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SEISMIC RETROFIT OF THE GRANVILLE STREET BRIDGE TRUSS SPANS

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ABSTRACT:

The Granville Bridge in the City of Vancouver includes a 538 m long, 7-span steel deck truss constructed circa 1950. The original roller bearings required replacement due to PCB contamination. The bridge had been previously retrofitted in the early 1980's, however the anticipated performance of the strength based retrofit was limited for the truss spans of the bridge. The required bearing replacement offered an opportunity to investigate possible seismic retrofitting improvements are part of the works. A seismic assessment confirmed potential vulnerabilities within the steel truss spans, and a variety of retrofit approaches were considered including strength based approaches as well as isolation. The presence of, and need to remediate, the PCB contamination required the development of unique details and construction procedures. The construction was complicated by the presence of Granville Island under the bridge, a popular tourist destination with more than 100,000 visitors on a busy summer day. Innovative designs were developed for the complex temporary works schemes needed to replace bearings of up to 7 MN load capacity. This paper presents the design considerations, retrofit strategies considered, proposed phasing of works and construction details for this complex retrofit as well as the range of benefits of base isolation. We highlight the complexities encountered and details that resulted due to the PCB contamination..

1. Introduction

The Granville Street Bridge was built in the 1950's. The main bridge across False Creek comprises seven steel deck truss spans, with a total length of 538 m, with an 8 lane concrete deck, supported on concrete piers. Figures 1 and 2 demonstrate the configuration of the truss spans. The south and north approach spans and ramps comprise multiple spans of cast-in-place concrete girder spans. The entire bridge had been previously retrofitted in the early 1990's. The primary requirement of our project was to remediate the existing bearings for PCB oils used to lubricate the roller bearings. PCB is classified as hazardous materials, and need to be removed to comply with Federal and Provincial legislation. There were originally 14 roller bearings and 6 fixed bearings supporting the steel truss. The City of Vancouver originally let the project with the scope to remediate the PCB's in the existing bearings without considering seismic upgrades. This approach was predicated on the bridge having been previously retrofitted. Through the course of the project development it became apparent that an opportunity existed to greatly enhance the seismic performance of the major structure as part of the bearing remediation project through the implementation of a seismic isolation retrofit. This retrofit would address the PCB issue by removing the existing roller bearings as well as enhance the seismic performance.

Fig. 1 – Aerial View of Granville Street Bridge (Looking West)

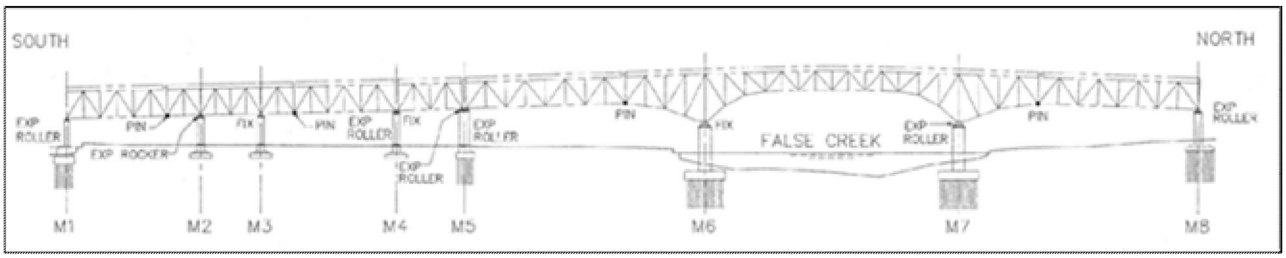

Fig. 2 – Main Span Elevation and Articulation (Looking West)

The truss spans are supported on four different types of bearings. All bearings use tapered steel plates and 'pins' between the truss and the piers. The four bearing types are:

.1 Fixed

.2 Expansion

.3 Fixed at Pier M6

.4 Expansion at Pier M7.

Table 1 shows the original articulation arrangement of the various bearings within the seven steel truss spans and the proposed seismic retrofit in the ultimate configuration.

Table 1 – Bearing Articulation.

Bearing Location	**Current Longitudinal Behaviour**	**Current Transverse Behaviour**	**After Retrofit Behavior (Both Directions)**
M1	Expansion (Roller)	Fixed	Movable w/stiffness
M2	Expansion (Rocker)	Fixed	Movable w/stiffness
M3	Fixed	Fixed	Movable w/stiffness
M4S	Expansion (Roller)	Fixed	Movable w/stiffness
M4N	Fixed	Fixed	Movable w/stiffness
M5S	Expansion (Roller)	Fixed	Movable w/stiffness
M5N	Expansion (Roller)	Fixed	Movable w/stiffness
M6	Fixed	Fixed	Movable w/stiffness [note1]
M7	Expansion (Roller)	Fixed	Movable w/stiffness [note1]

M8	Expansion (Roller)	Fixed	Movable w/stiffness

Note 1: At M6 and M7 isolation bearing will be introduced at a second stage.

2. Criteria

The earlier bridge retrofit targeted a “No collapse” criterion for the 475-year event. Record drawings for the truss span retrofit scheme state that the expected seismic performance had been “improved” for the main steel truss to an undefined extent, for a seismicity level of a 10% probability of exceedence in 50 years (475-year return period).

In the proposed seismic isolation scheme we targeted an immediate or near-immediate return to service for the truss spans for the design earthquake. Some minor damage is expected, including possible pounding of deck joints, but should not significantly impair function and be repairable. We also reviewed the expected performance of larger events, up to a 2475-year return period event, which is currently specified for new building design, and which is expected be specified for life-safety (collapse prevention) performance for new bridges in the 2014 Canadian Highway Bridge Design Code. Other objectives include:

1) Solution needed to be constructible; structure behavior during jacking operations should not cause damage to bridge elements.
2) Major elements that are part of seismic load path (such as portal braces and piers) to remain essentially elastic, or suffer only minor damage, during the design event.
3) A reserve 50% displacement capacity at isolation bearings under the design earthquake.
4) Design for acceptable changes in service conditions (live load, thermal loads and wind, deck joint movements) following bearing replacement and articulation changes.
5) Provide comparable or better seismic performance for the steel spans compared to the approach spans.
6) Eliminate all PCB’s in the bridge bearings.

A key factor that remained prominent throughout the project was that the PCB’s must be remediated. The need to eliminate the PCB’s from the existing bearings remained one of the key considerations throughout. However, as the project developed the team asked ‘is there complementary work that would provide additional enhancement to the bridge’? We undertook a preliminary seismic assessment which identified vulnerabilities in the existing substructure, lateral load transfer through the bearings, and plan and diaphragm bracing.

Several retrofit schemes, including strength and ductility enhancements, were considered as shown in Figure 3, however many considerations suggested that an isolation retrofit would be the most suitable. These considerations included the presence of PCBs, the previous retrofit work, the busy public spaces below the bridge, and the owners desire to be able to phase the project.

The presence of PCBs may have been the single most influential consideration in selecting an isolation retrofit. Due to the presence of PCBs any work undertaken had to include the replacement of the existing bearings. While a number of bearing alternative were available, isolation bearings had a significantly higher cost/benefit ratio over other alternative since the cost associate with bearing replacement would be included in any other retrofit scheme.

The previous retrofit work was another factor supporting isolation. The existing concrete piers had been strengthened including post tensioning of the cap beams. This retrofit provided enhancements to the capacity and ductility of the existing substructure; however it also made it challenging and costly to further strengthen and enhance the substructure. By isolating the bridge the substructure demands were reduced significantly, eliminating the need to further strengthen the piers.

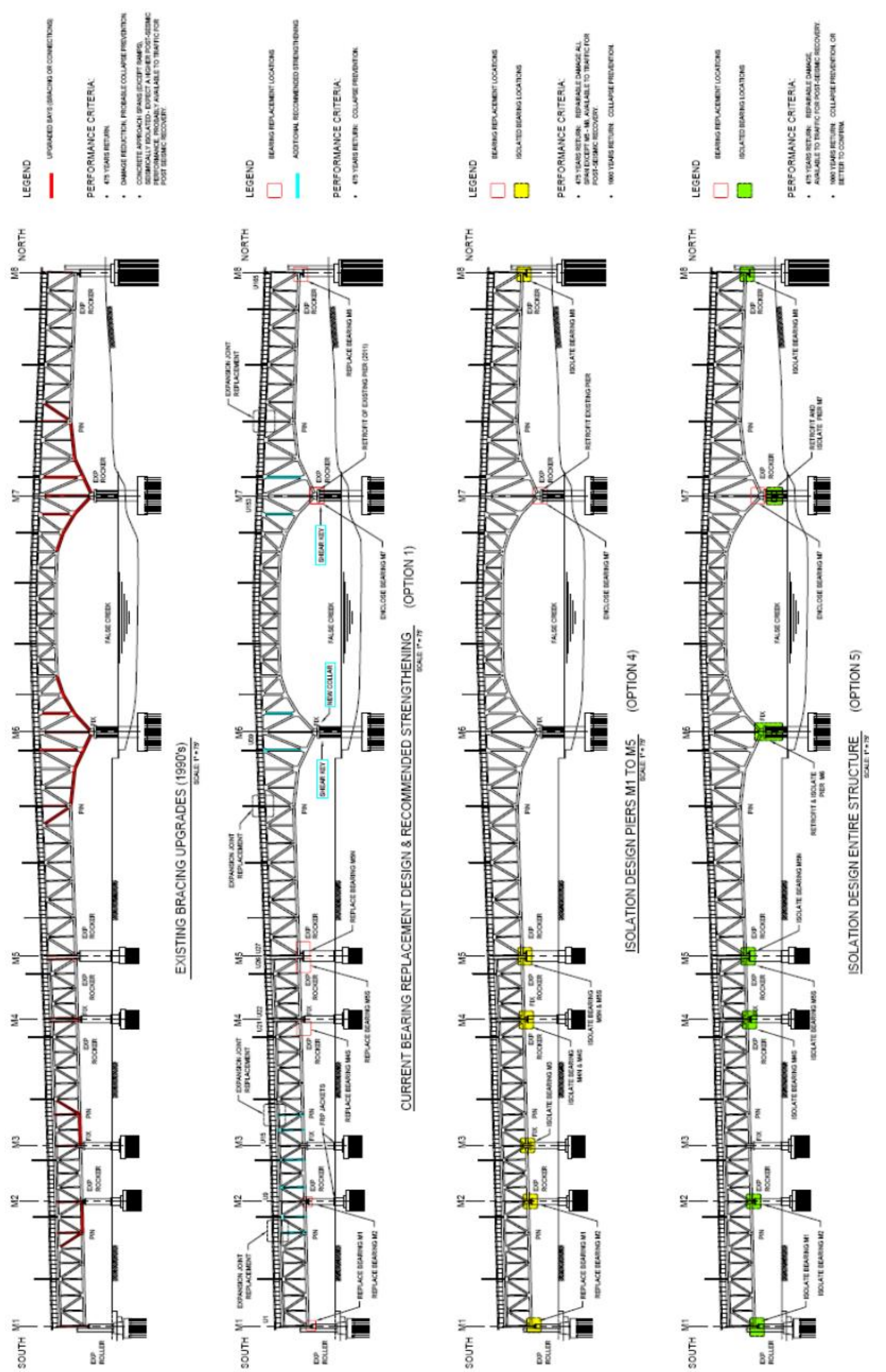

Fig. 3 – Retrofit Schemes Considered

Granville Island, a popular tourist area, is located immediately beneath the southern portions of the bridge, Pier M1 to M6. The area is occupied by markets, theatres, artisans, restaurants and a hotel. Popular throughout the year, activities peak with up to 100,000 people visiting on a busy summer day. The flow of traffic onto and off the island is a constant challenge and the bridge piers straddle the main routes in and out. The proposed isolation retrofit scheme eliminated the need for any excavation or significant scaffolding around the piers, minimizing the impact to the public. Access to each pier was via a scaffold stair located on the outside face of the piers, away from traffic. The existing bridge inspection traveller will also was also used for access. Activities requiring cranes for heavy lifting were scheduled for non-peak times, typically early in the mornings.

3. Phasing

An important consideration for the City was the ability to deliver the retrofit in phases to suit funding constraints. The PCB remediation project did not require replacement of the Pier M6 and M7 bearings, the largest and most complicated to replace. Due to funding constraints the original project budget was not sufficient to fund the full retrofit of the truss spans. In completing our assessment we considered several configurations including a fully isolated structure as well as a partially isolated structure. We were able to demonstrate that by isolating at all of the bearing except for Piers M6 and M7 the expected performance of the bridge would be achieved for the majority of the structure. In the first phase the bearings at M7 will be made fixed, addressing lateral load vulnerability in the bearings. In the phase 1 configuration a significant enhancement is achieve, although the design criteria is not met throughout. A second phase retrofit design has been completed to allow isolation of the two remaining piers. This work will be completed in the next few years once funding is secured. In addition a preliminary geotechnical assessment has been completed and identified potential liquefaction concerns adjacent, particularly near Piers M6 and M7. A more detailed liquefaction assessment is planned as well.

4. Design

The first design detail to determine was the type of isolation bearing to install. In preparing our design we considered multiple bearing types including the following:

1) Elastomeric laminated rubber bearings.
2) Lead core rubber bearings (LCRB).
3) Friction Pendulum Bearings (FPB).
4) Seismic Isolation Disk Bearings (SIDB).

A decision matrix was prepared to assist in the decision, which included performance, cost, geometry, structural modifications required, and compatibility with articulation. Generally all of the bearing types considered demonstrated very significant seismic benefits. The increased damping provided by the LCRB, FPB, and SIDB bearings was beneficial above the response from the plain laminated rubber bearings. Although the highest damping could be achieved with the FPBs, the incremental effect above the LCRBs was not critical for this structure. The result of the evaluation was that LCRBs were the preferred bearing type. The LCRBs provided a sufficient level of isolation and damping, were cost effective, required a minimum of structural modifications to install, and was compatible with the existing bearing pedestal articulation.

It is noteworthy that, for this bridge, the effectiveness of the isolation retrofit was not overly sensitive to the type of isolator selected. The key factor was the period shift that resulted from isolating the structure. Once the bridge period was shifted from around 1 second in the existing configuration out to 2 or more seconds, depending on the isolator properties, the other design parameters were not significant. Changes in period between 2 and 3 seconds resulted in nominal changes in demand, similar with adjustments in the level of damping incorporated. While final adjustment of the bearing properties to optimize the design period and the damping were done to refine the design they did not drastically impact the results.

In order to install the bearings it is necessary to implement some modifications to the bearing pedestals to allow the existing bridge grades to be maintained. The existing bearing pedestals sit on top of the roller bearings, or pier cap for fixed bearings, and have a pin located between the pedestal and the truss node.

Figure 4 shows the existing condition and figure 5 shows the retrofit condition. The entire bearing pedestal between the pin and the rollers is replaced with a new pedestal, for the typical bearings; refer to figure 4 for details. This achieved two goals; the first is to allow sufficient space to install the new bearings while maintaining the current bridge grades. The second benefit was to remove the PCB contaminated bearing top plate and rollers to allow them to be cleaned off site. At Pier M6 and M7, replacement of the bearing pedestals is not practical, not only are the loads much higher, the bearing pedestal also acts at the truss node gusset. For these two locations the bearings will be installed under the existing pedestal, requiring the bridge to be lifted approximately 200 mm. The existing bridge articulation and geometry allows for the re-profiling without any structural modifications as the grade change is minimal and no negative drainage impacts were identified.

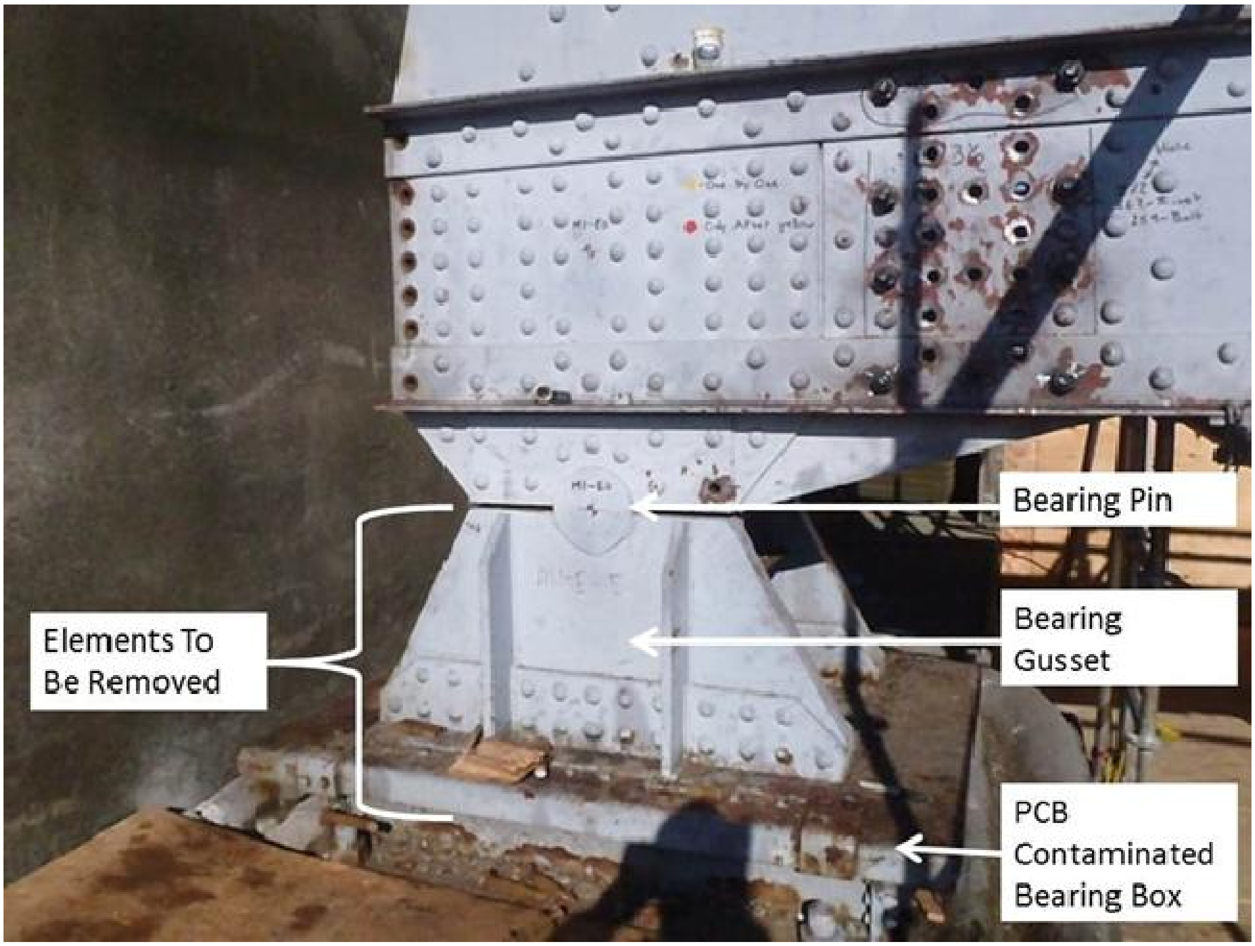

Fig. 4 – Typical Existing Bearing Condition

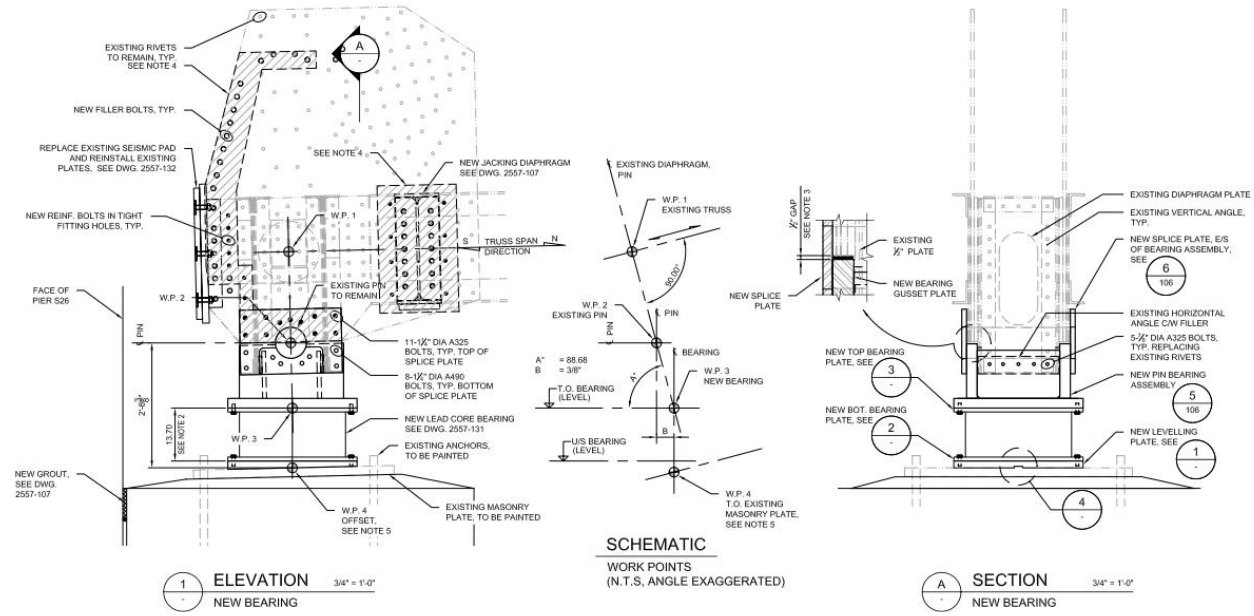

Fig. 5 – Typical Bearing Replacement Detail

5. Temporary Works

One of the most challenging design considerations was how the temporary works and jacking would be defined to allow safe replacement of the bearings. The bridge was to remain open to traffic during the bearing replacement with the exception of a short period while the jacks are being activated. Additionally, due to the need to replace the entire bearing pedestals and allow in-situ PCB cleaning of the existing masonry plates the bridge will remain on the temporary supports for one to two weeks at each location. Consequently the temporary works needed to be designed for full live loads as well as thermal considerations.

The existing truss bridge did not have any provision for jacking. Consequently it was necessary to develop a temporary works plan to allow the jacking to be safely completed. Several jacking configurations were considered including:

- Single jacking point in front of the bearing: Not practical as it induces too much bending into the truss chord.
- Lifting from the truss end post: Not preferred as it requires strengthening of the truss post connection to the gussets, requires jacks on both sides of the bearing limiting installation access as well as limited space on the pier caps to accept a jack on the inside of the bearing.
- Jacks located both sides of the bearings: Requires jacking brackets and diaphragms but allows space for installation and removal of the bearings to the outside of the bridge. This was our preferred solution.

Due to geometric constraints, it was necessary to provide prestressing the concrete substructure at some jacking locations to prevent failure of the concrete. The jack supports were also hinged to allow for longitudinal thermal deformations while the bridge is on the jacks. The temporary works design allowed for jacks on both sides of each bearing pin to remain on linked hydraulics to accommodate live load rotations of the truss.

The design and detailing of temporary works on bridge rehabilitation projects is frequently an area of challenge during design, bidding, or construction. There is a desire to leave temporary works design to the contractor, as this allows them to select their own means and methods. It also allows contractors an opportunity to innovate. However, during bidding it is unlikely that contractors will have the time or spend the engineering resources to sufficiently solve the temporary works challenges. Our approach on this project, and most bridge rehabilitation projects, was to completely develop a temporary works design that we were confident would be successful for the project. We then identified the components that would be permanent to the structure and those that were temporary. All of the permanent components were completely detailed on the drawings. Temporary components were detailed conceptually. This approach provided sufficient information to assist the bidding contractors with pricing. Our contract language then allowed for the contractor to propose alternative temporary works design, subject to review by the design team, which allowed for innovation by the contractor. As it turned out the Contractor utilized a temporary works scheme based on the design we developed with a few modifications.

6. Construction

Construction of the phase 1 isolation retrofit began in February 2013 and was completed in October 2013. Generally the retrofit construction proceeded smoothly with few unanticipated challenges. However, there were a number of interesting aspects and challenges.

As with most retrofits it was necessary for the contractor to field confirm dimension prior to fabrication. For this project the field measurement were particularly important and required tight tolerances for fabrication. Most of the connection holes for the fabricated steel bearing pedestals utilized existing rivet holes. It was necessary for the contractor to measure and fabricate with sufficient tolerance to allow smooth installation of complex connections. The Contractor utilized a cloud scan survey technique to document the existing structure. The cloud scan survey was supplemented by traditional survey methods as additional quality assurance. In locations where it was practical the contractor also match-drilled holes to facilitate field fitting. The techniques utilized by the contractor, particularly the cloud scan survey, were very successful in obtaining fabrications that fit within the existing structure. That being said, there was one element that did not fit adequately, ultimately identified as an operator error issue, highlighting the need to supplement the technique with traditional measurement methods.

As discussed earlier, the bridge retrofit was primarily located above Granville Island, a busy tourist and artisan destination within the City of Vancouver. However, much of the work required for the retrofit was extremely loud and impactful to the businesses, artisans, and visitors. One of the loudest activities was rivet busting to allow the removal of the existing rivets. Through a proactive communications program with local businesses, the work was completed with limited complaints. This highlights the importance of communications with the affected stakeholders. This activity, along with many others, had the potential for debris to fall from the work area. The addition of containment screens was critical to maintain public safety.

Fig. 6 – Rivet Busting Including Shrouding for Containment

Many methods of access to elevated components were possible for consideration, however due to Granville Island located beneath the bridge access impacts become critical. Generally access to elevated components was by tube and clamp scaffold stairs strategically located in areas of low traffic flows. Tube and clamp scaffold catwalks and walkways were constructed to connect the piers where practical to minimize the number of impact points on the ground and keeping the work zone above the busy public area.

The presence of the PCB's was a continuous challenge for the contractor. Components that were PCB contaminated had to be handled with care, removed, bagged, and transported off site for full cleaning. This process was complicated by the size of the elements to be handled and the space allowed for removal. One complicating property of PCB's are that when burned the fumes released are extremely hazardous. This meant that the contractor could not torch cut existing elements that may be PCB contaminated.

Fig. 7 – Preparing PCB Contaminated Rollers for Removal

The space constraint on the bridge piers was probably the biggest factor affecting the contractor's methods. Tolerances for installing bearings, placing equipment and materials, and locating jacks were severely restricted. Existing components were generally removed as soon as they were freed from the existing structure. New components were delivered only when ready for installation and slid immediately into place. Final tolerances for installation of the bearings were less than 15 mm.

Fig. 8 – Completed Bearing Adjacent to Removed Bearing

7. Conclusion

The retrofit of the Granville Bridge posed many challenges from lack of jacking provisions, presence of PCB's, Granville Island located below the bridge, and the owners desire to phase the work to meet budget constraints. The phase one retrofit is complete and under service conditions is performing well. The PCB's have been removed from the Granville Street Bridge meeting the federal regulation requirements. The design for the phase 2 retrofit is complete and will be implemented later providing a fully isolated solution.

8. Acknowledgements

We would like to acknowledge the following for their contributions to this project.

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- Graham Construction & Engineering, particularly Ronan Deane

9. References

CSA S6-06 Canadian Highway Bridge Design Code (CHBDC), Nov 2006, Incl. Supplement No.1 and No.2.

Seismic Retrofit Design Criteria, BC Ministry of Transportation and Infrastructure, June 2005.