 33 over the Mattaponi River at West Point, VA. HSLWC was used for the girders to achieve 240-ft (73.2-m) long spans.

HSLWC is produced in the United States using lightweight aggregates (LWA) manufactured by processing shale, clay, or slate at high temperatures. This article introduces the topic of specifying HSLWC for bridges; a key issue that must be addressed if the material is to be used successfully.

The main characteristics that must be addressed in a specification for HSLWC are the lightweight aggregate properties, aggregate absorption, concrete compressive strength, concrete density, air content, and resistance to freezing and thawing.(1) Each of these is discussed below. In some situations, other properties such as modulus of elasticity, creep, and shrinkage may be specified, especially for more complex structures where deflections or time-dependent effects are significant. To avoid unnecessary complication and expense, only properties that are essential to accomplish the project should be specified.

Aggregate Properties

Structural lightweight aggregates are just another type of aggregate that, when used in concrete, result in lower density concretes. Therefore, lightweight aggregate and concrete must meet the same structural and durability requirements that are imposed on normal weight concrete. Lightweight aggregate must satisfy the minimum requirements given in AASHTO M 195 Standard Specification for Lightweight Aggregates for Structural Concrete.(2) This specification stipulates several characteristics and properties for LWA and LWC, including grading and bulk density requirements and minimum average tensile splitting and compressive strength requirements. A maximum limit on drying shrinkage of concrete is specified, but it is only intended as an acceptance test for the lightweight aggregate.

Other aggregate properties may also be specified, such as resistance to freezing and thawing of aggregate, abrasion resistance, soundness, reactivity, and silica content. Some owners also specify the type of raw material from which the lightweight aggregate is manufactured.

Aggregate Absorption

The absorption of lightweight aggregates is greater than the absorption of normal weight aggregates. The moisture content of lightweight aggregate prior to batching must be carefully monitored especially when the concrete is to be pumped. Therefore, requirements to ensure proper moisture conditioning of the LWA prior to batching and/or limits on absorption should be specified. It is suggested that the specifications require the concrete supplier to submit a quality control plan for the production of LWC so that issues related to moisture control can be properly addressed.

Concrete Compressive Strength

HSLWC with design compressive strengths up to 10,000 psi (69 MPa) and an equilibrium density of 120 lb/ft3 (1920 kg/m3) has been successfully used.(3) The minimum specified compressive strength must be compatible with the density specified. As with any type of aggregate, the compressive strength of lightweight concrete may be limited by the strength of the aggregate. Designers should consult concrete suppliers to confirm that the desired combination of concrete strength and density are achievable.

Concrete Density

In most cases, lightweight concrete is used in a structure to reduce the dead load. Therefore, the density must be specified. Contract documents should specify the "equilibrium density," which is defined in ASTM C567(4) as the density after exposure to a relative humidity of 50% and a temperature of 73°F (23°C) for sufficient time to reach a constant mass. It generally takes at least 90 days to obtain equilibrium density.

The density of fresh LWC is measured at the point of placement and used for acceptance. Designers may specify the fresh density. Alternatively, they may require the concrete supplier to provide a fresh density corresponding to the specified equilibrium density. A concrete or lightweight aggregate supplier can assist the designer in selecting an appropriate pair of consistent values. It is recommended that maximum densities be specified rather than densities with a tolerance.

If the weight of a member for handling, transportation, or erection is a concern, the fresh density should be used to compute the member weight because the concrete will not lose much moisture before handling, transportation, or erection. Contract documents must also indicate the density of reinforced concrete used for dead load calculations. This includes an allowance for reinforcing steel that is usually taken as an extra 5 lb/ft^3 (80 kg/m^3).

Entrained Air

While entrained air is generally used to protect the paste in concrete from damage caused by freezing and thawing, it is also used in LWC to improve its workability and finishing characteristics and to further reduce the concrete density. Air content must be measured at the point of placement using the volumetric method per AASHTO T 196(5) and not the pressure method per AASHTO T 152.(6)

Freezing and Thawing Resistance

Where resistance to freezing and thawing is important, testing should be required according to AASHTO T 161 Procedure A.(7) The standard test method must be modified for lightweight concrete by allowing specimens to dry prior to testing as specified in AASHTO M 195.(2) This modification must be followed to obtain meaningful results.

References

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2. Standard Specification for Lightweight Aggregates for Structural Concrete, AASHTO M 195, American Association of State Highway and Transportation Officials, Washington, DC.
3. Georgia Department of Transportation, "Special Provisions: Section 500—Concrete Structures," Contract Documents for Project No. MSL-003-00(161) & IM-85-1(356), Coweta & Meriweth-

er Counties, August 23, 2006, 5 pp.

4. Standard Test Method for Determining Density of Structural Lightweight Concrete, ASTM C567, ASTM International, West Conshohocken, PA.
5. Standard Method of Test for Air Content of Freshly Mixed Concrete by the Volumetric Method, AASHTO T 196, American Association of State Highway and Transportation Officials, Washington, DC.
6. Standard Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method, AASHTO T 152, American Association of State Highway and Transportation Officials, Washington, DC.
7. Standard Method of Test for Resistance of Concrete to Rapid Freezing and Thawing, AASHTO T 161, American Association of State Highway and Transportation Officials, Washington, DC.

ASTM C1585

ASTM C1566

Concrete Permeability Testing – Part 2

D. Stephen Lane, Virginia Transportation Research Council

Recent attention to the durability of concrete used in bridge construction has focused on the development of service life prediction models. These models attempt to make use of the fundamental properties of concrete that govern its response to deterioration mechanisms. The principal mechanisms involved in the movement of chloride ions through concrete are sorption and diffusion. Sorption pulls the fluid carrying chloride ions into the concrete while diffusion moves the chloride ions from regions of high concentration towards regions of low concentration. For concretes exposed to the air and subject to wetting and drying, the capillary system of the cementitious paste is usually only partially saturated, and thus sorption (wicking) plays an important role in the penetration of fluids into the concrete. For concrete in which the pore system remains saturated, sorption becomes negligible and the primary mechanism for chloride penetration is through concentration driven diffusion. The water sorptivity of concrete can be determined using ASTM C1585,[1] and its chloride diffusion coefficient using ASTM C1556.[2] This article describes and discusses the sorptivity and diffusion tests. An article in HPC Bridge Views, Issue No. 58 discussed the ponding and electrical tests used to assess the chloride penetrability of concrete.

Sorptivity Test

ASTM C1585 measures the sorptivity of a concrete specimen that has been conditioned at a constant relative humidity and then allowed to equilibrate to a presumed stable internal relative humidity. The specimens are 4-in. (100-mm) diameter, 2-in. (50-mm) long cylinders. Prior to testing, the specimens are stored in a chamber at a temperature of 122°F (50°C) and a relative humidity of 80% for 3 days. The target relative humidity of 80% was chosen since this is a common value observed for in-service bridge decks. The specimens are then sealed in individual containers and stored in the laboratory at 73°F (23°C) for 2 weeks to allow the internal relative humidity of the specimens to come to equilibrium. The sides of the specimens are then sealed with tape and the ends of the specimens opposite the absorbing surface are covered to impede evaporation from this surface during the test. The specimens are then weighed, and the absorbing surfaces are exposed to water, either by immersion into a reservoir or by ponding. At increasing time intervals, the specimens are removed from exposure to water, the surfaces blotted to remove excess surface water, and the specimens reweighed. Frequent measurements are made during the first 6 hours of testing, followed by daily measurements for at least 8 days. The change in mass over time is used to calculate the sorptivity. Typically, the rate over the first 6 hours is higher than the rate over the succeeding days. These are expressed as initial and secondary rates, respectively.

Chloride Diffusion Coefficient

The chloride diffusion coefficient of concrete can be determined using ASTM C1556. Test specimens with a minimum dimension of 3 in. (75 mm) across the finished surface and a minimum length of 3 in. (75 mm) are used. Prior to final preparation for testing, specimens should be in a state of saturation to minimize the influence of transport mechanisms other than concentration driven diffusion. The specimens are then allowed to surface dry and the sides and one end of the specimens sealed. The specimens are then immersed in lime-saturated water for 6 days to complete re-saturation. The specimens are removed from the lime water, rinsed free of lime and immersed in salt solution. The standard solution is 15% by mass sodium chloride (NaCl), but other concentrations can be used. Specimens remain immersed in the salt solution for a minimum of 35 days, with longer periods necessary for high performance concretes with low permeability. Following exposure to the salt solution, the specimens are rinsed and allowed to dry for 1 day under laboratory conditions. If the sampling for chloride analysis is delayed more than 48 hours, the specimens should be sealed in a plastic bag and stored in the laboratory. If longer than 7 days, the bagged specimens should be frozen until sampling to prevent continued migration of chloride ions. Samples for chloride analysis are obtained by profile grinding in incremental depths of 0.04 to 0.08 in. (1 to 2 mm) parallel to the exposed surface. A sample of the concrete is also obtained prior to the salt exposure to provide its background chloride content. The samples are analyzed for total acid-soluble chloride content using either AASHTO T 260[3] or ASTM C1152.[4] The results of the chloride analysis tests are used to calculate the apparent chloride diffusion coefficient by fitting an equation to the data using non-linear regression analysis.

Test Results

The table below contains sorptivity values and chloride diffusion coefficients for four concretes reported by Lane.[5] Concretes C1, C2, and C3 were portland cement concretes, whereas C4 contained 6% silica fume as a portion of the cementitious material.

	Concrete	C1	C2	C3	C4
	w/cm	0.58	0.48	0.38	0.38
ASTM C1585	Intial Rate $mm/s^{1/2} \times 10^{-4}$	35.2	23.5	12.7	4.8
ASTM C1585	Secondary Rate $mm/s^{1/2} \times 10^{-4}$	15.3	11.2	6.5	2.3
ASTM C1556	Diffusion Coeffiecient $m^2/s \times 10^{-12}$	10.6	10.2	7.5	1.9

References

1. "Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes," ASTM C1585, ASTM International, West Conshohocken, PA.
2. "Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion," ASTM C1556, ASTM International, West Conshohocken, PA.
3. "Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials," AASHTO T 260, American Association of State Highway and Transportation Officials, Washington, DC.
4. "Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete," ASTM C1152, ASTM International, West Conshohocken, PA.
5. Lane, D. S., "Laboratory Comparison of Several Tests for Evaluating the Transport Properties of Concrete," VTRC 06-R38, Virginia Transportation Research Council, Charlottesville, 13 pp. 2006.