Design and Construction of Extradosed Bridges in Cold Temperature and Seismic Zones

Dr. Matthias Schueller, P.Eng.

Vice President

Parsons

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Abstract

Extradosed bridges are often described as a cross of a conventional prestressed concrete girder bridge and a traditional cable-stayed bridge because most extradosed bridges built combine a prestressed concrete superstructure with stay-cable technologies. However, this simple definition does not capture the various possible structural systems and different materials that can be found and used for extradosed bridges. Extradosed bridge technology is much more than a prestressed concrete girder with external tendons.

The Deh Cho Bridge in the Northwest Territories and the Canal Lachine Bridge in Montréal are two Canadian extradosed bridges featuring steel superstructures with slender composite concrete decks using full-depth precast panels. Although both bridges are very different, they share one important design aspect which governed the design of their superstructures: Both bridges are located in regions with prolonged extreme cold winter periods. Temperatures below 0 °C and cold weather periods lasting up to five months can be a major hindrance when erecting long bridges with conventional concrete superstructures. On the contrary, steel superstructures are light and can be quickly erected, even at cold temperatures without heating and hording given that field welding is avoided.

To avoid delays along the critical path in the erection of major superstructures in extreme cold temperature zones, designers should consider erection schemes which make best use of short warm weather periods and reduce negative impacts related to harsh weather conditions as best as possible. To achieve this design objective, it is recommended that proven construction schemes and technologies are investigated in the early phase of the superstructure design before superstructure type, cross sections, and materials are selected. This holistic approach goes far beyond what commonly is described as Accelerated Bridge Construction (ABC) because the goal here is a tailored superstructure design for the specific location of the bridge including the preferences of fabricator and contractor.

This paper will present design features and construction methods selected for the Deh Cho Bridge and the Canal Lachine Bridge. Structural details and achieved synergy effects by combining superstructure design and erection engineering will be discussed. Further, the advantages of lightweight construction principles over traditional heavy girder superstructure types will be emphasized to demonstrate their advantages when building bridges in seismic zones.

Introduction

The beam is one of the most common superstructure types chosen for bridges because it provides for regular spans of up to 100 meters a very cost-effective structural system for load transfer and stiffness. As the span length increases, the dead load of the beam requires deeper sections to cope with the exponentially increasing dead load bending moments. This is phenomena is described by the following formula for a solid rectangular beam cross section:

$$\sigma = \frac{M}{S} = \text{¾}\ \Upsilon \left(\frac{l}{d}\right) l \leq f$$

With: $\sigma =$ bending stress [kN/m²]

$M =$ bending moment [kNm]

$S =$ section modulus [m³]

$\Upsilon =$ weight of material [kN/m³]

$l/d =$ slenderness of the beam [ ]

$l =$ span length [m]

$d =$ depth of the beam [m]

$f =$ strength of material [kN/m²]

The reason for this behavior is simple: The weight and strength of the material are constant parameters. Assuming that with increasing scale the slenderness of the beam and its material remain unchanged, we find that the bending stress increases with the span length. Since the strength of the material does not change, the material (responsible for the dead load in this example) must be used more efficiently than this is done for a solid rectangular beam.

To solve this problem, engineers developed smarter cross sections and lighter superstructure types which allowed them to significantly increase the span length. Good examples are I-beams, trusses, and cable supported superstructures as we find them in suspension, cable-stayed and extradosed bridges. The most recent development in this regard is the extradosed bridge which can be described as a beam superstructure strengthened with a stay and kingpost system to increase the beam's negative bending capacity over the piers. More definitions for extradosed bridges can be found in Schlaich (2019).

The modern extradosed bridge type combines the advantages of a beam superstructure with the lightweight design principles of cable-stayed bridges. However, the typical cable-stayed bridge is a cantilever bridge type which relies on the outer back-stays (anchor cables) to satisfy equilibrium for unbalanced loads. Because of their "strongback" (a superstructure with inherent bending stiffness), extradosed bridges do not require anchor cables or limitations on stay-cable spacing to achieve equilibrium or control deflections. They are perfectly suited for multi-span bridges with spans up to 250 meters. Schueller (2013)

Extradosed Bridges versus Cable-Stayed Bridges

Many cable-supported bridges require only one to three major spans beyond 150 meters. Gimsing (1997), Walther (1988) The span length in other spans, e.g. approach spans, is often decreased to 100 meters or less to reduce construction costs. This is a disadvantage for the traditional three-span cable-stayed bridge (with two back spans and one main span) because the often selected very slender and elegant lightweight superstructure system is discontinued at the transition piers to permit conventional beam superstructure types for the approach spans.

The transition piers indicate the location where the anchor cables of a cable-stayed bridge are back-anchored. As mentioned before, for cost reasons often a completely new and independent superstructure type is chosen for the approach spans. This complicates design, fabrication, erection, and maintenance. For instance, the maintenance traveler (if provided) can only access the cable supported sections but not the approach spans. Besides these economically driven considerations, the change of the superstructure type from a slender cable-supported deck system to a much deeper beam structure for the approach spans has aesthetic drawbacks, even if an attempt is made to lessen the visual discontinuity.

Extradosed bridges can be equipped with a continuous beam superstructure type over the entire bridge length from abutment to abutment, including the approach spans. Good examples are two Canadian bridges, the Deh Cho Bridge and the Canal Lachine Bridge, which both will be discussed in this paper. Hereby, the beam superstructure type is designed for the typical approach span length and locally strengthened with the mentioned stay and kingpost system where longer spans are needed. This important design principle of an extradosed bridge allows to increase the span length for regular beam cross sections and simultaneously optimize design, fabrication, erection, and maintenance. For instance, an industrialized fabrication and production process for a large number of repetitive bridge components permits better unit prices, accelerates construction, and better mitigates risks during construction and service. Recommended is a uniform superstructure type with constant depth over the entire bridge length. Maintenance is minimized if at piers the number of bearings is reduced to one per girderline and expansion joints are completely avoided. In other words, extradosed bridges eliminate complex transition piers and provide continuity from a structural and aesthetic perspective.

Conceptual Design of Multi-Span Extradosed Bridges

"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. Conceptual design is one of the most important tasks because key design decisions are made during this early stage." Schueller (2013)

Conceptual bridge design specifically matters when designing major structures, such as extradosed bridges. For achieving economical and robust structures, continuity and reliability must be major design goals: Continuity stands in this context for continuous superstructure types which minimize the number of bearings and expansion joints (see previous section), and reliability represents a proven erection scheme well suited to overcome site restraints and construction challenges such as remote bridge locations and long cold weather periods.

Moreover, any innovative superstructure concept must consider adaptability for time dependent deformations (e.g. temperature, creep and shrinkage, and settlements), the stiffness needed for transitory loads, such as live load and wind, and flexibility for seismic events (if needed). Achieving adaptability, stiffness, and flexibility at the same time appears to be a contradiction but this is not necessarily true as shown later for the Canal Lachine Bridge.

Conceptual design of multi-span extradosed bridges includes the development and optimization of complex hyperstatic structural systems which are planned with a dependable construction method in mind. Construction and maintenance directly affect costs and the overall return-on-investment. For that reason, the design process must include aspects such as fabrication, transport, erection, weather conditions, seasonal access restrictions, and availability of resources depending on bridge location and site restraints. The development of sound solutions for new details is relevant and should be addressed in the conceptual design phase to avoid “showstoppers”. It is recommended that structural details along primary load paths follow best design practice by respecting the “flow-of-forces” and addressing fabrication, constructability, robustness, durability, and inspection aspects.

Deh Cho Bridge

“Serious design challenges often require new philosophies and strategies. On the other hand, they provide exceptional opportunities for innovation. The Assembly-line Design Approach, the Failure Mechanism Concept, and the Fuse Design Philosophy have been specifically developed for the Deh Cho Bridge with the purpose to cope with extraordinary schedule and design requirements.” Schueller (2012)

The Deh Cho Bridge, near Fort Providence in the Northwest Territories (NWT), is the first bridge over the Mackenzie River, Canada’s longest river. When the bridge was opened on November 30, 2012, it replaced the Merv Hardie ferry and ice road services along Highway 3 connecting Yellowknife, NWT with Highway 1 in the South. Braiden (2014) The bridge’s remote location in the North with severe winter conditions of up to -40 °C required a tailored design, fabrication and erection process that considered these extraordinary conditions.

An innovative design led to a unique 1045-m long continuous extradosed bridge with only two expansion joints at the abutments. The main design component was an ecological lightweight superstructure that carries two lanes of traffic by using a proven steel Warren-Truss with a structural depth of around 4.5 m. The bridge comprises of nine spans of 90 m – 3 x 112.5 m – 190 m – 3 x 112.5 m – 90 m. The steel superstructure is equipped with very slender full-depth and full-width precast deck panels at truss top chord level to form a composite superstructure type for transitory loads. Full-depth precast deck panels have been used for cable-stayed bridges before, Taylor (1991, 1994), but only in exceptional cases for regular spans where the welcoming effect of axial compression from the stay-cables is not present.

The Deh Cho Bridge deck contains only mild reinforcement steel, no pretensioned strands or Post-Tensioning (PT) was used. Composite action between the truss members and the deck was established after panels were placed by casting reinforced closure strips between panels at floor-beam/cross-frame locations and grouting shear stud pockets along the truss top chords. Consequently, the superstructure acts compositely for live loads without producing meaningful tensile dead load stresses in the concrete deck. This concept eliminated the construction disadvantages of the traditional casting sequence (midspan regions first and pier sections later) for cast-in-place concrete decks and even more importantly, it permits in the future to replace deck portions or the entire deck without compromising the structural integrity of the steel superstructure.

The second important design feature was consideration of an accelerated fabrication process which included a progressive trial assembly for the steel components of the entire superstructure. For continuity, a minimum of three and up to five segments were fully assembled in Quebec City in the yard of the fabricator for verifying proper fit and camber shape before segments were disassembled and shipped to the bridge site via train and truck. The sequence of segment delivery followed strictly the erection sequence shown on the plans. Shop production of truss components, trial assembly, shipping, and onsite erection were fully synchronized in a "country-wide assembly line" to keep pace with the accelerated erection schedule. The trial assembly mitigated the risk of fit-up issues and guaranteed proper final alignment of the roadway profile.

In a third step, the erection scheme was directly implemented into the final design. A comprehensive stage-by-stage launching analysis was performed parallel to the detailed design tasks to verify that the anticipated construction demands were within the permitted limitations defined by the Canadian Highway Bridge Design Code CAN/CSA-S6. CSA Group (2006) Conducting a launching analysis and the detailed design analysis together allowed to optimize truss cross-sections for structural performance during launching and service. The assumptions made for the launching analysis were documented in a detailed launching manual which became an integral part of the "Issued-for-Construction" (IFC) design package. This "integrated design philosophy" is an essential component of extradosed bridge engineering; it requires in-depth knowledge of both disciplines, complex bridge design and major bridge erection engineering.

The launching method is commonly not used for traditional three-span cable-stayed bridges, Virlogeux (1991), but it is a very cost-effective alternative for extradosed bridges if superstructure geometry follows a steady profile in elevation and plan and permits a constant girder depth and spacing. Beyond erection, these are important design parameters because simplicity and economy always matter in long-span and major bridge construction. As mentioned before, during the design process of the Deh Cho Bridge, the cross-sections of truss members were optimized for construction and service scenarios allowing a high degree of economy by taking advantage of synergy effects and repetition. Besides governing technical and economic aspects, this design goal allowed good proportions and overall harmony without discontinuities at any pier locations. The Deh Cho Bridge is therefore a good example for an engineered structure that satisfies both functional aspects and aesthetics principles.

The fast-tracked fabrication and erection schemes were specifically developed to address the harsh weather conditions during the prolonged winter periods and the remote site location with no specialized shops nearby. An accelerated and steady construction process without major interruptions and delays was one of the top design priorities. This included the cable installation and stressing sequence which is a routine job in mild-climate conditions but not in the extreme cold of the Canadian winter.

Most cable-stayed and extradosed bridges utilize modern multi-strand stay-cable technologies permitting onsite stay-cable assembly and mono-stand jacking operations. In case of the Deh Cho

Bridge, locked-coil cables were used instead. They come as customized and fully assembled cables to the bridge site. Only the turnbuckle components and anchorage pins are supplied as loose components to be fitted during installation. Typically bridge designers avoid locked-coil cables because this kind of cable can be only stressed as an entire unit requiring larger jacking forces and equipment. This was not required here because the cables were installed while the superstructure was still in an elevated position resting on Hilman Rollers, Hilman (2020), which permitted the launching operation.

The elevated superstructure position allowed the construction team to install the cables with a meaningful sag and thus relatively small jacking forces. After the superstructure was lowered onto the final bearings and loaded with the deck panels, the cables were automatically tensioned by the superstructure weight. In other words, the superstructure jack-down operation after removal of the Hilman Rollers did the job at no extra cost and time. All twelve cables attached to one A-pylon were hereby stressed simultaneously, a stage never done before for a major cable-stayed or extradosed bridge. Cable installation and stressing of the Deh Cho Bridge was no longer a critical path task in the overall superstructure erection schedule. This saved time and costs but most importantly it reduced the risk of bad weather delaying construction.

The construction of the Deh Cho Bridge is testament that major bridge construction can be done very efficiently even in extreme cold weather conditions and at remote construction sites. But it requires an increased planning and coordination effort to achieve the desired results within limited budgets. It is recommended to think about every possible detail from a technical and logistic perspective far ahead of execution (preferably during the conceptual design phase) because errors and omissions will be very difficult to correct later when shop production and onsite bridge construction are simultaneously in full swing. This was done for the Deh Cho Bridge and it worked well.

Canal Lachine Bridge

The second extradosed bridge presented in this paper is settled in an urban environment but design and construction were equally challenging as for the Deh Cho Bridge. The Canal Lachine Bridge (Chinese Channel Bridge) is the new signature structure in downtown Montréal, Québec. This curved extradosed bridge is the center piece of the $1.5 billion Design-Build Turcot-Interchange Project. The approximately 365-m long superstructure of the Canal Lachine Bridge has been built in stages to accommodate the overall project schedule and traffic management during construction. Delivered within the fast-paced Design-Build environment, the project required an excellent collaboration between designer, contractor, architect, fabricator and owner. Schueller (2017)

The 50-m wide superstructure carries two separated carriageways with a total of six traffic lanes. The bridge has spans of about 55 m – 88 m – 82 m – 75 m – 65 m. For the two longest spans, including the main span over the canal, the superstructure utilizes a single tower with a single plane of stays along the bridge's centerline in the small gap between the two carriageways. One of the new carriageways was opened early for traffic without the cable supports so the old bridge could be dismantled to clear the space for the second carriageway. Composite action was for each carriageway individually established to ensure geometric compatibility before both carriageways were structurally tied together at the lower cable anchorages and the tower base location. In its final configuration, the Canal Lachine Bridge's superstructure forms a highly redundant composite steel grillage system that achieves structural efficiency and modern aesthetic elegance.

This advanced bridge superstructure system utilizes multiple steel box-girders connected by cross-frames and transverse tie-beams to create one large superstructure unit from abutment to abutment. The individual box girders were fully assembled in the shops, shipped to site, and lifted with crawler cranes into final position using temporary supports. Composite action was achieved using slender full-depth precast deck panels (similar to the Deh Cho Bridge) to cope with the long cold winter periods in Québec. The continuous superstructure, with expansion joints only at the abutments, is fully isolated from the substructure, using friction-pendulum isolation bearings. They significantly reduce and balance seismic design forces for the numerous piers and their foundations. This permitted slender single columns (without cap beams) and efficient mono-pile foundations (without pile caps).

The new bridge replaces an old concrete structure at the same location. Hereby, the footprint of the old bridge covered a substantial section of the new bridge. To maintain traffic during construction, a phased construction sequence was a mandatory requirement of the owner. The partially completed northbound superstructure had to carry public traffic before the old bridge could be removed and the southbound structure be erected. Accordingly, the contractor's preferred construction sequence had to be fully developed and implemented into the detailed design of the bridge. This included verification and professional sign-off of the partially completed superstructure and meeting the SLS and ULS requirements of the Canadian Highway Bridge Design Code CAN/CSA-S6 CSA, Group (2014), for traffic during construction.

The hyperstatic system of an extradosed bridge meaningfully influenced the design of the Canal Lachine Bridge. Because of the girders' inherent bending stiffness, the degree of which the stay system participates in carrying loads could be selected. This is not possible for the traditional cable-stayed bridge system with slender superstructures where the cables are supposed to carry the vast majority of loads. For the Canal Lachine Bridge, the stay system was designed to carry only loads that match maximum SLS live loads in the cable supported spans. This decision reduced stay and tower forces compared to the traditional cable-stayed bridge where the tower and stay system is the primary load path. Gimsing (1997) Smaller fatigue demands and shorter stays (another feature of an extradosed bridge) significantly reduced lateral tower demands which are critical in curved cable bridges, especially for bridges with tall and slender tower shafts.

The single tower of the Canal Lachine Bridge is a free-standing mast without tie-backs that would balance the cable deviation forces in plan. For stability reasons a fully restrained tower base was essential to accommodate lateral tower bending moments. The reference concept showed a very stiff tower which had its own foundation and was not supported by the superstructure. However, this structural separation of tower and superstructure (but connected by the stays) would have had significant disadvantages in a seismic event when superstructure movements are not in phase with the tower. To mitigate this problem for the tower and its foundation, the tower was framed into the superstructure so that both systems (the beam and the stay/kingpost system) become one fully integrated system. This modified superstructure type was completely isolated from the substructure to improve the seismic performance of the bridge. During a seismic event this extradosed superstructure is comparable to a sailboat in fast changing currents.

The steel portion of the curved composite superstructure utilizes the bending and torsional stiffness of six coupled box girders to achieve structural redundancy, strength, and stiffness for vertical loads. Due to the principle of structural isolation this was achieved without compromising the superstructure's structural flexibility required for temperature change and seismic performance. Composite action between the concrete deck and the coupled box girders was only accounted for superimposed dead load and transitory loads (as for the Deh Cho Bridge). This design philosophy allowed slender full-depth precast deck panels without post-tensioning and future deck panel replacements without rebuilding the steel superstructure. This important design feature, introduced in North America on the Deh Cho Bridge, cannot be found in traditional cable-stayed bridges where the concrete deck is an integral part of the primary load path for dead load. The Canal Lachine Bridge is therefore an excellent example for Accelerated Bridge Construction (ABC) and Accelerated Bridge Rehabilitation (ABR).

Accelerated Bridge Construction

Accelerated Bridge Construction (ABC) is a methodology that utilizes mainly prefabricated bridge elements made of steel, concrete or a combination of both materials to minimize traffic impacts during construction. ABC projects are specifically designed with a detailed traffic management plan in mind. Public acceptance of ABC has gone this far that owners are willing to pay a premium if construction durations and traffic disruptions are meaningfully reduced. For newly constructed bridges, ABC typically does not play this important role because often the benefits do not outweigh the cost premiums.

This is different for bridge construction in very cold temperature zones where bad weather permits only small openings for good construction periods. Although the Deh Cho Bridge construction process was not affecting existing traffic patterns of ferry and ice road services, the overall construction schedule was vital to maintain public confidence in the project and the budget. For instance, the ice road typically built during the winter months, when ferry service was suspended, was an expensive way of maintaining road service to Yellowknife. Completing weather sensitive construction works before the upcoming winter season at the end of 2012 was critical to achieve the highly anticipated bridge opening scheduled for the last day in November. This day was crucial because in November the ferry's travel path in the freezing river narrowed down to a very small channel that the ferry kept open while operating with increasing ice build-up problems.

The planning and logistics of major construction projects are an enormous task, and it requires an excellent interdisciplinary collaboration between the parties involved. The designer and erection engineer alone cannot foresee and plan for all aspects that influence successful and timely project delivery. For that reason, it is recommended to early engage fabrication and construction specialists that know the industry and its limitation well. This is the advantage of Design-Build and Public-Private-Partnership (3P) projects where interdisciplinary teams already work together during the bid stage in developing feasible and cost-effective solutions. Besides engineering, construction planning, project scheduling, risk mitigation, and budgeting are key tasks in these alternative project delivery ventures. ABC can meaningfully contribute to achieve ambitious projects goals when undergoing bridge construction projects in cold weather zones and/or with challenging construction schedules.

Optimization and Synergy Effects

Bridge designers must plan for several events to achieve a fully integrated solution. This includes fabrication, supply, transportation, construction, maintenance, rehabilitation, strengthening, adaptability, and replacement. Often the demands during construction govern the overall design process, especially in major bridge construction when construction processes are not fully understood and anticipated.

Although the global safety factor during construction is typically smaller than for bridges in service, designers must anticipate that the partially completed structure may undergo construction stages that govern the design. If these stages are not recognized early, local strengthening or excessive temporary works required at a later stage can cause delays, budget overruns, and legal disputes.

But there is another advantage if design governing scenarios are foreseen and addressed early. The anticipation of feasible construction methods and stages permits structural optimization without paying cost premiums. For instance, during the anticipated and executed incremental launching operation the bottom chord of the Deh Cho Bridge truss was subject to significant local bending and shear demands of a magnitude that the truss chord would never experience again during service. It was therefore important to optimize the bottom chord cross section for the local construction demands and for the global axial force during service. By applying synergy effects, a custom-made built-up truss bottom chord cross section was developed. Consequently, the governing design scenarios were equally addressed without adding material only for the construction purpose.

In a similar manner the Canal Lachine Bridge superstructure was designed to manage traffic on the partially completed bridge without adding additional steel or concrete. Hereby, the positive structural effect of a redundant steel grillage system was fully utilized to achieve both strength and stiffness. Especially stiffness was an important design criterium because connecting two independent superstructure carriageways with live load on one carriageway is a major construction hindrance when deflections matter. For the slender inside curve girder, having a slenderness of 44 (see introduction), achieving the required stiffness in the 88-m long main span was a key challenge in designing the bridge. The solution was the selection of multiple slender box girders which do not permit torsional twist because of their inherent torsional stiffness. If no twist occurs, all girders must deflect equally. This behavior allowed to shift live load from the very slender inside curve girder to the much deeper outside curve girder which permitted more structural depth due the meaningful crossfall of 6%. Because of this load sharing effect, the bridge’s maximum live load deflections are less than 1/1000 of the span length. Again, efficiency and synergy were achieved by selecting cross sections that were optimized for structural performance during construction and service.

Lightweight and Seismic Design Principles

Dead load matters. This is true for the design of foundations of any bridge but particularly important for long-span structures as discussed in the introduction. But there are many more reasons why lightweight design principles are important in bridge design. They are ecologically friendly because the efficient use of material and the reduction of overall shipping tonnage and lifting weights help to manage our carbon footprint. Lightweight structures typically require more design work and fabrication labor which increase costs. However, the Deh Cho Bridge and the Canal Lachine Bridge are good examples how lightweight design principles (steel I-beams, steel trusses, multiple small steel box girders, steel grillage systems, slender precast concrete deck panels, cable-supported spans, etc.) can successfully reduce weight without creating an extra cost burden on the project. On the contrary, a commitment to lightweight structural design principles creates jobs and builds expertise, a priceless commodity in the race for economical supremacy in a world with diminishing resources.

Further, lightweight bridge superstructures have major advantages in seismic zones. Their limited mass significantly reduces demands on piers, abutments, and foundations. Abdel-Ghaffar (1991) This is especially of importance when designing bridges in bad soils, as we find them in the Lower Mainland of British Columbia. 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 the pay load. It is true that to a certain degree a larger superstructure dead load increases the moment and shear resistance of a reinforced concrete column or pile but P/Delta-effects make this positive effect worthless if the section cracks and lateral deformations over-proportionally increase.

Future Developments

The development of extradosed bridges and design solutions that this bridge type inherited from other well-known structural systems is by far not exhausted. For instance, the process of using this type of bridge for curved superstructures such as the Canal Lachine Bridge has just started. It is envisioned that even longer bridges, curved and super-elevated girders are incrementally launched with towers and cables installed to minimize disruption below and accelerate construction. An example for such a structure is the conceptual design for the new Nisutlin Bay Bridge in the Yukon, where the corridor of the old bridge was bypassed with an in-plan curved superstructure without giving-up the roadway alignment at the abutments. Saifuzzaman (2019)

Further, the combination of underslung midspan sections with extradosed pier sections will allow to maximize the span potential of the “strengthened beam” idea. There is no reason, why the increased leverarm philosophy should be limited to negative moments only. To avoid costly earth-anchored solutions, the underslung midspan sections could be designed as self-anchored drop-in spans or as basic steel box girders locally strengthened after launching. Such lightweight box girder sections will be completed to their full width and strength after the underslung tendons are installed and tensioned.

Conclusions

The design and construction of extradosed bridges is a challenge because their hyperstatic systems require a good understanding of the multiple structural systems participating in carrying loads, and because of the various construction aspects to be considered in the design. This challenge is amplified when spans increase and the geometry becomes complex. Especially for bridges in the Canadian North, designers must focus on reliable construction methods proven to work at extreme low temperatures.

Accelerated Bridge Construction (ABC) is one design approach to overcome the challenges of short good construction periods. Therefore, it is recommended that the overall process of fabrication, supply, transportation, and construction is investigated in the conceptual and detailed design phases to ensure successful project delivery.

Every extradosed bridge utilize a beam superstructure type which is locally strengthened to increase the negative bending capacity of the cross section. Most extradosed bridges built so far utilizing a conventional prestressed concrete cross section for the beam. In seismic regions, weight and mass matter and therefore, extradosed bridges should utilize a lighter composite steel superstructure instead. This will result in smaller seismic demands on substructure elements and save overall costs.

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