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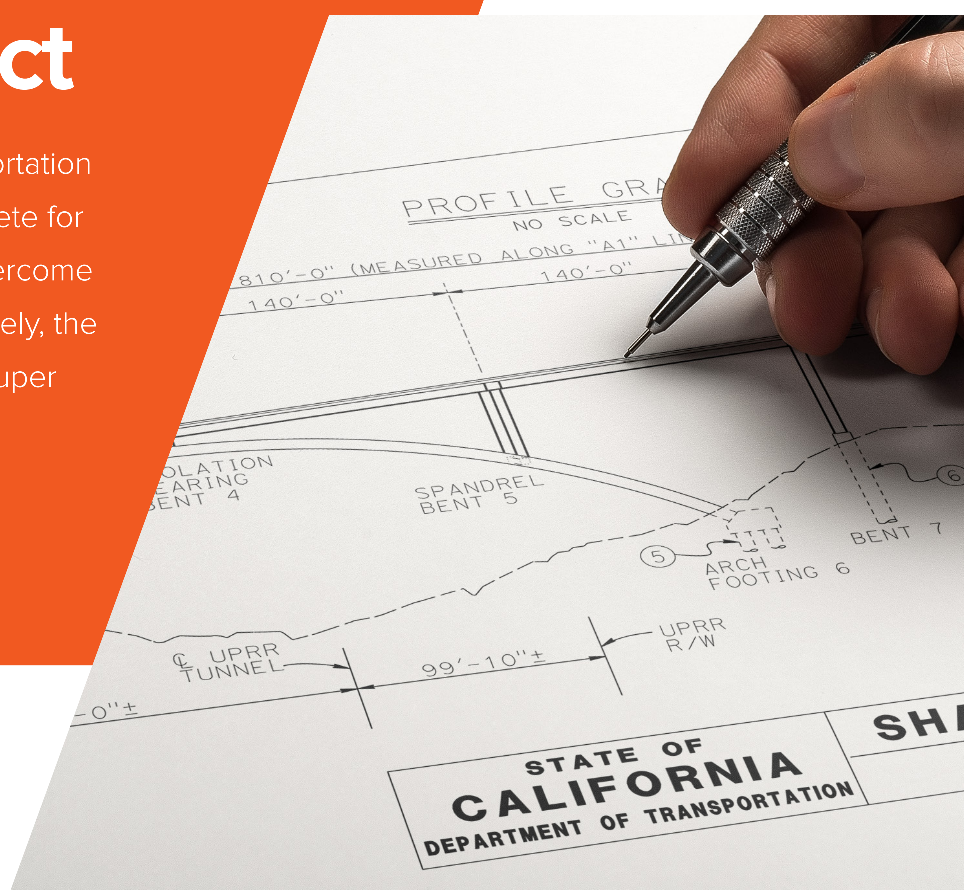
Lightweight Concrete for CALTRANS' Shasta Arch Bridge Project

The California Department of Transportation (Caltrans) specified lightweight concrete for the Shasta Arch Bridge Project to overcome some unexpected conditions. Ultimately, the concrete they used was labeled a "Super High Performance Concrete".



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This unusual designation of Super High Performance Concrete resulted from a combination of factors:

- Structural load requirements dictated the use of lightweight concrete with a maximum equilibrium density of 120 pounds per cubic foot (pcf).
- The specified compressive strength for the lightweight concrete was 5,500 psi @ 28 days, and 6,000 psi @ 56 days.
- The remote project location required extended travel times of up to 1½ hours for delivery of the readymix concrete.
- The concrete had to be pumped into place, so it was designed for pumping to a vertical height of 100 ft at a rate of 60 cubic yards per hour.

Why Lightweight Concrete?

Following the construction of the arch ribs and after the completion of a deflection analysis of the partially completed structure, the original design requirement of using normal weight concrete with a density of 150 pcf was altered to require lightweight concrete with an equilibrium density of 120 pcf. This revision would naturally lighten the superstructure and would reduce the structural demand by decreasing the dead-loads on the in-place arches, foundations, thrust blocks, pile caps, etc.

Mr. Ric Maggenti, P.E., Senior Materials & Research Engineer/Senior Bridge Engineer for Caltrans stated, "…Lowering demand consisted of changing the structure concrete (stem, bent caps, and deck) from a normal weight, normal strength concrete to a high strength, lightweight concrete…".
He went on to state, in summary, that there are hundreds of examples of lightweight concrete bridges throughout the world, with no small number of large, significant bridge structures, two of which are the Caltrans Bay Bridge, showing no observable deck distress after more than 80 years in service, and the Napa River Bridge, which is more than 40 years old and still functioning well even after the 2014 Napa earthquake.

Why High Performance, High Strength Lightweight Concrete?

Originally, the bridge was designed using normal weight concrete with a specified compressive strength of 4,000 psi. Mr. Maggenti reported that the "…increased design strength [for the lightweight concrete] eliminated any need to significantly adjust for rebar developmental lengths, or accounting for lower shear, creep, modulus of elasticity and modulus of rupture values used in the original design. Per the design criteria, these empirically derived properties for a given specified compressive strength differ for normal weight concrete vs. lightweight concrete. By simply increasing the compressive strength of the lightweight concrete, these other property values converge to those of a lower [strength] normal weight concrete …"

Although a specified compressive strength of 5,500 psi would have satisfied the above issues, the increase to 6,000 psi would enhance fatigue resistance and would eliminate concerns such as Alkali Silica Reaction (ASR), Delayed Ettringite Formation (DEF), deck permeability and deck cracking. So, perhaps the rationale to specify a 56 day requirement of 6,000 psi was to alleviate maintenance concerns for long term durability.

Finally, with the 6000 psi strength requirement, the concrete meets the definition of High Strength Concrete (HSC). All told, these new lightweight concrete requirements meeting the definition of

HSC also met the definition of High-Performance Concrete (HCP).

"This combination of added lightweight concrete properties, travel time, pumpability, and HSC properties may qualify for establishing it to be in its own category of Super High Performance Concrete (SHPC)." stated Mr. Maggenti.

Arcosa Lightweight Aggregate for the Shasta Arch Bridge Project

The lightweight aggregate used to produce the "Super High Performance Concrete" for the Shasta Arch Bridge was Arcosa Lightweight's Hydrolite® expanded clay aggregate produced in Frazier Park, California. Hydrolite is pre-conditioned at the Frazier Park plant so it can be delivered to the readymix concrete plant in a nearly saturated condition. The typical readymix plant in California has limited aggregate storage capacity. By pre-conditioning Hydrolite, it is easier for the readymix concrete producer to maintain the aggregate's moisture content to make pumpable lightweight concrete.

Pumping Lightweight Concrete

According to Maggenti, Caltrans "was not at all subjectively distracted by a belief that lightweight concrete is inherently difficult to pump…"

"The difficulty in pumping lightweight concrete arises when the lightweight aggregate is not saturated, and the Arcosa aggregate was saturated. Disregarding friction which would be similar for a given normal weight concrete and a lightweight concrete, a 125 pcf concrete imparts by its mass a pressure of 0.87 psi resisting its vertical motion inside the pipe while a 150 pcf concrete imparts by its mass a pressure of 1.04 psi per cubic foot of concrete. That is a 20% increase in force to move normal weight concrete. So why would a lightweight concrete be more difficult to pump than a normal weight concrete?"

With regard to the Shasta Arch Bridge project, Maggenti said, "The mix pumped better than anybody expected, and no additional pumping agent chemical admixture was used. Pumping rates at times exceeded 100 cy/hr, which was as much as the crew could handle, that rate still being less than capacity."

Mass Concrete Issues

There were concerns about exceeding the maximum allowable temperature in the mass concrete in the diaphragms or bent caps, due to the high (900 pounds per cubic yard) cementitious material content, and the fact that slag was used as the supplementary cementitious material instead of fly ash. Two cooling pipes running longitudinally through the bent caps were used to control the concrete temperature, which had a maximum target of 160 degrees F. Although the target temperature was exceeded at times due to the difficulty in controlling the water temperature in the pipes and the extreme ambient air temperatures when the concrete was placed, the temperatures were not considered excessive.

"Initially it was believed the lightweight aggregate would exacerbate mass concrete issues," Maggenti said. "However, this was not the case for the Arcosa aggregate. The difference was the amount of water in the lightweight aggregate."

The Arcosa Lightweight aggregate, with its absorption of more than 24%, requires more energy to increase its temperature than the same mass of a mineral aggregate with a lower absorption. Consequently, the lightweight aggregate did not further contribute to thermal issues caused by the high cementitious content.

Conclusions

For this project all of the requirements for a lightweight, air-entrained concrete mix that was pumpable, could withstand an extended transport duration, obtain high strength, and achieve high performance, were certainly met.

All of the concrete strengths exceeded the specified requirements for high strength concrete, and the equilibrium density requirements were met. The results of air content field tests on the plastic concrete were acceptable and were verified by petrographic examination of the hardened concrete.

The requirement for a lighter structure was met by using Arcosa Lightweight Aggregate, producing concrete with a maximum equilibrium density of 120 pcf. The preconditioned lightweight aggregate helped lower pump line pressures helping achieve the requirement of pumping 60 cy/hr. Actually, at times the rate exceeded 100 cy/hr. The pre-conditioned aggregate also contributed to a stable concrete consistency throughout the extended transport duration of up to 1½ hours.

With those unique attributes, it's no surprise Caltrans labeled the resulting material “Super High Performance Concrete” and anticipates it to be a “model for future challenging situations”.

Ref: *Lightweight High-Performance Concrete, Shasta Arch Bridge: Box Girder Superstructure*. Ric Maggenti, P.E. Senior Materials & Research Engineer / Senior Bridge Engineer, California Department of Transportation