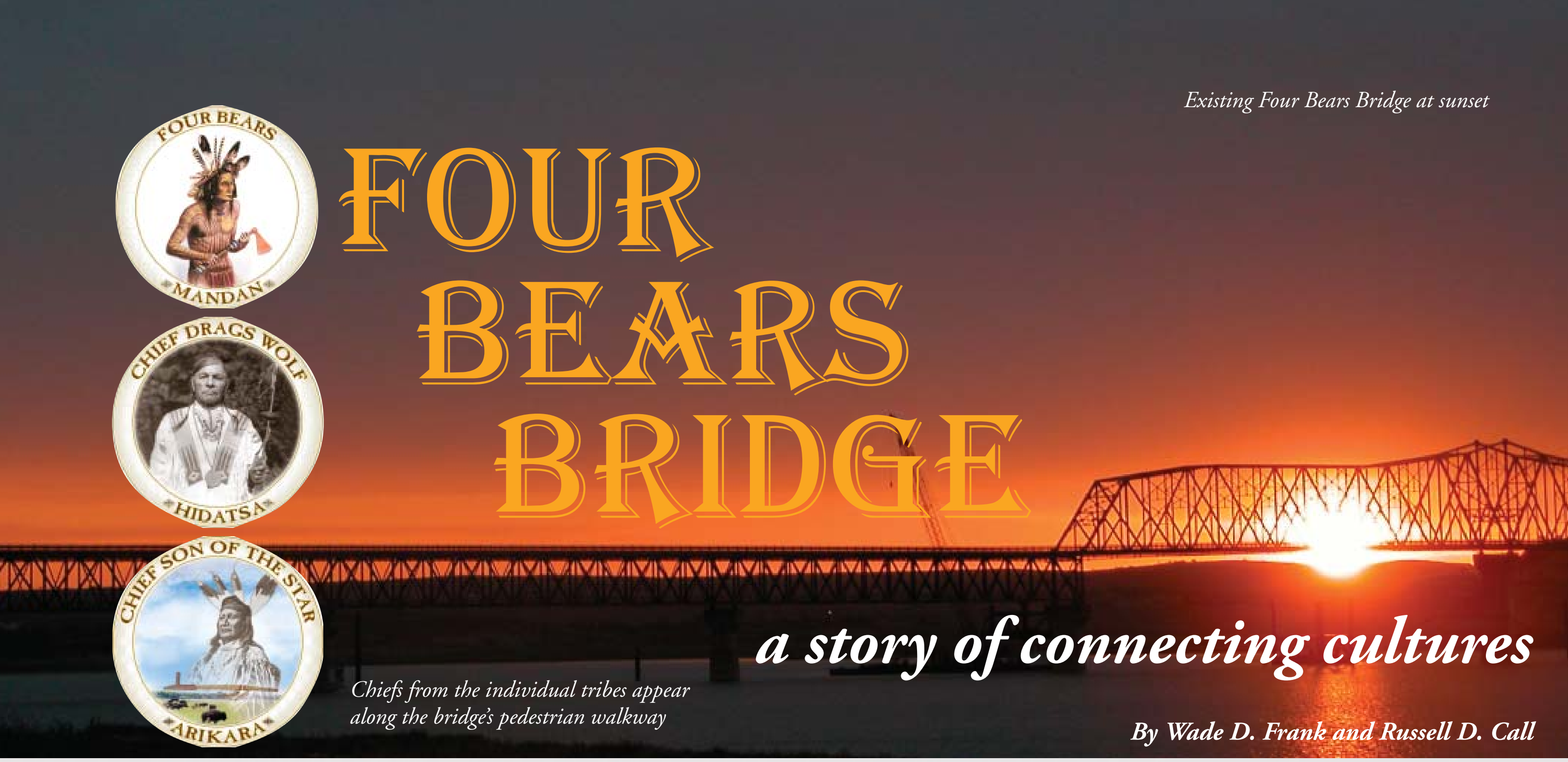

Existing Four Bears Bridge at sunset

Four Bears Bridge

a story of connecting cultures

Chiefs from the individual tribes appear along the bridge's pedestrian walkway

By Wade D. Frank and Russell D. Call

The 4,500 foot long Four Bears Bridge, currently under construction, is the only crossing of the 150-mile long LakeSakakawea, a Missouri River reservoir that was formed by the Garrison Dam. The story of this replacement structure, set on the prairies of the Fort Berthold Reservation, is rich with cultural issues, as well as design and construction challenges. Perhaps the most fascinating aspect about the Four Bears Bridge is that its designers were very concern-ed with its users. So much so that its primary users, members of the Three Affiliated Tribes, the Mandan, Hidatsa, and Arikara who live on the reservation, became integral players in the bridge's design concepts. The completed project, expected in late 2005, will truly be a product of the people it serves.

Background

Since historical and cultural aspects were acknowledged in the bridge design, it is important to understand the background of the area. The first Four Bears Bridge was constructed in 1934 in Elbowoods, North Dakota. Named for two chiefs, one Hidatsa and one Mandan, the bridge proved important in the social and economic well-being of the region, as it was the first river crossing in this area. The flooding associated with the construction of the Garrison Dam in the early 1950s, forced relocation of both the bridge and many residents.

The three-span continuous main span from the first bridge was moved to New Town, and with approach spans added to it, provides the sole crossing of Lake Sakakawea. To this day, the bridge holds symbolic value to the Three Affiliated Tribes because the primary elements came from their former home. In addition to its symbolic and historical significance, the bridge's importance is also economic-based as the bridge provides a critical link to many of the area's primary destinations.

Understanding this rich history, the North Dakota Department of Transportation (NDDOT) required the implementation of Context Sensitive Design (CSD) elements for the replacement structure. In 2001, the NDDOT selected a design team. Kadrmas, Lee & Jackson (KL&J), with offices located throughout North Dakota and the upper Midwest brought local knowledge and led the team. FIGG Bridge Engineers (FIGG), Lichtenstein Consulting Engineers, Braun Intertec, and Trillium Engineering completed the team.

Letting the People Decide

The design team, and representatives from the Three Affiliated Tribes held meetings at six communities on the Fort Berthold Reservation to discuss CSD concepts. These meetings informed tribal members about the project and solicited volunteers on a cultural advisory committee (CAC). This CAC was responsible for providing Native American input.

The CAC volunteers established the bridge's overall theme. They sought input to ensure that the completed bridge would represent the entire reservation, meeting with groups such as the tribal elders and high school students.

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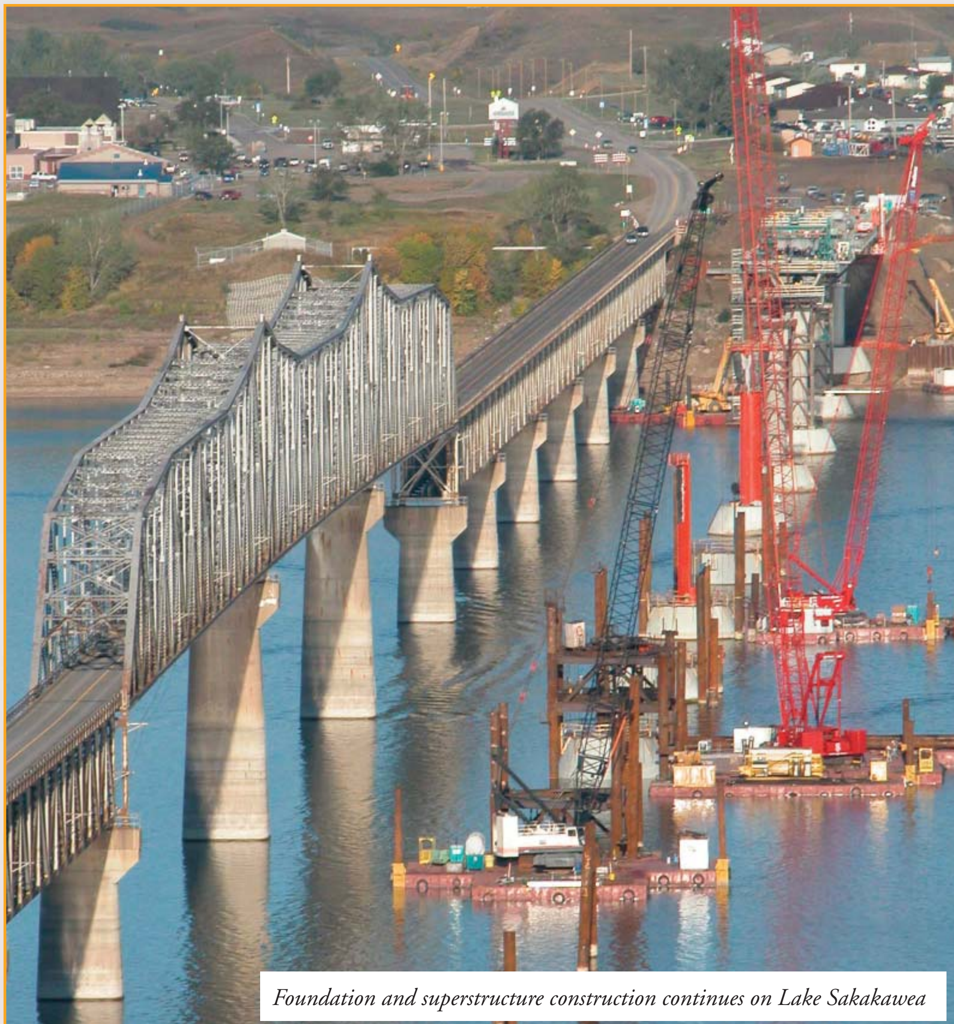
A casting cell with the rebar cage in place in the building that was constructed to protect the casting operation from the severe winter weather of North Dakota



Foundation and superstructure construction continues on Lake Sakakawea

Subsequently, the CAC decided that the theme should focus on the area's historical and cultural aspects and that symbols from each tribe would be used on the bridge.

A design charette was another component the design team used to facilitate the CSD process. The charette was a two-day meeting, occurring in April 2002, in Bismarck, North Dakota's capital city. Representatives from the NDDOT, the Federal Highway Administration and the North Dakota State Historical Society joined the CAC and the design team to determine several of the bridge's aesthetic elements, such as pier shapes, lighting, railings, colors, and textures. Representatives also discussed possibilities for artwork place-ment on the bridge and decided that tribal members should select this artwork to re-present their respective tribes.

The CAC worked with artists and the design team to develop concepts and symbols to be placed in a linear library on the bridge's pedestrian walkway. Ed Hall, a tribal member and project liaison between the design team and Three Affiliated Tribes, stresses that it took a focused effort for everyone to agree on images.

"Because our [Native American] history is handed down orally and there are many versions, it was challenging at times to settle on one image to represent each tribe."

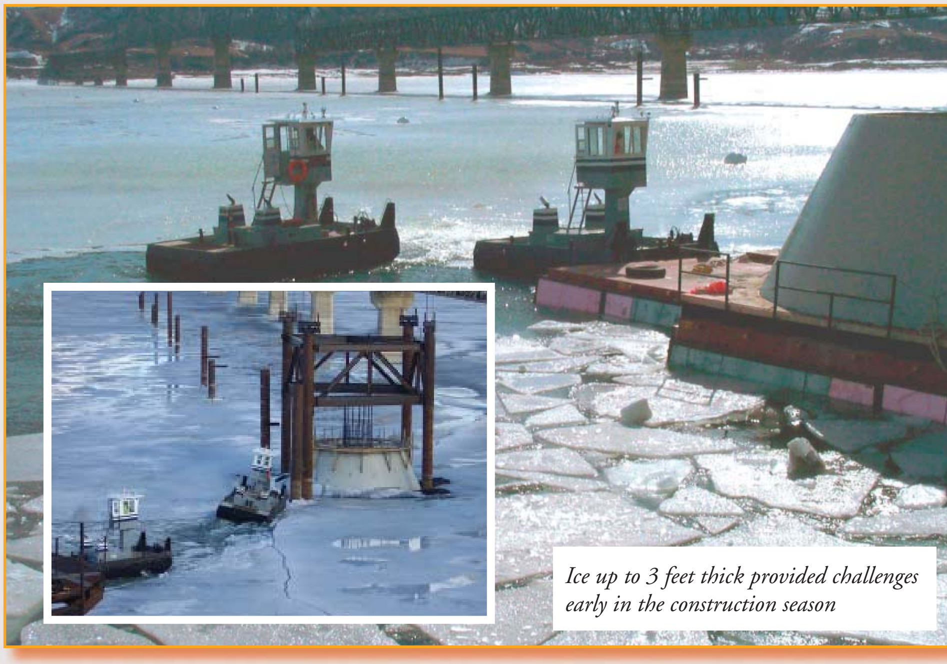
Ultimately, though, each of the tribes decided on four images and one symbol to represent them as a united group. Medallions, measuring four feet in diameter, represent each tribe's culture. There will be 14 medallions. An image of Mandan Chief Mato-Tope, Hidatsa Chief Pehriska-Ruhpa, and Arikara Chief Son of Star appears twice in the library, as a unifying element among the tribes. Roadway lighting and decorative railing with animal images at the piers frame the linear library medallions in earth-toned colors that mimic the surrounding landscape. In addition to the medallions, colored patterns are cast into the concrete surface of the bridge walkway. Tribal members selected three patterns to represent their respective tribes and a fourth to represent the tribes united. On the exterior sides of the bridges there is additional artwork. Members of the Mandan, Hidatsa, and Arikara selected fourteen emblems of various animals that hold tribal significance.

The Bridge Structure

After the conclusion of the preliminary engineering and environmental documentation stages, the NDDOT directed the design team to develop alternative designs of steel and concrete for bidding, fostering competition between the steel and concrete industries and contractors who specialize in each. The NDDOT's alternate choices included steel box girder and segmental concrete box girder designs.

KL&J and Lichtenstein Consulting Engineers designed the steel alternate, which consisted of twin, variable-depth trapezoidal box girders supported by dual-drilled shaft piers. The box girders varied in depth from eight feet at midspan to twelve feet at the piers, specifying Grade 70 High Performance Steel at the negative moment regions over the piers. The piers consisted of tapered columns on top of eight-foot diameter drilled shafts, tied together with a reinforced concrete strut. The strut near the top of the drilled shafts allows the two columns to share the load caused by ice forces transverse to the piers. Also, the bearings at the tops of the piers were fixed, allowing the piers to work together in resisting longitudinal ice and temperature loads. As the design progressed, engineers updated a computer model of the structure, incorporating the calculated stiffness of the piers and girders to ensure their ability to endure all force effects.

Segments delivered by barge were lifted into place with a beam and winch system



Ice up to 3 feet thick provided challenges early in the construction season

FIGG was responsible for the precast concrete segmental bridge design and chose to offer two foundation designs, allowing contractors with particular types of equipment the option of their preferred construction method. One design offered very large diameter drilled shaft foundations, the other a pipe pile option. The 4,500 foot bridge consists of 15 spans, typically 316 feet in length, being constructed in balanced cantilever from crane-mounted barges on the lake. The design calls for two expansion joints: one at each abutment of the bridge. The modular expansion joints allow for significant movement generated by thermal variations, along with creep and shrinkage of the structure as it ages. Extensive modeling and analysis were completed in order to determine the amount of movement necessary to be accommodated by the expansion joints. Minimizing the number of expansion joints decreased maintenance requirements and associated expenses. Additionally, the piers are designed to respond to the thermal movement of the bridge, along with creep and shrinkage. The four piers in the center of the bridge are fixed by pot bearings that are grouted, while the others are designed as expansion piers.

Ultimately, when the bids were opened on February 14, 2003, the low bid was for the concrete segmental alternate, with the pipe pile foundation option. Fru-Con of Ballwin, Missouri was selected at a bid of just under $55.5 million.

Design Challenges

North Dakota's typical winter weather and Lake Sakakawea's distinction as one of the largest man-made lakes in the United States create large ice floes. Substantial investigation of ice forces and their effects on the bridge design, particularly the deep foundations, were a challenging aspect of the design. A minimal amount of site specific ice data had been collected over the years, although significant data existed from nearby Lake Ashtabula. Trillium Engineering performed a probability analysis and simulation of ice thickness on Lake Sakakawea that was confirmed through local residents' observations. The maximum simulated ice thickness (normally found in late winter) was calculated to be between 20-inches and 43-inches. However, because ice breakup normally occurs under windy conditions, the thickness at breakup is typically no more than 90 percent of the maximum. Trillium determined the appropriate design ice thickness to be 36-inches. The Four Bears Bridge project was designed in accordance with the AASHTO *Standard Specifications for Highway Bridges*. Since the LRFD code has more comprehensive ice-loading requirements, the LRFD-based ice loads were used in the load combinations required by the project's standard specifications. Based on simulations of ice-crushing strengths for Lake Sakakawea and the LRFD code requirements, an ice-crushing strength of 100 psi was used for the design of the new Four Bears Bridge.

Variations in the lake bed posed challenges as well. The soils under Lake Sakakawea consist of glacial and lake deposits on top of the Fort Union Shale formation, a bedrock suitable for supporting deep foundations, but soft enough to be excavated or drilled. The top of the Fort Union formation varies from an approximate elevation of 1800 at the ends of the bridge, down to elevation of 1650 at mid-span. These variable depths were accommodated by the foundation design.

In response to requests from recreational boating organizations, the NDDOT agreed to provide additional navigational clearance beyond the 30-foot minimum required by the US Coast Guard. Lake Sakakawea is home to many sailboats, some with mast heights exceeding 50 feet. Providing additional navigational clearance resulted in a variable roadway profile, with the center of the bridge approximately 20 feet higher than the ends of the bridge, opening more of the lake to use by large sail boats.

Building the Four Bears Bridge

Construction of the Four Bears Bridge began in 2003. It is the largest bridge project undertaken in the state of North Dakota and the first use of the post-tensioned precast concrete segmental bridge technology in the state. Fru-Con elected to use four to five barge-mounted cranes to accomplish construction of the bridge superstructure.

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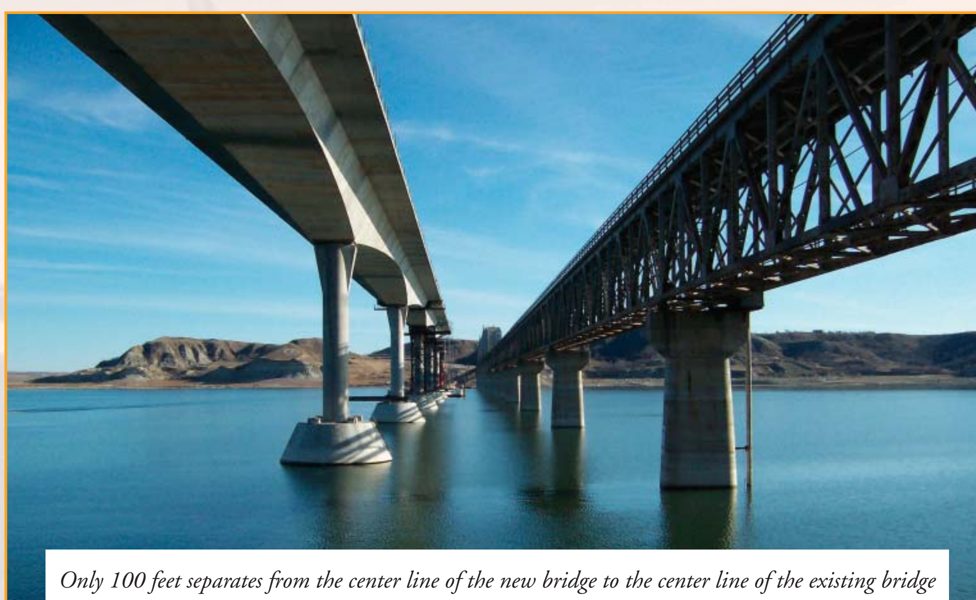

Only 100 feet separates from the center line of the new bridge to the center line of the existing bridge

Waves breaking on Lake Sakakawea

Built as a flood control project, water levels on Lake Sakakawea traditionally fluctuate with the need for water downstream. The possibility of lake waters as deep as 80 feet had to be accommodated by the design and prompted the use of precast concrete "lost" cofferdams, rather than sheet pile cofferdams. This process involves building the cofferdam onshore and "floating" it onto the water. The cofferdam is then suspended with high-strength rods, allowing piling to be driven through it. Each cofferdam is supported with 13 to 14 piles. After pile driving has been completed, seal concrete is placed and reinforcing steel is tied in place for the pier footings. Finally, the "lost" cofferdam is filled with concrete. In essence, the formwork for the bridge is created with cofferdams that do not extend to the full depth of the lake.

To obtain strength in short time frames, precast concrete segments were cast in a controlled environment. Typical segments were cast using three different machines in a casting building. The 28 pier segments were cast outside. Given the extreme North Dakota winter weather and the project's isolated location, segment casting continued at a slower pace through the most challenging part of winter, and erection operations were suspended for approximately 4 months of the most severe weather while the lake was iced over. The bridge opened to traffic on September 1st, 2005 and demolition of the older bridge is underway. A dedication event for the new bridge will be held on October 3rd, 2005.

Conclusion

The Four Bears Bridge engineering design team met the challenge to construct a replacement for North Dakota's only deep water bridge, which will survive temperature extremes and water elevation fluctuations, all the while preserving the culture rich heritage of the Three Affiliated Tribes. The bridge transcends function and fulfills the role of landmark, providing a tribute to history. Lake Sakakawea will host one of the national signature events celebrating the bicentennial of the Lewis & Clark expedition in August of 2006. At that time, Americans will be introduced to North Dakota's newest landmark.▪

The cofferdam served as a template for pile driving operations

Pier segments were cast in halves to allow for the use of the same erection equipment throughout the project

Wade D. Frank supervised the substructure design for the steel alternate and assisted in the overall project management of the Four Bears Bridge Project. He is the manager of Kadrmas, Lee & Jackson's Bridge Design Group and is a registered professional engineer in four states. Russell D. Call was FIGG's project manager for the Four Bears Bridge project. He is a specialist in long span and complex bridges. He is a registered civil engineer in four states and holds an Illinois structural engineering license.

COFFERDAMS

Contributed by Russell D. Call, P.E., S.E., FIGG

Large diameter drilled shafts along with a pipe pile option were designed to resist the ice forces and ranged from 100 to 250 feet deep to reach to the shale bearing layer. Pipe piles from 90 to 160 feet driven into the shallower alluvium layer required a fairly large footing/pile cap to capture the number of piles needed to resist the ice forces. Both the monoshaft and pile foundation option required multiple operations to construct in 80-foot deep water. Alternate foundations were designed and competitively bid to ensure the greatest economy.

The pipe pile foundation option was selected by the low-bidder. Driven pipe piles provide for an economical solution to achieve bearing in the deep stratum. While driven piling is economical, the placement of a conventional pile cap placed at mudline with sheet piling could be expensive and difficult to construct and to maintain in deep water. A "floating cofferdam" provides the preferred economical solution for the pile cap or footing. The cofferdam/footing does however present a fairly large surface area that would be subject to ice forces. As a result, the optimum location for the footing was just below the statistic low water elevation. This location also was aesthetically preferred allowing the piling below the footing to be exposed to view, approximately only once every 50 years. Since the major ice forces occur as a result of the wind and can occur in any direction, a symmetrical foundation was designed.

Suspended cofferdam prior to pile driving operation

36-inch steel encased concrete pile support pier footing, cofferdam and pier

A conic frustum (truncated cone) was chosen for the 39-foot diameter precast cofferdam, along with battered 36-inch diameter, one-inch wall thickness pipe piles in a circular arrangement. The holes in the base of the precast cofferdam function as a template for the pile driving operations, while the one-foot thick sloped sides of the cofferdam serve as a lost-form for casting the footing. Once piles are driven, a tremie seal is placed in the base of the cofferdam. The cofferdam is then dewatered, pipe piles are cut off, reinforced and filled with concrete. Footing and column reinforcement are placed in the dry and then concrete is placed, which completes the footing. Should the water level rise above the cofferdam, a steel follower is attached to the precast cofferdam.

By sloping the face of the precast cofferdam, reduced lateral ice forces were realized. The force imparted to the footing is a combination of the force to fail the ice in bending and the frictional force required to push the ice up the face of the sloped surface of the cofferdam. In order to reduce the frictional force on the outside surface of the precast cofferdam, two coats of an epoxy sealer was used. A lateral ice force of 845 kips is imparted on the pile cap for the maximum ice loading design case.■