Manitoba Floodway Expansion Project
Bridge Replacement

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Paper prepared for presentation at the
Bridges - Economic and Social Linkage Session
of the 2007 Annual Conference of the
Transportation Association of Canada
Saskatoon, Saskatchewan

ABSTRACT

The Red River Floodway around the City of Winnipeg was constructed in the 1960s as a result of a major flood event in 1950, which required the evacuation of over 100,000 people, flooding of 10,000 homes, and damages in excess of $75.0 Million. The original Floodway is 29 miles long with an average bottom width of 450 feet, flow depth of 30 feet, and design discharge of 60,000 cfs. Six highways and six railway lines cross the Floodway.

In 1997, the third largest Red River flood in recorded history passed through Winnipeg with a peak flow of 140,000 cfs. Approximately one half of this flood was diverted through the Floodway. A post-1997 study recommended increasing the Floodway capacity from 60,000 cfs to 140,000 cfs, which has a major impact on the six major highways and six rail lines.

A pre-design study of all highway and railway bridges was undertaken in 2003/2004 and included load rating and life cycle costing analysis. The study results recommended the replacement of all highway bridges and one railway bridge and the raising, lengthening, and retrofitting of five railway bridges. Estimated construction costs of the bridges and related roadworks is $225.0 M.

The final design and construction began in 2005 with Dillon Consulting Limited as the lead consultant in association with EarthTech; ND LEA; UMA, and Wardrop.

All the highway bridges are either 6, 7, or 8 spans. All spans utilize 2000 mm deep, 43.5 m long, prestressed precast concrete Nebraska University (NU) girders. Concrete decks are continuous for live load and utilize Glass Fibre Reinforced Polymer (GFRP) reinforcing bars for negative moments. One structure (the TransCanada Highway) will have remote sensors installed, and its performance will be monitored by ISIS. Prior to final design, an extensive life cycle study of deck systems was undertaken which examined several different types of reinforcing and deck construction alternatives. The paper will elaborate on the overall design and mitigation of environmental impacts of all six highway bridges.

The six railway bridges are owned by four different authorities: two – CNR; two – CPR; one – Central Manitoba Railway (CEMR); and one – Greater Winnipeg Water District (GWWD). All bridges utilize steel deck plate girders with the exception of the GWWD bridge which is precast prestressed concrete girders. For the most part, the railway girders are utilizing the existing substructure units, which will be retrofitted to accommodate new superstructures. The superstructures will all be replaced with ballasted steel through plate girders, which will provide additional hydraulic capacity with only minimal adjustments to track profiles. Unlike the highway bridges, each of the new and retrofitted railway bridges has a unique design, which will be elaborated in the final paper.

A unique feature of the railway portion of the project is that three of the bridges will require temporary detour structures. Staging of the railway bridges has been set so that the new girders for the CEMR bridge will be fabricated first and used in sequence as the superstructure for the detours at three other bridge sites.

The overall Floodway Expansion Project, including the bridges, is scheduled for completion in 2010.

1.0 INTRODUCTION

The Red River Floodway around the City of Winnipeg was constructed in the 1960s as a result of a major flood event in 1950, which required the evacuation of over 100,000 people, flooding of 10,000 homes, and damages in excess of $75.0 Million. The original Floodway is 29 miles long with an average bottom width of 450 feet, flow depth of 30 feet, and design discharge of 60,000 cfs. Six highways and six railway lines cross the Floodway.

In 1997, the third largest Red River flood in recorded history passed through Winnipeg with a peak flow of 140,000 cfs. Approximately one half of this flood was diverted through the Floodway. A post-1997 study recommended to increase the Floodway capacity from 60,000 cfs to 140,000 cfs, causing a major impact on the six major highway bridges and six rail bridges.

A pre-design study of all highway and railway bridges was undertaken in 2003/2004 and included load rating and life cycle costing analysis. Initially the hydraulic analysis focused on deepening and widening the existing channel. This approach would mean that several of the bridges would be either totally or significantly submerged during the design flood event. Further analysis showed that raising the bridges above the design flood event resulted in significantly lower hydraulic losses. Therefore, the final pre-design study results recommended the replacement of all highway bridges and one railway bridge and the raising, lengthening, and retrofitting of the other five railway bridges. These bridges are vital economic and social linkages for the Province of Manitoba and Canada, since in an extreme flood event the Red River can be a barrier to the east-west movement of goods and people.

The final design and construction began in 2005 with Dillon Consulting Limited as the lead consultant in association with EarthTech; ND LEA; UMA, and Wardrop.

2.0 HIGHWAY BRIDGES

2.1 Design Considerations

The following design considerations were found to be significant to achieve an efficient and economical project:

- Create a design that can be adopted to each site with similar sub-structure design, span length, barriers, etc.
- Minimize the number of deck expansion joints to reduce the future maintenance costs and improve the appearance and the riding qualities.
- Provide the most cost effective deck system based on Net Present Value (NPV) analysis.
- Use the less expensive and yet durable reinforced elastomeric bearing pads.
- Provide effective bridge deck drainage to minimize the susceptibility of the deck structure to deterioration.
- Provide for a Structural Health Monitoring System on a selected bridge.

2.2 Design Vehicular Live Load

The design vehicular live load of all the highway bridges, except the Floodway Bridges on Trans Canada Highways, is based on the extreme force effect of the following:

- AASHTO-LRFD HL "93" Loadings
- AASHTO MS 27 (HS30) Lane Loading and
- Modified AASHTO MSS 22.5 (HSS25) Design Truck Loading

The design vehicular live load of the Floodway Bridges on Trans Canada Highways is based on the extreme force effect similar to the above, except the following:

- Modified AASHTO MSS 27 (HSS30) Design Truck Loading

2.3 Deck Study

In total, an estimated 43,000 square metres of new bridge deck will be required on the six new highway bridge structures. Bridge decks being one of the weakest links in terms of long term performance of concrete bridges, the Manitoba Floodway Authority wanted to ensure that the bridge deck system chosen provided the most cost-effective solution over the 75 year design life of the bridges.

A comprehensive bridge deck study for the highway bridges was commissioned and was undertaken as part of the detailed design process. The study investigated different types of reinforcements, overlays, and membranes. Maintenance scenarios were developed for each of the systems investigated based on their maintenance history. The deck systems were then compared using a present value life cycle cost comparison to the standard bridge deck system used by the Province of Manitoba.

The current bridge deck standard for the Province of Manitoba is empirically designed for 225 mm thick concrete reinforced with black steel. The concrete typically has a compressive strength of 35 MPa and contains 8% silica fume and 15% fly ash. The reinforcing steel is placed to provide 60 mm clear cover to the top of the deck. Strict quality and curing controls are in place to ensure the highest possible quality of the concrete for durability. Their bridge decks are usually protected with a 85 mm thick asphalt wearing surface and complete with hot applied bituminous waterproof membrane. The wearing surface and waterproof membrane are generally designed to be replaced every 25 years.

Beside the traditional empirical design method, the design team also investigated the design resulting from the CHBDC, Section 16, for fibre reinforced concrete (FRC) deck slabs using the “arching” bridge deck concept. This design requires, amongst other things, that the girders be restrained using external steel straps to provide confinement to the bridge deck. This confinement promotes a natural arching effect under load, within the thickness of the bridge deck, eliminating the need for transverse reinforcing the deck. There are several successful applications of this type of bridge deck in Canada already.

Different types of reinforcing materials considered in the study included:

- Galvanized steel
- Epoxy coated steel
- MMFX2
- Stainless Clad 316
- Solid Stainless 316LN
- Glass Fibre Reinforced Polymer (GFRP)

A chloride diffusion analysis was performed to determine the length of time for which it would take chlorides to penetrate to the depth of the reinforcing. It was determined that the corrosion of the reinforcing in a bridge deck with black steel would be occurring in approximately 20 years if the concrete surface was exposed to chlorides. In Manitoba the observed life span of the hot applied bituminous waterproof membrane is between 15 to 20 years. For the standard bridge deck system, this means that the concrete surface beneath the wearing surface is being exposed to chlorides for about 5 to 10 years before the membrane is being replaced with the wearing surface. Thus the bridge deck will likely require significant localized patching at year 50 and into the future.

The analysis revealed that a bridge deck designed using the "arching" concept reinforced with GFRP with an asphalt wearing surface (no membrane) would provide the most cost-effective system for the Floodway Bridges over the 75 year life span. No membrane is required because chlorides do not effect the GFRP reinforcement, however a membrane and asphalt overlay was recommended as a wearing surface. The design team recommended based from a present value perspective that MFA proceed on this basis. The increase in the initial capital investment to MFA was estimated to be approximately 2% greater than if the Standard Deck was used. The ratio of the present values of the recommended deck to the standard deck were determined to be approximately 0.94. A value less than one (1.0) means that the system is more attractive from a present value perspective.

2.4 Superstructure Design

All the highway bridges are either 6, 7, or 8 spans. All spans utilize 2000 mm deep, 43.5 m long, prestressed precast concrete Nebraska University (NU) girders. There are a total of 417 girders for the project. Concrete decks are continuous for live load and utilize GFRP reinforcing bars for negative moments. Based on the aforementioned deck study, Corrosion Resistant Deck (CRD) slabs are used for all the bridge decks. However, a small amount of GFRP bars are placed at the bottom to minimize the typical longitudinal cracking that would normally occur between the girders of CRD slabs.

All the deck slabs are 200 mm thick with hot poured rubberized asphalt membrane and protection board and 80 mm of bituminuous pavement except the Floodway Bridges on Trans Canada Highway. Due to the high truck traffic, acceleration lane on the eastbound structure and deceleration lane on the westbound structure, asphalt overlay is not applied. The deck slab's thickness of these twin structures is 225 mm with an allowance for a 13 mm thick of wearing surface in the future.

The concrete clear cover for the top GFRP reinforcing bars at the negative moments over the piers is 65 mm. This would provide sufficient protection for the GFRP bars for future top surface concrete repair work either by hydro demolition or roto-milling processes.

Typical design lane is 3.7 m with either 2 m shoulder or 1.5 m shoulder. The bridge railing system consists of National Highway Co-Operative Research Program (NHCRP) Test Level 4 or Performance Level 2 crash-tested F shape concrete barrier. Double headed stainless steel studs and GFRP bars are used to reinforce the barriers. Effective bridge deck drainage is achieved by providing a 2% crossfall and a minimum longitudinal grade. The deck drains are located near the piers and abutments and the amount and size of deck drains are based on 1 in 10 years rainfall.

The NU girders are cast with normal weight concrete that contain 10% silica fume by weight of cement. The concrete release strength is 40 MPa, the 28-day specified strength is 55 MPa. All prestressing strands are seven-wire, low relaxation strands with a nominal diameter of 15.2 mm. The strands have a minimum ultimate strength of 1860 MPa. CSA G30.14 Grade 480W Welded Wire Fabric (WWF) is used for shear reinforcement.

A key component is to simplify the girder manufacturing to allow the girder to be stripped out and a new girder cast each day. Maintaining this daily casting cycle provides several challenges: the girder's inherent ability to accommodate large prestressing force required a very high early concrete release strength. This is achieved with an optimum concrete mix design and curing concrete in a heated form. Other strategies developed to maintain daily casting includes utilization of pre-bent WWF reinforcement ready for placement into the open form and is easily handled by workers. In addition, the use of 15.2 mm diameter strands required less pulling and stressing labour per unit of force than traditional 12.7 mm diameter strands.

The lateral stability of the section of the NU girder due to handling and transportation was analyzed. The wide bottom NU girder flange provided substantial lateral restraint during both shipping and erection. Wind load does not present any problems during the shipping and installation. Galvanized steel angels are used at the intermediate diaphragms, spaced at 7.5 m on centre, since they are significantly more economical than the concrete intermediate diaphragms. However, concrete diaphragms are cast at piers for structure continuity and concrete diaphragms are also used at the abutments. The permanent steel cross bracing, designed for structural integrity, facilitated girder stabilization during erection.

Multi-cell expansion joints, one at each end of the structures, are installed on all the highway bridges.

2.5 Bearings

The steel-reinforced elastomeric bearing pads have been used extensively in the Province of Manitoba for simply supported short and medium span bridges because of their greater strength, superior performance, easy installation and are less expensive compared to other types of bearings. The temperature Grade 5 elastomer with shear modules (G) greater than 1.1 MPa and a nominal hardness of 60 Durometer is used. The design provisions and dead loads compressive stresses and defections, shear deformations, combined compressive and rotational stresses and stability.

2.6 Structural Health Monitoring System

A structural health monitoring (SHM) system was designed to be incorporated into the replacement bridge over the Floodway on the TransCanada Highway. The SHM system will be used to observe the bridge by focusing the monitoring on the dynamic behaviour of the bridge. The idea is that if there is a change in the natural frequency of the bridge, a structural change is likely occurring on the bridge.

Components for the SHM system were selected based on previous successful installations. The supply of all components was incorporated into the general contract, including a high speed internet connection. The general contractor is to provide access for the design team to install the sensors. The brains of the SHM will be housed in a standard vandal proof, weather tight, steel enclosure on top of the Floodway embankment near the bridge abutment. The enclosure will be heated to keep the equipment such as the data acquisition and the computer systems within their operating temperatures during the winter months.

The general contractor was responsible to install all conduits and junction boxes from the enclosure to the locations of the sensors on the bridge. All wire installation within these conduits was performed by the general contractor, who was required to ensure that they were tested and in working order prior to connection to the sensor and data acquisition system. Remote monitoring program is being set up to provide basic information on the structural behaviour of the bridge. The system will be tested using a control vehicle to obtain the initial responses and to calibrate the system.

Data management will be achieved through the development of dual websites. One website will be for the use of the general public to observe the behaviour. Graphical representations of the bridge monitoring will be provided to depict the measured behaviour. The other website will be for the use of the design team and the owner for long-term engineering monitoring. Decision based software will be used to develop the long-term monitoring and data mining process to record data that is relevant to changes in the behaviour or significant events that exceed the normal operation bounds of the data being observed.

2.7 Substructure Design

The soil stratigraphy varies along the floodway channel. At the upstream, the soil stratigraphy at the bridge sites consists of a top layer of high plastic lacustrine clay, followed by a layer of soft buff peebly till underlain by a layer of dense till with limestone fragments. This type of soil profile permits the driving of prestressed precast concrete piles. The piles penetrate and bear on the dense till. The 406 mm diameter hexagonal shaped precast stressed concrete piles are typically used. At the downstream, in some cases, the dense till is almost at the bottom of the floodway channel. Either spread footings or short steel piles are used at these bridge sites. However, prestressed precast concrete piles are used at the abutments.

All the substructures consist of reinforced concrete abutments and reinforced concrete hammer head piers.

2.8 Hydraulic Forces

The 1 in 700 years discharge is 3,960 m^3/s (140,000 cfs) and it translates to a velocity of between 1.52 m/s to 2.13 m/s at various bridge sites. In addition, the structures are designed to accommodate maximum size of ice floe of 15 m in diameter by 0.6 m thickness. Two levels of ice strength are used; 1100 kN/m^2 at a higher flood elevation or 1500 kN/m^2 at 1.5 m below the higher ice level. All the bridges have a minimum of 300 mm freeboard to underside of girders at high water level (HWL) and at abutments.

3.0 RAILWAY BRIDGES

3.1 Background

The Floodway Expansion Project railway bridge inventory consists of six existing crossings, which are each identified by the name of the railway operator and the name of the subdivision: CPR Emerson, CN Sprague, Greater Winnipeg Water District, CN Redditt, CPR Keewatin, and CEMR Pine Falls. These structures date back 40 years, to the construction of the original floodway, and represent critical links in the operations of their users. Since the railways have been around for much longer than 40 years, the railway operators have seniority at all of the crossing locations, which bestows certain rights on them that are contained in Agreements with the Province of Manitoba.

The six existing railway bridges each consist of 11 spans, and range in length from 245m to 275m. One is a single track ballasted through plate girder (TPG) bridge, three are single track deck plate girder (DPG) bridges with open deck, one is a single track ballasted concrete I-girder bridge, and one is a double track ballasted plate girder bridge with concrete cradle. Underlying soils consist of bedrock, till, and clay, with a pressurized aquifer, and bridge foundations are a mix of timber piles, concrete piles, steel piles, and spread footings.

Design of the railway bridge modifications and development of integrated construction staging plans involved considering diverse railway operation requirements and various technical parameters associated with the bridges and their immediate surroundings, including the channel. An iterative approach was used through the preliminary design stage to gather information and disseminate ideas within the major stakeholder group. Refining the project needs through consensus building proved very effective in managing the diverse interests of the various parties. The result was a cost-optimized overall plan for expanding the channel that addressed major stakeholder needs and met with their approval.

Railway operation requirements for the four bridges used by the two national railway companies, which are all located on high-speed main-line track, consisted of keeping the existing tangent alignments, maintaining traffic without any significant delays or interruptions during the work, limiting longitudinal gradients to avoid the need for additional locomotive effort, and increasing the level of live loading by up to 50%. The remaining two railways are low-speed low-volume short-line operations that service the City of Winnipeg's main public water supply (via a 100-year old gravity aqueduct from Shoal Lake, Ontario) and a paper mill, respectively; these smaller operations placed fewer demands on the design, and were more flexible in terms of shutdowns.

3.2 Existing Conditions

The base-of-rail elevation on the existing railway bridges matched the pre-floodway railway design profile, and the DPG-style superstructures represent a very economical form of construction. Unfortunately, these original design configurations resulted in a series of bridges that encroach into the hydraulic opening of the proposed expanded floodway channel they are crossing. The decision to replace the DPG-style superstructures with TPG-style superstructures was driven by several factors, including the need to raise the railway bridges above the expanded channel 1:700 year flood event high water level, the need to avoid long gradient run-outs resulting from significant raise in elevation, limited remaining fatigue service life of some of the existing spans, and insufficient strength capacity for increased live load requirements.

3.3 Modification Strategies

Since the main-line operators would not permit a permanent 'kink' in the horizontal alignment of track on tangent, which affected three sites, construction strategies for replacing the spans on line were explored. The extreme difference in elevation of the underside of girder and the significant difference in width between the DPG's and the TPG's, combined in some cases with a raise in base-of-rail, made it impractical to utilize a change-out strategy to replace the spans one at a time. Therefore, it was decided to use temporary shoo-fly detours at the three affected sites. In order to satisfy the railway operators, these detours contain relatively long horizontal and vertical curves at each end to maintain traffic speed and sight lines. The fourth main-line bridge is located on a long curved section of track, so it was decided to realign the track to the outside of the curve using a slightly tighter radius, and keep the existing bridge in service until construction of the new bridge is complete. Negotiations with the two short line operators resulted in agreements to shut down their tracks for a few months to facilitate completion of the modification work.

3.4 Temporary Detours

In order to minimize overall project costs, a single temporary detour design was developed to be compatible with the existing channel cross-section at all three sites that require a detour structure. Further, the spans for one of the short-line bridges were designed for main-line live loading so that they could be used in the detour bridges, and a construction staging plan was developed that cascades the detour bridge along the project one site at a time until the spans become free for installation on the short-line bridge at the end of the project timeline.

The decision not to re-use the spans from one of the existing bridges for use on the detour bridges was made at the preliminary design stage, and was based on the results from load rating that identified insufficient load carrying capacity, and on timing constraints created by having to wait for the first set of spans to become available.

The substructures for the temporary detour structures are all founded on precast prestressed concrete piles with reinforced concrete pile caps. The temporary piers for the three detour rail bridges used match-cast precast segments, varying from three to eight segments high. Typical segments were 7750 mm long, 2500 mm wide and 1120 mm high, each containing 3 voids to reduce the weight. Cap pieces were solid precast, 500 mm high, to receive the bridge bearings and superstructure. Typical segments weighed 27.2 t. Base units were accurately located 40 mm above the pile cap, using levelling cleats, before the base joint was grouted. A bond breaker was applied to the underside of the base unit to accommodate future removal. Vertical sleeves were cast through all the segments for temporary post-tensioning bars that stressed the segments together.

The Phase 1 construction sequence for the detour piers was:

- Precast the pier segments using match casting.
- Place the pile caps.
- Erect the precast segmental pier segments.
- Stress the pier segments to the pile cap.
- Erect the steel deck plate girders.
- Divert the rail traffic onto the temporary bridge.

The Phase 2 construction sequence for the detour piers was:

- Disassemble the steel deck plate girders.
- Destress the pier segments.
- Disassemble the segmental pier segments.
- Move the girders and pier segments to the next site.
- Repeat the Phase 1 construction sequence.

3.5 Retrofit Details

The existing foundations were assessed to determine if they could be incorporated into the modified bridge designs based on increased dead and live loads and revised channel geometry. This assessment differentiated between structural capacity, frost protection, and projection into the reshaped channel cross-section. The foundations located in the existing side slopes of the channel would no longer be buried once the channel was reshaped, so they need to be demolished and rebuilt. Those in the flatter middle portion of the channel were found to be over-stressed for the new levels of loading based on considering the spans to be simply supported single entities. Therefore, further modeling was carried out during preliminary design to try to reduce the load effects on the piers and foundations to see if some of the existing foundations could be retained, thereby reducing project costs and schedule. First, structural steel haunches were introduced at the ends of each span to lower the point of application of the horizontal forces on the substructure and reduce the resulting moment. The outcome was that haunches would be beneficial on three of the bridges that are being modified, although they were eliminated on the first one of these bridges during detailed design. Second, the spans were tied to each other to equalize the high longitudinal forces due to traction and braking across all the substructures and foundation units. This configuration represents the use of lock up devices (shock transmission units) at the expansion end of each span, and utilizes the relative stiffness of the substructure units to distribute resultant forces on the foundations. Lock up devices permit normal girder expansion and contraction, but create a temporary rigid link during the application of a shock load. They consist of a loose-fitting piston head attached to a transmission rod that moves through an enclosed cylinder filled with an unpressurized silicone-based compound. The use of lock up devices in the design has a significant positive impact on project costs and schedule. Strengthening of individual foundations was also considered during preliminary design, but this strategy was found to be far less economical than the other methods described above.

With several existing foundations saved, the pier geometries and capacities were assessed for the new girder configurations (width, elevation) and loading conditions to determine if they needed to be totally or only partially replaced. The bearing points for the new TPG's are much wider apart than for the existing DPG's, and the underside of girder elevations have been raised significantly. Therefore, the pier tops are being widened and raised to suit the new geometry. The existing pier shaft capacities were checked for the new geometry, and found to be adequate.

All of the three existing mainline railway bridges are being lengthened as part of the floodway expansion project to accommodate the revised channel cross-sections. In most cases, this is being achieved by replacing existing short end spans with longer spans, although the first railway bridge in the program has been lengthened further by an additional full span to account for reduced channel side slope gradients caused by slope stability concerns.

4.0 PROJECT STATUS

The predesign for the Floodway Expansion project followed a three phase iterative design process which considered channel deepening, channel widening, raising bridges, and lengthening bridges. As a result an optimum design was achieved. At this time, two highway bridge site crossings and one railway crossing have been completed. Two other railway crossings are under construction and another railway crossing is in the tendering stage. The four remaining highway bridge sites have been transferred to Manitoba Infrastructure and Transportation for possible inclusion in their capital program. Discussions of the two remaining short-line railway operation bridges are taking place for other strategies which may involve future retrofit; abandonment, or potential for removal under extreme flood events. Completion for the project is currently scheduled for 2010.