CONCRETE BRIDGE TECHNOLOGY

# Shasta Viaduct Arch Bridge: Improved by Pumping a Lightweight Concrete Solution

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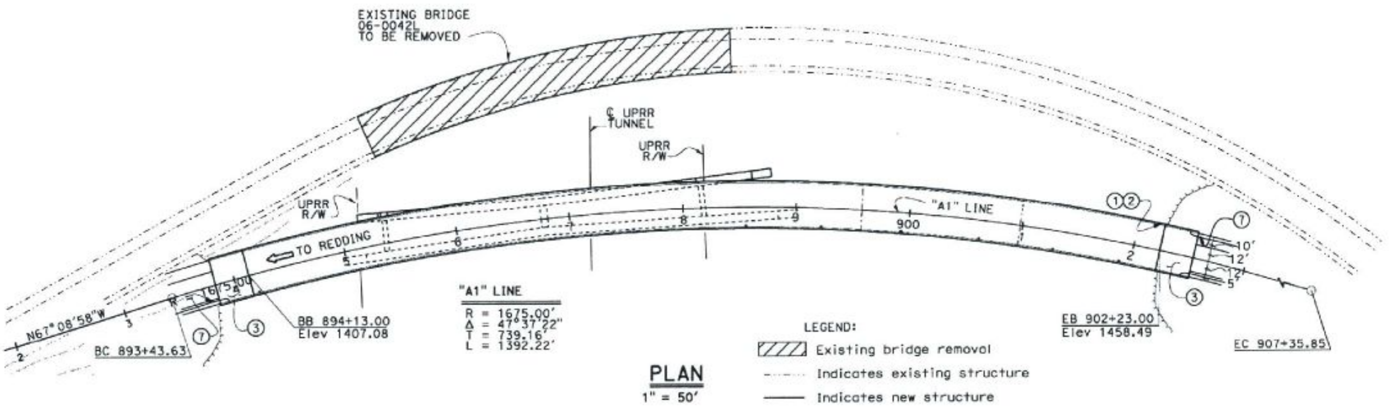
The Shasta Viaduct Arch Bridge is located on southbound Interstate 5 (I-5), in Shasta County, Calif., about 15 miles north of Redding and just north of Lake Shasta. This new bridge replaces the 78-year-old cast-in-place (CIP), conventionally reinforced concrete Sidehill Viaduct. The new arch bridge, which was partially opened to traffic in July 2019, is part of an improved horizontal alignment at that portion of southbound I-5. An arch support system was chosen to avoid conflict with the Union Pacific Railroad tunnel that passes beneath the bridge.

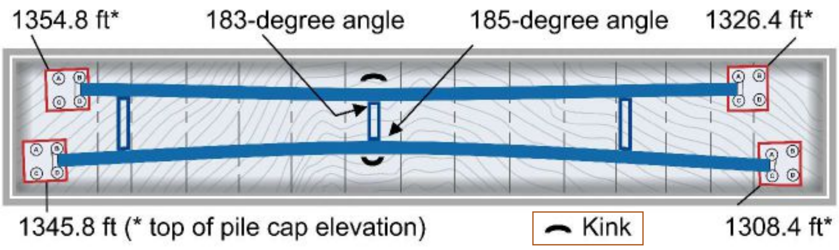
The Shasta Viaduct Arch Bridge is a six-span, post-tensioned, CIP, continuous concrete box-girder superstructure, with four of the spans supported by a two-ribbed arch. The arch support was designed to be within the perimeter of the superstructure. To accommodate the horizontally curved alignment, the ribs making up the arch are asymmetric, with each rib having a lateral kink near its apex. These kinks have different angles; therefore, four separate alignments make up the ribs and no two alignments are parallel. Given the steep hillside, each rib is footed on thrust blocks at differing elevations and the chord lengths of each rib vary accordingly. Thus, the left rib spans 366 ft while the right rib spans 400 ft.

The asymmetric ribs complicated the design analysis. After the initial design and completion of the arch ribs and columns, the structure was evaluated using a nonlinear, second-order analysis with time-dependent effects. Following the evaluation, modifications to the initial design were made to ensure the structure's design life. The most significant modification was lowering the dead load on the arch ribs by using lightweight concrete (LWC) instead of normalweight concrete (NWC) in the superstructure box girder including deck, webs, bottom slab, intermediate and abutment diaphragms, and bent caps. All other bridge elements used NWC, including the bridge rail. Capacity of the ribs was increased by providing a 1-ft-thick NWC collar, placed by shotcrete, around the lower 17 ft of the 7-ft-square ribs. Struts connecting the two ribs were also carbon-fiber wrapped to improve the arch struts' performance.

## Lightweight Concrete Mixture Proportions

The original NWC 28-day design compressive strength $f'_c$ of 4000 psi was increased to 5500 psi for the LWC. The increased strength eliminated any need to adjust the shear, creep, modulus of elasticity, and modulus of rupture values used in the original design. In design codes, these empirically derived material properties based on the compressive strength are assumed to be higher for NWC than LWC. By increasing the compressive strength of the LWC, the values of these properties converge to those of the lower-strength NWC that were used in the original design. A target equilibrium density for the LWC of 120 lb/ft$^3$ was selected for the design; in the interest of time, an oven-dry density of no more than 112 lb/ft$^3$ was used for the trial batches. With a density of 120 lb/ft$^3$, there was no need for lightweight sand; therefore, local sand was used in the mixture. The same LWC mixture was used


Plan for the Shasta Viaduct Arch Bridge showing the horizontal curve with spiral transitions, as well as the existing horizontal alignment and the existing bridge. Figure: Ric Maggenti.



Plan view of the two asymmetrical arch ribs. Located on a steep hillside, the ribs, which span 366 and 400 ft, have lateral kinks near their apexes, and their ends are supported on thrust blocks at different elevations. Figure: Ric Maggenti.

for all LWC components except the deck, which was modified to include fibers.

The bridge structure is located in an area prone to freezing and thawing, so entrained air was to be no less than 5%. The concrete needed the capability of being pumped at a minimum rate of 60 yd$^3$/hr. Therefore, a maximum ¾-in.-diameter lightweight aggregate (LWA) sourced from Frazier Park, Calif., was selected. This LWA could be delivered fully saturated, which is a necessary condition for pumping the LWC. Proof pumping to a height of 100 ft was done at the bridge site.

## Trial Batching

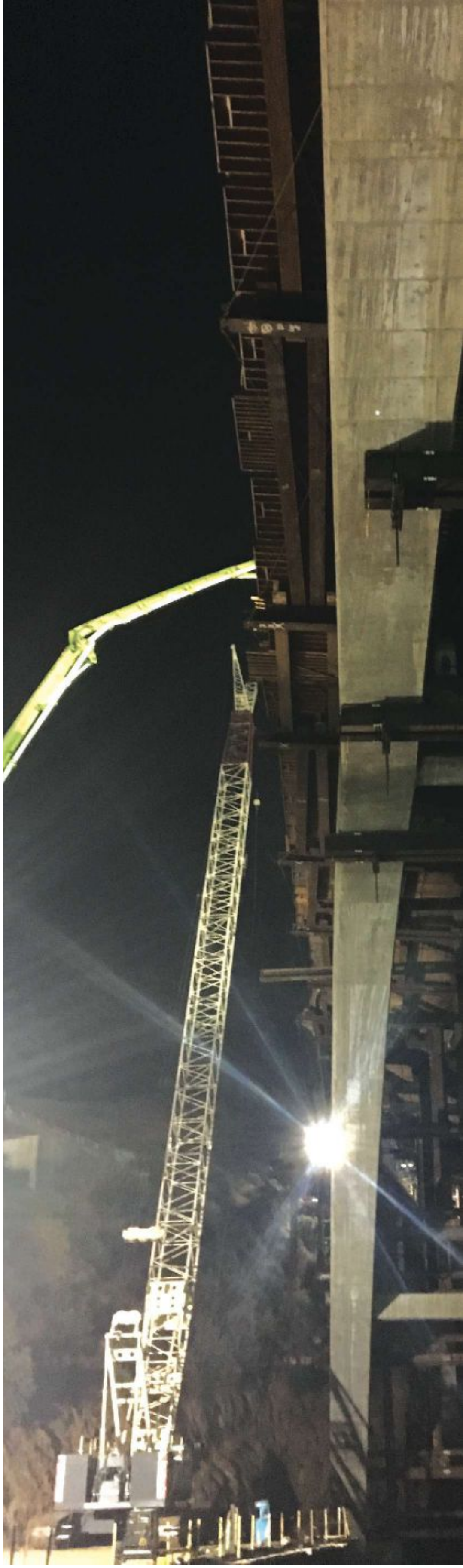
Iterative trial batches revealed that properly air-entrained mixtures with a maximum water–cementitious materials ratio (*w/cm*) of 0.35 achieved adequate strengths and met the 120 lb/ft$^3$ equilibrium density criterion. Because the batch plant was located more than an hour away from the bridge site, chemical admixture types and dosage rates were adjusted to provide a stable slump and, more importantly, consistent air content, which affects both strength and density.

Some of the first trial batches could not be pumped at even a 30 yd$^3$/hr rate. However, the pumping issues were eventually solved, and the final mixture could be pumped at a rate exceeding 100 yd$^3$/hr and to a height of 100 ft.

## Pumpable Lightweight Concrete

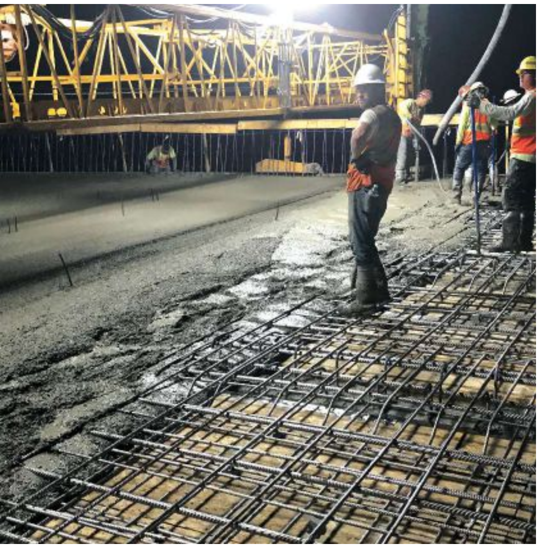
LWA must be fully saturated prior to pumping, which may be accomplished by vacuum or thermal methods for some LWAs. Aside from that requirement, fresh concrete properties necessary for pumping LWC are the same as for pumping NWC. Pumpability is related to dynamic behavior under pressure and the viscosity of the mixture as measured by slump. Slump is directly related to water content and admixtures. However, slump gained by admixtures changes the rheology of a mixture, making the "water slump" (the slump before admixtures are added) important. All things being equal, a higher slump enhances pumping as long as the mixture remains cohesive. The cement paste is the transport fluid that moves the concrete through the pump. The mortar conveys the coarse aggregate, keeping it in suspension and making the concrete pumpable, which is why the sand gradation is an important factor for pumpability. The coarse aggregate affects the plastic and cohesive qualities of fresh concrete, as well as the water demand to achieve slump values.

An early pumpability trial was a failure. The pump was overly strained before even a 30 yd$^3$/hr rate was achieved, and then the pump plugged. For a subsequent trial, the amount of cementitious material was increased from approximately 850 to 900 lb/yd$^3$, and the aggregate proportions were adjusted. Because of the high cementitious materials content, with 50% slag and no fly ash, the mixture required mass concrete cooling tubes at the bent caps. Although the LWC was prone to some countertendencies, such as a hotter or stickier mixture, increasing the cementitious content provided several pumpability benefits. First, it allowed an increase in water content without exceeding 0.35 *w/cm*. This increased water slump. Second, it increased the paste content, which is the fluid transporting the aggregate. Third, it indirectly enhanced aggregate gradation regarding pumping because the extra cementitious material could be treated as part of the fine aggregate.



Lightweight concrete being pumped from a working platform on a work trestle up to the bridge superstructure. Photo: California Department of Transportation.

Placing lightweight concrete for bent caps by pumping. Because of the high cementitious materials content, active (cooling tubes) and passive measures were used to control the concrete temperature to avoid thermal cracking and the potential for later cracking caused by delayed ettringite formation.



Nighttime placement of lightweight concrete with polyfibers for the bridge deck. Photo: Ric Maggenti.

Proprietary tables and graphs for optimizing aggregate gradations for pumpable mixtures were developed back in the days when a 700 lb/yd$^3$ cement content was considered very high. Such mixture resources were used as guidance for developing a pumpable mixture with a cementitious content of 900 lb/yd$^3$ by considering 200 lb/yd$^3$ of the cementitious materials as fine aggregate. The gradation of the local natural sand was within the gradation band of ASTM C33, *Standard Specifications for Concrete Aggregate.*[1] By adjusting the sand gradation to include a portion of the cementitious materials as sand, as suggested by ASTM C33, the fineness modulus dropped from 2.91 to 2.51. A lower fineness modulus allows for a larger volume of coarse aggregate, optimizing a pumpable mixture without adding water.

## Production Rates— Pump Them Up!

On the Shasta Viaduct Arch Bridge construction project, work shifts began in the evening and continued until the early morning. After 1600 yd$^3$ of concrete for the box girders and bent caps were pumped in four shifts during three weekends in August 2018, 900 yd$^3$ of deck concrete were pumped in two shifts during one weekend in September.

There were no issues with workability and pumpability. Inspection after form removal showed good consolidation. The pump rates at times exceeded 100 yd$^3$/hr. The net placement rates for the stem and soffits, which included stopping to move the pump and intermittent placement as the crews moved from stem to stem, were greater than 50 yd$^3$/hr. The last deck placement rate exceeded 75 yd$^3$/hr, despite some logistical problems that led to production delays. The concrete mixture for the deck included 4 lb/yd$^3$ of polyfibers, one of the provisions for California Department of Transportation (Caltrans) "CRACK-Less" concrete deck mixtures.

## Conclusion

The LWC met or exceeded all expectations, including the capability to be pumped over 100 ft high. The Caltrans standard design life for a highway bridge is 75 years. Many design features and upgrades were included with service life in mind, such as stainless steel deck reinforcement, polyfibers in the deck concrete mixture, and inclusion of a 1-in.-thick protective polyester concrete deck overlay. With the reduced load resulting from the use of LWC for the superstructure, the support components should also see improved longevity. The resulting structure is anticipated to last as long and be as durable as the initially planned NWC bridge.

## Reference

1. ASTM International. 2018. *Standard Specifications for Concrete Aggregate* (ASTM C33-18). West Conshohocken, PA: ASTM International.

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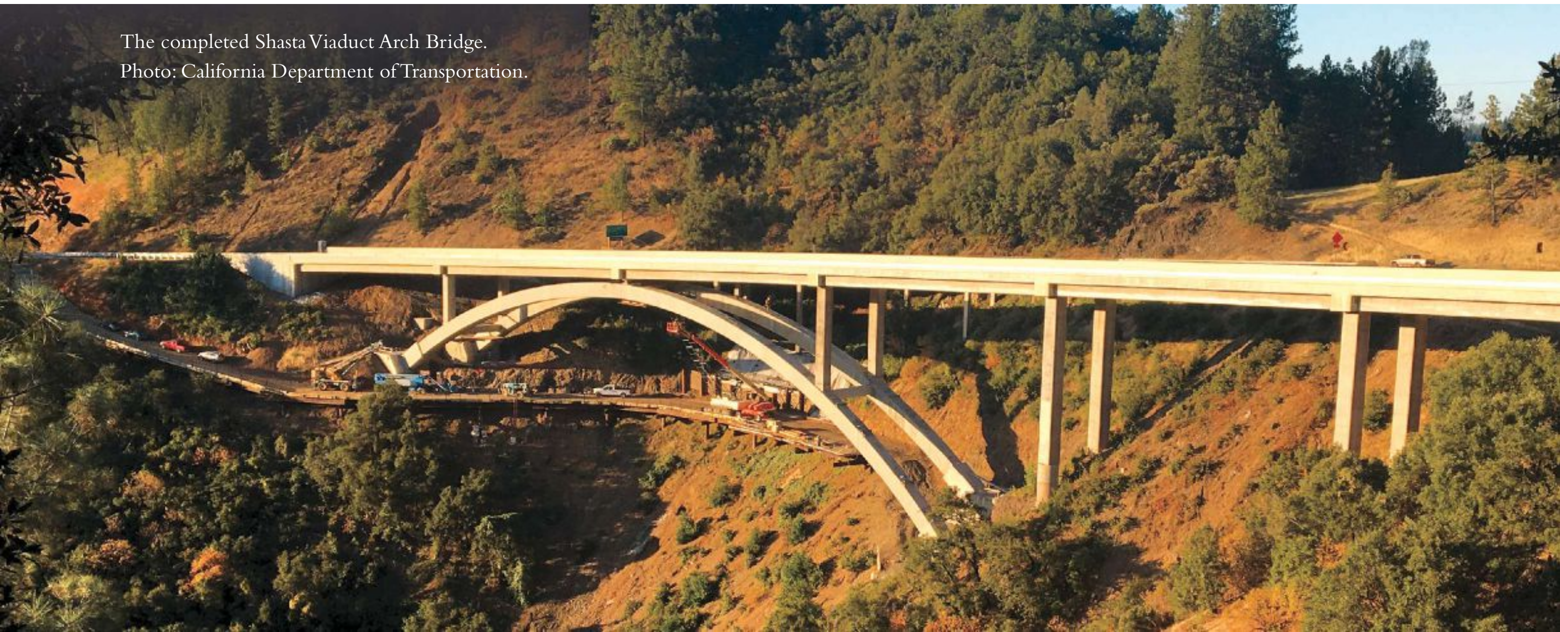

The completed Shasta Viaduct Arch Bridge. Photo: California Department of Transportation.