CHALLENGES AND INNOVATIVE SOLUTIONS FOR BRIDGE FOUNDATION REPAIRS

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ABSTRACT

The Province of Manitoba experienced a record flood in the spring of 2011 and a record heavy rainfall event in the summer of 2014. The flooding occurred on major and minor rivers, including the Assiniboine River, Souris River, and Portage Diversion channel. These unprecedented floods produced higher than normal water levels, flows and velocities, reaching levels of three times design values at several locations. The flood events impacted over 100 bridge structures on the provincial highway network, crippling local access and transportation in the areas. Several bridges required complete replacement, while others experienced significant foundation undermining, instability and overall risk of collapse due to significant scour. Record water levels and turbulent flows caused significant erosion and scour resulting in undermined spread footings and exposed foundation piles. Five bridges contended with high risk of foundation loss beneath river piers, requiring emergent repair solutions to re-establish full original design loading and prevent any further risk during future flooding.

The innovative, yet challenging rehabilitation strategy was to provide increased foundation capacities and stability using deep foundation methods. Driven piles were not considered a viable option in most cases, due to existing sub-surface stratigraphy, the potential of shallow depth refusal and potential for achieving insufficient capacities. Various drilled caisson techniques were primarily used. During construction, many challenges were encountered due to site conditions, high water flows and geotechnical restraints. Special consideration was made to avoid disturbance and softening of shale material within and around the drilled holes, working adjacent to the existing structure with traffic still using the bridge, and to maintain temporary access and slope stability of the riverbanks. The most challenging aspect of the assignment was working within tight construction timeframes and adapting foundation design as issues arose, in order to complete all construction and protection measures prior to the potential for next year's spring flood event. This paper presents how these structures were saved using innovative rehabilitation strategies and unique repair methods to restore and increase foundation capacities, and to provide overall structural stability for five bridge structures.

1 INTRODUCTION

The Province of Manitoba experienced a record flood in the spring of 2011 and a record heavy rain event in summer of 2014. Flooding occurred on both major and minor rivers, including the Assiniboine River, Souris River, and Portage Diversion channel. These unprecedented floods produced higher than normal water levels, flows, and velocities, significantly exceeding design water levels. The flood impacted over 100 bridge structures on the provincial highway network by crippling local access and transportation in the affected areas. Several bridges required complete replacement, while others experienced significant foundation undermining, instability and overall risk of collapse due to significant scour. Record water levels and turbulent flows caused significant erosion and scour, undermining spread footings and exposing foundation piles. Five bridges contended with high risk of foundation loss beneath river piers, requiring emergent repair solutions to reestablish full original design loading and to prevent any further risk during future flood events.

Figure 1 – 2011 Manitoba Flood Along Assiniboine River in Brandon, MB (left) and Souris River in Souris, MB (right)

1.1 Project Background

Five bridge structures in Southwest Manitoba were identified for substructure and foundation modifications, to be completed as part of MIT's emergent flood repair works:

- Bridge on Road 71N over Portage Diversion channel;
- Bridge on Trans-Canada Highway (TCH) 1 West (1W) over Assiniboine River (Grand Valley);
- Bridge on Provincial Trunk Highway (PTH) 2 over Souris River (Wawanesa);
- Bridge on PTH 10 over Souris River (Minto); and
- Bridge on PTH 41 over Assiniboine River (St. Lazare).

These structures were selected for pier repairs and modifications, as they were located along major or important rivers and channels, and experienced a high risk of additional foundation loss if subjected to flood events of similar magnitude in the future without implementing remedial measures. The presence of scour, undermining, slope instability, and structural instability were shared among all five bridge sites. The geometric, topographic, and geologic constraints, however, varied for each site. Therefore detailed design strategies would be unique for each structure.

MIT completed full time construction inspection and contract administration services. Engineering services involved emergency inspection, site investigation and assessment, preliminary design, detailed design, contract administration (CA), advisory services during construction (ASDC), and monitoring and inspection during construction. This paper summarizes the innovative rehabilitation strategies and repair methods undertaken for each project site that was used to restore and increase foundation capacities, and provide overall structural stability.

1.2 Rehabilitation Needs

The probability of a significant flood occurring in the future was a reality that could not be ignored. Therefore, MIT required that all construction works be designed and scheduled to be completed during low flow conditions, which would occur during late summer, fall, or winter months. Alternatively, construction could be scheduled during periods of high water levels, provided that consideration be given to working with limited construction access. No instream work was permitted during the spring flood event, which characteristically occurs between April 1 and June 15 each year. Environmental and navigational permits were necessary, which would require that best management practices be implemented during construction.

Traffic accommodation was also required for all structures during construction. Detour routes were not feasible alternatives due to the importance of the routes and lengthy detours, given site geometry. In order to maintain traffic at all times, construction staging was considered for four of the five bridge sites.

While considering integrity and safety of the existing structure, the rehabilitation design was required to:

- Provide a minimum 75-year design service life and support foundations on competent material;
- Evaluate slope stabilities for channel and roadway embankments;
- Develop permanent erosion control measures to protect foundations from future scour; and
- Consult with prospective contractors to review design and discuss constructability concerns.

1.3 Project Challenges

There were several key issues and challenges surrounding each bridge site including: designing foundations with complex geological parameters and working with shale foundations, developing designs with limited confirmatory data, working with high river levels and flows, working within tight construction timeframes and work zones, utilities, adapting foundation design as construction issues arose, and maintaining bank and structure stability during construction. Although each structure had its unique challenges, lessons learned were valuable tools for developing better rehabilitation strategies for other structures.

2 SCOUR REPAIRS TO BRIDGE ON ROAD 71N OVER PORTAGE DIVERSION CHANNEL

The bridge on Road 71N over the Portage Diversion Channel is a two lane, 127.9 m long, five-span, simply supported bridge, which was constructed in 1967. The substructure consists of reinforced cast-in-place concrete abutments founded on timber piles and reinforced cast-in-place concrete piers founded on steel H-piles. The bridge is located immediately downstream of the Portage Diversion Drop Structure No. 1. During the 2011 Flood, the bridge foundations were subjected to severely turbulent flow as water entered the diversion channel, with inflows substantially greater than the inlet was designed to accommodate. This resulted in scouring of the piers, which exposed the steel H-pile foundations up to six metres at several pier locations. Turbulent flows also contributed to scouring and bank instability of the channel between the bridge and the drop structure.

Figure 2 – Scouring Beneath Bridge Piers

2.1 Rehabilitation Needs

Priority was given to complete the substructure modifications and scour repairs prior to the end of March 2012, so that the Portage Diversion Channel could be available for operation if required. Traffic was to remain fully open to serve as a detour route for other bridge reconstruction nearby taking place within the diversion channel. Finally, MIT required that any substructure modifications and channel reconstruction would accommodate a future widened diversion channel, with increased storage, increased design flows, and potential for increased ice loading during spring break-up.

2.2 Site Investigation, Condition Assessment, and Structural Foundation Evaluation

A site investigation and condition assessment was completed in November 2011. Despite the extent of pier scouring, the overall substructure was determined to be in good condition. Structural analysis of the existing foundations was completed to confirm whether additional piling was required to maintain the current level of service. Existing subsurface stratigraphy and pile driving records were utilized to complete the structural analysis. Existing foundations were determined to have sufficient capacity to support existing loads, and accommodate future increased ice loading for an expanded diversion channel.

2.3 Design

The design consisted of new 3.0 m deep reinforced cast-in-place concrete pier footings, which would encase and join together the two existing 900 mm deep pier footing components to provide overall structural continuity. Detailed design was fast-tracked and all design elements considered an extremely tight construction schedule, with consideration made for an early spring melt. Connectivity between new and existing concrete was provided by means of dowels to fully and effectively transfer loads to the new foundations. Stability of the existing channel slopes was evaluated between the drop structure and around the bridge. A monitoring program was developed, along with a construction staging plan to not only maintain stability of the existing channel banks, but to also maintain integrity of the bridge itself during construction and exposure to live loads. Staging consisted of offloading of the upper channel embankments and providing toe stability, sequencing the construction of pier footings, moving from the centre of the channel outward, and phasing construction of the pier footings to maintain vehicular access at all times. Erosion protection around the bridge was coordinated with other work at the drop structure that was concurrently being undertaken by MIT. This consisted of placing Class 600 and 900 stone rip-rap. Design was completed in only 45 days. Figure 3 illustrates the proposed pier footing modification.

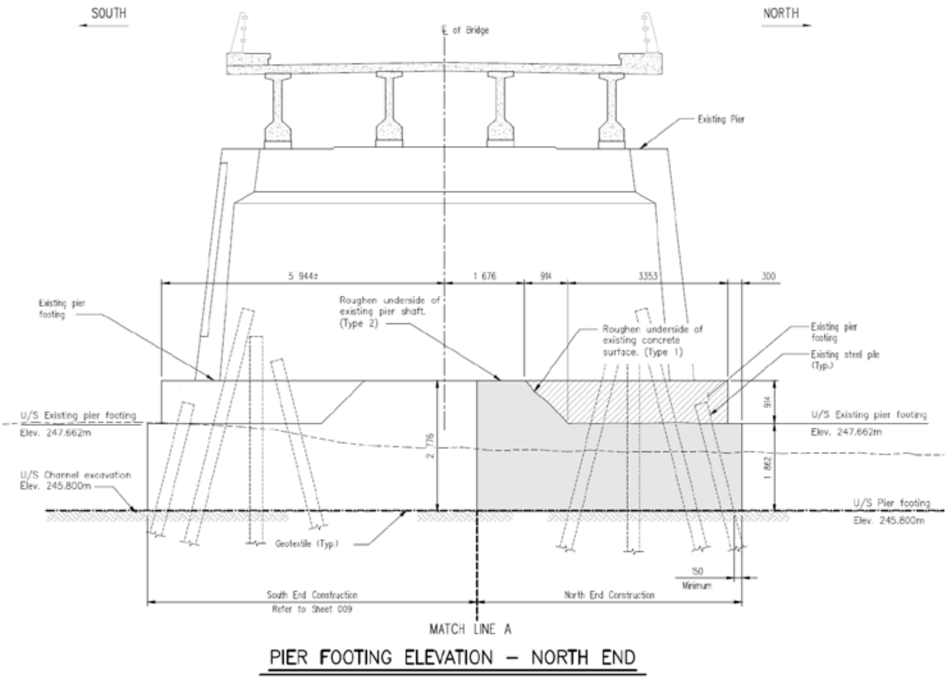

Figure 3 – Pier Footing Modifications

2.4 Construction

Construction began in late February 2012. Tetra Tech supported with CA services during construction, which served well for making timely design decisions in order to accommodate site variations and accelerate the construction schedule. Coordination and partnering efforts were undertaken by the client, designer, and contractor in order to complete construction within a tight timeline. One major modification which served as a means for accelerating the construction schedule was to completely eliminate phasing of the pier footings, to allow each footing to be excavated, reinforced, and cast together as one complete unit. A monitoring program consisted of slope inclinometers on embankments to monitor channel movement and a combination of prisms on piers and abutments to ensure that no movement was observed on the structure during construction. Daily monitoring confirmed that no movement occurred as the pier foundations were constructed. The pier modifications and channel erosion protection was successfully completed by the end of March 2012. The Portage Diversion was opened two days after completion of construction to divert flow from the Assiniboine River. Figure 4 shows the progression of construction.

Figure 4 – Excavation Complete Beneath Pier (left), Reinforcing Steel for New Pier Footings (centre), Completed Pier Footing (right)

Figure 5 – Completed Bridge Scour Repair Works

3 SUBSTRUCTURE MODIFICATIONS TO BRIDGE ON TCH 1W OVER ASSINIBOINE RIVER (GRAND VALLEY)

The bridge on TCH 1W is a two lane, 127.6 m long, five-span, simply supported bridge, which was constructed in 1983 and is located immediately west of Brandon. The substructure consists of reinforced cast-in-place concrete abutments and piers founded on concrete hexagonal piles. MIT first observed severe scouring of the easterly-most pier (Pier SU.5) on the WB structure following the 2011 Flood. Follow-up work and investigations in March 2012 at the site found undermining of approximately four metres of the existing precast concrete piles below the underside of the concrete footing. The bridge was immediately closed to traffic, with traffic rerouted onto the EB structure. Rip-rap was placed temporarily in the vicinity of the Pier SU.5. MIT requested that an emergency foundation rehabilitation design be implemented, which would require a design-build delivery model, working directly with a selected contractor to restore traffic to the highway as quickly as possible. Figure 6 shows the extent of flooding of the structure during the 2011 Flood and the scouring that occurred at Pier SU.5.

Figure 6 – TCH 1W During 2011 Flood (left), Exposed Piles Due to Scour at Pier SU.5 (right)

3.1 Emergency Inspection

An emergency inspection was completed in early March 2012 to confirm the extent of scour and undermining of Pier SU.5. Scouring occurred due to constriction of the river at the bridge, combined with a bridge skew which exacerbated flow conditions, forcing spill out of the main channel to the adjacent flood plain. Divers confirmed that the extent of scour was restricted to only SU.5. An emergency drilling program was undertaken for two test holes to the east of SU.5 to confirm soil stratigraphy, to assess pile current pile capacities, and to evaluate the capacity of driven steel HP piles. Finally, slope stability of the existing banks was evaluated to determine if stabilization measures were required.

3.2 Design

Detailed design proceeded with cooperation between all parties. Design transitioned quickly as the contractor mobilized to site, sourcing and supplying all required locally available materials to begin construction. Due to the need to restore traffic to the WB structure and urgency to expedite repairs, all design considered that work would be completed under flood stage conditions. The subsurface investigation program confirmed that steel H-piles would be a suitable foundation alternative, as piles would be driven to refusal into a layer of soft clay shale 36.0 m below the ground surface. Evaluation of channel banks confirmed that both short-term and long-term stability targets were achieved and no further measures were required.

The design consisted of a new 3.0 m deep reinforced cast-in-place concrete pier footing, which enveloped the existing pier footing. The pier footing was supported on steel H-piles driven into shale, with anticipated lengths of 35.0 to 40.0 m. Eighteen additional steel piles were located around the perimeter of the existing pier footing to satisfy design loads for the foundation, eight of which were to be driven through the bridge deck. The use of a custom segmental steel cofferdam was required to isolate flow and enable construction of the new pier footing. A tremie concrete cofferdam plug would be necessary to isolate river flow within the cofferdam and support construction of the new pier footing. Steel reinforcing dowels were utilized to effectively transfer loads to the new foundation.

3.3 Construction

Construction took place between March and August 2012. MIT provided full time construction inspection and Tetra Tech provided ASDC and on site construction inspection for elements of work that impacted the overall foundation design. All work took place under flood conditions, which varied from all other bridge sites due to the urgency of the work. Piling work was completed effectively, operating from the existing deck surface and using subsurface data to develop an appropriate foundation design that could be constructed prior to the end of March. However, cofferdam operations and the tremie concrete cofferdam plug were interrupted and delayed due to high spring flows and difficulties isolating and dewatering the cofferdam. Divers were used to identify the areas of the breach, but dewatering operations proved to be unsuccessful. The cofferdam was inundated with water in April, with operations halted until water levels receded to accommodate foundation construction. Figure 7 shows the extent progress of foundation construction.

Figure 7 – Steel Support for Driving of New Piles (left), New Piles Driven Through Existing Deck (centre), Partial Concrete Tremie Plug for New Foundation (right)

Construction resumed in July, at which time the Contractor worked to dewater and isolate the flow within the cofferdam and successfully placed the new pier footing by means of structural tremie concrete. Construction was completed in August and the bridge was reopened to traffic.

Figure 8– Final Concrete Pour for New SU.5 Pier Footing

4 PIER MODIFICATIONS TO BRIDGE ON PTH 2 OVER SOURIS RIVER (WAWANESA)

The bridge on PTH 2 over the Souris River is a two lane, 112.6 m long, five-span, simply supported bridge, situated in a river valley to the west of the town of Wawanesa. The bridge was constructed in 1958 and lengthened in 1976 to alleviate problematic hydraulic issues. The substructure consists of two cast-in-place concrete abutments founded on driven steel H-piles, while four cast-in-place concrete piers are supported on shallow spread footings founded on shale.

The rapidly moving river continuously contributed to erosion around the piers and abutments. Furthermore, river flow in the vicinity of the bridge was in a constant state of change; gravel bars formed within the channel, a series of braided channels formed around gravel bars, the river bed became unstable, and the main channel developed a tendency to migrate between its east and west banks. Scour protection efforts were undertaken for the west span in 2000 and 2009 by MIT to provide rock rip-rap protection to the channel slope. During the 2011 Flood, scouring was identified for at river piers with water levels nearly overtopping the bridge deck. Rip-rap was placed within the river to fill in scour holes and to protect pier foundations and the bridge was monitored for movement or channel settlement.

Figure 9 – Existing Bridge on PTH 2 over Souris River Following 2011 Flood

4.1 Site Investigation and Assessment

Site investigation and confirmation of existing conditions was extremely difficult for all surfaces below water. Bathymetric survey and a diving program to confirm underwater conditions were planned, but could not be executed due to turbulent river flows and rip-rap around the bridge. Sounding and probing at piers was performed, but could not tangibly confirm the extent of scour due to the presence of rip-rap. Topgographic survey was performed during periods of low flow to collect subsurface data where possible. Finally, subsurface investigation was undertaken confirm to soil stratigraphy, to gain further information of the properties of the shale layers, and to determine to susceptibility of shale to erosion and softening. A Heritage Resource Impact Assessment was completed in the immediate vicinity of the bridge, although no concerns were noted due to low risk of impact to heritage resources.

4.2 Rehabilitation Needs

MIT originally required that scour repairs be completed by March 2012, with all foundation modifications completed by March 2013. However, with limited confirmation of subsurface conditions, the plan for the structure rehabilitation changed. Common practice for bridge construction in the 1960s and 1970s was to construct piers on shallow spread footings. However, these spread footings were founded on layers of fractured shale, which were not only susceptible to scour, but also presented a risk to the stability of the structure if any undermining were to occur. The rehabilitation strategy was to design a deep foundation system that could fully support the dead and live load of the structure, without dependency on the existing spread footing foundation. With this rationale considered, if any failure of the spread footing were to occur, it would be fully supported by the deep foundation system and would not face risk of bridge failure. MIT also required consideration to eliminate the use of cofferdams, where possible, to avoid the potential for construction delays, which had occurred during high flow conditions at Grand Valley. MIT required that work be completed prior to the end of March 2014 and that the structure remain fully open to traffic.

4.3 Design

Deep foundations were considered to be the only feasible alternative to underpin the existing spread footings. The subsurface investigation confirmed that the shale at the site was clay shale, exhibiting behavior between that of soil and rock. Non-cemented shale was found in the upper layers, which would be susceptible to scour, fracturing, and softening. Beneath non-cemented shale layers, however was cemented clay shale, which would be suitable for foundation support. Pile foundations were not considered a suitable foundation alternative due to the presence of rip-rap, difficult driving conditions through shale layers, and the likelihood of insufficient end bearing capacities. Drilled shaft caissons, extending into cemented shale layers would be suitable for providing the necessary end bearing capacities and lateral resistance to fully support the bridge. Since a new pier and foundation system would need to tie into the existing structure, design incorporated uniformity and flow of concrete elements.

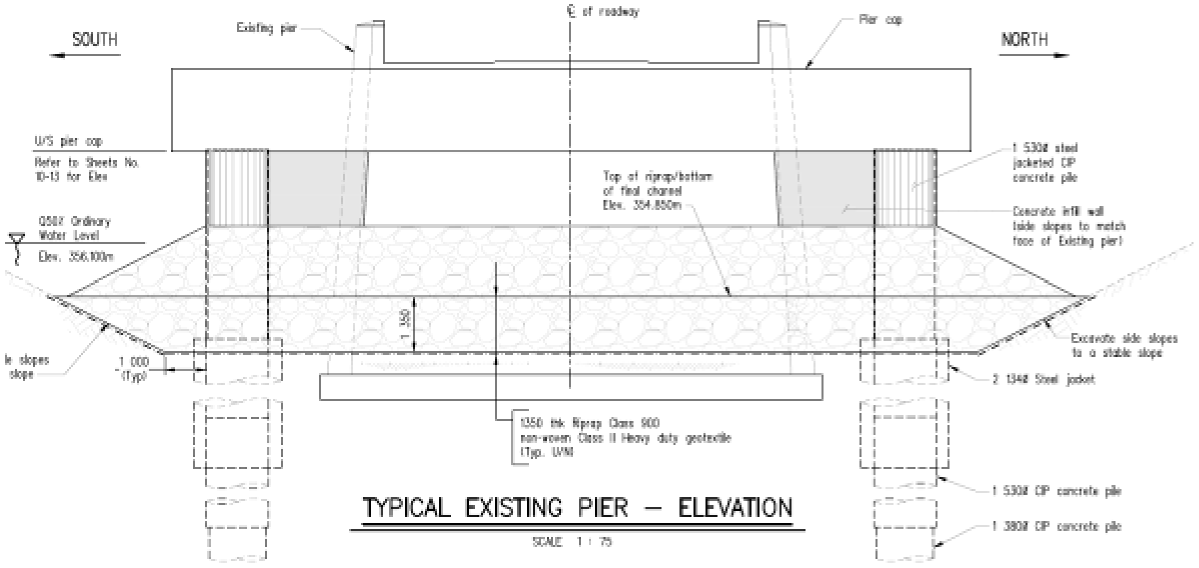

Figure 10 – Section of Pier, Showing Drilled Shaft Foundation, Concrete Pier Cap, and Concrete Infill Walls

The deep foundation system consisted of two reinforced concrete cast-in-place drilled shaft caissons. Each shaft consisted of two different diameters; the lower 5.0 m was 1,380 mm diameter supported against earth, while the upper 16.0 m was 1,530 mm diameter supported by a metalized steel jacketed sleeve. Drilled shaft caissons were reinforced using 35M black steel reinforcing for the full length of the shaft and developed into a reinforced cast-in-place concrete pier cap. Drilled and grouted steel dowels were used to transfer loads from the existing piers to the new foundations. Galvanic protection, consisting of DAS anodes, was used in the pier caps and infill walls to protect new and existing reinforcing steel against corrosion. Concrete infill walls between the pier and caissons were provided to enhance the load transfer. Temporary sleeves would be required through alluvial deposits and within the surface of the shale layer to control seepage and to minimize softening of shale. During tender, prospective bidders were required to read the geotechnical design report to be made aware of subsurface conditions. Figure 9 provides a section of the modified pier showing the existing concrete pier and footing, along with the two new drilled shaft caissons and extended concrete pier cap.

4.4 Construction

MIT provided full time construction inspection while Tetra Tech provided ASDC, full time inspection for all drilling and installation of caissons, and monitoring of piers for movement or instability. Installation of the temporary shaft sleeves was inspected and installed successfully to isolate seepage flows and minimize the occurrence of softening of shale layers. A monitoring program, using a combination of survey prisms installed on several locations of each pier, was implemented specifically to inspect for the occurrence of movement in the piers, and was monitored three times every week. Survey data was analyzed and plotted within 24 hours of survey. No significant movement was recorded during the course of construction. Minor design changes to the caissons were completed to accommodate an elevated concrete plug to allow construction of concrete infill walls above the water level. Additional thickness of stone rip-rap was in turn placed around piers. Erosion protection consisted of Class 450 and 900 stone rip-rap on the channel banks and around piers. Construction was successfully completed between January and March 2014. Figure 11 shows the progression of foundation construction and Figure 12, the completed structure.

Figure 11 – Reinforcing Steel for Drilled Shaft Caisson (left), Drilling of Caisson, Metalized Steel Jacked Caisson and Reinforcing Steel (right)

Figure 12 – Completed Pier Modifications and Channel Erosion Protection

5 PIER MODIFICATIONS TO BRIDGE ON PTH 10 OVER SOURIS RIVER (MINTO)

The bridge on PTH 10 over the Souris River was constructed in 1979 as a two lane, 137.5 m long, three-span, continuous bridge, situated in a deep valley north of Minto. The substructure consists of two cast-in-place concrete abutments founded on driven steel H-piles, and two cast-in-place concrete piers supported on shallow spread footings founded on shale. During the 2011 Flood, scouring of the river bottom led to concerns for the potential of undermining of river piers. Armouring of piers took place prior to and following the flood, but additional scour was observed again in the spring of 2013. Due to the height of the existing piers (approximately 12.0 m high), MIT was concerned with risks associated with the stability of the structure if any undermining were to occur, especially since the spread footings were supported on a layer of shale.

Figure 13 – Existing Bridge on PTH 10 over Souris River

5.1 Site Investigation and Assessment

Site investigation consisted of bathymetric survey to confirm river bottom elevations, topographic survey, and subsurface investigation to confirm soil stratigraphy, and potential foundation alternatives.

5.2 Rehabilitation Needs

MIT required that pier modifications and permanent scour protection be undertaken for the structure. Similar to the design being developed for PTH 2, a deep foundation design strategy was employed to provide overall structure redundancy, and to prevent the risk of future bridge failure due to scour if exposed to another extreme flood event. Construction was to be completed by March 2014, with the structure remaining fully open to traffic.

5.3 Design

The rehabilitation strategy was to design a deep foundation system that could fully support twice the existing superstructure dead loads and two lanes of live load of the structure for future widening of the bridge. Deep foundations were considered the only feasible alternative to underpin the existing spread footings due to the presence of a dense cemented shale layer at the underside of spread footings. The shale layer at this site was more rock-like clay shale than was encountered at PTH 2, for which piles would be too shallow beneath existing footings. Therefore, the use of drilled shaft caissons extended into the shale was selected. The deep foundation system consisted of twelve 750 mm diameter, 9.6 m long, reinforced cast-in-place concrete drilled shafts. The upper 1.5 m was supported by 914 mm steel jacketed caisson. Caissons were fully reinforced with 25M black steel vertical reinforcing. Figure 14 illustrates the expanded pier foundation system.

Maintaining stability of the existing piers during construction was of paramount importance due to the height of the piers, and the potential that small movements at the pier base would translate to large movements at its top. Two new pier footings 2.8 m thick were located above existing spread footings. This methodology was employed to ensure that the caissons remained supported for their entire length, and to minimize excavation of the existing footings. Tension and compression reinforcing dowels into existing footings were used to provide full load transfer between existing and new structures. Galvanic protection was also used between new and existing concrete surfaces.

Similar to conditions at PTH 2, temporary casings were necessary to control seepage and to facilitate drilling operations. Water levels at this particular site were unseasonably high, which necessitated the use of cofferdams to permit construction under dry conditions. The use of sheet pile cofferdams was not preferred due to the possibility of weakening shale layers around existing foundation during driving operations. Discussions with contractors also confirmed that driving of sheet piles into the shale would not be a feasible alternative. The use of earth cofferdams was specified, but the project team recognized that there would be challenges for creating a continuous seal to accommodate efficient and effective dewatering. Parameters for cofferdam design were outlined in the tender document, requiring also submission of an engineered cofferdam submission prior to commencing construction. Permanent erosion control using Class 450 and 600 stone rip-rap was incorporated around piers and on channel banks to provide protection against scour and overall toe stability.

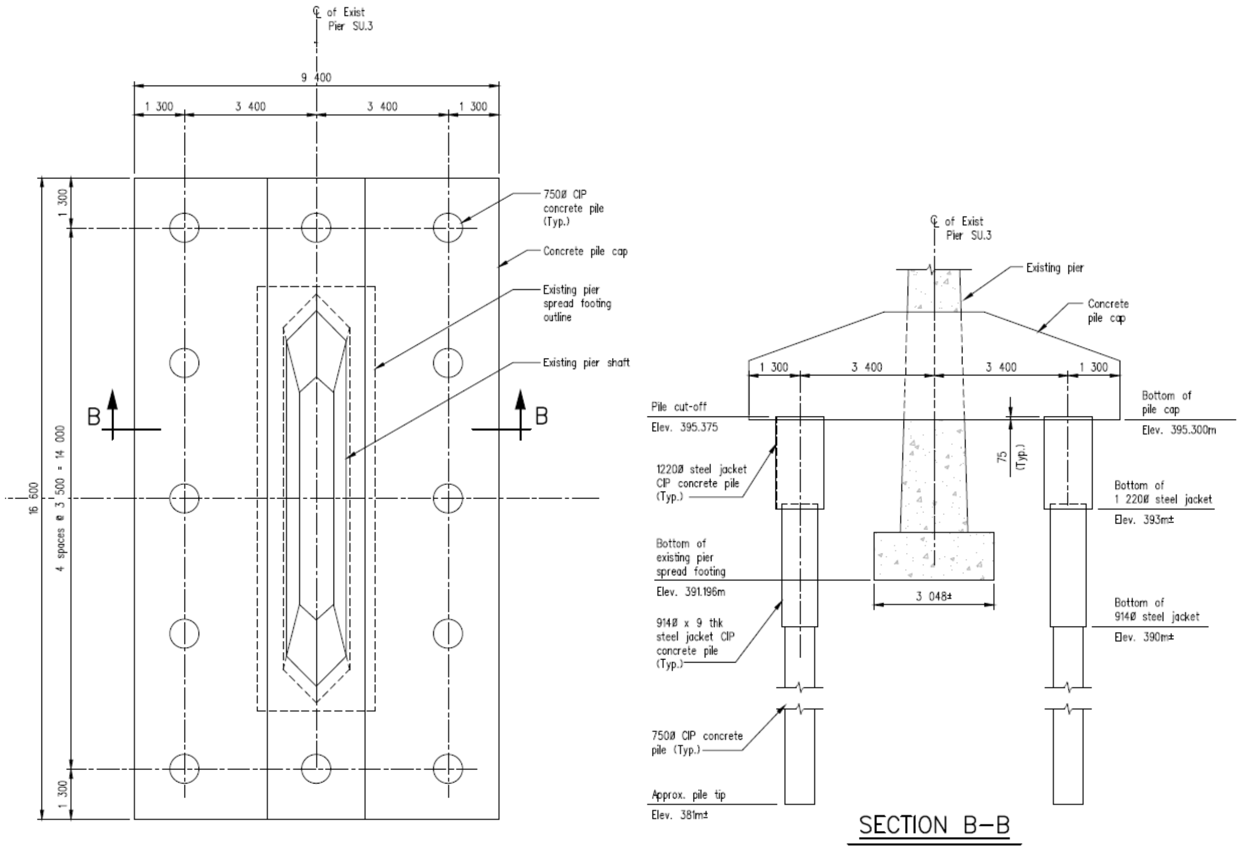

Figure 14 – Plan and Section Views of Modified Pier Cap and Deep Foundations

5.4 Construction

Tetra Tech and MIT provided the same services as those used during construction at PTH 2. Dewatering within the cofferdam at the north pier was problematic during construction and required ongoing coordination. In order to move forward with construction, the elevation of the underside of pier footing was increased above the existing ice elevation, thickening the pier footing by 200 mm. The length of piles were also increased by 3.0 m to maintain specified design capacities, which required the use of an additional temporary casing to prevent collapse of the shaft extension. Additional stone rip-rap was needed to provide scour protection for the pier footing.

Due to concern of disturbing bridge foundations, limitations were imposed for excavation around piers and regular monitoring of piers, abutments, and slopes took place. No significant movement was recorded during the course of construction. The pier modifications and channel erosion protection works were successfully completed between January and late March 2014. Figure 15 demonstrates the progression of pier modification works during construction. Figure 16 shows the completed pier substructure.

Figure 15 – Drilled Shaft Caissons for Footing (left), Anchoring Reinforcing Into Existing Pier (centre), Pier Footing Reinforcing (right)

Figure 16 – Completed Pier Foundations

6 PIER REPAIR WORKS TO BRIDGE ON PTH 41 OVER ASSINIBOINE RIVER (ST. LAZARE)

The bridge on PTH 41 over the Assiniboine River, constructed in 1969, is a two lane, 102.4 m long, four-span, continuous bridge, situated approximately one kilometre west of St. Lazare, Manitoba. The substructure consists of two cast-in-place concrete abutments founded on driven steel H-piles, and two cast-in-place concrete piers supported driven steel H-piles founded on shale. During the 2014 Heavy Rain Event, severe scouring of the outer bend of the Assiniboine River occurred, which produced a large scour hole downstream of the bridge and significant scouring of the easterly-most pier (Pier SU.4). An emergency inspection and evaluation of the existing piers took place following the heavy rain event, which led to a recommendation that immediate pier repairs be undertaken and that traffic be limited to a single lane with maximum gross vehicle weight of 39,500 kg. Based on the analysis, it was determined that the axial capacity of the driven steel H-piles had been reduced due to scour beneath the footing, the east embankment headslopes were marginally stable, and that changes in river levels would lead to instability of the channel slopes.

Figure 17 – Existing Bridge on PTH 41 over Assiniboine River

6.1 Emergency Inspection

Site investigation was a necessary requirement to fully understand the extent of scour around the piers. A bathymetric survey was completed to confirm river bottom elevations. A diving program was attempted to complete an underwater inspection of Pier SU.4, but this was not possible due to high water velocities. A topographic survey was completed, along with a subsurface investigation to confirm soil stratigraphy and to gain a better understanding of the shale layer properties, which would be critical for foundation design. A monitoring program on the east embankment and on the pier began in the fall of 2014 and carried on through April 2015 as a means of verifying if any movement had occurred. Prior to the start of construction and during work bridge construction, a Heritage Resource Impact Assessment was completed in the immediate vicinity of the bridge. No concerns were noted.

6.2 Rehabilitation Needs

MIT requested that an emergency investigation and evaluation of Pier SU.4 be undertaken. This eventually led to preliminary and detailed design for a pier modification rehabilitation strategy, using similar experiences gained from the repairs undertaken from the 2011 Flood. Similar to the design being developed for PTH 2, a deep foundation design strategy was employed to provide overall structure redundancy, and to prevent the risk of future bridge failure due to scour if exposed to another extreme flood event. Construction was to be completed by March 2015, with a single lane of traffic to remain open on the structure during construction. Finally, MIT directly assigned a contractor to perform the work. Although the detailed design assignment was to take place independently, the contractor was involved in planning of the construction staging and sequencing process to best suit his operations and to ensure full understanding of the overall scope of work.

6.3 Design

As a result of the bathymetric survey, the extent of scour became much more apparent. Scouring was observed to be approximately 2.0 m beneath Pier SU.4. Downstream of the bridge, however, a 20.0 m deep scour hole was present. The concern was that high river velocities would further contribute to scouring of the pier and lead to overall bridge instability. Deep foundations were considered the only practical solution for this site, due to the decrease in existing foundation capacity, the possibility of piles refusing before obtaining sufficient end bearing capacity, the requirement to keep the structure open to a single lane of traffic at all times, and the understanding of site conditions and an extremely tight construction schedule to meet. Subsurface stratigraphy consisted of alluvial sand interbedded with silt and clay, with an overlying hard soil-like clay shale. The design of the deep foundation system considered only shaft adhesion for foundation serviceability due to the practical limitations associated with cleaning and inspecting the base of the shaft and the possibility of a weak discontinuity in the shale below the termination of the socket. In addition, MIT had 1830 mm diameter steel sleeves available for use. Figures 18 and 19 show the extent of scour around Pier SU.4 and downstream of the bridge.

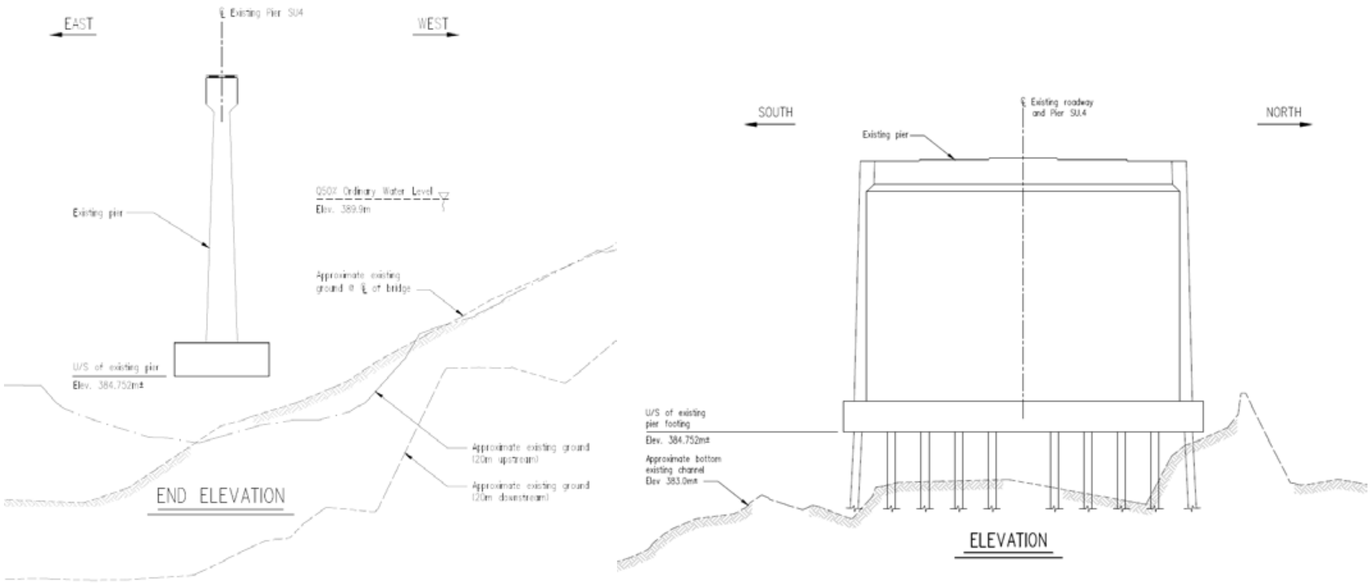

Figure 18 – Section of Pier SU.4, Showing Depth of Scour

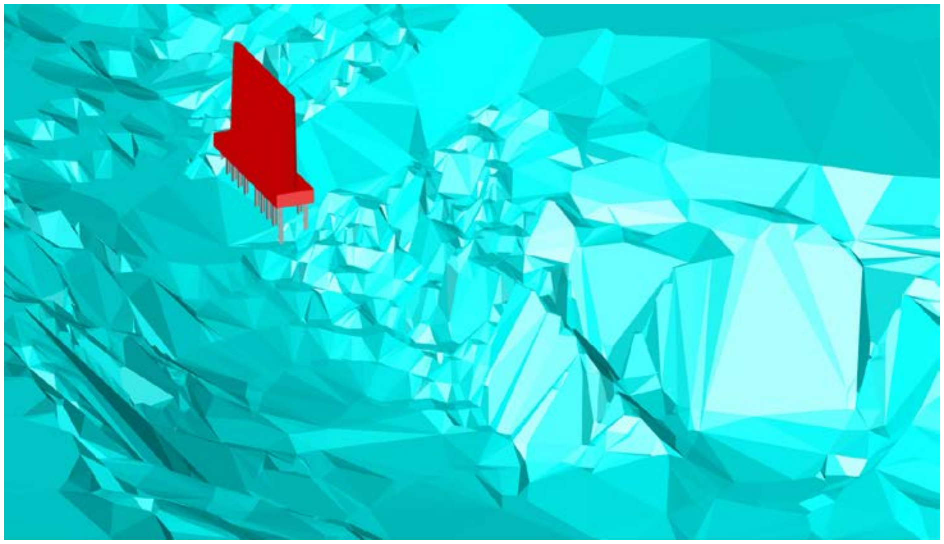

Figure 19 – Three Dimensional Image of Assiniboine River, Showing Existing SU.4 and Extent of Scouring Around Pier and Downstream of Bridge

The deep foundation system consisted of two 1830 mm diameter, 22.5 m long, steel jacketed reinforced cast-in-place concrete drilled shafts positioned on the upstream and downstream ends of a new cast-in-place concrete pier shaft. The lower 12m of the drilled shaft reduced to a diameter of 1530 mm, below the shale layer. Caissons were fully reinforced with 35M black steel vertical reinforcing for the full length of the shaft and developed into the pier cap. The massive new pier cap was designed to be 2.0 m wide, 20.2 m long, and 2.7 m deep, which trumped the size of the existing piers. The pier cap was designed to fully transfer superstructure loads to the new foundations. Drilled and grouted steel dowels were used to transfer loads from the existing piers to the new foundations. Installation of temporary sleeve casings was deemed to be necessary to control seepage and sloughing through the alluvial sands. Consideration was made for multiple sleeves to penetrate into layers as necessary, while still providing sufficient space and working within crane capacities during construction. Figure 20 provides a typical modified pier section.

The hydraulic section of the river had changed significantly than the original section when the bridge was first constructed. Sedimentation had taken place for the two westerly-most spans, contributing to increased river velocities and significant erosion around SU.4. Channel dredging was recommended to reduce river velocities in the east spans. Permanent erosion control using Class 600, 900, and locally available smaller rounded stone rip-rap was incorporated for the construction of the work bridge and for permanent protection works of the pier and east channel banks.

Stability of the east embankment was determined to be at a point of instability, with risk of sliding failure. Critical areas were identified downstream of the bridge, where scour extended from 20.0 m to 50.0 m. Remedial works involving the construction of a stabilizing toe berm was required to satisfy both short-term and long-term requirements. Construction staging to accommodate all elements of the work, while maintaining a stable bridge structure and east embankment was a challenging prospect. A temporary rock work bridge was required with specific sequencing and construction limits to maintain bank stability. In addition, staging and limits of the work bridge were completed to control loss of rock material in the large scour hole downstream of the bridge.

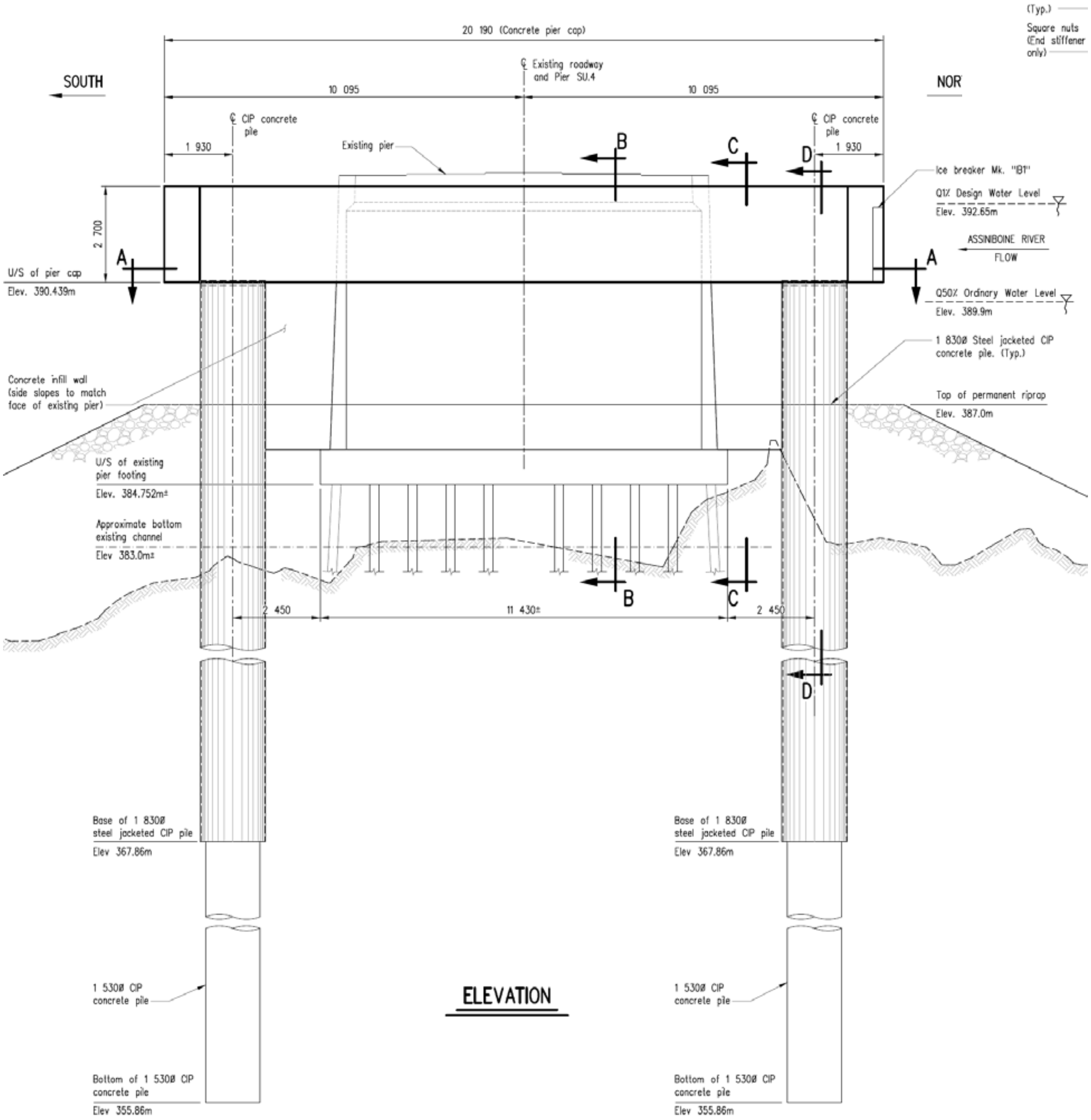

Figure 20 – Section of Pier, Showing Drilled Shaft Foundation and Concrete Pier Cap

6.4 Construction

MIT and Tetra Tech services provided during construction were similar to services provided for PTH 2 and PTH 10. MIT and Tetra Tech worked closely with the contractor as construction began, providing guidelines during construction of the work bridge and general construction sequencing. A monitoring program, using a combination of survey prisms installed on several locations of SU.4 and a slope inclinometer on the east embankment was implemented specifically to inspect for the occurrence of movement in the piers and the embankment. Monitoring was completed once each week, with data was analyzed and plotted within 24 hours of survey. No significant movement was recorded during the course of construction.

Due to the extremely tight timelines to complete all the required works, channel dredging on the west side of the river was eliminated from the immediate scope of work, with focus to be completed on the east side. Construction of the work bridge was undertaken to minimize constriction of the channel as much as possible to help control river velocities adjacent to the work. It was determined that channel dredging and any outstanding embankment works east of SU.4 would be completed under a separate contract in the fall of 2015.

During construction, overhead and underground utilities were moved to allow for the permanent caisson installation and overhead crane and drilling equipment clearances. During placing of the north steel jacket, the contractor encountered several subsurface obstacles that prevented placement of the jacket in accordance with the original design. The caissons were shifted an additional 0.45 m away from the centerline of the bridge. This meant that modifications would be required to the pier cap, increasing the length of the pier cap to accommodate the shifted caissons, but also an increase in the cap depth of 0.3m.

Finally, modifications were made to the rock rip-rap placed on site, to suit material available locally and the expedited supply of rock for the project. A total of 24,885 tonnes of rip-rap was used to construct the permanent stabilizing berm, the work bridge, and the permanent erosion protection. Class 900 rip-rap was placed around SU.4, downstream of the bridge, and other key locations. Temporary materials 150 mm in diameter were placed during construction of the work bridge. The pier modification, bank stabilization, and channel erosion protection works were successfully completed between January and late March 2015. Figures 21 and 22 show the progression of the pier modifications and bank stabilization works.

Figure 21 – Work Bridge Construction (left), Completed Caisson (centre), Pier Shaft Reinforcing (right)

Figure 22 – Completed Pier Foundation

7 CONCLUSION

Five bridges on key highways were in critical need of repairs following the 2011 Flood and 2014 Heavy Rain events. Unique and specific rehabilitation strategies were considered, designed, and constructed to restore and increase full structural capacity and stability to foundations, and provide protection against future flooding. Repairs were completed considering durability, longevity, with consideration made to maintaining continuity and flow between new and existing foundation components, and blending into the existing environment. Strategies were successfully employed to identify, manage, and mitigate project risk by providing a simple, technically complete, and constructible design. Design contingencies were developed to accommodate unforeseen events and site variations during construction, which was reflected in tender quantities and provisions for extra work. All bridge modifications were completed in tight design and construction timeframes and within specified budgets. The project was a successful venture, contributing to a safe and sustainable future for the benefit of the next generation of Manitobans.

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