Replacement of the Chehalis Bridge – Design, Construction, and Demolition

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ABSTRACT

The Chehalis Bridge serves the Morris Valley Road to cross the Chehalis River, 6 km North of HWY 7 and around 17 km West of Agassiz. The bridge is the only connection between the communities on both sides of the river and an important local link for the Sasquatch Mountain Resort and many campgrounds in the neighborhood. The over 70-years old timber through truss structure was due for replacement due to its deteriorated condition, limited roadway width, and modern hydraulic requirements. The construction method for the given span arrangement of the new bridge with one major main span and two symmetrical but relatively short side spans was decisive for the type of the new structure. Since a total traffic closure of the old bridge was not an option, the new bridge had to be realigned in parallel configuration right next to the old bridge. This paper describes the design and construction aspects of the new bridge in context to modern design philosophies as well as the engineering tasks behind the demolition of the old structure.

KEYWORDS

Design for Climate Change, Conceptual Bridge Design, Performance-based Design, Integral Bridge, Structural Redundancy and Resilience, Incremental Launching, Aesthetics, Engineered Deconstruction

1. INTRODUCTION

The Province of British Columbia (BC) experienced in the past decade increasingly severe losses due to flooding, landslides, and forest fires, catastrophic events which are often referred to as the consequences of climate change. Most recently, in November 2021 during an extreme weather period with heavy rain fall, major floods and landslides caused heavy damage to BC's road and rail infrastructure with major service interruptions impacting BC's economy and the lives of many. [1]

From an engineering perspective, the way critical bridges were destroyed without or little warning is alarming, and it requires a rethinking regarding how bridges shall be designed or retrofitted at critical locations where the power of the elements and associated hazards cannot be mitigated otherwise. Due to its prone location, the new Chehalis River Bridge has been considered as an excellent pilot project to implement the lessons learned with the goal of improving structural resiliency of bridges without increasing budgets for construction and maintenance.

2. SITUATION

The Chehalis River connects the upper Chehalis Lake with the lower Harrison River and is subject to extreme flooding because of its large retention zone and limited water absorption capacity. The specific river characteristics required the best possible freeboard elevation and a minimum span of 60 m. On the other hand, the roadway profile should not be elevated and the overall bridge length be kept as short as possible to maintain good sight distances and a cost-effective solution.

Originally, a hybrid superstructure type was envisioned with 60-m long composite steel plate girders framed into the two piers and 18-m long approach spans on both sides made of precast pre-tensioned concrete box girders (see Figure 1). However, the lack of superstructure continuity at the piers required very deep and heavy girders for the main span to cope with the large dead load moments in mid span. In addition, the construction of this major span would have required to place a very heavy crawler crane on one of the already constructed approach spans to facilitate single-crane girder lifts. Since the bridge design prepared by the Ministry was delivered using the traditional Design-Bid-Build model, contractors were not part of the design team.

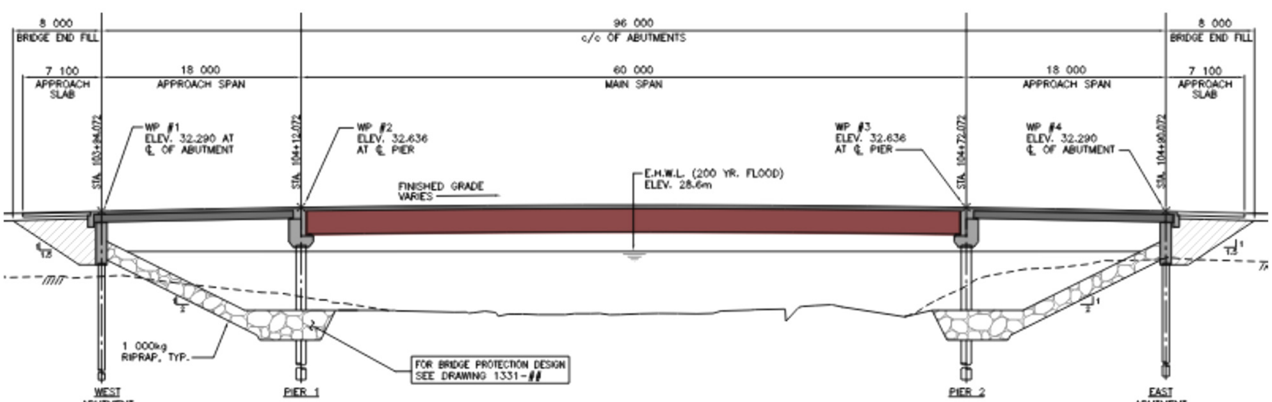

Figure 1: Original design concept: Composite steel plate girders in the main span and precast pretensioned concrete box girders for the approach spans [BC MoTI]

At this early design stage, Parsons was asked to provide input regarding constructability of the main span. At a conceptual design review meeting, the Ministry/Parsons team realized that the construction of the new bridge should be the design driving aspect and that a continuous and integral steel girder superstructure concept in contrast to the envisioned hybrid solution has many other advantages (synergy effects) besides the identified construction aspects.

3. CONCEPTUAL BRIDGE DESIGN

Conceptual bridge design is an overarching task that involves many relevant design aspects, such as safety, functionality, constructability, economy, robustness, durability, inspection and maintenance, adaptability, ecology, aesthetics, and recycling. [2] Conceptual design is one of the most important tasks because key design decisions are made during this early stage. The designer focuses on the general concept and ensures that the newly developed design is feasible, complies with the design criteria, and satisfies stakeholders' expectations. Conceptual bridge design is very helpful when designing complex bridges which require a good understanding of proven construction methods. In order to achieve synergy effects and cost-effective solutions, continuity and reliability should be major design goals:

Continuity in this context stands for a continuous superstructure that eliminates as many bearings and expansion joints as possible. Modern concepts consider structural systems that are flexible and adaptable in respect to time dependent deformations (e.g. temperature, creep and shrinkage, and settlements) but at the same time provide sufficient stiffness for transitory loads, such as live load and wind. Conceptual bridge design includes the development and optimization of complex hyperstatic systems to achieve this objective.

Reliability stands for dependable construction methods and for a durable and resilient structure. Construction and in-service aspects affect costs, the initial construction costs as well as the overall return-on-investment. For that reason, conceptual bridge design shall include an investigation of reliable construction methods and the development of important details. Finding appropriate solutions for atypical details is pertinent and should already be addressed in the conceptual design phase in order to avoid "showstoppers" at the detailed design stage. Detailing shall follow sound design principles, such as the load path analogy and good design practice, and respect constructability, robustness, and durability, especially if integral bridges are proposed and/or seismic demands govern the design.

4. FINAL DESIGN CONCEPT

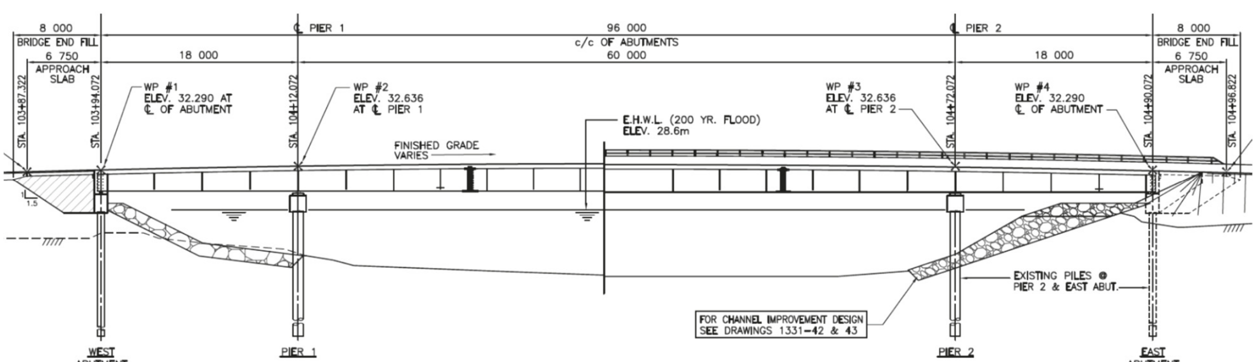

Figure 2: Final design concept: Continuous composite steel plate girders over the entire length of the bridge [BC MoTI]

The conceptual design review for the Chehalis Bridge led to an integral bridge concept (steel girders are framed into the abutments) with the goal to eliminate joints and increase structural resiliency. The incremental launching method was early identified as the most economical way to erect a light-weight steel superstructure type which was required to make the 60-m main span. To facilitate onsite an assembly-line erection process and reduce the structural girder depth, a continuous steel plate girder superstructure type for all three spans was selected (see Figure 2). Hereby, the final bottom flange profile under dead load is following a horizontal line while the girder top flange profile directly mirrors the hogged Profile Grade Line (PGL) of the road.

This new girder configuration and hyperstatic structural system allowed to maintain the roadway profile while optimizing girder demands, the hydraulic freeboard, and the overall slenderness of the structure. This new meaningful lighter superstructure type with four girder lines (see Figure 3) eliminated joints and required only access for small mobile cranes near the abutments for girder assembly and tip support during the last push. The final design concept fully incorporates the continuity and reliability aspects of the conceptual bridge design philosophy pointed out earlier and capitalizes on synergy effects resulting in an overall better performing and looking structure. The new Chehalis Bridge is a good example for modern bridge design confirming that structural simplicity and efficiency in combination with constructability and durability can deliver on all aspects without increasing construction and maintenance budgets.

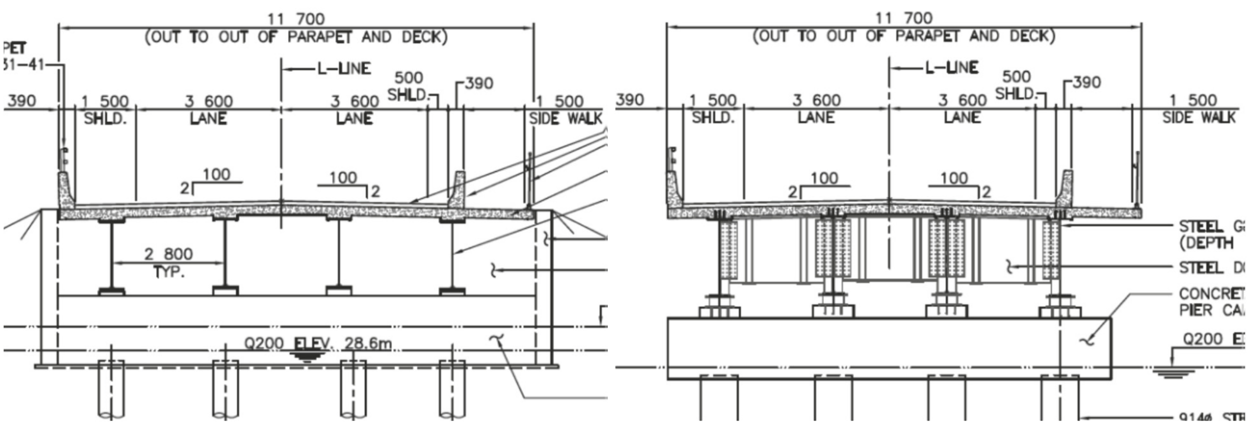

Figure 3: Final design concept: Cross Sections at the abutment (left) and at the pier (right) [BC MoTI]

5. PERFORMANCE-BASED DESIGN

It is generally recommended to study and optimize structural performance if hyperstatic structural systems are utilized. The performance-based design approach, often used for seismic bridge design in Canada [3], is the foundation for this task. The philosophy encourages bridge designers to investigate and intentionally influence the bridge's structural behaviour when developing global systems and verifying local sections. Plastic design principals and/or isolation/damping devices in combination with the performance-based design approach allow to actively steer structural flexibility and improve structural response and behaviour for service stages as well as extreme events. [4]

The performance-based design approach is ideal for integral bridges. This type of structure with its integral girder/abutment connections typically requires to investigate soil/structure interaction to capture restraining effects (for stiff soils) and P/Delta effects (for soft soils). If the performance of the structure depends on stiffness and designers are able to predict this performance accurately within reasonable boundaries, then it is recommended to capitalize on the high strength of modern materials and purposefully shaped cross sections with high degrees of rotational capacity and ductility. Hyperstatic structural systems with the build-in ability to redistribute extreme local demands can meaningfully increase global structural resilience and durability when critical sections are properly detailed and constructed.

For the Chehalis Bridge, the performance-based design led to an innovative integral bridge concept considering the extreme span configuration with an approach span to main span ratio of 0.3. In addition, hydraulic and seismic resilience have been factored into design together with durability and aesthetics although the design team maintained a strong focus on constructability and return-on-investment. The result is a testimony that these factors can go hand-in-hand without forfeiting one or the other design aspect. In other words, the Chehalis Bridge demonstrates that the performance-based design approach is much more than a modern seismic design philosophy.

6. LIGHT-WEIGHT AND SEISMIC DESIGN PRINCIPLES

Dead load matters for cost reasons, especially when designing for seismic activity. This particularly applies to bridge foundations and substructure elements. [5] But there are more reasons why lightweight structures should be generally the preferred choice. They are ecologically friendly because the efficient use of material and the reduction of shipping tonnage and lifting weights helps to reduce our carbon footprint. Lightweight structures typically require more design work and fabrication labor, but they do not necessarily increase overall costs. The example of the Chehalis Bridge shows how a composite lightweight design can successfully reduce weight without creating an extra cost burden on the project. A commitment to lightweight design principles creates good paying jobs and builds expertise on all levels, a priceless achievement in the race for economical supremacy in a world with diminishing resources.

Lightweight and continuous superstructure types have major advantages in seismic zones. Their limited mass significantly reduces demands on piers, abutments, and foundations. This is especially of importance when designing bridges in bad soils, as we find them in the Lower Mainland of BC. Soil liquefaction and limited lateral pile resistance meaningfully increase foundation costs and for that reason it is even more warranted to apply lightweight design principles where seismic demands govern the design of substructure elements. Seismic devices, such as isolation bearings, shock-transmission units or lock-up devices, and dampers specially designed to mitigate the negative effects of mass accelerations, are even more powerful if the structural resilience of the substructure is not dominated by large payloads. To a certain degree, a heavier superstructure type may increase moment and shear resistance of reinforced concrete columns and piles, but P/Delta-effects make this positive effect worthless if critical sections crack and lateral deformations over-proportionally increase.

7. VERIFICATION FOR LAUNCHING

If the incremental launching method is envisioned as a feasible and economic superstructure erecting method, the designer shall ensure that geometry, structural details, and launching demands are compatible with this highly specialized method:

The geometry of the bridge should follow a straight line or a curve with a constant radius. Although exceptions are possible, this applies particular to the bridge geometry in plan. The vertical girder profile is typically more forgiving if the girders are slender and flexible. It is recommended that girders are intentionally so spaced that each girder will see an equal share from dead load. This will allow to use identical girders for each girderline with the same cross sections, camber profiles, and structural details. Even if girders are unevenly loaded by the concrete deck or other permanent loads, differently cambered girders should be avoided by any means because cross frames and diaphragms will lock different girder profiles into the final bridge geometry before the major component of the dead load is applied and camber variances are neutralized. Launching girders with different camber profiles may still be feasible using a “floating roller support system”, but it is definitely not a desirable solution from an erection engineer’s perspective.

Structural details of the steel girder grillage system shall be verified so they respect the path of rollers and guides with sufficient clearance. This includes a constant width for the bottom flanges, no steps in the bottom flange soffit profile, and a splice plate arrangement that generally provides a gap of around 250 mm right at the centerline web. Different bottom flange plate thicknesses are possible but the transitions from a thinner to a thicker plate shall be made at splice locations (preferably at the dead load zero moment points of a continuous girder system) using filler plates only for the upper splice plates. Diaphragm and cross frame connections to vertical web stiffeners shall provide ample clearance for lateral guides which are in contact with the lateral faces of the bottom flanges. As a general rule a 250-mm vertical clearance measured from the centerline of the bottom flange should be provided.

Girder and substructure demands may be governed by the launching operation, especially for the leading cantilever if no launching nose or any other temporary support system is provided. Therefore, it is important to fully understand the launching demands already in the conceptual design phase and to include them in the design criteria. For instance, it is recommended to design bottom flanges with a width-to-thickness (b/t) ratio according to Class 2 or better to avoid a local instability due to flange buckling. Most critical sections for the leading cantilever demands shall be checked for maximum flange axial stress superimposed with flange lateral bending stresses (due to lateral guide support forces applied between cross frames) and for web crippling due to vertical roller support reactions. Wind forces and safety factors shall be appropriately selected to meet safety standards imposed by the CHBDC or other requirements acceptable to the stakeholders. In this context, it is common practice to use the 10-year return wind pressure defined by the CHBDC but in extraordinary construction stages with the governing cantilever demands this requirement may be withdrawn if a critical wind window of 48 hours with smaller forecasted demands (e.g. wind speeds not exceeding 20 km/h) is found to be acceptable.

8. STRUCTURAL DETAILING

Structural detailing is a key design task and an engineering discipline on its own. Even the strongest bridge is only as strong as its weakest detail. However, not every detail has the same importance regarding local failure and/or global bridge collapse. Therefore, it is important that designers have a good understanding of primary load paths and intentionally investigate important details by evaluating the failure potential and possible consequences. The CHBDC has many good design practices implemented to ensure that standard details are well designed even if the design demands do not require the strength or ductility. For instance, girder splices shall be designed for at least 75% of the factored resistance of the weaker member to be spliced CHBDC, Cl. 10.18.1.1 (b), or bracing systems between straight compression members or straight flanges shall be designed to carry the shear forces from external loads plus 1% of the compression forces in the supported members CHDBC, Cl. 10.14.3.5.

However, as designers we shall not assume that every detail in modern bridge design is addressed by the code. Therefore, it is necessary to understand the safety concepts of modern codes regarding ductility and the mobilization of structural reserves to prevent unannounced failure modes. The Failure Mechanism Concept [6] is a good example for intentionally designing fuses into the structure to prevent sudden collapses and to protect sensitive structural elements via the capacity protected design methodology. Designers shall be encouraged to think beyond demand-over-capacity ratios by intentionally increasing loads and/or deformations with the purpose of gaining a better understanding of likely failure mechanisms.

Figure 4 shows standard details for the Chehalis bridge specifically designed to avoid excessive cracking, buckling of slender members, loss of support, and enhance structural continuity.

Figure 4: Structural Details of the Chehalis Bridge: Integral abutment/girder connection (left), girder support at pier (middle), and bolted girder field splice (right).

9. BRIDGE AESTHETICS

Bridge aesthetics are often considered as a secondary design objective although well-proportioned bridge structures do not necessarily need to cost more. [7], [8] The beam is probably the most commonly used superstructure type and still many beam bridges lack good aesthetic quality. Why?

Before answering this question, good aesthetic quality must be defined and this is already the core problem. We engineers do not have a commonly accepted definition for this quality, neither have we been trained to search for better solutions nor to investigate different design approaches and evaluate them. Therefore, a discussion about bridge aesthetics is an important first step. Generally spoken, we can state that good looking bridges are no coincidence. They are the result of an interactive process that considers well-defined proportions, the desire for slenderness and elegance, the play with light and shadow, the rhythm of repeated elements, the scale of the structure and the size of its elements, the context of the structure to its location, the color and texture of visible elements, the degree of boldness and simplicity, and much more.

The topic bridge aesthetics could fill a book of its own because it would require a comparison of many different types of existing structures and a discussion of what went well and why. However, for the Chehalis Bridge a few aspects will be discussed in more detail. Generally, the Golden Ratio is widely considered as an aesthetically pleasing approach to create harmonic proportions.

Figure 5: Structural simplicity and efficiency satisfy economic, hydraulic, and roadway design objectives and simultaneously achieving slenderness and elegance.

The Golden Ratio is based on the Fibonacci numbers which can be described as the sequence in which each number is found by the sum of the two preceding ones (0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55...). The interesting part of the Fibonacci Sequence is that the ratio of two following numbers is representing better and better the Golden Ratio as the numbers increase. For instance, we find for 55/34 = 1.618 and for 34/55 = 0.618. Considering the difference of the two ratios 1.618 and 0.618, we find that the difference is precisely 1 which is a characteristic feature of the Golden Ratio.

Figure 5 shows the size and scale of various structural and non-structural elements of the Chehalis Bridge. Their proportions relative to each other form harmony and elegance. This includes the steel railing, the barrier, the slab thickness, the girder depth, the abutment body, pier cap beam, and even the length of the piles supporting the pier cap beam. In addition, the various colors for the galvanized railing steel, concrete barrier and deck, weathering steel for the girders, again concrete for the abutment and the pile cap, and weathering steel for the piles create contrast and highlight the various materials which have been purposefully chosen to achieve strength, stability, and durability. And finally, the shadow of the cantilevering deck creates another line dividing the steel girders in an upper and lower portion which additionally enhances the slenderness of the structure (compare Figure 5 with Figure 6). The symmetry of the structure and hogged roadway profile with its highest point in mid span enhance the aesthetic quality (see Figure 6). The pure shape and simplicity of the structure is best described with the following statement: From a structural and aesthetic perspective, the Chehalis Bridge is a structure where nothing should be added and nothing be removed. This typically constitutes aesthetic quality for bridges.

Figure 6: Upstream side of the Chehalis Bridge showing the symmetrically hogged roadway profile and the direct load path from the girders into the piles.

10. STEEL GIRDER ERECTION

As mentioned before, the incremental launching method [9] was envisioned by the designer. The contractor decided to precisely follow the recommended superstructure erection process by assembling the four steel girder lines behind the northern abutment and push them together over the piers to the other side. Hereby, the short distance of only 18 m between the abutment and the first pier helped to reduce the length of the launching bed because the first push could already progress without significant counterweight behind the abutment. A mid-size crawler excavator in conjunction with a force distribution beam behind the girders was used to push the steel girders (see Figure 7).

Figure 7: Pushing excavator behind the northern abutment to facilitate incremental launching.

As the girders entered the main span, the cantilever moments increased. To avoid a launching nose, a mobile crane was placed near the southern pier. When the launched girder tip reached around the mid span position, the mobile crane was assisting the launching operation by picking up the tips of the four plate girders via a spreader beam (see Figure 8 and 9).

Figure 8: Assisting mobile crane reduces the maximum cantilever moments and ensuring girders safely land of the rollers installed on the southern pier.

Figure 9: Girder tip support via spreader beam and mobile crane in the main span.

Figure 10: Released mobile crane support after landing onto the rollers installed at the southern pier.

After landing the girders onto the rollers at southern pier, no further tip support was required anymore and the mobile crane was disconnected from the spreader beam (see Figure 10). Figure 11 shows the steel girder in the final position after completion of the launching operation. The vertical gap between the concrete pedestals and the girder bottom flanges indicates that the girders are still resting on the rollers and the lowering of the girders onto the pier bearings is still come.

No bearings were installed at the abutments. The integral solution avoids abutment bearings to minimize future maintenance efforts, activate the abutment dead load as counterweight to address uplift forces resulting from the extreme side span to main span ratio of 0.3, and increase structural redundancy against flooding forces and scour effects.

Figure 11: Girders in their final position after the last push was executed.

11. DEMOLITION OF THE OLD BRIDGE

The demolition of the wooden approach spans was a simple task without the need for engineering (see Figure 12). This was very different for the main span which required an engineered deconstruction sequence to safely remove the trusses without debris falling into the sensitive natural river habitat. Typically, the deconstruction of complex bridge superstructures follows the erection process in a reversed sequence. The original erection process of the old timber trusses was not known but it is fair to assume that it was done using temporary supports in the riverbed. In 2022, temporary supports in the river were no longer permitted because of environmental concerns, so a different solution had to be developed.

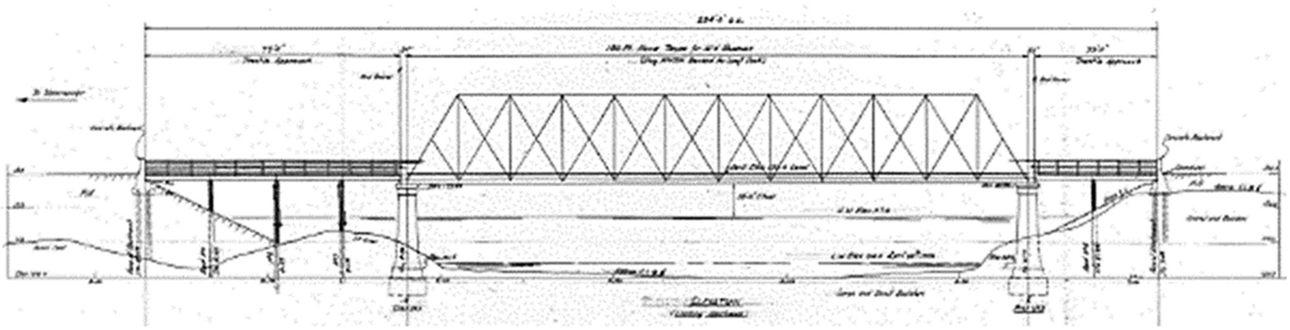

Figure 12: Old Chehalis Bridge: Timber Howe Truss with timber approach spans [BC MoTI]

A weight take-off of the naked timber truss structure indicated that a two-crane lift of the remaining superstructure would have required heavy duty crawler cranes on each shore and that using the new bridge as transportation path via self-propelled modular transporter (SPMT) would overload the new structure. In this context, the naked timber truss structure is hereby defined as the stripped-down superstructure which is considered to be stable on its own to carry its reduced dead load (see Figure 13).

Figure 13: Old Chehalis Bridge: Naked truss structure with minimal lateral bracing components remaining at the day of removal.

To reduce the crane loads and avoid overloading the new structure, it was required to break down the naked timber truss structure into smaller pieces while spanning the river. Originally the erection engineer proposed to cut the one vertical truss next to the new bridge (near side truss) in mid span while mobile cranes on each shore are supporting the element. The complexity of this operation and stability concerns for the remaining truss on the far side led to a new idea. This idea considers inclined support struts which laterally support the top chord of the near side truss (see Figure 14) and removing the far side truss first as one whole piece. Hereby, the new bridge acts as an anchorage for the inclined struts which ensure that the near side truss is stable on its own without the lateral support of the far side truss.

Figure 14: Old Chehalis Bridge: Top chord of truss next to the new bridge (near side truss) stabilized with inclined struts which use the new bridge as anchorage.

Special consideration had to be given to the truss nodes which were post-tensioned with vertical steel tension rods to maintain compression in the diagonals and the connection even under most unfavorable live load conditions (see Figure 15 left). The chosen lift points create tension forces in the diagonals near the ends. To avoid that critical nodes are compromised in their structural integrity to transfer loads, additional straps were installed and tensioned before lifting the trusses (see Figure 15 right).

Figure 15: Old Chehalis Bridge: Post-tensioned top chord node to maintain compression in truss diagonals (left) and temporary straps to ensure truss integrity in critical nodes during the lift (right).

After cutting the remaining lateral bracings at top and bottom chord levels as well as the top beams of the two end portals (see Figure 16 left), the two truss were completely separated. During this stage the near side truss is still carrying its own weight but its top chord is laterally stabilized by the new bridge. The far side truss is supported at four bottom chord nodes via spreader beams and the two mobile cranes. During a night shift when the new bridge was closed to public traffic, the two mobile cranes slightly lifted the far side truss and moved it laterally next the near side truss to increase the distance to a nearby powerline which could not be shut down (see Figure 17 left). Then, in a second step the far side truss was lifted over the near side truss and placed onto the new bridge (see Figure 17 right). While supported by the new bridge and secured by the two mobile cranes, the truss was cut in two halves (see Figure 16 right). After cutting, each truss half was maneuvered by one mobile crane to its designated break-down location behind the abutments. Hereby, the mobile cranes turned around by almost 180 degrees (see Figure 18).

Figure 16: Old Chehalis Bridge: Cutting the top beam of the end portal (left) and cutting the bottom chord in midspan while the truss is resting on the new bridge (right).

Figure 17: Old Chehalis Bridge: Far side truss is lifted as one piece by two mobile cranes onto the new bridge.

Originally, the contractor planned to completely remove both truss in one night shift. This goal was not achieved. After full bridge closure which started at 10:00 pm, cutting of bracings and the end portal beams took more than two hours. The first truss was moved in the early morning hours and it was dawn when the two halves safely landed at the break-down areas. At that point the crew had worked 12 hours non-stop and needed a break. The contractor made the right decision to postpone the second truss lift to the next night. This was possible because the remaining truss was fully secured by the new bridge. However, a speed limit of 30 km/h was imposed on traffic before reopening the new bridge for public traffic.

Figure 18: Old Chehalis Bridge: Swing operation to guide the first truss half of the far side truss to the designated break-down location behind the abutment. In the background, the second half is still sitting on the new bridge before lifted to the second break-down area behind the opposite abutment.

12. CONCLUSIONS

The new Chehalis Bridge is a firm commitment to design and construct better bridges; bridges specifically designed to resist the forces of nature in form of flooding, scour, and debris flow. The integral nature of the Chehalis Bridge paired with the extraordinary clearance envelope for the river is evidence that challenging design criteria can create great opportunities for innovation and smart solutions. The big picture approach of combining design, fabrication, construction, and demolition in one big package and specifically looking for synergy effects guaranteed best cost and schedule performance. Last but not least, the new bridge with its lightweight and slender superstructure can be considered as an elegant and logical solution to bridge the Chehalis River.

The design and construction of the new bridge and the deconstruction of the old bridge were a challenge for all involved in the project. After successful completion of the project, it can be stated that all expectations were fully achieved if not exceeded. The team approach during all phases of the project including owner, designer, contractor, and various engineers responsible for erection and deconstruction paid off. We are inclined to say that the more complex a project is, the more teamwork is required to deliver the project safely on time and budget. And that is what happened here.

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Demolition: PDI Priestly Demolition Inc.

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