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MORDEN COLLIERY HYBRID SUSPENSION ACTIVE TRANSPORTATION BRIDGES

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ABSTRACT: The Morden Colliery Regional Trail requires two clear-span bridges over the East and West Channels of the Nanaimo River in Nanaimo, British Columbia. The bridges must provide comfortable access for pedestrians, cyclists, equestrians, and maintenance vehicles while fitting within a narrow former railway right-of-way, avoiding in-stream supports, and respecting environmental, archaeological, and adjacent land-use constraints. Construction has not yet begun; therefore, this paper focuses on the detailed design and erection-engineering approach developed to make the cable-supported concept buildable. The preferred structural form is a hybrid suspension-stayed bridge with a stiffened truss-style deck. Stay cables engage the deck near the towers to improve stiffness and vibration performance, while the main suspension cables and hangers support the central portion of the span and permit lightweight segmental erection. A staged finite element model was developed to follow the deformed geometry of the bridge during erection. A geometry-control procedure, referred to here as the tangent guide method, used stiff, temporarily massless deck elements to guide segment placement without forcing later segments to elongate unrealistically to meet the deflected shape of previously installed work. The geometry-control process defined segment end coordinates, cable force adjustments, and a target 430 mm midspan camber corresponding to a 1% drainage profile over the 86 m main span. The design illustrates how hybrid cable systems, staged analysis, and site-driven detailing can reduce environmental disturbance and improve user comfort on remote multi-use trail bridges.

1. INTRODUCTION

The Morden Colliery Regional Trail is planned to form an active transportation and recreational connection between Morden Colliery Historic Provincial Park and Hemer Provincial Park near Nanaimo, British Columbia. The central segment of the trail crosses Thatcher Creek and the East and West Channels of the Nanaimo River, creating four bridge sites with very different span and access requirements. The two Nanaimo River crossings are the critical structures in the project because they require clear spans over a sensitive river corridor, while the adjacent creek crossings are shorter and more amenable to prefabricated truss solutions.

The project is still in detailed design. Consequently, this paper is written as a design and erection-engineering case study rather than a construction record. Its focus is the development of a lightweight hybrid suspension-stayed bridge that can be assembled from manageable segments under difficult access constraints, while still providing the stiffness required for pedestrians, cyclists, equestrians, and maintenance vehicles. This emphasis is appropriate for a project where the most important decisions are made before construction begins: selecting a structural system that can be built with limited equipment, defining an erection sequence that is compatible with the final geometry, and providing wind and vibration data for specialist review.

The main technical contribution described in this paper is a staged finite element modelling procedure used to control erection geometry. In cable-supported bridges, the shape visible during construction is not the final unloaded geometry; it changes with each segment installation, cable stressing operation, and self-weight application. If the analysis model simply connects each newly added segment to the already deflected end of the previous segment, the software may introduce unrealistic geometric distortion and element elongation that do not reflect actual erection conditions. To address this, a tangent guide method is used, in which stiff, temporarily massless elements define the evolving erection geometry and establish segment start and end coordinates throughout construction.

The following sections summarize the site constraints, the hybrid bridge concept, the staged construction sequence, the geometry control method, constructability-driven detailing, and remaining work before construction.

2. PROJECT CONSTRAINTS

The form of both Nanaimo River crossings was governed by several overlapping constraints: a narrow former-railway right-of-way with limited and partly seasonal access, a sensitive river corridor carrying hydraulic, scour, environmental, and archaeological risk, and the comfort and performance requirements of a mixed-use trail. Each is described below.

2.1 Site Access and Right-of-Way

The bridge sites lie within a narrow former railway right-of-way that curves through dense forest, marshland, and riverbank terrain. The key constraints along the corridor are summarised in Figure 1, which illustrates the right-of-way, the two bridge crossing locations, and the range of hydrotechnical, environmental, archaeological, and constructability considerations that bear on the design. The right-of-way constrains both permanent bridge geometry and temporary construction work. The East Channel Bridge benefits from comparatively better access from the northeast approach, while the West Channel Bridge is more isolated because access to the central island is seasonal and depends on water levels in the East Channel.

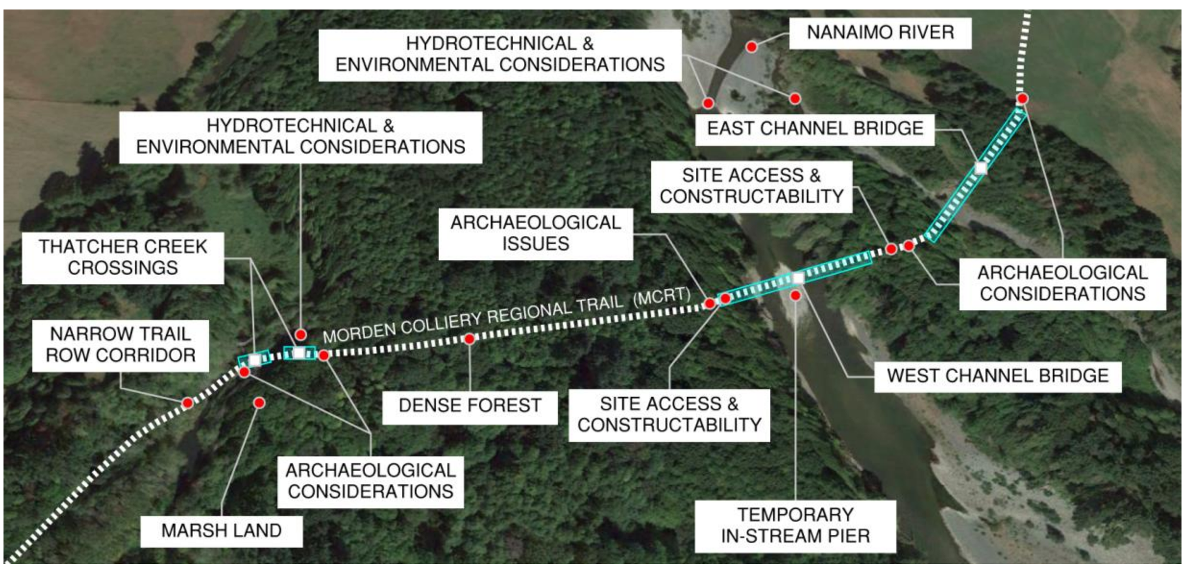

Figure 1: Project setting and key constraints along the Morden Colliery Regional Trail corridor.

2.2 River and Environmental Constraints

The river environment strongly favours clear-span solutions. Permanent piers within the Nanaimo River were avoided because they would increase hydraulic, scour, environmental, archaeological, and permitting risks. Temporary in-stream works were also treated as undesirable because they could lengthen approvals and increase environmental mitigation requirements, such as fisheries habitat offsetting, restricted in-stream work windows and additional sediment and erosion controls. An aerial view of one of the bridge sites is shown in Figure 2, illustrating the clear channel, densely vegetated banks, and the environmental sensitivity of the corridor. The resulting structural problem is therefore not only to span approximately 86 m, but to do so with a system that can be fabricated, delivered, and erected without large launch beds or extensive work platforms within the river corridor.

Figure 2: Aerial view of the Nanaimo River at one of the crossing locations.

2.3 Functional and Performance Requirements

The bridges must serve a mixed-use trail. Pedestrian and cycling traffic control the general trail function, while equestrian access introduces additional requirements for user comfort, railing geometry, vibration performance, and perceived openness. The alignment must also maintain accessible approach grades and provide drainage. For the current design, the vertical profile includes a 430 mm midspan camber over an 86 m span, equivalent to a 1% slope from midspan to each end for drainage.

Wind response is a significant design concern because the deck is light and slender. Conventional side wind cables are unattractive for this location because they could leave the right-of-way or conflict with adjacent First Nations field areas. The ongoing wind engineering review is therefore focused on whether adequate lateral stiffness can be obtained through the bridge’s primary cable arrangement, possible lateral deviation of tower-head cable geometry, deck stiffness, and damping. These requirements made a conventional suspension bridge alone undesirable and led to a hybrid system that combines suspension and stay-cable action.

3. HYBRID SUSPENSION-STAYED BRIDGE CONCEPT

3.1 Structural System Selection

The selected structural form is a hybrid suspension-stayed bridge, in which main suspension cables and stay cables act together to support a stiffened truss-style deck. This form was chosen after feasibility work compared full truss and conventional suspension bridge options for the Nanaimo River crossings. A full truss bridge offers high stiffness and favourable vibration behaviour, but construction would require large segments, launch staging, in-stream piers, or temporary supports that are difficult to accommodate within the curved and environmentally sensitive corridor. A conventional suspension bridge is more compatible with segmental erection and the limited access available at this site but is comparatively flexible and may provide less comfort for equestrian users. The hybrid form keeps the constructability and material efficiency of a suspension bridge while using stay cables to recover much of the stiffness and vibration performance of a deeper truss superstructure.

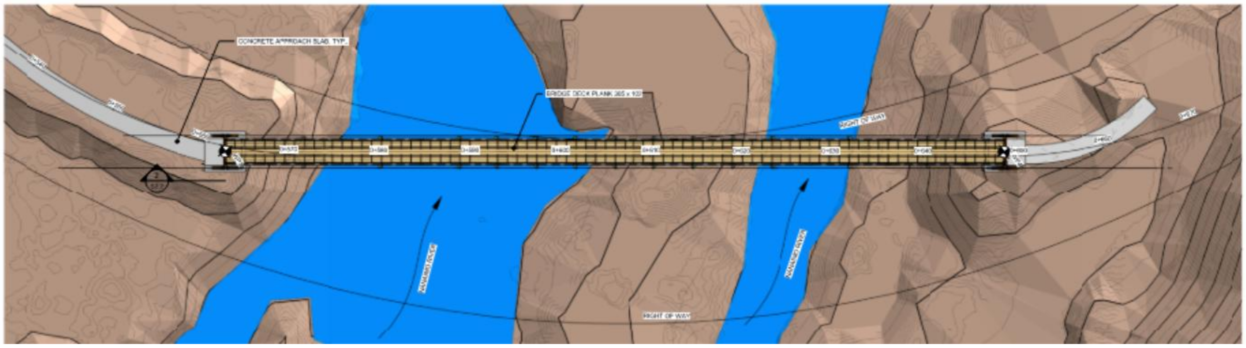

Figure 3: Plan view of the cable-supported concept showing the bridge plan layout within the narrow right-of-way and anchorage constraints for the curved right-of-way for the East Channel Bridge.

The hybrid bridge uses stay cables to support the deck near the towers and main suspension cables with hangers to support the central portion of the span. The stay cables increase vertical stiffness, improve vibration performance, and reduce the demand that would otherwise be placed on the main cable system. The main suspension cable, in turn, permits a simple repetitive hanger arrangement and reduces the need for heavy temporary works. For the West Channel Bridge, the approach and side-span geometry can also take advantage of a truss-style span similar in scale and detailing to the Thatcher Creek bridge units, which are two other smaller 26 m-long truss bridges part of the project but to the west, improving repetition across the project and avoiding a bespoke support condition where the right-of-way geometry is most restrictive.

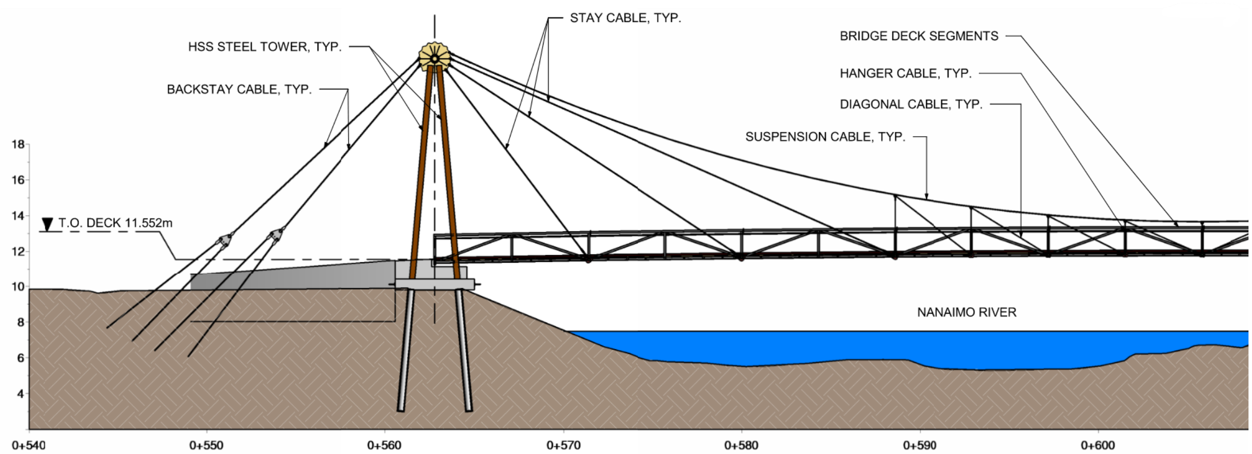

Figure 4: Hybrid cable-supported arrangement showing stay cables, main suspension cable, and hanger cables.

3.2 Deck, Pylons, and Cable Arrangement

The bridge deck is a stiffened truss-style superstructure with segment lengths selected to balance structural efficiency, helicopter lifting limits, and site access. Main suspension cables and stay cables are 28 mm diameter, while vertical and diagonal hangers are 12 mm diameter. The cable sizes remain subject to final confirmation after the ongoing wind and vibration review, but they provide the basis for the detailed staged construction modelling described in this paper.

Table 1: Preliminary design parameters used in staged analysis

Parameter	**Current design value**	**Design relevance**
Main span length	86 m	Balances river clearance, right-of-way fit, and cable anchorage geometry.
Target midspan camber	430 mm	Provides a 1% drainage profile from midspan to each end.
Main cable maximum sag	9660 mm	Keeps the cable profile close to the railing zone while maintaining workable cable forces.

Primary cables	28 mm diameter	Used for main suspension cables and stay cables in the staged model.
Hanger cables	12 mm diameter	Used for vertical and diagonal hangers, with final values subject to wind review.
Segment lift limit	Approximately 6000 lb	Controls segment length, shop assembly, and helicopter erection planning.

The deck top chord is kept horizontal to improve lateral stability and to provide a consistent interface for the deck planks, railing posts, and splice detailing. The bottom chord and bracing form the load path between floor beams, hanger points, and segment splices. At the end segments, inclined post braces are oriented downward because shear in a simply supported truss is greatest at the support. Orienting these end diagonals down toward the bearing provides a direct, low-eccentricity load path.

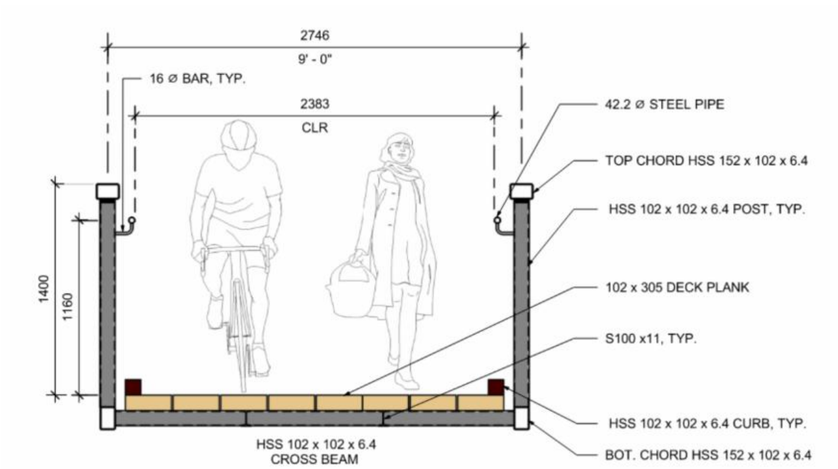

Figure 5: Typical bridge section.

The pylon system transfers stay and main-cable forces into the substructure and backstay anchorage system. At the pylon head, a circular spreader plate assembly receives the cable socket connections for the backstay and main span cables, distributing the concentrated cable forces into the splayed pylon legs, as shown in Figure 6. Pylon height is governed by maximum fabrication length, installation difficulty on site, and individual unit weight limits for helicopter lifts. Pylon height also determines cable geometry, as it sets a practical upper bound on the stay cable inclination and influences the overall cable arrangement. To reduce the backstay forces to manageable levels within the narrow available right-of-way, each backstay is split between two rock anchors rather than concentrated at a single point. This reduces the required anchor depth sufficiently to keep both anchors within the right-of-way boundary while maintaining adequate load capacity. The railing and curb geometry are designed with equestrian use and user confidence in mind.

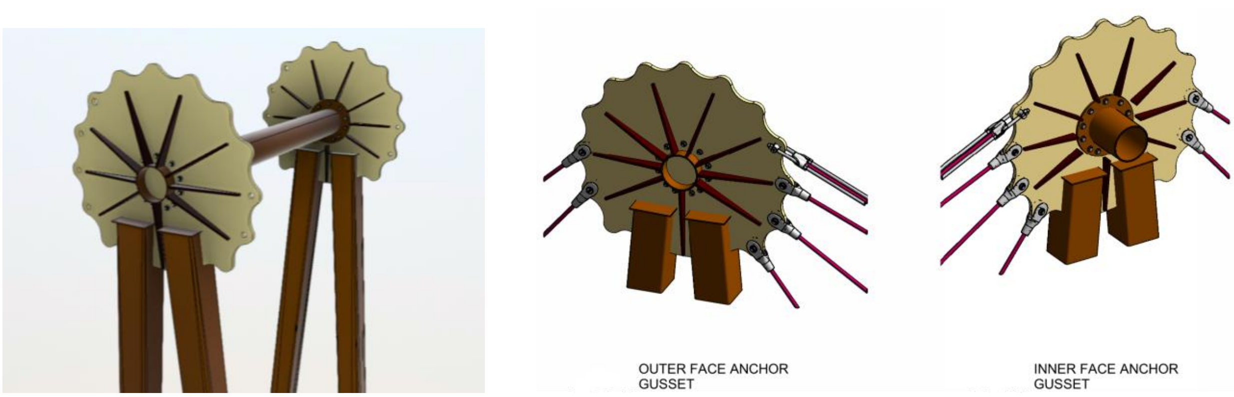

Figure 6: Rendered view of the pylon head assembly, showing the cable socket connection points for the backstay and main span cables.

The pylon head geometry draws on the industrial heritage of the Morden Colliery site. The reinforced concrete headframe and tipple, the last remaining structure of its kind on Vancouver Island, stands within the park that the trail corridor passes through, and a distinctive iron wheel crowns its headframe. This element is referenced directly in the pylon head plate geometry, where the circular plate and radiating stiffeners are shaped to echo the form of the wheel, intentionally rooting the bridge's engineering expression in the working heritage of the corridor it serves.

Figure 7: The Morden Colliery reinforced concrete headframe and tipple, showing the iron wheel at the crown of the headframe.

3.3 Cable Type Selection

Both open spiral strand (OSS) and fully locked coil (FLC) have been considered for the cable system, each presenting distinct technical characteristics that bear on the final selection. OSS is manufactured from high-strength steel round wires helically wound in layers, typically spun in opposing directions around a central core. FLC shares this round wire core but introduces one or more outer layers of interlocking Z-shaped wires, also wound in opposing directions, which close the outer surface into a sheath. This difference in the cross-section drives the practical distinctions between the two cable types.

OSS has historically been considered more flexible and therefore easier to reel, transport, and install on site. Consultation with the cable supplier indicates that this distinction is less significant in practice than previously assumed, and that FLC does not present meaningful handling disadvantages for a project of this nature. The more consequential difference lies in durability. The interlocking Z-wire outer layer of FLC sheds water and resists moisture ingress more effectively than OSS, where spaces between adjacent round wires provide pathways for water and chloride penetration. This is of particular concern given the exposed nature of the site.

Inspectability presents a more nuanced comparison. The smooth outer surface of FLC is straightforward to inspect visually, however the interlocking Z-wire construction prevents access to the internal round wire layers. By contrast, OSS permits visual inspection between the outer wires and into the cable cross-section more readily, though it is inherently more susceptible to the corrosion that such inspection would seek to identify. FLC is the preferred cable type for this project. The durability advantage is well suited to the site conditions, and consultation with the supplier confirms that the cost differential relative to OSS is not sufficient to alter this conclusion.

4. ERECTION ANALYSIS AND GEOMETRY CONTROL

4.1 Analysis Methodology

The bridge was analyzed using a finite element model developed to represent both erection behaviour and final in-service performance. The model was first used to simulate the construction sequence, including deck segment installation, cable installation, and cable stressing operations. Ultimate limit state (ULS) load combinations were then applied to the completed structure using the final stressed configuration obtained from the staged analysis.

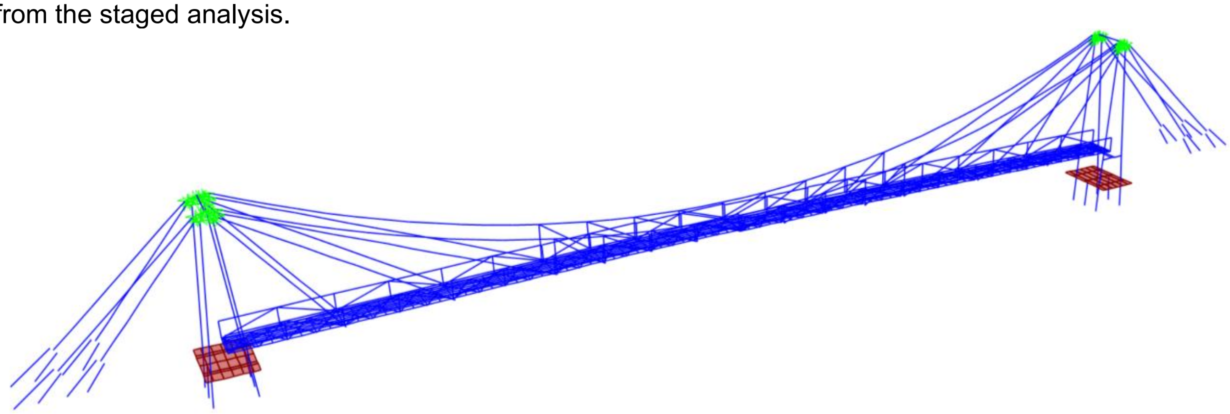

Figure 8: Finite element model showing the full bridge geometry.

The staged-construction approach was considered essential because the bridge derives its behaviour from the interaction of multiple structural systems that become active at different points during erection. A conventional analysis that assumes the completed structure exists from the beginning would not capture the actual sequence of load transfer between the deck, stay cables, suspension cables, hangers, and pylons. By introducing structural components in the order they would be installed in the field, the model provides a realistic representation of force development, geometry evolution, and cable-force redistribution throughout construction.

4.2 Construction Sequence

The installation sequence was developed to maintain stability, limit unbalanced pylon forces, and preserve practical access for segment placement. The bridge deck is erected segmentally, with the cable system progressively activated as construction advances from the towers towards midspan.

The sequence begins with substructure and pylon construction, followed by installation of the backstay system. The first three deck segments are lifted in from each tower individually. As each deck segment is installed, its corresponding stay cable is connected to provide immediate support and limit cantilever deflections. This sequence is completed from both sides to establish balanced cantilevers extending from both pylons. Once the stay-supported portions of the bridge are complete, the main suspension cable is installed. Additional deck segments are then erected toward midspan and connected to the suspension system using vertical hangers. After the midspan splice is completed, diagonal hangers are installed and the cable system is retuned through a series of stressing operations to achieve the desired final geometry and load-sharing characteristics.

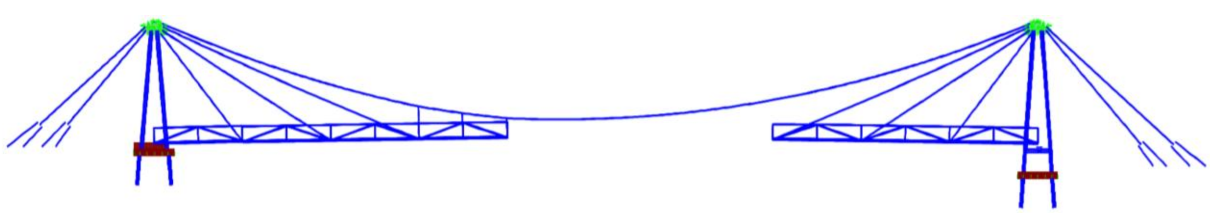

Figure 9: Mid-erection stage showing cantilever construction from both pylons with stay cables active, main suspension cable installed, and an initial midspan deck segment connected by vertical hangers.

4.3 Tangent Guide Method

Accurate representation of segmental cantilever erection presented a significant modelling challenge. In the field, each new deck segment is installed tangent to the previously erected segment. However, finite element programs typically activate new elements at their originally defined undeformed coordinates. As the cantilever deflects under self-weight and cable forces, this approach can introduce geometric discontinuities that do not represent actual construction conditions. A potential resolution is to re-stress the cable system after each segment installation to restore the structure to its original design geometry. While this eliminates geometric discontinuities within the model, it introduces unrealistic cable strains and force levels that are not representative of field conditions and may consume adjustment capacity intended for final system tuning. To address this, a tangent guide method was developed using a separate geometry-control model. The purpose of this model was not to determine member-level design forces, but to establish realistic installation coordinates for each construction stage. The deck was represented by a single equivalent frame element with stiffness properties corresponding to the truss system, initially defined at the target bridge profile.

At the start of the analysis, all deck elements were added to the model with a gap maintained at the midspan closure location so that the two cantilevers could behave independently throughout erection. The deck was assigned artificially high stiffness and no self-weight. As construction progressed, the segment being erected was converted to its actual stiffness properties, its corresponding cable was added, and its self-weight was activated. The remaining unconstructed segments continued to act as stiff geometric extensions of the cantilever, defining the tangent geometry that would exist during actual construction without contributing meaningful structural response. As the erected portion of the bridge deflected under self-weight and cable forces, the guide elements maintained the tangent extension of the deck, allowing stage-by-stage installation coordinates to be read directly from the evolving geometry. These coordinates were then transferred into the detailed staged construction model and used to define the undeformed locations of deck segments prior to activation. When segments were introduced into the staged construction analysis, they entered the model at the tangent geometry that would exist in the field rather than at their original design coordinates. This approach captures realistic erection geometry while avoiding artificial element elongation and unrealistic cable-force development.

4.4 Cable Tuning and System Interaction

One of the most important observations from the staged analysis is that load does not automatically distribute in proportion to intended design roles. The truss-style deck, stay cables, and pylons are comparatively stiff relative to the main suspension cable, and consequently attract a disproportionate share of gravity load during the early erection stages. Left uncorrected, this behaviour leaves the main suspension cable under-engaged at closure, producing a final force distribution that is inconsistent with the intended system and that cannot be fully recovered through stressing operations alone.

The design therefore uses staged cable tuning to actively manage load sharing throughout construction. Selected stay cables are de-stressed after several deck segments are installed, while hangers are shortened or tensioned to engage the main suspension cable progressively. Backstay cables are then restressed to achieve compatible equilibrium between the fore-stay and backstay systems at each pylon. Following midspan closure, a final stressing operation is performed on the main suspension cable and diagonal hangers to bring the completed structure to its target geometry and force state. These adjustments are inherently iterative because the cable systems are highly interdependent. Increasing tension in one cable family alters force distribution throughout the bridge and may reduce force in adjacent cables. The tuning strategy was therefore developed alongside the construction sequence rather than after it, with target cable forces at each stage established as design outputs.

4.5 Final Verification

Following completion of the staged construction sequence and final cable tuning operations, the model is checked for compatibility of camber, cable forces, pylon reactions, deck stresses, and overall geometry. The resulting configuration forms the basis for subsequent ultimate limit state analyses. The staged-construction model also serves a practical role beyond structural design. The stage-by-stage installation coordinates it generates can be used directly to support fabrication tolerancing, survey control, and erection planning. The analysis therefore serves both as a structural design tool and as a means of controlling bridge geometry throughout construction.

5. CONSTRUCTABILITY-DRIVEN DESIGN DETAILS

The detailed design is driven as much by access and lifting constraints as by final structural demand. Segment mass was checked against a maximum helicopter lift of approximately 6000 lb. This limit influences segment length, splice locations, deck plank installation timing, and the amount of shop assembly that can occur before delivery. Where practical, components are designed to be repetitive so that fabrication, rigging, and erection procedures can be standardized across the two Nanaimo River bridges and the shorter Thatcher Creek structures. Helicopter delivery changes the definition of an economical segment. A heavier segment might reduce the number of field splices, but it can also require a larger aircraft, longer lift windows, and more temporary bracing to control rotation under rotor wash. The current segment breakdown therefore favours repeatable pieces that can be rigged with predictable centre-of-gravity locations. The lift plan should confirm the bare steel weight, optional deck-plank installation sequence, sling geometry, and temporary lateral restraints before final release of shop drawings. Splice details are also treated as construction-control features. Each field splice is expected to carry final design loads, but it must also tolerate temporary rotations, survey corrections, and staged cable tuning. The closure splice between the opposing cantilevers is the most sensitive location because the final camber and the final cable force state meet there. The staged model provides target coordinates and predicted force ranges at this location so that field measurements can trigger a planned subsequent.

The concept also leaves room for construction-phase refinement. For example, deck panels may be installed after steel segment lifting where weight control is critical, and temporary bracing may be adjusted based on the contractor’s lift plan. The key requirement is that any refinement be reflected back into the staged model before cable forces are finalized, because even small mass or stiffness changes can alter the balance among stay cables, hangers, and the main suspension cable. The contractor’s means and methods will ultimately govern some details, but the design intent is to keep the structural model and the erection procedure aligned. Any change in lifted segment mass, temporary support stiffness, cable stressing order, or closure sequence should be fed back into the staged analysis before final cable settings are approved. This feedback loop is expected to reduce the risk of accumulating small geometry errors that become difficult to correct near midspan.

6. ONGOING STUDIES AND FUTURE WORK

Specialist wind engineering review is ongoing. The design team has provided the wind consultant with drawings, bridge geometry, natural frequencies and mode shapes of the dominant modes, mass distribution of the bridge section, deck centre of gravity, mass polar moment of inertia about the centre of gravity, modal properties, and finite element model output. These data will be used to assess static wind demand, dynamic response, potential vortex shedding sensitivity, and user comfort under wind-induced vibration.

Once the wind recommendations are finalized, the bridge model will be updated to reflect any cable geometry, damping, or stiffness modifications. The resulting model should become the baseline for the contractor’s erection submittal review. During construction, measured pylon-top coordinates, segment endpoints, and cable forces can then be compared with the same baseline model, allowing the design team to separate normal construction tolerance from a response that requires correction. One potential refinement is to deviate the tower-head geometry and main suspension cable alignment laterally so that the primary cables contribute more lateral stiffness. This option is being considered because external wind cables beside the bridge are not practical within the constrained right-of-way and may conflict with adjacent First Nations field areas. Final decisions on cable geometry, damping needs, and detailing will be made after the wind study is complete. Construction is currently planned for 2027, with the staged geometry-control method available for use in erection planning, survey hold points, and final cable tuning.

7. CONCLUSIONS AND LESSONS LEARNED

The Nanaimo River Bridges demonstrate how a lightweight trail bridge can be governed by constructability, comfort, and geometry control as much as by strength. The hybrid suspension-stayed system was selected because it combines the constructability advantages of a suspension bridge with the stiffness benefits of stay cables and a truss-style deck. This balance is particularly valuable where equestrian access, wind sensitivity, limited equipment access, and environmental constraints all act at the same time.

The project also illustrates that, for remote trail bridges, a visually simple final structure can require a relatively sophisticated erection model. The decisions that reduce site disturbance, such as small segments, helicopter delivery, and minimized temporary works, increase the importance of strong and carefully-guided geometry control monitoring and adjustment capability and procedures.

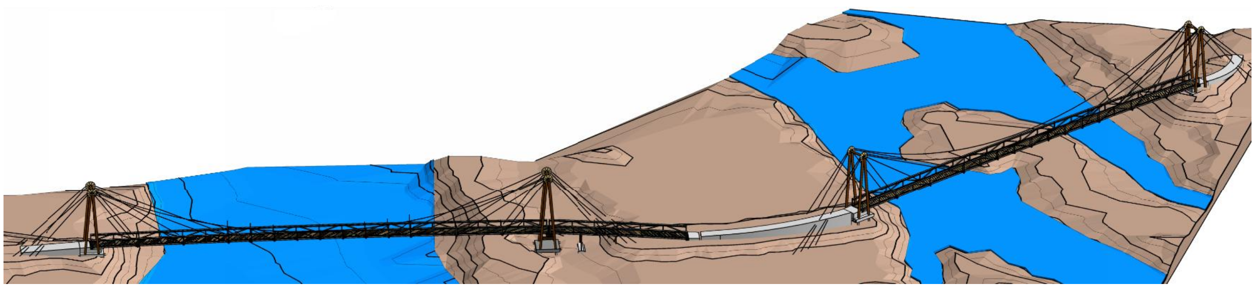

Figure 10: High-level isometric view of the Revit Model displaying the West and East Channel Bridges over the two channels of the Nanaimo River on the left- and right-hand side of the figure, respectively.

The tangent guide method provides a practical lesson for staged modelling of segmental cable-supported bridges. A model that follows deformed geometry must distinguish between structural elements that carry load and guide elements that define placement geometry. By using stiff, massless tangent elements and then converting them to real deck properties stage by stage, the analysis avoids artificial segment elongation and produces usable erection coordinates.

A second lesson is that cable force tuning should be treated as an iterative construction process, not a one-time final design step. The stay cables, main suspension cable, vertical hangers, diagonal hangers, and deck stiffness interact throughout erection. The final geometry and final cable forces are therefore achieved through staged de-stressing, hanger adjustment, backstay restressing, and final main-cable tuning. This approach will be carried forward into the construction planning and wind engineering review.

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