ABSTRACT

Alternative design schemes to replace the 76-year-old Provencher Bridge over the Red River in Winnipeg, Manitoba are presented. Future long-term objectives and site constraints were the major factors affecting the choice of a precast prestressed concrete system incorporating a unique post-tensioned connection. Preliminary design indicated that this concept is economical and efficient. An erection scheme for construction of the bridge is discussed.
BACKGROUND
Provencher Bridge is a four-lane undivided roadway bridge over the Red River, near the geographic centre of Winnipeg, Manitoba, as shown in Figure 1. The bridge links the community of St. Boniface with Winnipeg’s central business district. The bridge carried approximately 37,000 vehicles a day in 1987, and functioned at a level of service F during the p.m. rush hour and D during the a.m. rush hour. Built in 1914, the bridge structure consists of seven spans with an overall length of 280.8 metres. The superstructure is comprised of two riveted steel plate half-through girders with interconnecting transverse floor beams.

In 1987, the City of Winnipeg commissioned Wardrop Engineering Inc. to investigate the traffic capacity, the structural integrity of the existing bridge, and to provide recommendations to address the following long-term objectives:

1. Provide a river crossing with a traffic capacity adequate for the predicted future growth.
2. Improve the horizontal and vertical roadway and approach alignments.
3. Upgrade load-carrying capacity of the existing structure to the proposed legal limits.
4. Improve the navigation channel.
5. Maintain an acceptable level of service throughout implementation of the rehabilitation or replacement of the existing structure.

The investigation concluded that rehabilitation of the existing structure, to meet the above long-term objectives, would be uneconomical due to the type of superstructure and deterioration of the bridge river piers. The study also recommended an extensive strengthening and upgrading. The investigation also required replacement of all bearings, expansion joints and high density concrete overlay. The work could require closure of the bridge for a six-month period.

PROPOSED ALTERNATIVES
Three upgrading alternatives were selected to achieve these specified demands:

Alternative 1: New six-lane superstructure on the existing rehabilitated piers
Alternative 2: New three-lane bridge and rehabilitation of the existing bridge
Alternative 3: Two new three-lane twin structures

Evaluation of the above three were based on functional, structural and cost considerations. Using a matrix method of evaluation with each area of consideration assigned a relative importance weight totalling 100 points, it was found that alternative 3 was found to be the optimum overall solution.

Based on this study it was recommended to replace the 76-year-old structure with two new three-lane twin bridge structures. The proposal included future provision for widening the bridge to four lanes. The future expansion includes connecting the river piers to provide support for the future additional median lanes. Using the same bridge piers, two alternative solutions for the superstructures using precast concrete and steel girders were provided.

Due to funding constraints, the project is proposed to be constructed in three phases with the following milestone dates:

Phase I - completion November 1992, as shown in Figure 2
- construction of the first (eastbound) new three-lane bridge
- utilizing existing bridge as the westbound 3-lane bridge with the appropriate upgrading of the bridge deck

Phase II - completion November 1999
- use of the complete bridge in the first phase as two lanes, each way, as shown in Figure 2
- demolition of the old bridge
- construction of the second three-lane (westbound) bridge

Phase III - completion 2020 (if required)
- extension of the two completed bridges into four lanes each way by connecting the bridge piers and widening each superstructure with one additional lane.

Final design for the first phase is currently in progress.
Figure 1. Overall view of existing Provencher Bridge

Figure 2. Models of the proposed Phases I and II
DESIGN CONSIDERATIONS

The following considerations were found to be crucial to yield an efficient and economical project:
1. Pier locations were set to provide equal spans for the main girders of the two precast and steel superstructure alternatives. This resulted in using two abutments located on the east and west bank of the river and four river piers. The foundation types were caissons for the piers and H-piles for the abutments.
2. The vertical alignment should match the existing intersection at the east approach which could not be economically altered.
3. Elevation of the bottom of the main girders should allow passage of 160-year flood predictions.
4. Central river spans should improve the navigational channel in width and height.
5. Aligner, length and location of the bridge piers as well as the superstructures should accommodate an additional fourth lane expansion of the bridge.
6. The structural capacity of the bridge should be upgraded to the proposed HSS30 City standard.
7. The overall structures on the Red River should be aesthetically pleasant, since the bridge is very close to the historic “Forks” development in Winnipeg, where the Assiniboine River flows into the Red River in the centre of Winnipeg.

DESIGN LOADS

The bridge will be designed according to the AASHTO Standard Specification for Highway Bridges, 14th Edition, 1989. The live load will be based on the HS30 lane load and HSS30 vehicle load. The HS25 wheel load will be used for the deck design.

The HS30 lane and HSS30 vehicle loading provide a sufficient reserve capacity not only for the current legal vehicle, but also for the proposed future legal vehicles, as designated by the City of Winnipeg.

Due to the horizontal curvature and skewed river piers shown in Figure 1, an ANSYS finite element analysis program was used to determine the distribution of the moments, shears and torsional forces in the superstructure. Thermal stresses were included in the analyses to determine the lateral load and required expansion joints.

The deck was simulated using a plate element and the prestressed girder was modelled using a beam element with specified height to the neutral axis to determine the torsional stresses. The finite element model used for the analysis is shown in Figure 3.

SUPERSTRUCTURE DESIGN

Based on the standard requirements of the City of Winnipeg for large projects such as the bridge under consideration, two alternative structural design concepts were considered. The first design concept utilizes precast concrete girders to provide a continuous beam with composite action of the concrete deck slab. The second design alternative uses trapezoidal steel box girders also with composite action of the concrete deck slab.

The bridge consists of five continuous spans for a total length of 266.3 m, as shown in Figure 4(a) and (b).

The restricted elevation of the bridge, controlled by the approach roads and the 160-year flood level, imposed the need for constant depth girders for both concrete and steel design concepts. Use of a haunched section for the girders at the piers will reduce the navigation channel and result in a very uneconomical design, since the girders should be designed to withstand the impact forces due to floating debris. Using constant depth girders will also have the advantage of using the same steel form available from local contractors and therefore provide considerable economical advantage. The constant depth leads to the optimization of the span length and the number of bridge river piers. The precast concrete segmental construction concept was not considered due to the lack of experience of the local contractors in this field.
Figure 4(a). Elevation of Phase I of the Bridge
Figure 4(b). Plan view of the existing and Phase 1 of the bridge.
Concrete Alternative

The design concept challenge, to provide a constant depth girder along the entire bridge, was solved by using the following special design configuration:
- a double cantilever pretensioned precast concrete I-girder over the piers,
- centre drop-in precast pretensioned concrete I-girder
- unique arrangement of post-tensioned tendons to provide continuity through the end block of the centre drop in girders.

The proposed design concept eliminated the need for haunched girders over the piers and significantly reduced the length and cost of the post-tensioned tendons and consequently enhanced its efficiency. Using a constant depth girder significantly reduces not only the cost of fabrication, but also the erection cost.

Based on a maximum capacity of the local precast plants in Manitoba to handle a 42 m long by 2.3 m deep I-girder, a maximum length of the three intermediate spans was determined as 39.5 m. Nine rows of the precast concrete I-girders are proposed to support the superstructure. The selected spans also provide an improved length of the navigation channel over the Red River. The horizontal curvature of the bridge and the skew location of the piers will be accommodated at the connections of the precast girders. The location of the river piers in Phase I was designed to be in line with the river piers of Phase II to facilitate connection of the two piers and support the additional girders for the future deck expansion. The skew alignment of the river piers and horizontal alignment of the second phase resulted in reduction in the span length of the first phase to an approximate length of 58 m.

The proposed structural system consists of short precast pretensioned double cantilever I-girders with a length of 19.5 m at the bridge pier supporting a centre drop-in precast pretensioned I-girder of approximately 40 m in length, as shown in Figure 5. The dapped ends of the double cantilever girder at the piers will speed the erection and eliminate the use of temporary river piers on each side of the pier. The dapped ends will also accommodate the change in the girder alignments required to achieve the horizontal curvature of the bridge.

A total of nine rows of girders were required for the 4-lane section of the bridge. The storage capacity of the turning lane at the end of the bridge required the turning lane to extend over the last two spans. Therefore, the spacing between the precast girder was varied to accommodate the increase in the width of the bridge from three lanes to four lanes. The spacing between the girders in the first two spans was designed to accommodate the three lanes. The spacing between the girder in the third span was varied to accommodate the changes from a three lane to a four lane width. The girder spacing in the fourth and fifth spans was designed to accommodate a four-lane bridge.

Prestressing System

The precast concrete double cantilever girder at the pier is pretensioned to support its own weight, and weight of the drop-in girder. The double cantilever section is also designed to accommodate the post-tensioning ducts for the continuity of the bridge required to support the moments due to deck dead load and to live loads acting on the composite section of precast girders and cast-in-place deck slab.

The precast concrete drop-in girders are pretensioned to resist their own weight, the weight of the deck and the continuity moment due to the live load as composite sections with the cast-in-place deck. The end blocks are also designed to provide the anchorage for the post-tensioning system of the double cantilever section required for the continuity.

The dapped ends of the double cantilever section are also used to provide the curvature required for the bridge in place. The resulting space due to the change of angles of the straight lines of the girders at the dapped end will be filled by concrete cast monolithically with the cross diaphragms at the same location.

This design concept limits the need for post-tensioning only in the double cantilever portion over the piers. This significantly reduces the prestress losses associated with post-tensioning due to the reduction in length and
PROPOSED POST TENSIONING SYSTEM
FOR CONTINUITY OF THE BRIDGE

SECTION A-A
CANTILEVER GIRDER OVER THE PIER

NOTE:
ALL DIMENSIONS ARE IN METERS.

SECTION B-B
END BLOCK OF THE PRE-TENSIONED DROP-IN GIRDER

SECTION C-C
MIDSPAN OF THE PRE-TENSIONED DROP-IN GIRDER

Figure 5. Proposed post-tensioning system for continuity
curvature of the tendons. This system eliminates the need for haunched girders at the pier and results in a more efficient and economical design of the girders. The short lengths of the tendons also reduce the lateral forces on the girders due to the horizontal curvature of the bridge. However, creep effect due to post-tensioning and its effect to increase the moment at the mid-span was considered.

Due to the short length of the tendons, the post-tensioning will be jacked from one end only, which will certainly minimize the cost. The thickened end of both the double cantilever and the drop-in girder was found to be large enough to distribute the anchorage stress and allow easy access for jacking.

**Erection Scheme**

Erection starts by placing the double cantilever section on the river pier with temporary bracing from one side only, as shown in Figure 6(a). The temporary bracing will be used to balance the weight of the drop-in girder from one side supported by the abutment and the unsupported end of the double cantilever section as shown in Figure 6(b). The same scheme will be repeated for the second river pier until the completion of the bridge, as shown in Figure 6(c) and (d). Casting of the cross diaphragms follow completion of each span. Post-tensioning will be applied after achieving strength of the concrete of the diaphragms sufficient for prestressing specified by the code.

During post-tensioning, bridge bearings are designed to slide freely to prevent any stresses on the bridge piers and additional secondary moments on the superstructure of the bridge. After completion of the erection, some of the bearings are replaced to provide the proper support systems under service loading conditions.

The bridge deck slab will be 240 mm thick, consisting of a 100 mm thick normal concrete layer and a 140 mm high density concrete overlay. All reinforcement bars for the deck slab, traffic barriers, sidewalk and the reinforcement projecting from the precast girders into the deck are epoxy-coated.

**STEEL ALTERNATIVE**

The steel alternative design consists also of five continuous spans based on the same arrangement of the bridge pier and abutments described for the concrete alternative. Based on the same limitations of the horizontal and vertical elevation constraints, the design consisted of three rows of 2.3 m deep trapezoidal box girders supporting 240 mm slab deck in a composite action, as a continuous beam. Preliminary discussion with the steel fabricators indicates that using a plate girder system could be more economical, due to the horizontal curvature of the bridge. Therefore, the design may be altered to six rows of 2.3 m deep steel plate I-girder for the superstructure.

The erection scheme follows a similar concept described before for the concrete design concept. Erection will start by placing a double cantilever section over the river pier and temporarily support the two drop-in girders from both sides. Continuity of the system will be provided by field splices. After completion of the girder erection and installation of the cross-bracing, the concrete deck will be cast using the same design described before.

**SUMMARY AND CONCLUSION**

Selected upgrading schemes for a 76-year old riveted steel plate half-through girder bridge in Winnipeg, Manitoba are discussed. The design consideration and limitations of the site lead to the development of a economical design approach using precast pretensioned double cantilever girders with dapped ends to support drop-in precast prestressed girders. The continuity of the bridge is provided by a special design of the post-tensioning tendons for the short double cantilever portion over the piers with an anchorage system into the end block of the drop-in girders. An erection scheme for the proposed system is presented and proven to be economical due to savings in temporary erection supports and construction time.
Alternative design schemes to replace the 76 year old Provencher Bridge over the Red River in Winnipeg, Manitoba are presented and compared. Future long-term objectives and site constraints were the major factors affecting the eventual choice of a precast prestressed concrete system incorporating a unique post-tensioned connection. Preliminary design indicates that this concept is economical and efficient. An erection scheme for construction of the bridge is discussed.
Provencher Bridge is a four-lane undivided roadway bridge over the Red River, near the geographic centre of Winnipeg, Manitoba, as shown in Figure 1. The bridge links the community of St. Boniface with Winnipeg's central business district. The bridge carried approximately 37000 vehicles a day in 1987, and functioned at a level of service F during the p.m. rush hour and D during the a.m. rush hour. Built in 1914, the bridge structure consists of seven spans with an overall length of 280.8 metres. The superstructure is comprised of two riveted steel plate half-through girders with interconnecting transverse floor beams.

In 1987, the City of Winnipeg commissioned Wardrop Engineering Inc. to investigate the traffic capacity, the structural integrity of the existing bridge, and to provide recommendations to address the following long-term objectives:
1. Provide a river crossing with a traffic capacity adequate for the predicted future growth.
2. Improve the horizontal and vertical roadway and approach alignments.
3. Upgrade load-carrying capacity of the existing structure to the proposed legal limits.
4. Improve the navigation channel.
5. Maintain an acceptable level of service throughout implementation of the rehabilitation or replacement of the existing structure.

The investigation concluded that rehabilitation of the existing structure, to meet the above long-term objectives, would be uneconomical due to the type of superstructure and deterioration of the bridge river piers. The study also recommended an extensive strengthening and upgrading. The investigation also required replacement of all bearings, expansion joints and high density concrete overlay. The work could require closure of the bridge for a six-month period.

PROPOSED ALTERNATIVES
Three upgrading alternatives were selected to achieve these specified demands:
Alternative 1: New six-lane superstructure on the existing rehabilitated piers
Alternative 2: New three-lane bridge and rehabilitation of the existing bridge
Alternative 3: Two new three-lane twin structures

Evaluation of the above three were based on functional, structural and cost considerations. Using a matrix method of evaluation with each area of consideration assigned a relative importance weight totalling 100 points, it was found that alternative 3 was found to be the optimum overall solution.

Based on this study it was recommended to replace the 76-year-old structure with two new three-lane twin bridge structures. The proposal included future provision for widening the bridge to four lanes. The future expansion includes connecting the river piers to provide support for the future additional median lanes. Using the same bridge piers, two alternative solutions for the superstructures using precast concrete and steel girders were provided.

Due to funding constraints, the project is proposed to be constructed in three phases with the following milestone dates:
Phase I - completion November 1992, as shown in Figure 2
- construction of the first (eastbound) new three-lane bridge
- utilizing existing bridge as the westbound 3-lane bridge with the appropriate upgrading of the bridge deck
Phase II - completion November 1999
- use of the complete bridge in the first phase as two lanes, each way, as shown in Figure 2
- demolition of the old bridge
- construction of the second three-lane (westbound) bridge
Phase III - completion 2020 (if required)
- extension of the two completed bridges into four lanes each way by connecting the bridge piers and widening each superstructure with one additional lane.

Final design for the first phase is currently in progress.
DESIGN CONSIDERATIONS

The following considerations were found to be crucial to yield an efficient and economical project:

1. Pier locations were set to provide equal spans for the main girders of the two precast and steel superstructure alternatives. This resulted in using two abutments located on the east and west bank of the river and four river piers.
2. The vertical alignment should match the existing intersection at the east approach which could not be economically altered.
3. Elevation of the bottom of the main girders should allow passage of 160-year flood predictions.
4. Central river spans should improve the navigational channel in width and height.
5. Alignment, length and location of the bridge piers as well as the superstructure should accommodate an additional fourth lane expansion of the bridge.
6. The structural capacity of the bridge should be upgraded to the proposed HSS30 City standard.
7. The overall structures on the Red River should be aesthetically pleasant, since the bridge is very close to the historic "Forks" development in Winnipeg, where the Assiniboine River flows into the Red River in the centre of Winnipeg.

DESIGN LOADS

The bridge will be designed according to the AASHTO Standard Specification for Highway Bridges, 14th Edition, 1989. The live load will be based on the HSS30 lane load and HSS30 vehicle load. The HS23 wheel load will be used for the deck design.

The HS30 lane and HSS30 vehicle loading provide a sufficient reserve capacity not only for the current legal vehicle, but also for the proposed future legal vehicles, as designated by the City of Winnipeg.

Due to the horizontal curvature and skewed river piers shown in Figure 1, an ANSYS finite element analysis program was used to determine the distribution of the moments, shears and torsional forces in the superstructure. Thermal stresses were included in the analyses to determine the lateral load and required expansion joints.

The deck was simulated using a plate element and the prestressed girder was modelled using a beam element with specified height to the neutral axis to determine the torsional stresses. The finite element model used for the analysis is shown in Figure 3.

SUPERSTRUCTURE DESIGN

Based on the standard requirements of the City of Winnipeg for large projects such as the bridge under consideration, two alternative structural design concepts were considered. The first design concept utilizes precast concrete girders to provide a continuous beam with composite action of the concrete deck slab. The second design alternative uses trapezoidal steel box girders also with composite action of the concrete deck slab.

The bridge consists of five continuous spans for a total length of 266.3 m, as shown in Figure 4(a) and (b).

The restricted elevation of the bridge, controlled by the approach roads and the 160-year flood level, imposed the need for constant depth girders for both concrete and steel design concepts. Use of a haunched section for the girders at the piers will reduce the navigation channel and result in a very uneconomical design, since the girders should be designed to withstand the impact forces due to floating debris. Using constant depth girders will also have the advantage of using the same steel form available from local contractors and therefore provide considerable economical advantage. The constant depth leads to the optimization of the span length and the number of bridge river piers. The precast concrete segmental construction concept was not considered due to the lack of experience of the local contractors in this field.
Figure 4(a). Elevation of Phase I of the Bridge

Figure 4(b). Plan view of the existing and Phase I of the bridge
Concrete Alternative

The design concept challenge, to provide a constant depth girder along the entire bridge, was solved by using the following special design configuration:

- a double cantilever pretensioned precast concrete I-girder over the piers,
- centre drop-in precast pretensioned concrete I-girder
- unique arrangement of post-tensioned tendons to provide continuity through the dapped end of the centre drop-in girder.

The proposed design concept eliminated the need for haunched girders over the piers and significantly reduced the length and cost of the post-tensioned tendons and consequently enhanced its efficiency. Using a constant depth girder significantly reduces not only the cost of fabrication, but also the erection cost.

Based on a maximum capacity of the local precast plants in Manitoba to handle a 42 m long by 2.3 m deep I-girder, a maximum length of the three intermediate spans was determined as 59.5 m. Nine rows of the precast concrete I-girders are proposed to support the superstructure. The selected spans also provide an improved length of the navigation channel over the Red River. The horizontal curvature of the bridge and the skew location of the piers will be accommodated at the connections of the precast girders. The location of the river piers in Phase I was designed to be in line with the river piers of Phase II to facilitate connection of the two piers and support the additional girders for the future deck expansion. The skew alignment of the river piers and horizontal alignment of the second phase resulted in reduction in the span length of the first phase to an approximate length of 58 m.

The proposed structural system consists of short precast pretensioned double cantilever I-girders with a length of 19.5 m at the bridge pier supporting a centre drop-in precast pretensioned I-girder of approximately 40 m in length, as shown in Figure 5. The dapped ends of the double cantilever girder at the pier will speed the erection and eliminate the use of temporary river piers on each side of the pier. The dapped ends will also accommodate the change in the girder alignments required to achieve the horizontal curvature of the bridge.

A total of nine rows of girders were required for the 4-lane section of the bridge. The storage capacity of the turning lane at the end of the bridge required the turning lane to extend over the last two spans. Therefore, the spacing between the precast girder was varied to accommodate the increase in the width of the bridge from three lanes to four lanes. The spacing between the girders in the first two spans was designed to accommodate the three lanes. The spacing between the girder in the third span was varied to accommodate the changes from a three lane to a four lane width. The girder spacing in the fourth and fifth spans was designed to accommodate a four-lane bridge.

Pre stressing System

The precast concrete double cantilever girder at the pier is pretensioned to support its own weight, and weight of the drop-in girder. The double cantilever section is also designed to accommodate the post-tensioning ducts for the continuity of the bridge required to support the moments due to deck dead load and to live loads acting on the composite section of precast girders and cast-in-place deck slab.

The precast concrete drop-in girders are pretensioned to resist their own weight, the weight of the deck and the continuity moment due to the live load as composite sections with the cast-in-place deck. The end blocks are also designed to provide the anchorage for the post-tensioning system of the double cantilever section required for the continuity.

The dapped ends of the double cantilever section are also used to provide the curvature required for the bridge in place. The resulting space due to the change of angles of the straight lines of the girders at the dapped end will be filled by concrete cast monolithically with the cross diaphragm at the same location.

This design concept limits the need for post-tensioning only in the double cantilever portion over the piers. This significantly reduces the stress losses associated with post-tensioning due to the reduction in length and...
curvature of the tendons. This system eliminates the need for haunched girders at the pier and results in a more efficient and economical design of the girders. The short lengths of the tendons also reduces the lateral forces on the girders due to the horizontal curvature of the bridge. However, creep effect due to post-tensioning and its effect to increase the moment at the mid-span was considered.

Due to the short length of the tendons, the post-tensioning will be jacked from one end only, which will certainly minimize the cost. The thickened end of both the double cantilever and the drop-in girder was found to be large enough to distribute the anchorage stress and allow easy access for jacking.

**Erection Scheme**

Erection starts by placing the double cantilever section on the river piers with temporary bracing from one side only, as shown in Figure 6(a). The temporary bracing will be used to balance the weight of the drop-in girder from one side supported by the abutment and the unsupported end of the double cantilever section as shown in Figure 6(b). The same scheme will be repeated for the second river pier until the completion of the bridge, as shown in Figures 6(c) and (d). Casting of the cross diaphragms follow completion of each span. Post-tensioning will be applied after achieving strength of the concrete of the diaphragms sufficient for prestressing specified by the code.

During post tensioning, bridge bearings are designed to slide freely to prevent any stresses on the bridge piers and additional secondary moments on the superstructure of the bridge. After completion of the erection, some of the bearings are replaced to provide the proper support systems under service loading conditions.

The bridge deck slab will be 240 mm thick, consisting of a 100 mm thick normal concrete layer and a 140 mm high density concrete overlay. All reinforcement bars for the deck slab, traffic barriers, sidewalk and the reinforcement projecting from the precast girders into the deck are epoxy-coated.

**Steel Alternative**

The steel alternative design consists also of five continuous spans based on the same arrangement of the bridge pier and abutments described for the concrete alternative. Based on some limitations of the horizontal and vertical elevation constraints, the design consisted of three rows of 2.3 m deep trapezoidal box girders supporting 240 mm slab deck in a composite action, as a continuous beam. Preliminary discussion with the steel fabricators indicate that using a plate girder system could be more economical, due to the horizontal curvature of the bridge. Therefore, the design may be altered to six rows of 2.3 m deep steel plate T-girders for the superstructure.

The erection scheme follows a similar concept described before for the concrete design concept. Erection will start by placing a double cantilever section over the river pier and temporarily support the two drop-in girders from both sides. Continuity of the system will be provided by field splices. After completion of the girder erection and installation of the cross-bracing, the concrete deck will be cast using the same design described before.

**Summary and Conclusion**

Selected upgrading schemes for a 76-year old riveted steel plate half-through girder bridge in Winnipeg, Manitoba are discussed. The design consideration and limitations of the site lead to the development of a economical design approach using precast pretensioned double cantilever girders with dapped ends to support drop-in precast prestressed girders. The continuity of the bridge is provided by a special design of the post-tensioning tendons for the short double cantilever portion over the piers with an anchorage system into the end block of the drop-in girders. An erection scheme for the proposed system is presented and proven to be economical due to savings in temporary erection supports and construction time.