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SUBJECT: St. Croix River Crossing
Constructability Memo

The St.Croix River Bridge crossing at this stage of the project consists of three options of the extradosed structural type over the St.Croix River proper with an adjacent transition structure on Minnesota side with similar cross-section and supporting piers to accomplish a uniform visual expression.

This structure preferred construction material is concrete/prestressed concrete. The steel is considered a less desirable option, so further constructability review remains focused on concrete as a material of choice.

Major restrictions with impact on constructability are:
- environmental: Wisconsin bluff, St.Croix River, a mussel bed adjacent to Wisconsin river bank, primary and secondary wetland areas on the Minnesota river bank, and Minnesota Highway 95 running parallel to St.Croix River south of the City of Stillwater
- design induced: the split of the structure over the wetland on Minnesota side, depressed vertical clearance over Hwy 95
- maintenance consideration: minimum number of expansion joints and bearings, location of the expansion joints over the piers only.

Those restrictions will not have only a major impact on location of the permanent structure piers/abutments but they will also play a major role in selection of the construction/method and technology.

Foundation:
According to the preliminary geotechnical investigation the bridge supporting elements are located on less than desirable soil. Therefore a deep foundation types have to be used to reach layers of rock to support the structure. The largest reactions are to be expected in the river were the span length reaches almost 500 feet. The available structural types are piles, shafts and caissons. Each of them is a viable alternative but the selection of the most economical one will have to consider the foundation type and technology throughout the whole project.
Foundation construction in the river can utilize wide variety of the large diameter shafts for which transportation of the large structural elements on the barges can prove to be highly economical and with the limited access over the mussel bed very advantageous. While caissons were used in the Midwest for the river crossings quite extensively, the significant labor cost related to this method may deem this alternative prohibitive. The use of smaller pile elements (steel and/or concrete driven piles) to support relatively large reaction of the structure, with almost 50,000 sq.ft. tributary area of the superstructure, may require so many piles that a pile cap needed will be quite sizable and heavy. But using the small foundation elements used by local contractor may bring more competition into the bidding process. The use of the large diameter (5 to 10 ft dia) of

drilled shafts may be highly mechanized and river access allows for minimum impact on environment in the project location even when large elements of steel shafts are transported to the locale.
Alternatively, the contractor can opt for building a trestle to provide for an access to the pier location which can be helpful for construction of the pile caps and piers as well.
The pile caps are restricted to a depth -15 feet bellow the median water level in the St.Croix River. This may require de-watering of the pile cap perimeter using a cofferdam/sheet pile protection of the working space to secure construction site.

The construction side in Minnesota between the western river bank and Highway 95 has serious environmental restrictions with no or a very limited access over and into a primary wetland so the piers are located strictly outside of the primary and only a few in the secondary wetland area. Therefore no construction activity is to be assumed in the primary wetland for the construction of the foundation and the piers. Outside of the wetland any construction activity alongside Hwy 95 will accommodate the traffic on this thoroughfare to the largest extent if a detour is not secured to take the traffic completely outside of the construction site.

Piers
All three options being considered entertain the pier shapes which, while aesthetically pleasing, represent the challenge to the design of the economical form and speedy and quality construction. In general, the towers of all three options are unusual, relatively difficult and expensive to construct. Unit costs may be a multiple of that for more conventional stay towers.

The long expansion length of the structure of 3,000 feet represents another challenge to the designer. While all reasonable effort is being made to accommodate this length and horizontal movements due to temperature, creep and shrinkage, with split piers and frame connection to the superstructure without the bearings, to satisfy the client's maintenance concerns, it is possible that the most economical solution would call for bearing supports on the external piers of the river crossing. This would complicate the balanced cantilever construction providing additional stability of the cantilevered structure during the construction phase. Another option would be inserting an additional expansion joint within the river crossing structure. However, an expansion joint at midspan is unacceptable due to the client's serious concerns with a deflection control of this option.

The type of the pier form utilizing to the largest possible extent highly repetitive construction cycle and could be used on the piers both for the river crossing and for the transition structure will be at premium.

Concept 1 – "Organic Option"

1. The tower section has a number of contact surfaces varying in shape and dimension. This results in very expensive forming and reinforcing. The relatively "simple" form for structure concrete and architectural "add-ons" may help to lower the construction cost.
2. Depending on the designer/contractor choice where to anchor the cables (either in the towerhead or at the deck), the following applies. At the towerhead (which is the preferred location for jacking) there is little room for a typical live end anchor. If jacking takes place at the lower end, there will be a premium cost for access and duration for stay

jacking. If iso-tension method using a monostrand jack is allowed, the 8 ft space between the tower walls should be sufficient to stress the cables. Isotension is permissible nowadays for cable-stayed bridges. This will avoid the unsightly live end anchorages to appear irregular at the girder which will be visible. Because this area in the tower is enclosed by glass shroud anyway, it may be advantageous to use a steel frame with steel saddle pipes for each individual cable. This will offer the best force transfer.

3. The sloping the double leaves of the tower from 25'-6" to about 13'-0" will increase cost.
4. The diaphragm at the tower should go through the column legs fully so as to engage the tow plates of the column. Because of the experience with another extradosed structure built in the United States, the 3rd central pier is added for safety reasons. The final design may prove that replacement of this pier by other engineering means is possible.
5. The transition between architectural/structural concrete requires a lot of attention in the final design so the structural concrete is sound. The architectural concrete may be limited to the nose only. The section in the water shall be solid.

Concept 2 – "Hull Option"

1. Multiple taper on unique tower section will add to the unit cost by a complicated form and extra time required for adjustments of the form.
2. The anchorage design and securing access for jacking will require a lot of detailing and hard decisions. But in the event that below deck access is required, it will add time and cost. If tower access is planned, then the limited space allotted will make jacking quite expensive. The cables have to be continuous over the towers. There is no space for stressing at the tower. But the form is well suited for saddles. The live ends will be located at the girder side. It is suggested that a large steel form be used to cast the bottom portion of the tower legs, probably up to the level of girder deck. Climbing form can be used for the rest of the tower. It will all be cast –in-place. The inclination will increase the cost of construction. The repetitive use of one set of good form will reduce the construction cost.
3.
4. Tower reinforcing may be quite heavy, which will add to the cost for an already unique tower configuration.
5. There will be a solid diaphragm inside the girder at the tower location.

Concept 3 – "Portal Option"

1. Unique tower shape with multiple curves, sections and tapers will increase the cost both for the form itself and for labor intensive construction adjustments as well. It is recommended to build one set of good form and reuse it for seven times at other towers.
2. The top tower arch element will require a supporting falsework or precast member with additional detailing required for fully functional connection to make it an integral part of the pier structural system. The entire upper portion of the towers above the deck should be cast-in-place. It is too heavy to be precast.
3. If sufficient access for stay installation cannot be provided within in the tower, alternative of the live access to the jacking below deck may be a solution with extra cost attached.
4. The outside branches of the lower portion of the towers should best be constant.

5. The cables should be resting on saddles at the towers. At the girder end, the cable should be centered at each blister.
6. The arch shape tower should be properly checked to assure the dimensions are approximately appropriate. The arch will have significant in-plane bending due to the cable forces. It is possible to curve the arch in the third direction to increase the rigidity of the arch.

Superstructure:
All three options were designed for the concrete being a material of choice. Different environmental and functional restrictions over the length of the crossing may limit the feasible construction method but in general there are two areas of the similar consideration when construction method is selected:
Area 1 – bridge structures over the St.Croix River and the area between the Hwy 95 and the gore area
Area 2 – end spans with abutment landings, the gore area separated from the rest of the structure by expansion joints on both sides, end span over the Hwy 95 with depressed structure depth and possible variable depth.

Area 1 provides for at least two construction methods such as construction on supporting falsework or balanced cantilever construction method. The later one is more advantageous especially over the water where the height above the water over 100 feet and a need for a temporary foundation in the river may be impractical. High clearance, optional material transportation on barges and minimum impact on the river will make balanced cantilever construction very competitive. Both precast and C.I.P. method could bring different pros and cons when evaluating their respective suitability for each of developed options.
Precast segment production:

Pros

- the total length of the structures cca 5,000 feet with total number of segments reaching easily 500 and possibly 1,000 (when structure is divided in the cross-section into 2 pieces) with a constant depth of the structure and relatively simple casting cell (e.g. cheap) to operate will allow for reasonably efficient casting yard with a year round production of the segments.
- a simple constant depth form may allow the local subcontractors bid competitively
- the barge transportation, if a casting yard is established in a vicinity of the St.Croix River, would allow for easy transportation of larger and heavier segments which otherwise would not be feasible with the road transportation alternative
- erection of the segments can accommodate a very aggressive construction schedule, while mature and hard concrete of the segments erected would limit the impact of the creep and shrinkage effects on relatively long sections of the structure between expansion joints.
- the precast segments could erected both in the river and wetland environ utilizing different erection method (balanced cantilever and span-by-span with gantry)
- limited use of a wet process

Cons

- a need for additional real estate space to build a casting yard and storage area

- securing the transportation links and means. While the river corridor with barges can be quite advantageous to accommodate large segments the road transport imposes additional restriction on the size of the segments to accommodate the local hwy restrictions (horizontal and vertical clearance, loading capacity of the bridge crossings, etc.).
- match cast production and geometry control on horizontally curved structure require higher standard both in production and in an erection phase

Cast-In-Place segment production -

Pros

- the large number of the same length spans provides for a repetitive use of the travelers.
- a simple constant depth form traveler will keep the manufacturing cost down
- no need for transportation of large and heavy elements (the travelers can be delivered on the barges on the St.Croix River
- easier correction of the geometry deficiencies through adjustments in a future cast-in-place segment production
- no limits on the size and weight of the segments other than design considerations.

Cons

- construction schedule limited by the number of travelers and length of a typical cycle
- increased impact of creep and shrinkage on large horizontal movement (can be mitigated by delayed closure of the superstructure
- a need for qualified crew and/or expertise to handle the from travelers
- limited use of travelers outside of the river crossing

Apart from the general constructability considerations for all three options the following individual constructability issues were identified:

Concept 1 – “Organic Option”

1. the shape of the box girder is unusual (if not further simplified disregarding the aesthetic considerations over economical limitation), but provided it remains constant along the length, it should not result in much of a premium for forming (assuming it is precast segmental) or manufacturing smaller form travelers which may be used for transition structures as well (when C.I.P. option is considered).
2. providing the access to each tower for delivery of materials to each pier tree is established, the precast segment delivery can be more economical. Delivery only to a pier station and re-handling these large segments would likely push the costs into the use of a cast-in-place solution for the deck. This would lengthen the construction time, and increase cost.
3. The twin boxes improve handling if the section is precast, and should lower costs vis a vis a single box solution, assuming cable diaphragm design can be modular as well. Alternatively, a full section like the one used for the Hull option can be used here as well. It will probably be less expensive.

The pedestrian path can probably be configured as a cantilever from the top slab of the box instead of being supported by the diaphragms.

Concept 2 – “Hull Option”

1. the single box section will make precasting difficult, and related transportation logistics may make it impossible if the River corridor cannot be used.
2. if one full cross-section form is used then it cannot be used for the ramp portion of the transition structure unless the form is significantly adjusted.
3. a cast in place solution utilizing a form traveler needs a modification of the number of interior webs to minimize the labor intensive form adjustments to keep the labor cost at bay
4. CIP does not need along station access, although it would help for material access at the workfront.
5. both precast and C.I.P. options needs a lot of attention to be given to the detailing to provide for effective and economical segment production
6. The cross section still require attention on details if selected. The section, if built without diaphragm, will be very soft. With the cable supports at the outside edges, the interior section is like a vierendeel truss where the bending in the webs can be significant. Therefore, the web will probably be thicker than shown. The outside cells, at least, must have a diaphragm, especially if we want to keep the curved soffit.
7. The cable anchorages at the girder may not look good. A kind of cover should be used to hide them.

Concept 3 – “Portal Option” – in general both Hull and Portal Options are similar in cross-sections and therefore the comments from above are applicable as well.

Area 2 with serious restrictions both due to a structure from and due to external conditions may have just one reasonable economical alternative – using the supporting falsework. Even for this method of construction the height above the terrain up to 100 feet plus a limited access to primary (none) and secondary (very limited) wetlands may require to use large span horizontal carrying beams (trusses?) supported on the tall towers using already built permanent foundation or, where allowed, the temporary foundation in compliance with environmental restrictions.
For construction over Hwy 95 with a very limited vertical clearance and possible public traffic under the supporting falsework, a temporary non-standard vertical clearance permit is necessary if the construction detour for the full length of superstructure construction period cannot be secured.

In conclusion, all three options developed, while representing a significant aesthetic accomplishment, bring significant challenges for a contractor. To solve many of those challenges identified in this memo will require a significant effort on both designer and contractor side. It has to be recognized that the final solutions of those challenges will increase the construction time and the construction cost over a standard structure type which would be considered otherwise.

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