FOCUS

CONCRETE INNOVATION IN HAWAII

KSF's focus on creating innovative designs has led to several breakthroughs in concrete materials and construction that have been incorporated into many of the firm's projects

by Craig A. Shutt

The Kahoma Uka Bridge uses an innovative combination of precast, post-tensioning, and cast-in-place concrete elements to achieve the 360-ft span without intermediate supports. All Photos: KSF Inc.

KSF Inc. faces a variety of challenges designing infrastructure projects in Hawaii. Not only must it deal with the full range of seismic zones (and volcanoes) along the chain of islands, but many materials are either limited in supply or available only via overseas shipments. To offset these obstacles, KSF has devised innovative concrete mixture proportions that are becoming standard issue for its projects.

"Most of the projects we create are concrete structures," says Eric Matsumoto, vice president with the Honolulu-based firm. "Hawaii DOT [department of transportation] prefers concrete due to maintenance concerns in the corrosive environment. As a result, we have spent considerable time developing new concrete mixtures and techniques to help us handle the challenges."

Key insights come from Kirk Hashimoto, construction engineer, who previously worked in the concrete industry in engineering, marketing, and concrete mixture development. "He has helped to ensure we are creating the best concrete mixture for a project's needs," Matsumoto explains. "He is involved with the material usage from selection through placement and final finish."

KSF's success has derived in part from developing in-house expertise, Hashimoto notes. "The company's goal has been to provide core competencies in-house so we can take care of every aspect of a project. We are always looking to improve the materials we are using, and since most of our projects are concrete, that has been a point of focus."

The company also has an employee with past experience as a contractor to ensure every design maximizes constructability and efficiency. "He can give us insights into how the project will be constructed to help us create the most efficient and economical product," explains Matsumoto.

In part, that in-house expertise was dictated by the island's isolation, Hashimoto says. "Labor costs are high on the island, and specific skills are not always accessible. We have to be aware of the limitations and work around them. We developed a lot of in-house expertise to avoid having to fly in people to consult on projects."

Materials also are in limited supply. Hawaii basically has one cement supplier, who ships from Asia, and there are no fly ash or other supplementary cementitious materials locally available that meet ASTM requirements consistently. "Those materials are more expensive than cement," Hashimoto says. "Costs generally are higher here."

Innovative Materials

Those obstacles are in part the genesis for some of the company's innovation in concrete. Two innovations that were recently developed in a research program, which was performed in tandem with the Hawaii Department of Transportation (HDOT), were put to use on one recent project and now are used more often.

The first innovation developed structural concrete for use in drilled shafts with special characteristics for workability, nonsegregation, bleeding, in-place concrete density, and mass concrete. "Concrete in drilled shafts in Hawaii historically has demonstrated undesirable behavior," explains Hashimoto. The bleed water migrates to the top of the shaft during placement, resulting in lower-density concrete at the top of the shaft. That often interferes with the tie-in to the structure, creating a weak point and adding stress. The combination of materials available in Hawaii also increases the heat of hydration, especially with larger shafts. The increased heat can reduce long-term durability.

KSF's engineers experimented with options and devised a concrete mixture that would account for the typical characteristics of local concrete to reduce heat of hydration and bleed water. Lower heat minimized internal cracking, and the reduction of bleed water resulted in more uniformity of the concrete. The result was a drilled shaft superior to previous designs.

'Our goal was to create a tougher mixture that exhibited less shrinkage.'

The second innovation focused on meeting challenges presented by decks with greater water-cementitious materials ratios, which could lead to shrinkage and cracking. "Our goal was to create a tougher mixture that exhibited less shrinkage," says Hashimoto. "We looked at mixture options and optimized them to reduce the factors causing problems. Then we looked at blends of fibers that could increase toughness."

The result was a high-performance concrete that contains entrained air and a combination of macro and micro fibers that minimizes shrinkage and creep characteristics typically encountered with local deck concrete mixtures. The materials and proportions minimized bleeding and improved toughness of the concrete.

Both innovations were applied to the North-South Road bridges on the Island of Oahu, which consist of twin, 165-ft-long, single-span,

The North-South Road project featured several innovative concepts, including a high-performance concrete deck and a new composition for drilled-shaft concrete. The concrete diaphragm is located at the quarter-point splice between girder segments.

The North-South Road on Oahu features twin 165-ft-long, single-span, integral-abutment bridges with post-tensioned, spliced girders and precast concrete deck panels.

integral-abutment bridges. They feature 5.5-ft-deep, post-tensioned spliced girders and precast concrete deck panels with a high-performance concrete deck topping. Five-ft-diameter drilled shafts at each abutment support the structures.

"This project provided a good opportunity to try both ideas," says Hashimoto. "It was the first one we'd worked on for some time that was not a repair or replacement project, which gave us an opportunity to design strictly for the site. It was a chance to try these fresh ideas, and that gave the research a major push."

KSF used a different shrinkage-reducing admixture for its work on the Kii Bridge, an 80-ft-long, single-span, integral-abutment bridge. The superstructure consists of 2-ft-deep, precast, prestressed concrete planks with a 5-in.-thick topping and is supported by 3-ft-diameter concrete drilled shafts. The admixture's impact was examined with laboratory tests, field measurements, strain-gage readings, and finite-element analysis. Staged construction, post-tensioning, and soil-structure interaction were modeled with a finite-element program. An additional research project studying soil-structure interaction also was performed.

Contractor Input Critical

Creative results are often achieved in conjunction with contractors, a process enhanced by design-build method and value engineering. "We always work closely with the contractor from conceptual phase to project completion. Good relationships and collaboration result in better designs and construction

The Kii Bridge, an 80-ft-long, single-span, integral-abutment bridge on Oahu, has a superstructure featuring 2-ft-deep, precast, prestressed concrete planks.

in addition to quick resolutions when issues arise," says Matsumoto.

One recent design-build project that benefited from close cooperation was the Kahoma Uka Bridge that traverses the Kahoma Stream in West Maui. As the project was being designed, it was discovered that the path included 30 acres of historical agricultural terraces. To respect this culturally significant site, native Hawaiian groups and lineal descendants were consulted.

With their input, the bridge was designed to realign the roadway away from the terraces. That required the previously straight bridge to have a horizontal curve with a 1200-ft radius and superelevation. The design features precast, post-tensioned, and cast-in-place concrete elements that allowed production of a 360-ft-long curved bridge with no intermediate supports.

The superstructure consists of precast concrete U-girders, stay-in-place precast concrete deck panels, and a cast-in-place concrete topping. Six lines of U-girders placed longitudinally between abutments were framed with eight chords to produce the curved, horizontal alignment.

The bridge can expand, contract, and rotate without imposing significant horizontal loads and moments on the structure and foundation with the aid of friction-pendulum bearings placed at the top of 9-ft-high pedestals at each footing. Each bearing has an 88-in. effective radius of curvature that results in a dynamic period of 3 seconds.

The design allowed the bridge to be built without placing any piers in the stream. "That saved considerable time, as disrupting the stream would have required permitting that would have slowed the schedule," Matsumoto says. "It was an efficient design for many reasons."

Environmental Concerns Common

Environmental concerns and permitting that can slow construction are becoming more commonplace, Matsumoto notes. "We are encountering obstacles of different types more regularly that have to be worked out ahead of time," he says. "Our goal is to resolve any challenges that arise in advance. In Hawaii, the terrain always comes into play in our designs."

According to Matsumoto, some of those issues arise due to the seismic activity on the chain of islands, which includes active volcanoes. "The Hawaiian island chain was created by hot-spot volcanism. The oldest island is located in the northwest portion of the chain while the youngest is in the southeast. The island of Hawaii has an active volcano and is subjected to frequent seismic activity. Due to this hot-spot volcanism, the State of Hawaii has seismic zones ranging from 1 to 4. Thus, we have varying seismic issues to deal with in each project."

Many locations are also in mountainous areas along winding roads. That can restrict the length of precast concrete girders that can be shipped, requiring splicing the segments along with creative techniques for placing them. "Access to sites can be an issue," says Matsumoto.

An example is the Kealakaha Stream Bridge on the Hawaii Belt Road on Hawaii, which traverses a 165-ft-deep and 610-ft-wide ravine with a main span of 360 ft. The bridge is close to an active volcano, which subjects the area to high seismic activity.

The original design was value-engineered by KSF when the contractor realized that building a curved segmental box structure with a travel way superelevation of 6.2%, shoulder slope of 2%, and no topping would be very difficult to construct. KSF redesigned the structure to incorporate Washington state's new precast concrete "super girders" to span 100 and 205 ft along with 150-ft-long cast-in-place box girders above the piers and a cast-in-place concrete deck.
The W95PTG precast concrete girders

The Kahoma Uka Bridge was redesigned after 30 acres of historical agricultural terraces were discovered in the bridge's path.

The 360-ft-long main span of the Kealakaha Stream Bridge crosses a 165-ft-deep ravine. The long span is achieved using a combination of cast-in-place concrete box girders over the piers and 205-ft-long spliced precast concrete girders that close the gap between them.

The Kealakaha Stream Bridge features 205-ft-long W95PTG "super girders" that were spliced and post-tensioned using 50-ft-long segments. In this photo, the completed spliced girder has been moved across the ravine using a launching truss and is being set in place.

were shipped from Spokane, Wash., to the site, but due to the winding roads, the maximum length for any segment was 50 ft. The segments were spliced and post-tensioned at the site.

The 50-ft-long girder segments were placed on a custom rail system of wide-flange members and rollers where they were spliced and post-tensioned. A steel stiffening truss was attached to the middle 90 ft of the 205-ft spliced girder and two four-strand tendons were placed in the girder top flange and stressed to improve lateral stability during installation. The assembled girder was then pulled across the ravine on a launching truss. Once in position, the girder was attached to strand jacks that lowered it into place. When all of the girders were in place, they were spliced to the box girders and post-tensioned.

"It provided a creative way to erect girders over a deep ravine in a restrictive location," says Matsumoto. "We worked closely with our in-house contractor to produce the plan and to ensure it was safe and efficient to work from the top down."

KSF's value-engineering redesign also included friction pendulum seismic isolation bearings on each abutment and pier, their first use in the state. The bearings provide displacement capacities of 12 in. at abutments and 10 in. at piers. The seismic isolation bearings lengthen the natural period of the isolated structure which reduces the lateral loads transmitted to the structure. This approach allowed the team to raise the elevation of the footing, decrease the size of drilled shafts, and eliminate costly soil nail walls around the footings. "In retrospect, without the redesign, the contractor would have lost a considerable amount of time and money, because installing the drilled shafts was more complex and costly than anticipated."

Reinforced Soil

Another implementation of new technology arose with the Kauaula Stream Bridge, which was constructed in conjunction with a University of Hawaii research project on geosynthetic reinforced soil (GRS) integrated bridge systems (IBS). The first bridge in the state to use this process, its abutments feature biaxial, woven polypropylene geotextile, compacted granular fill material, and concrete masonry units for the facing. "This project provided a good opportunity to use the GRS-IBS system and monitor its behavior," says Matsumoto.

The 112-ft-long, 47-ft-wide superstructure comprises precast concrete, post-tensioned U-girders, along with stay-in-place concrete deck panels, and a cast-in-place concrete deck. The installation required neither heavy equipment nor specialized labor, Matsumoto notes. KSF's in-house contractor devised a scheme to place the U-girders that only required steel beams, rollers and hydraulics jacks.

This approach has proven to be effective and economical, he says. "There is a time and place for all of these techniques that we use, and we want to have many options to deal with any variables. Placement of the Kauaula girders proved to be an effective method of erection. We'll continue to propose it when it will help the contractor."

22 Years of Service

KSF Inc. was established in January 1994 by Yuji Kasamoto, Myles Shimokawa, and David Fujiwara, who is now president. The firm originally designed both buildings and bridges but has evolved to focus on infrastructure and especially concrete bridges.

The firm has 18 staff members, including seven licensed and six unlicensed engineers. KSF Inc. also has more than 70 years of collective construction experience. Among its projects are bridges, concrete pavements, underground utility boxes and culverts, and retaining structures.

Always Innovating

The firm is analyzing other innovative techniques, including some focusing on ultra-high-performance concrete, modified concrete mixtures, lightweight concrete, and corrosion inhibitors. "We are working on some new ideas, but nothing is at a stage we can talk about," says Hashimoto. "Overall, we are always looking at developing and refining materials to provide more durability with lower impact, especially as service lives are extending from 50 or 75 years to 100 years."

Matsumoto agrees. "Our research and investigation of new techniques will continue to drive our company. We are always looking at new methods and materials. Our goal is to provide clients with the most innovative, economical, and elegant designs possible."

EDITOR'S NOTE

A project article on the Kahoma Uka Bridge appeared in the Summer 2014 issue of ASPIRE,™ *and the Kealakaha Stream Bridge was featured in the Summer 2010 issue. A list of references related to the projects and research mentioned in this article can be found on the* ASPIRE *website.*