Emergency Demolition of a Partially Collapsed Railway Bridge

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Abstract:

This paper concerns the demolition project at CP Bridge mile 172.5 Brooks Subdivision near Calgary, part of an emergency response to a partially collapsed railway bridge from a 1 in 200-year flood event. It consists of 5 sections:

The first part is an introduction of the bridge. The bridge was constructed as two truss spans in 1897. The pier was constructed with masonry on spread footing. These spans were replaced with four pony truss spans in 1912. To accommodate the pony truss spans, the previous pier was extended with spread footing resting on shale rock and clay.

The second part outlines the bridge partial collapse incident. Bridge 172.5 Brooks Sub partially collapsed during Southern Alberta flood on June 27, 2013. Inspection indicated that pier 2 south extension spread footing was undermined by flood caused scour. Remaining structures were stable; however, the large size and weight was a challenge for span demolition.

The third part focuses on demolition access, three possible demolition plans and the final demolition plan selection.

The fourth part describes project execution and problems encountered during demolition.

The conclusion discusses response procedures for this type of emergency project. It also provides strategies for preventing railway bridge substructure failure during flood events, such as spread footing foundation monitoring and structural modification.
1. Introduction

Canadian Pacific Bridge 172.5 Brooks Subdivision was a 4-track railway bridge over the Bow River close to downtown Calgary, Alberta. Three tracks were carried by one skewed 64-ft Through Plate Girder span and four skewed 100-ft pony truss spans. The north track is carried by five Ballast-Deck Plate Girder spans. The track alignment is tangent, and train speed is 25 MPH. More than 30 heavy axle load freight trains cross this bridge every day.

In 1897, Bridge 172.5 Brooks Subdivision was constructed as two 206-ft truss spans with a single track. The single central pier was constructed with stone masonry on a spread footing. In 1912, the bridge was extended north and south for two additional tracks and the two existing 206-ft truss spans were replaced by four 100-ft Pony Truss spans (Spans #1 to #4) and one 64-ft Through Plate Girder span (Span #5) as shown in Figure 1. The existing pier (new Pier #2) was extended north and south to accommodate the additional tracks and two new piers (Piers #1 and #3) were constructed at the same time. Pier #2 extensions were constructed with unreinforced concrete on spread footings which were supported on shale rock with a portion of the spread footing foundation at the south end resting on clay.

This bridge was extended again to the north for an additional fourth track in 1969. The new pier extensions were attached to the existing 1912 piers with pier footings were 2 ft. to 3ft. deeper and socketed into the rock.

The original stone masonry and concrete pier extensions safely and reliably carried railway freight traffic for over 100 years.

Figure 1: Bridge Configuration after 1912 Reconstruction
2. Incident

In June 2013, southern Alberta suffered a 1 in 200-year return period flood. According to Water Office data at Calgary Bow River station 05BH004, the water level rose from 5.6 ft. to 13.5 ft. during the flood. Associated with the higher water level, the water flow velocity also significantly increased. CP track and bridge inspectors inspected Bridge 172.5 Brooks Subdivision 18 times during the flood and found no evidence of substructure distress or instability. Unfortunately, due to high flow velocity and poor visibility underwater, no underwater inspections could be conducted during flood.

Nevertheless, in the early morning hours of June 27, Pier #2 Bridge 172.5 Brooks Subdivision partially collapsed as a result of the failure of Pier #2 and a train with tank cars derailed on the bridge. As a part of the emergency response plan, the City of Calgary specified a half mile radius evacuation zone and closed a nearby major highway.

After several hours, CP crews successfully separated and emptied the six derailed tank cars on deck and then carefully pulled all cars off the bridge. An immediate bridge inspection found that a large portion of Pier #2 had separated and rotated southward causing subsidence of the two Pony Truss spans supported by Pier #2 (Spans # 2 and #3) and the subsequent train derailment. This inspection also revealed that the south end of Pier #2 had separated and failed. It is noted that, although all train cars had been pulled off of bridge, Pier #2 was unstable and both Spans #2 and #3 were suspended precariously above the river. The southwest corner Span #2 subsided almost 5 ft. and was cantilevered above the river as shown in Figure 2. The inspection also indicated that the remaining portion of Pier #2 shifted slightly to the south. An inspection of the substructures and superstructures constructed in 1969 revealed it was safe to use the fourth track. Figure 3 shows the large vertical crack at the interface between the original stone masonry pier and northward 1912 concrete pier extension. Further inspection, drawing review and analysis indicated the likely cause of Pier #2 failure was scour at the south end of the pier due to the high flow velocities associated with the extreme flood event and possibly exacerbated by an upstream obstruction. This was verified by subsequent bathymetric survey work conducted immediately following the flood event. Also, as a supplemental safety measure, pier stability monitoring devices (accelerometers) were installed at Piers #1, #2 and #3. CP immediately began planning for the demolition of the damaged spans (Spans #2 and #3) to accommodate removal as soon as possible without compromising river activities.

![Figure 2: Subsidence of Spans #2 and #3 at Failed Pier #2](image-url)
3. Structural Analysis and Demolition Plans

Spans #2 and #3 were skewed 100 ft. long Pony Truss spans. Each span consists of upstream (north) and downstream (south) truss chords with 7 floor beams and 42 stringers to carry triple tracks on each span. Total deck weight was estimated as 120 tons/ span and steel weight estimated as 300 tons/span.

CP immediately began planning for the demolition of the damaged spans and developed three possible demolition schemes based on site access. Access from the top, side and bottom of the failed spans was considered in the early stages of developing the demolition plan.

Top access considered setting of cranes on the deck of Spans #1 and #4. Inspection found that Spans #1 and #4 and their supporting substructures were still in good condition without any evidence of damage from the flood event.

Side access considered building a road approaching the damaged Pier #2. However, this access scheme required that the river surface opening would be narrowed by almost 50%, which was not possible during or immediately following the flood event.

Bottom access deliberations focused on utilization of a barge from the river surface. However, this access scheme was not possible during or immediately following the flood event due to river flow velocity. In addition, barge access is not possible as, under normal flow conditions, the Bow River is too shallow for barge navigation.

Therefore, it appeared that only top access, using Spans #1 and #4, was feasible considering demolition timelines.

3.1 Demolition Plans

It was decided that Spans #1 and #4 can be used to accommodate cranes for steel and deck removal. Due to time concerns, three possible methods for steel removal from Spans #1 and #4 were evaluated. These methodologies involved consideration of direct cutting, use of strong back beams or use of a supplementary crane on top of Pier #2.
Method A: Direct cutting

When Pier #2 collapsed, the southwest corner span 2 dropped almost 5 feet and then stayed in a suspended condition. Inspection found only a few stringers cracked at the locations where stringers connected to floor beams. Therefore, except for losing one bearing, the floor system of Span #2 remained essentially intact as shown in Figure 4. In addition, successful removal of the rail cars was good evidence of floor system rigidity.

Based on the evidence of Span #2 floor system being intact and rigid, the entire floor system consisting of 7 floor beams, 2 pony truss bottom chords and 42 stringers was divided into 17 panels for sequential removal as shown in Figure 5.

This method requires two cranes. One crane will be used for holding a working platform or man basket (cutting process) and the other for steel component removal.

Figure 4: Floor System of Span #2 at Pier #2
The steel removal sequence was generally planned as:

Step 1: Remove downstream side pony truss top chords.

Step 2: Take the SW damaged corner as panel 1 and remove the two unloaded stringers between the two transverse floor beams.

Step 3: Remove the bottom truss chord in the first panel.

Step 4: Take out one third of the first floor beam. After removal of the first panel progress to the second panel. Any structure component which is not supporting others will be cut out.

Step 5: Repeat these steps for each subsequent panel (panels 3 to 17) until the entire span is removed.

The advantage of this method is it an easy start plan without further preparation required.

However, the disadvantages are:

1. The structural analysis must be relatively sophisticated and steel components removal sequence must be accurate to preclude a portion of the span or individual components falling into river.

2. Removal of the last piece, the north side Pony Truss bottom chord, will be very challenging. The bottom chord weights almost 45 tons and can’t be cut into small pieces. This will be a problem for the crane to lift with radius of over 100ft.

3. Floor beams may need to be cut into small pieces. Also, the floorbeams have 3 inches of flange cover plates that would require substantial time and effort to cut.
Method B: Use of strong back beams

This methodology would install strong back beams on Piers #1 and #2 for removal of Span #2 using chains to tie all floor beams to the strong back beams. Steel removal would start from intermediate stringers; and then progress to removal of the Pony Truss top chords and bottom chords on the downstream and upstream sides of the span. Finally, the floor beams would be removed.

The same methodology would be used to install strong back beams on Pier #2 and #3 for removal of Span #3. As with Method A, this plan requires a two-crane operation plan.

A major advantage of Method B is that it is a structurally safe plan. While cutting structure components, the strong back beams and floor beams can maintain the floor system rigidity. In addition, the steel cutting sequence is simple and crane efficiency is higher than with Method A. Furthermore, cutting of the floor beams can be avoided.

However, the disadvantages are:

1. Strong back beam and lateral brace system design and fabrication will take time.
2. Preparation and installation of strong back beams will also take considerable time.

Method C: Supplementary crane on pier top

This method is a very aggressive plan. It requires welded I beams on existing span 3 as a temporary “jump span” to install the third crane on top of Pier #2 area. This would reduce the required crane lifting radius by almost 100ft.

As opposed to Methods A and B, Method C requires a third crane operation plan. With the third crane installed over Pier #2, one crane can be used for holding the working platform (man basket), one crane can hold components which need to be removed and the third crane can be used for supporting the various structural components.

An advantage of this methodology is that steel removal will be faster than Method A because the smaller boom radius provides higher capacity for crane thereby allowing bigger pieces of steel to be removed at every cycle. Moreover, with the support provided by the crane on Span #1, the remaining structure benefits from increased insurance from a safety perspective.

However, a disadvantage is that it increases the risk of further damage to Pier #2. Although Pier #2 remained stable during and after the rail cars were removed from the bridge, it is not guaranteed that the pier will still in stable condition when new loads are applied on it. Moreover, preparation and installation of new welded I beams would take considerable time.

Selected demolition plan

The local construction market was very busy after the 2013 Southern Alberta flood. While making demolition plans, the CP sourcing department could only locate two 300 ton cranes available from contractors in early July. Considering safety, site conditions and other operational factors, Method B utilizing strong back beams was selected as the demolition plan.

4. Project execution and challenges

4.1 Demolition execution:

Step 1: Site preparation.

The General Contractor for the demolition project was Tervita Corporation who was supported by Stampede Crane and Rigging and Read Jones Christoffersen (RJC) Structural Engineers.

On July 5th, two Liebherr 300 ton cranes were set on the deck of Span #1 and #4.
Vacant areas close to the bridge were established as a site office area, deck panel storage area and structural steel storage area. A security line was also installed for safety during demolition operations.

**Step 2: Deck removal and strong back beam design.**

Based on safety considerations, all workers who worked on the damaged bridge deck must either stand in the man basket or securely tie themselves to the basket. Crane 1 (on Span #1) worked on lifting and crane 2 (on Span #4) carried a jib for holding the man basket. When deck of Span #2 was removed, the two cranes shifted their duty to be in place for removal of the deck of Span #3.

The contractor’s Engineer designed three strong back beams for Span #2 and #3 structural steel removal. They were W44×230 beams and required to be over 100 feet in length.

**Step 3: Strong back beam fabrication and installation.**

All three strong back beams need to be over 100 feet long but, because the top of Pier #2 concrete was broken at several locations, the second and third strong back beams would have to be fabricated more than 110 feet long and skewed over 20º to the center line of the span.

During deck removal, both the CP and Tervita Corporation sourcing departments were attempting to source beams on the local market. Unfortunately, after a few days, they found only one 90 ft. long W44×230 beam in Calgary and a second-hand special customized beam in Winnipeg. The special beam was over 120 ft. long with web and flange plates that satisfied the strength requirements for a W44×230 section.

The 15 ft. length shortage of the W44×230 beam was compensated by extending with an equivalent welded section spliced to the W44×230 beam with welded flange and web fish plates as shown in Figure 6.

The special beam (with existing web plates and flange plates of adequate size for strength) was longitudinally cut and separated at the center of the web plate into two “T” sections. New flange plates were then welded to each “T” section to form an I shaped strong back beam of adequate strength and length.

![Figure 6: Strong-back Beam Comprised of W44x230 and Welded Extension](image-url)
The strong back beams were then installed on Piers #1 and #2 for removal of Span #2. After removal of structural steel at Span #2 (intermediate stringers, top chords and bottom chords, floor beams) the strong back beams were relocated to be supported on Piers #2 and #3 for removal of structural steel at Span #3.

**Step 4: Span #2 Structural steel removal.**

While one group was working on fabricating the strong back beams, the other group of workers was focusing on stringer cutting and removal in Span #2.

After installing the first strong back beam at Span #2, crews started to cut at the south side (downstream side) Pony Truss as shown in Figure 7. Cutting sequence was from top chords to bottom chords. The size of removed pieces was limited by their weight as governed by the crane’s capacity. With a boom radius of 100 ft. 5-7 tons could be lifted. When the crane radius was reduced to 30 ft. 15-20 ton pieces could be safely lifted and removed.

The north side (upstream side) Pony Truss removal at Span #2 followed the same procedure as was performed at the south side truss.

The final step at Span #2 was floor beam removals (some with stringer segments and portions of bottom chord attached), which was a considerable challenge for the crane operator. A 10 ton chain fall was added on the crane rigging and a nylon strip was also banded on the floor beam end. The floor beam removal steps were:

1. Crane holds the floor beam, worker slowly releases chains.
2. Crane lowers the floor beam down 10-15 feet as shown in Figure 8.
3. One worker stands on strong back beam, and pulls the chain fall to make the floor beam turn up.
4. Worker then uses nylon strip to pull the floor beam end to the middle of two strong back beams. When the floor beam was clear of the two strong back beams, crane lifts the floor beam out.

![Figure 7: Strong-back Beams Installed for Structural Steel Removal](image-url)
Step 5: Span #3 Structural steel removal.

During Span #2 removals, the water level of the Bow River kept lowering and the City of Calgary terminated restrictions to accessing the Bow River. Based on these new conditions, the original plan was modified and an access road was built to access Pier #2.

After Span #2 removal, the crane on Span #1 was moved to the west side of the river bank. Span #3 was then removed using the same procedures as for Span #2 removal with the exception that floor beam removal was simplified because all floor beams can be lowered to the ground instead of being lifted and moved by crane as shown in Figure 9.
4.2 Challenges during demolition:

Several challenges occurred during the demolition. Some of the more significant challenges were related to health and safety, weather, river traffic, equipment and substructure movement issues.

4.2.1. Health & safety issue

Laboratory results indicated that the original steel paint contains high levels of lead. This required the use of special uniforms and respirators for workers torch cutting the steel. After each day’s work, the use of a special wash station was mandatory before leaving the work site.

4.2.2. Weather problem

According to the crane safety guide, crane operation must be ceased when wind speed exceeds 67 mph. Lightning and thunder storms are also reasons to cause crane operation shut down.

Unfortunately, high wind and thunderstorm weather is quite common in Calgary during the summer. Extreme weather caused more than 20 hours of lost time during demolition.

4.2.3. River traffic

After the flood, river traffic such as kayaks and boats became another safety issue for the bridge demolition. Operation had to be shut down when boats were approaching to the bridge. Total time lost due to river traffic was up to 8 hours.

4.2.4. Equipment problem

During demolition, one 300-ton crane had a pump failure. Execution had been interrupted for 30 hours for ordering and installing a new pump.

4.2.5. Movement on pier 2

Survey data indicated that Pier #2 had further movement during the bridge demolition. Movements were not great, but this outlined that previous concerns regarding proposed Method C were reasonable. Substructure movements continued to be monitored during demolition to ensure there were no safety concerns related to the movement of train traffic across the 1969 bridge during the demolition work.

5. Conclusions and recommendations

Flood induced scour and spread footing foundation undermining at the south extension of Pier #2 was the reason for the partial failure of CP Bridge mile 172.5 Brooks Subdivision. River bed scour at the south end of Pier #2 was confirmed by both bathymetric survey and the underwater diver’s inspection video following the flood event when river levels allowed for these investigations. Frequent inspection of structures during flood events by track and bridge inspectors is an appropriate response to such flood failures, but scour that can occur as a result of extreme flood events, such as the 2013 Southern Alberta flood, can rapidly cause substructure foundation failure.

Bridge Safety Management Programs should contain protocols for the emergency inspection of bridges during flood events. These protocols should outline bridge inspection requirements for track inspectors who would be performing continuous track inspections during the flood event. These requirements for track inspectors would typically involve inspection of track alignment and elevation on the bridge and overall bridge geometry. The protocols should also outline requirements for inspection by bridge inspectors during the flood event. These requirements for bridge inspectors would typically involve inspection of track, superstructure and substructure displacements at appropriate intervals during the flood event based on flood severity and known foundation conditions.

Bridge Safety Management Programs should also contain protocols for the underwater inspection of bridges with substructures in waterways to be performed at appropriate intervals. The frequency and type (visual, tactile, divers, NDT methods) of the underwater inspections should depend on bridge crossing attributes as:

- flow velocity
- watercourse depth
- historical scour
- bridges with spread footings on erodible bridges which collect ice and/or debris
- bridges with deteriorated or exposed footings
- deteriorated scour protection works
- substructures in unstable channels with known scour potential

Critical attributes should be identified in bridge inventory records. In addition to these inspection protocols, the following recommendations are often relevant;

- Concrete, stone rip rap or other pier protection methods should be applied to prevent scour occurrence
- For spread footings, micropiles installed in footing extensions may be used to pin the footing into rock or other stable substrate
- Monitoring systems with appropriate sensors can be installed on bridges to monitor movements of the substructure.

When emergency response is required, sufficient resources, reliable contractors and appropriate planning and execution management are key factors for successful restoration of rail traffic. Moreover, they are also key factors for managing safe and timely restoration of rail traffic and controlling the cost of emergency projects.

**Bridge reconstruction:**

After demolition of Span #2, Span #3 and portion of Pier #2 (original stone masonry and 1912 concrete extension), a new extension to Pier #2, the installation of four new TPG spans (the new bridge will be a triple track bridge instead of four track bridge as a result of operational efficiencies in nearby yard) and modifications to Piers #1 and #3 to accommodate the new spans was constructed. Figure 10 outlines the reconstruction.
Figure 10: Reconstruction of Bridge, New Pier #2 and New TPG Spans
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Overview

• Introduction
• Incident
• Structural Analysis & Demolition Plans
• Project Execution & Challenges
• Conclusions & Recommendations

Introduction

CP Bridge 172.5 Brooks Subdivision

Bridge location and structure:
Canadian Pacific Bridge 172.5 Brooks Sub was a 4-track railway bridge over the Bow River close to downtown Calgary, Alberta. Three tracks were carried by one skewed 64-ft Through-Plate-Girder span and four skewed 100-ft pony truss spans. The north track is carried by five Ballast-Deck-Plate-Girder spans.

Bridge history:
In 1897, two 206-ft truss spans, single track, single central pier, stone masonry, spread footing.

In 1912, spans replaced. Four 100-ft Pony Truss, one 64-ft TPG, three tracks. Existing pier extended, two new piers added, unreinforced concrete, spread footings, south end partly resting on clay.

In 1969, extended to north for fourth track. Add five BDGP spans, concrete, attach to 1912 footing, rest on rock.

Incident

• 1:200-Year Return Period Flood

Bridge condition after incident:
Bridge condition after incident:

Demolition Access Analysis

Span length: 100-ft
Span weight: 300-ton

Demolition Plan

• Plan A – Direct cutting
  • 2 cranes

Demolition Plan

• Plan B – Strong back beam
  • 2 cranes
  • Plan C – Supplementary crane on pier top
  • 3 cranes

Plan comparison:

Plan A is easy start plan.

However, the disadvantages are:
1. The structural analysis must be relatively sophisticated and steel components removal sequence must be accurate.
2. Removal of the last piece, the north side Pony Truss bottom chord, will be very challenging.
3. Floor beams may need to be cut into small pieces.

Plan comparison:

Plan B is a structurally safe plan.

However, the disadvantages are:
1. Strong back beam and lateral brace system design and fabrication will take time.
2. Preparation and installation of strong back beams will also take considerable time.
Plan comparison:

Plan C is a fast plan.

However, a disadvantage is that it increases the risk of further damage to Pier #2. It is not guaranteed that the pier will still be in a stable condition when new loads are applied on it. Moreover, preparation and installation of new welded I beams would take considerable time.

Demolition Plan

- Plan A – Direct cutting
- Plan B – Use of strong back beams
- Plan C – Supplementary crane on pier top

Project Execution

- Step 1: Site preparation
- Step 2: Deck removal and strong back beam design
- Step 3: Strong back beam fabrication and installation
- Step 4: Span #2 structural steel removal
- Step 5: Span #3 structural steel removal

Deck removal

Floor system:

Strong back beam fabrication:
Demolition Challenges

- Health & safety issue
- Weather problems
- River traffic
- Equipment problem
- Movement on Pier #2

Conclusions & Recommendations

- Frequent inspection
- Flood event bridge inspection requirements for track inspectors
- Protocols for the underwater bridge inspection
- Additional recommendations
New Span:

Thank You