KAHOMA UKA BRIDGE

by David Fujiwara and Eric Matsumoto, KSF Inc.

Elevation view of Kahoma Uka Bridge. Photo: Chad Nikaido.

In order to improve the quality of life for the western Maui community, the Hawaii Department of Transportation (HDOT) assessed the input from the public and made the dream of a Lahaina Bypass into a reality. The bypass provides an alternative route to Honoapiilani Highway in the vicinity of Lahaina town, which alleviates traffic congestion and improves circulation of vehicles in the area. This new roadway also contains a truly unique structure to traverse Kahoma stream.

The final design of Kahoma Uka Bridge was selected after considering a myriad of structural types and construction methods. The evaluation process included the desired span length, existing conditions, environmental impacts, material strengths and capabilities, aesthetics, and cost. As a result, the community was presented with a horizontally curved, 60-ft-wide, 360-ft-long, single-span, low-profile, inverted tied arch bridge that neither obstructs the scenic view nor interferes with the stream environment below.

Request for Proposals

In 2006, the contractor was awarded the design-build contract to complete phase 1A of Lahaina Bypass. Based on the request for proposal requirements, the design team developed a straight, 350-ft-long, single-span, inverted tied arch bridge with a constant cross slope of 2%.

A Cultural Discovery

Work on the project was halted in May 2007 when 30 acres of historical agricultural terraces were discovered in the path of the new roadway. To respect this culturally significant site, native Hawaiian groups and lineal descendants were consulted. With their input, a plan was developed to re-align the roadway toward the ocean and away from the terraces. The bridge, which was previously straight, now required a horizontal curve with a radius of 1200 ft and superelevation. This new configuration significantly magnified the complexity of the structure. With the full cooperation and dedication of everyone involved, the redesign of Kahoma Uka Bridge expeditiously proceeded in September 2009.

profile

KAHOMA UKA BRIDGE / LAHAINA, MAUI, HAWAII

BRIDGE DESIGN ENGINEER: KSF Inc., Honolulu, Hawaii

PRIME CONTRACTOR: Hawaiian Dredging Construction Company Inc., Honolulu,Hawaii

POST-TENSIONING CONTRACTOR: Schwager Davis Inc., San Jose, Calif.

OTHER MATERIAL SUPPLIERS: Reinforcement, Associated Steel Workers Ltd., Kapolei, Hawaii; Friction pendulum bearings, Earthquake Protection Systems Inc., Vallejo, Calif.

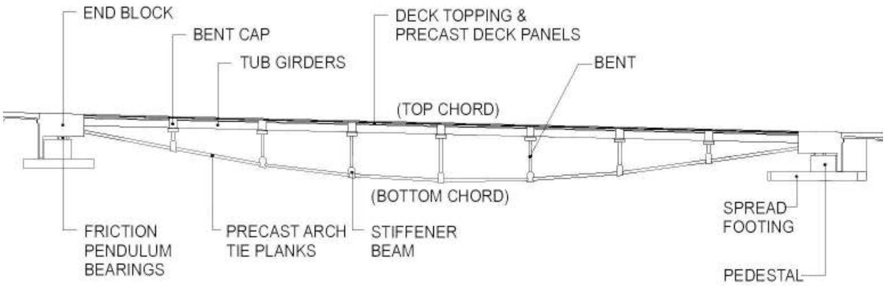

Diagram of Kahoma Uka Bridge. Diagram: Vivian Takagaki.

Bridge Substructure

Kahoma Uka Bridge is supported by spread footings at both abutments. Footings are 4 ft thick and cast with 6.0 ksi concrete. Above the footings are 9-ft-high pedestals. Two friction pendulum bearings are situated at the top of each pedestal. These bearings allow the bridge to expand, contract, and rotate without imposing significant horizontal loads and moments on the structure and foundation. Each bearing has an 88-in. effective radius of curvature that results in a dynamic period of 3 sec. Displacement capacity of the bearings is 10 in.

Bridge Superstructure

The inverted tied arch bridge consists of an innovative combination of precast, post-tensioned, and cast-in-place concrete. In order to produce a 360-ft-long curved bridge that does not require intermediate supports, 270 ksi post-tensioning strands and high-performance concrete are utilized. All superstructure concrete has a minimum specified compressive strength of 8.0 ksi.

Kahoma Uka Bridge's top chord is comprised of 5-ft-wide by 4-ft 9-in.-deep precast concrete tub girders; 3.5-in.-thick, stay-in-place, precast concrete deck panels; and a 5.75-in.-thick, cast-in-place concrete topping. The girders are connected to the deck to form a composite section that supports vehicle loads. Due to the shape of the structure, the top chord is also subjected to tremendous axial forces, bending moments, and torsion.

There are six lines of tub girders that are placed longitudinally between abutments. The tub girders are framed with eight chords to produce the curved horizontal alignment. These girders are supported by end blocks at the two abutments and seven cast-in-place bents spaced at approximately 42 ft between the end blocks. Bents consist of five 1-ft 4-in.-thick columns with variable widths that form arched openings. Heights of these members vary from 10 to 25 ft. High-strength steel bars connect the bents to the stiffener beams below.

The bridge bottom chord is comprised of the stiffener beams and 10 lines of precast concrete arch tie planks that are also framed with eight chords. Stiffener beams transfer forces between bents and arch tie planks. These beams also provide stiffness to the inverted arch by bracing individual precast concrete arch tie planks at each end. The 1-ft 4-in.-deep by 5-ft-wide precast concrete arch tie planks encase the continuous post-tensioning strands. These high-strength strands transfer loads to the end blocks and provide compressive and lifting forces in the bridge. In order to address the twisting associated with the curved shape of the structure, post-tensioning tendons vary from nineteen 0.6-in.-diameter strands on the inside of the curve to twenty-seven 0.6-in.-diameter strands on the outside.

Top and bottom chords are connected to the cast-in-place concrete end blocks at each abutment. The 11-ft-deep end blocks, where the forces from the top and bottom chords and reactions from the bearings converge, also anchor the continuous post-tensioning tendons.

Construction Phase

Construction of the Kahoma Uka Bridge commenced in December 2010. Falsework for this project was designed to have the least impact on the environment. A 65-ft-long truss, which spanned Kahoma Stream, was installed. Thus, construction was allowed to proceed without disruption to the stream.

Shoring towers were placed below each of the seven bents. Sand jacks were also

Precast concrete tub girders are placed on the cast-in-place concrete bents. Photo: Chad Nikaido.

HAWAII DEPARTMENT OF TRANSPORTATION, OWNER

PROJECT DESCRIPTION: Horizontally curved, 60-ft-wide, 360-ft single-span, low-profile, inverted tied arch bridge

STRUCTURAL COMPONENTS: 80 precast concrete planks and cast-in-place concrete beams for the bottom chord; 48 precast concrete tub girders with 3.5-in.-thick precast concrete deck panels and a cast-in-place concrete deck topping for the top chord; cast-in-place concrete bents, end blocks, and footings; post-tensioning; and friction pendulum bearings

BRIDGE CONSTRUCTION COST: $27 million

AWARDS: 2013 ASCE Hawaii Outstanding Civil Engineering Achievement Award, 2014 ACEC Hawaii Grand Conceptor Award

Falsework truss installed to span Kahoma Stream. Photo: Eric Matsumoto.

Post-tensioning ducts and anchor heads are placed in the end block. Photo: Eric Matsumoto.

utilized at each tower. These temporary supports allowed the contractor to construct the bridge at a pre-cambered elevation. Once the structure was self-supporting, the contractor was then able to lower the falsework in a controlled manner.

The planks were cast with five 4⅝-in. diameter ducts for the continuous post-tensioning tendons. These members were also stressed in their simply supported condition for transportation and handling purposes with four tendons, each comprised of four 0.6-in.-diameter strands.

As the precast concrete components were fabricated, abutment spread footings and pedestals were constructed. Above the pedestals, friction pendulum bearings were placed. A three-dimensional drawing, verified with manual calculations, was created to locate each member. This process was challenging because the structure has a horizontal curvature, parabolic bottom chord, longitudinal slope, superelevation, and pre-cambering. Due to the effort expended in developing the drawings, the contractor was able to efficiently place all precast concrete components.

Continuous post-tensioning ducts are spliced at the stiffener beam of the bottom chord. Photo: Eric Matsumoto.

Cast-in-place concrete end blocks were then constructed above the friction pendulum bearings. Due to the size and function of these components, the concrete mixture was proportioned to address heat generation that occurs when placing mass concrete within the forest of reinforcing steel required to resist all forces. The concrete for the bottom portion of the end blocks was placed concurrently with the stiffener beams that connect the ends of the planks that form the bottom chord. Above the stiffener beams, cast-in-place concrete bents linking the top and bottom chords were then built.

Upon completion of the bents, the top chord was constructed. Due to the tremendous axial forces, bending moments, and twisting, a considerable amount of reinforcing steel was placed in all top-chord components. To ensure a quality product, a high level of attention was also paid to these concrete mixture proportions, handling of materials, and placement of concrete. To increase the durability of the traveling surface, polypropylene/polyethylene macro-fibers and alkali-resistant glass micro-fibers were added to the deck concrete. This blend of fibers increased the fatigue endurance limit and toughness and decreased micro- and macro-cracking. In addition, admixtures were incorporated to minimize bleeding, increase workability for proper placement, and reduce plastic shrinkage.

Once the deck was sufficiently cured, post-tensioning strands were placed in the bottom chord arch tie planks and stressed. The tendons were then anchored at the rear face of the end blocks. At the completion of this stage of construction, the structure was self-supporting.

Sand jacks were then released in a controlled manner, which minimized stresses in the structure and ensured the safety of workers below. The bridge then settled into its final position. Vertical deflections and horizontal displacements were subsequently monitored. Measurements compared closely with results from the three-dimensional, finite element analysis.

Conclusion

In retrospect, the collective efforts from HDOT and the contractor's design-build team produced the desired outcome. Engineering projects of this magnitude have historically encountered numerous obstacles throughout the construction process. However, issues that arose were easily and immediately rectified due to the cooperation of all parties. As a result, in March 2013, the long-awaited Kahoma Uka Bridge was opened to the public.

David Fujiwara is president and Eric Matsumoto is a structural engineer with KSF Inc. in Honolulu, Hawaii.