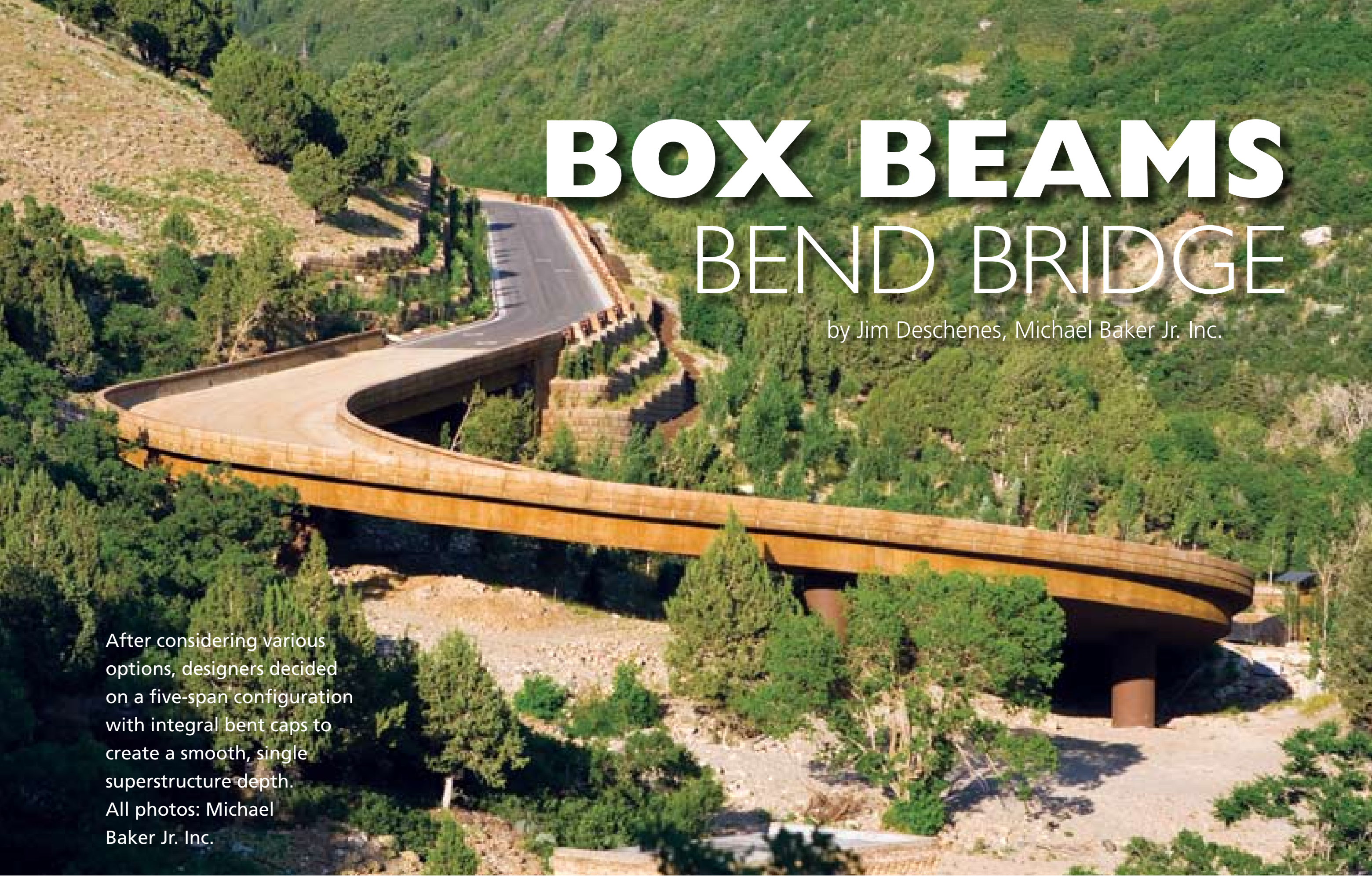
BOX BEAMS
BEND BRIDGE

by Jim Deschenes, Michael Baker Jr. Inc.



After considering various options, designers decided on a five-span configuration with integral bent caps to create a smooth, single superstructure depth. All photos: Michael Baker Jr. Inc.

Concrete girders offer only alternative for five-span bridge with severe horseshoe bend

Access to a new upscale development in the foothills of Utah's Wasatch Mountains just outside Salt Lake City required a grand welcoming entrance, along a path with difficult terrain. To meet the variety of needs produced by the site, especially environmental concerns and functional demands, two reinforced concrete bridges located on "switchback" curves were built. The lower bridge, discussed in this article, was an exceptionally challenging five-span, 450-ft-long bridge with a complete switchback curve along a centerline radius of only 80 ft and a 12% grade.

Access to the site was limited by steep grades, limits of a conservation easement, and a requirement to provide for wildlife crossing. The project also was located less than 1000 ft from the Wasatch Fault. Typically, the most economical solution would involve building large walls and excavating steep slopes into the existing hillside. But foothill preservation and concerns from county officials, coupled with the desire to create an aesthetically pleasing entrance, led the owner to investigate nonconventional alternatives.

Once the concept for the switchback curves was devised, a series of design challenges developed. The curve was too severe for tangent girders without reducing span lengths to less than 30 ft, while curved steel girders were not economical at such a small radius. Designers determined that the most feasible bridge type was a conventionally reinforced, cast-in-place concrete, box girder bridge. The girders could not be post-tensioned due to the severe curvature, which would have made it difficult to resist the bursting forces in the walls of the boxes.

profile

BIG COTTONWOOD CANYON LOOP ROAD BRIDGE / SALT LAKE CITY, UTAH

ENGINEER: Michael Baker Jr. Inc., Midvale, Utah

PRIME CONTRACTOR: Ralph L. Wadsworth Construction Co., Draper, Utah

CONCRETE SUPPLIER: Harper Ready Mix, Salt Lake City, Utah

AWARDS: *2008 Portland Cement Association Bridge Award*

The most feasible bridge type was a conventionally reinforced, cast-in-place concrete, box girder.

Extensive evaluations led to a five-span configuration with integral bent caps that provided a smooth, single superstructure depth. The superstructure itself consists of a three-cell box girder with an overall depth of 5 ft 6 in.

Due to the bridge's severe curvature, the length along the outside perimeter of the deck was considerably longer than the inside perimeter. This resulted in more dead load on the curve's exterior side than on the inside. To minimize the dead-load eccentricity, the columns supporting the bridge's curved portion were offset from the centerline of the structure. Fortunately, the offset was minor relative to the superstructure's width and was not visible, so it did not affect the design's aesthetics.

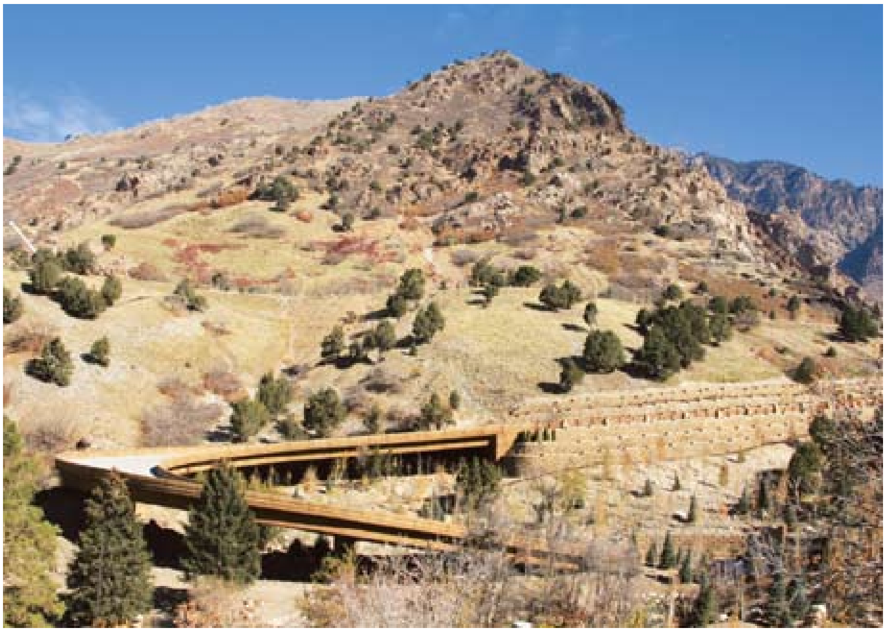
Reinforcement Added Challenges

Reinforcement layout proved complicated. The curvature was enough to require the No. 8 main longitudinal reinforcement to be bent at the bridge radius. Smaller No. 5 bars were flexible enough to be field bent and tied into place. Spacing of the transverse No. 5 bars in the deck was determined by the deck's outside edge. Around the deck's curved portion, this required a radial placement of the bars. The result was a much closer spacing around the curve's inside edge. Epoxy-coated reinforcement was used for the top slab and parapets, while the remainder of the reinforcement was uncoated.

Several analytical models were created to determine the best seismic design for the bridge, which is located along the largest and most active fault line in Utah. A site-specific analysis showed a peak ground acceleration of 176% of gravity. The final solution used Seismic Design & Analysis Procedure D from the Multidisciplinary Center for Earthquake Engineering Research guideline. A response spectra analysis was performed to determine the seismic design forces, and specific elements were designed for the maximum overstrength properties of the columns.

Two concentric reinforcement cages were used in the columns to achieve three goals: maintain an aesthetically pleasing 7-ft-diameter column size, provide the seismic design strength required in the column, and limit the column strength for which the footings had to be designed. Only the inner cage extended into the bent cap and footing. The outer cage was essentially temperature reinforcement although its effects on column strength were taken into consideration for seismic analysis of the structure and for determining the design strength for the capacity protected foundation and bent cap elements.

Post-tensioning the girders was not an option due to the severe curvature, which would have risked damage to the box girder walls.



The dramatic switchback curve achieved for the entrance to a new housing development in the foothills of Utah's Wasatch Mountains near Salt Lake City minimized the impact on the environment, but created tremendous challenges to design and construct.

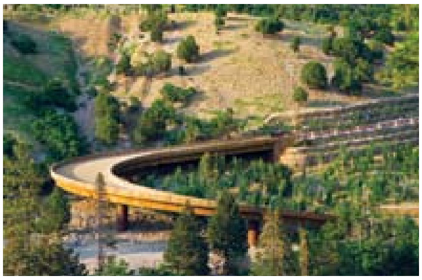
450-FT-LONG REINFORCED CONCRETE BOX GIRDER BRIDGE / WASATCH PACIFIC LLC, OWNER

BRIDGE DESCRIPTION: Conventionally reinforced, five-span, three-cell, concrete box girder bridge designed for steep grade and centerline radius of 80 ft, as well as high seismic forces

BRIDGE CONSTRUCTION COST: \$170/ft^2 (bridge only)

As the bridge climbed the steep hillside, adjustments were made to make the footings deeper and create a more balanced distribution of seismic forces between the columns.

Reinforced concrete offered the only option for reaching all the desired goals.



The cast-in-place concrete option provided flexibility for the tight radius and steep grades, but it also fits well with the rocky surroundings.

As the bridge climbed the steep hillside, adjustments were made to make the footings deeper and create a more balanced distribution of seismic forces between the columns. Substantial cheekwalls and finwalls at the abutments engaged soil passive pressure in the transverse direction. The columns and bent footings were required to resist longitudinal seismic forces, as the abutments were parallel to each other and could only resist seismic forces in one direction.

Ultimately, because each span was relatively short, at about 90 ft, the seismic forces that the columns were designed to meet were not unusual. The structure acts much like a table, with the superstructure so stiff that there is a significant load transfer through the box section to all of the foundations.

Aesthetic Goals Expand

Initial budget restraints limited architectural concepts to staining the concrete and adding some fractured-fin relief in the parapet. As the design developed, the owner realized the opportunity to create a showcase entrance to the development, and the budget was expanded to include architectural enhancements. The additions were made too late to include some early suggestions proposed on the owner's renderings, such as tree planters, variable-depth barriers that extended below the deck, or asymmetrical trapezoidal piers.

The design was modified to provide a more modern-looking parapet that included an LED lighting strip placed under an overhang in the parapet's

A Sustainable Solution

Preserving the natural habitat around this bridge, especially for deer and small-animal crossings, and minimizing impact to vegetation on the hillsides, were key goals in designing the structure. The county also required a public trail that could be maintained through the property. All agreed that creating a bridge was an aesthetic improvement over the other option—a large hillside cut.

Choosing the cast-in-place concrete option was driven by its flexibility in creating the structure's tight radius and steep grades, but it also fits well with the rocky surroundings. The finished structure was stained to complement the colors of the canyon.

Concrete also used Utah's abundant natural-aggregate sources. Steel would have had to be shipped from mills and then fabricated and transported to the site, whereas aggregate was readily available within a few miles of the site. The narrow space constraints also played to concrete's strengths, as steel girders would have required a large crane pad and pull-through areas for trucks. Concrete allowed the contractor to minimize site impacts by having one small crane to handle formwork, and the same pad was large enough to accommodate the concrete pump and trucks.

A critical constraint was a conservation easement located just outside the roadway's proposed edge. Spread footings were found to work well with the available soil pressure, while shoring kept the spread-footing excavations from encroaching into the easement. Caissons would have minimized the hillside cut and remained clear of the easement but would have cost more than spread footings.

LED lighting was placed under a lip at the parapet's interior, delineating the parapet's edge to drivers without casting light upward or outward to detract from the canyon's darkness. This approach alleviated light pollution and enhanced the natural environment.

The concrete design allowed the bridge to not only meet all of the owner's functional and aesthetic needs but provided a minimal impact on the natural environment, blending it with its surroundings successfully.

The owner realized the opportunity to create a showcase entrance.

face. Two 3-in.-diameter conduits were provided in the barrier to carry power and fiber optics to the LED lights, with custom light boxes embedded in the parapet.

Formwork and Concrete

Design and analysis did not stop when the design plans were released, as designers also had input into the shoring design and concrete placement sequence. Numerous site visits were made and a number of geometry checks were performed at the request of the builder, with minor detail changes made to facilitate forming.

The bridge's location allowed the superstructure's concrete slabs and walls to be cast on continuously supported formwork. Hundreds of conventional scaffold shoring towers supported a plywood deck and wall forms. The scaffolding was left in place until the top deck was cast. Parapets were placed after shoring was removed.

Bottom slab and wall forming required an enormous amount of surveying to create the correct curvature and slope. The goal was to generate smooth lines and not rely on short tangent sections to produce the curve. The web walls were short enough to allow 1/2-in.-thick plywood to be used, and it was warped around the curve. The deck was particularly difficult to form and place, as no two interior box cells had the same dimensions. The deck was formed by painstakingly custom-cutting 2x6 timbers and plywood.

Placement of the deck concrete proved to be one of the more challenging aspects. The horizontal curve, super-elevation, and difference in length between the deck's interior and exterior walls produced a warped surface. A simple roller screed was used, and the deck was placed in four separate sections.

Despite the 12% centerline grade, the deck was placed with the screed traveling downhill. The contractor's experience building the Olympic bobsled track and ski-jump landing hill alleviated fears that are typically associated with placing concrete downhill. The relatively light roller screed had to be pulled downhill to screed the concrete. The contractor maintained a head of concrete in front of the screed, and no evidence of poor consolidation or downhill slumping occurred.

As a final measure of protection, a 3/8-in. thick modified polymer overlay was placed on the deck approximately 1 year after the final deck placement.

Designing and constructing this project were challenging, yet the designers remain convinced that reinforced concrete offered the only option for reaching all the desired goals. The use of many computer models and hand calculations was essential, as the unique geometry pushed the engineering well beyond the scope and codes of conventional bridge design. Close interaction between the designer and builder was critical in constructing the bridge within the owner's schedule and achieving a design that provides an impressive gateway into the development.

Jim Deschenes, is an engineer, office principal, and assistant vice president with Michael Baker Jr. Inc. in Midvale, Utah.

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The bridge's initial budget was expanded when the developer realized he could make a strong statement for the entry to the residential development.

AESTHETICS COMMENTARY

by Frederick Gottemoeller

Context-sensitive design has become the goal for much bridge design. The Big Cottonwood Canyon Loop Road Bridge is as fine an example of context-sensitive design as one is likely to see. Tucked into a fold in the landscape, with its single, almost centrally located columns hidden in the shadows, the bridge seems to float over the ground, looking like it has always been there. The cast-in-place concrete box girder, with all of the connections and points of force transfer hidden inside the box, shows only a smooth continuous surface following the geometry of the roadway. The torsional stiffness of the concrete box girder form allows for all of the difficult forces resulting from the extreme geometry, loads, and seismic effects to be handled gracefully. All of the details support the overall form. The parallel shadow lines of the parapet emphasize the geometry, while the color well suits the location.

The renowned twentieth century architect Mies van der Rohe famously said, "Less is More," meaning that adding more detail often detracts from, rather than adds to, a design. It is fortunate that time did not allow the addition of the "asymmetric trapezoidal piers" and "variable depth barriers" to this structure. They would not and could not have improved its appearance. The unusual geometry of the bridge has brought out the best in the designers. Best of all, it means that users can enjoy the appearance of the bridge even while crossing it.