SELECTION CRITERIA FOR LONG-SPAN BRIDGES CONSTRUCTION METHODS

Mohamed Darwish, PhD, PEng[12]
Ramy Ghowiba[2]
Mohamed Afifi[2]
Mahmoud Elhosary[2]
Monira Yazeed[2]
Ahmed Abdelaziz[2]
Omar Ghaly[2]
Ahmed Elmahdy[2]
Asmaa Mohamed[2]

Abstract:

Long-span bridges crossing water ways and varying topographies are necessary for transportation all over the world. Construction of such structures involves utilizing unique construction methods due to various characteristics like structural system, cost, constructability, resources and time. This paper covers different methods of long-span bridge construction by concentrating on different construction methods of every type of long-span bridges. Moreover, a comparative analysis is provided to show when to use every method of construction according to the conditions available. Two projects involving long-span bridges with different sizes and project conditions were studied and examined against the developed selection criteria in order to evaluate the validity of the applied construction methods in each case.

Keywords: Long-span Bridges; Construction Engineering; Bridge Engineering; Cable-Stayed Bridges; Suspended Bridges

1 INTRODUCTION.

Designs of bridges vary depending on the function of the bridge, the nature of the terrain where the bridge is constructed, and the material used to make it. All bridges have the same purpose of transporting people, vehicles and trains from one point to another, yet there are several types of bridges to choose from when you build one. Long span bridges have several types which differ from the structural point of view, the span it can cover and practicality of construction. From a structural perspective, long span bridges are either arched, cable stayed, suspended or truss bridges.

In an arch bridge we mainly have compression forces within the arch with a minimal moment depending on the design as the arch effect minimizes the mid-span moment. Of course, those compression forces are transferred to thrust force at the foundation of the structure, so the foundation of the arch bridge should be designed to withstand these large thrust forces, acting as if they want to open the arch. The bridge deck could be directly supported on the arch or a series of columns or truss members could be used to transfer the load from the deck to the arch (Au, Wang, & Liu, 2003).

On the other hand, a suspended bridge mainly consists of a deck, cable suspender, and a tower backstay. The idea of the suspension bridge is that the main cable carrier hangers that support the bridge deck and these hangers are in tension as they are carrying the bridge deck, and so the hangers also pull the main cable creating a tension force in the main cable. Hence, the main cable transfers the load mainly

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[1] Corresponding author, email: mdarwish@aucegypt.edu
[2] The American University in Cairo, Egypt

to the bridge towers (pylons) and the anchorage zone. However, these types of bridges need to be carefully designed as they are of very low lateral stiffness making them very sensitive to lateral loads like wind and seismic loads, and this case is obviously noticed after the disaster of the old Tacoma Bridge which collapsed due to the lack of consideration of lateral loads in its design (Arco & Aparicio, 2001).

A cable stayed bridge mainly consists of a pylon (tower), and cables that connect the pylon to the deck, as the deck is loaded the cables are in tension, and this tension force is transferred to the pylon, and the idea of the pylon is to have an equal weight to the left and the right of pylon, and to balance the weight, and avoid extra moment, and that is why when some engineers decided to make a pylon with the weight from the left and the right of the pylon not balanced, they did the pylon in a inclined position in order to account for this unbalance (Reddy, Ghaboussi, & Hawkins, 1999).

On the other hand, within a truss bridge, the truss members carry either compression or tension forces but the difference is that trusses are less bulky or lighter in weight in comparison to other structural systems. This difference between the truss and beam bridges made truss bridges more economical as they use less material efficiently. The idea of truss bridges is very old and it has been used in other types of bridges such as arched bridges. Truss bridges can be used in some site condition or in constructions that need balancing between labors, equipment, and costs of materials used (Durkee, 2003).

From a construction methods perspective, the methods used to construct long-span bridge decks could be all classified as segmental methods in which the bridges are made of repetitive structural elements that are repeatedly joined together to form the complete bridge structure. This method is the most traditional bridge construction method, as it was used in history in many bridges. Builders have always found it easier and more efficient to create a larger durable bridge structure from smaller segments. This approach could be used to construct bridges out of steel or concrete (whether cast-in-situ or precast). It could also be used to construct bridges involving any of the bridge structural systems described above however the detailed construction steps may change from one structural system to another (Barker, 1981).

2 CONSTRUCTION METHODS.

Bridges in general could be either constructed using the conventional construction methods or using segmental construction methods. Segmental construction is the most traditional long-span bridge construction alternative as constructing a long-spanned deck in one piece is practically impossible. Builders have always found it easier and more efficient to create a larger durable bridge structure from smaller segments. Segmental bridges today are used in several applications, such as the construction of highway projects in areas of already existing streets and urban density, or the construction of bridges across sites that are environmentally fragile and require specific care (Barker, 1981).

2.1 Conventional Method

This is the traditional way of constructing a bridge, if the bridge is made of reinforced concrete the formwork is supported on the false work and temporary supports, and the construction process takes place conventionally. If the bridge is made of precast concrete or structural steel the segments are installed using cranes and rested on the temporary supports then connected to each other to form the bridge body. However, if this method is used to construct decks of suspended bridges or cable-stayed bridges the cables must be connected and post-tensioned before removal of the temporary supports (Dunn, 1996) (BBR, 2014).

This method is cost-saving as it doesn’t involve designing the structure for special load cases related to the construction method and most of contractors could implement it due to the conventionality of its activities. However, due to the use of false work and temporary supports, bridges constructed using such a method are of a limited height, since if the bridge is high it would require a great deal of formwork, and bracings that is not practical to use. Additionally, it is nearly impossible to place temporary supports and false work in the middle of waterways (seas, oceans or rivers) or valleys to apply such a method. Hence, this method is rarely used in long-span bridge construction as most of long-span bridges are either crossing waterways or valleys. Even when doing such activities is possible, the false work will create an obstruction for any type of traffic beneath the bridge and the installation of the temporary supports, the false work and formwork will require a great deal of time and effort, and also its removal will take a great deal of time making this method the slowest of all methods. In addition to all of that the false work stability is an issue, since the false work will require a complicated design for the bracing system in order to be able to resist lateral loads (Dunn, 1996).

One alternative used to reduce the use of dense false work for arched bridges is using vertical rotation which is basically that each half of the arch is constructed on ground using traditional methods. After that the each half is lifted vertically to its position. However, doing so requires a hinge at each end of the bridge, and this hinge is then sealed using concrete or any other mechanism after the bridge is vertically rotated. Again, within this alternative there is a need for space in order to construct the arch on ground, since the arch would need a place until it is constructed using any of the traditional methods. Also, this alternative creates additional design requirements as there will be different cases of loading, and design checks should be made in order to insure that the design is still safe in the vertical rotation positions (Xu, Zhou, & Wu, 2010).

On the other hand, horizontal rotation is conceptually very similar to vertical rotation but instead of the bridge being built in its vertical position, and then rotated horizontally to its position. Of course, in order to do so, a complicated rotating mechanism should be done. This alternative could be used to construct arched, cable-stayed and truss bridges and its major merit is that it transfers the working location from the permanent location that is crossing valley or a waterway to a perpendicular location that could be more suitable to place false work and temporary supports on. However, and as the vertical rotation alternative, this alternative creates additional design requirements as there will be different cases of loading, and design checks should be made in order to insure that the design is still safe in the horizontal rotation positions. In addition to that, this alternative involves using a complicated rotating mechanism, which would require a special mechanical design that creating an additional cost (Sun, Guo, Zhang, Guan, & Zheng, 2011).

2.2 Balanced Cantilever Method

Within this method of construction the deck segments are placed and attached as cantilevers supported on the piers of the bridge, after constructing the bridge piers. The pre-cast concrete (or steel) segments are placed equally at both sides of the pier to ensure stability of the structure. The additional moment progressively increasing within the deck as more segments are added to the cantilever from the pier is resisted by post-tensioning the deck segments near and on top of the pier, and extending this post-tensioning to the body of the pier itself, in order to stabilize the structure such that the connection between the deck and pier will be a moment-resisting connection. The segments added to the cantilever are most commonly placed using cranes. A launching crane is very useful in situations where the land below the superstructure of the bridge is not accessible as shown in Figure 1 (VSL Inc., 2013).

Figure 1: Construction of the İstanbul - Golden Horn Metro Bridge using the balanced cantilever method (VikiPicture, 2013).

If cast-in-place concrete is poured instead of pre-cast segments then there will be a need to use two traveler forms (one from each side of the pier). However, careful care should be taken as the traveler forms are advanced due to the fact that the full strength of the concrete is not achieved yet (Dunn, 1996). Hence, unless early strength concrete mixtures and curing procedures are used, striking and advancing the forms should take at least three days (as 50% of the strength would be achieved by that time). The major merit of this method is that there is minimal disturbance for the area beneath the bridge deck hence it could be used when the bridge is crossing major roads, water ways, forests or difficult topographies (Blank, Blank, & Luberas, 2003).

This method could be used in its classical form to construct multi-spanned arched bridges however it is not that common to find it used for arched bridges as typically such bridges are not symmetric over the pylon. On the other hand, on using this method in constructing a cable-stayed bridge, the process starts after constructing the cables tower and suspending the cables from the towers, as after constructing each deck segment this segment is connected to the cables and the cables are post-tensioned. The following segment will not be installed (if prefabricated) or constructed (if cast-in-place) unless the cables connected to the preceding segment are post-tensioned as shown in Figure 1. The process is very similar if this method is used to construct a suspended bridge however the cables are hanged from a main cable hanged from the tower (pylon). Whether used to construct suspended or cable-stayed bridges each segment installed is considered as a load case by itself and the structural soundness of the pylons, deck and the cables should be checked under each of these different load cases (Reddy, Ghaboussi, & Hawkins, 1999). Additionally, this method could be problematic from the perspective of guaranteeing the proper vertical position of the bridge deck due to the deflections when the deck is cantilevered. Hence, proper monitoring using accurate surveying methods is a must and reducing such deflections could be performed by increasing the post-tension forces in the cables (whether stay cables or suspension cables) in order to achieve the proper vertical position (Liang, Zhai, Fan, & Shi, 2015).

2.3 Unidirectional Cantilever Method

This method (also called progressive placing construction method) is similar to the balanced cantilever method but instead of moving in both directions from a pier with cantilevering segments, the segments are instead added to the pier in a unidirectional manner (in one direction). In this method since the casting is done in one direction only, the overturning moment is significantly high on the segment at the pier which should be taken into consideration on designing the deck, the pier and the pier-deck connection. Additionally, a temporary support system is used to reduce this moment (Barker, 1981).

This construction process is less complicated than the balanced cantilever method since work is done in one direction only as shown in Figure 2. Also, completing one span of the bridge gives better accessibility to construct subsequent spans; this is not possible when the construction is done in both directions from the pier. Accordingly, this method needs temporary supports; it is slower and could be applied for shorter spans when compared to the balanced cantilever method (Barker, 1981).

In both cantilever construction methods the cantilevering segments from each pier will reach to a point where they meet at mid-span between the two piers and these segments need to be joined. Joining the segments is either done using a hinged connection which is a simple connection but could lower the load-bearing of the bridge structure or the segments could be kept suspended and allowed to rest on bearings between the cantilevers. This might be more structurally complex, but is more structurally sound. Due to all of that, both cantilever methods could be used for various lengths of bridge spans ranging from short spans to long spans although the balanced cantilever method is capable for constructing longer spans than the unidirectional cantilever method (BBR, 2014).

The unidirectional cantilever method is more common in the construction of arched bridges than other structural systems. This is due to the fact that most of long-spanned arched bridges are not structurally symmetric about their pylons/columns as the spans to the left and to the right of the main arched spans are typically abutments or short-spanned as this type of bridges is most commonly used to cross a river or a valley. There are two alternatives by which this method could be used to construct an arched bridge. The first alternative is called the “Pylon method” where an arch rib is suspended with cables (acting as temporary supports) from a pylon. It is very common to utilize such cables to connect the arch, the pylon and the point of fixation (anchorage) on the land where the forces are transferred as shown in Figure **2**. The second alternative is called the “truss method” where a bridge is constructed while truss structure is formed with arch ribs, vertical columns, stiffening beams and diagonal members. So, simply the difference between the two methods is simply that in the Pylon method the Arch is fully constructed first, and then the other components of the bridge like the hangers and the bridge deck, while in the truss method both the hangers, deck, and the Arch are constructed together. It should be noted that in both types the Arch is mostly being built using a traveler formwork or a slip form depending on the situation. Also as any staged construction alternative the different structural components should be designed to withstand the different load cases associated with the different construction stages (Au, Wang, & Liu, 2003).

Figure 2: The construction of the Hoover Dam Bypass Bridge using the unidirectional cantilever construction method (Wikimedia, 2010).

2.4 Mid-span Suspension Bridge Construction

The construction of suspension bridge depends, and varies upon the project itself, but mainly the construction sequence of the suspension bridge begins with the construction of the anchorage zone, which is a very huge structure that is used to anchor and support the suspension cables, and sometimes, the anchorage zone is simply a rock or a huge concrete structure, if it is able to withstand the pressure of the cables. Then the pylons are constructed, the saddles (side cables), and the main cables are pulled to position, and then tensioned to reach the desired design profile. Then, the hangers are tied to the main cable. Finally the deck is constructed most either using the balanced cantilever method described above or starting from the mid-span. The presence of the main suspension cables spanning between the two pylons before the deck construction enables the construction of the deck to start from the mid-span. Hence, suspension bridges are the only type of long-spanned bridges in which the deck construction could start from the mid-span as a winch lifted on a locomotive rests on the main suspension cables and it lifts each prefabricated (steel or RC) deck segment from the barge (if constructed over a waterway) to its vertical position then the hanger cables are connected to the new segment and now the locomotive is free to move leftwards or rightwards to lift the following segment which will be connected to the hangers and the previous segment after located in position. Two locomotives could be used to perform a faster construction involving the lifting of a rightward and a leftward segment at the same time as shown in Figure **3**. This method causes less moments in the deck when compared to the cantilevered construction methods however it still needs to be designed as each construction stage is a load case by itself (Adanur, Günaydin, Altunisik, & Sevim, 2012). In addition to that the deck is susceptible to lateral loads (whether seismic or wind loads) if constructed from the middle to the left and right directions as the bridge deck will be oscillating in a mode similar to that of a pendulum. This problem could be solved if the erection sequence is altered to be non-symmetric as this will reduce the pendulum-like motion of the deck under-construction (Arco & Aparicio, 2001).

Figure 3: Assembly of the deck segments of the first Severn Bridge, UK (Spicer, 2011).

2.5 Incremental Launch Method

This method involves the casting of continuous segments at a specific location of the site, then pushing this continuous chain using hydraulic rams to be placed in position. Casting beds in this method have formwork that is adjustable and movable. After constructing the piers the segments (which are usually pre-stressed concrete) are cast in continuous chains on site. Typically, on constructing bridges using this method, three types of pre-stressing are usually utilized: the central, the eccentric and the transverse pre-stressing each increasing the section strength in a certain direction. After that, the chains are pushed into position using hydraulic jacks that act in both vertical and horizontal directions, these lift and push the segments into place. The segments are supported with temporary supports as they advance from the casting yard to the pier (if the chains of segments are of long spans). The first segment is attached to a launching nose (usually steel). This nose will rest on the temporary supports and then rest on the permanent supports providing more stability which is the main difference between this method and the unidirectional cantilever method (VSL Inc., 1977).

On constructing long-spanned bridges using such a method, temporary supports are necessary. Hence it is very difficult to use this option for long-spanned bridges crossing waterways. On the other hand, it is economically sound as the transportation of the segments for long distances is avoided and the use of large amount of formwork is reduced. However, this method could only be used if the bridge has a constant cross section and a straight alignment (Barker, 1981). This limitation makes it impossible to use this method to construct the arch of an arched bridge however it could be used to construct the deck above the arch if the distance between the columns (transferring the load from the deck to the arch) is limited to be less than 60 m as due to the need to launch a significant weight using a set of jacks this method is limited to having a distance between the different supports limited to be less than 60 m (BBR, 2014).

3 CONSTRUCTION METHODS SELECTION CRITERIA.

Based on the discussion of the different methods presented in the previous section, a selection criteria could be developed to aid the decision making process concerning the long-span bridge construction methods. Typically, the conventional methods whether involving simple installation of steel or precast concrete girders or involving cast-in-place concrete using conventional false work carrying formwork is more economical than segmental methods however, if the bridge is planned to pass over a busy road, a waterway or a valley that could not allow false work to be placed the segmental erection methods are the only remaining alternative. Hence, and since most of long-spanned bridges are crossing waterways or valleys, the conventional methods are not applicable for most of these bridges and segmental construction methods are used in such cases. The bridge type, length and location are the most important factors governing the choice between the different methods. The need for special design considerations, temporary supports, level of risk, time frame, resources (especially equipment) and constructability also affect the method selection. A summary of the selection criteria between different segmental construction methods could be found in Table 1.

Table 1: Selection criteria for long-span segmental deck construction methods.

	Mid-span erection	Balanced Cantilever	Unidirectional Cantilever	Incremental Launching
Suitable Bridge Type	Suspension	Cable-stayed, Truss and Suspension	Mostly used for Arched type	All except Arch
Need for temporary supports	Not needed	Not needed	Needed	Needed
Material	Precast concrete or steel	Concrete or steel	Concrete or steel	Concrete or steel
Level of mechanization	Moderate	Moderate	High	High
Need for special design consideration	Needs special wind load design	Should account for additional number of load cases		Additional load cases and limited for decks of constant sections and slopes
Suitable Locations	Crossing waterways	Any Location		Not suitable if crossing waterways
Construction Speed	Fastest	Fast	Moderate	Moderate
Risk	High	Moderate	Highest	Low

4 CASE STUDIES.

4.1 Russky Island Cable-Stayed Bridge, Russia

The Russky Island Bridge is constructed to link Vladivostok mainland and island areas. The construction started in 2008 and ended in 2012 with a total duration of 43 months. The cable-stayed bridge is 1886 m long with a center span of a length of 1104 m. The shortest stay cable was 136 m long while the longest cable has a length of 580 m, the deck height is 70 m while each pylon had a height of 320.9 m. The job was done by a consortium of contractors: USK, MOST and OJSC while the design was performed by NPO Mostovik. Due to the bridge location the design criteria involved designing the bridge to withstand a wind speed of 36 m/sec, snow thickness of 700 mm, a thermal variation load between -31 ^{o}C in winter and 37 ^{o}C in summer and a storm wave up to 6 m high in addition to the cantilevered construction load cases (SK MOST, 2014).

4.1.1 Applied Method

The bridge decks in the leftwards and rightwards spans were made of pre-stressed reinforced concrete girders. The concrete was cast in place as these segments were located on land and using formwork supported by false work and temporary supports at these locations was feasible. Within these spans plastic ducts were installed in addition to reinforcement bars after the formwork was placed. High tensile pre-stressing steel bundles were installed in the ducts and bundles were tensioned using pre-stressed jacks, workers filled the voids in the duct with special cement based mortar and the concrete was poured (SKMOST, 2012).

The real challenge was in the middle span that was the largest span and crossing a water way. Hence, the designer decided to make it a steel stiffening girder composed of 103 panels. Each panel was 12 m long and 26 m wide. The panels were fabricated on the land at the production facility on the Nazimov Peninsula and at Nakhodka shipyard and delivered by barges to the project location. To guarantee accurate positioning, these panels were positioned with the aid of a global navigation satellite system (GLONASS) using cranes (of a lifting capacity of 1350 tons) supported on the constructed portion of the decks. The process was done using the unidirectional cantilever method and the different panels were joined. Welded connections were used for longitudinal and transversal connections of the orthotropic plate cap sheet and the lower ribbed plate. However, for joints of vertical walls of the blocks, longitudinal ribs, transversal beams and diaphragms, the connections used were high-strength bolts. After the installation and connection of each panel, the stay cables were connected to it and tensioned before the subsequent panel was installed. Each stay cable was composed of a number of strands ranging between 13 and 85 strands. Each of these strands had a diameter of 15.7 mm and consisted of 7 galvanized steel wires. The protective sheath of each stay cable is made of high-density polyethylene (HDPE) providing protection form ultraviolet rays and thermal variations (SK MOST, 2014).

4.1.2 Construction Method Evaluation

The decision of using a conventional method in the outer two sides was a correct decision as there were no obstructions beneath the medium-spanned bridge deck preventing this option. Hence, this was the most cost-saving way of doing the job. However, using conventional methods was nearly impossible in the middle span as it crossed the water and using a segmental method was a necessity. In such a situation the ideal condition was to use the balanced cantilever method however as the sides on land were medium-spanned and the mid-span was significantly longer it was more economical to use the unidirectional cantilever method as the overturning moments would be resisted by the system of stay cables, bridge girder and columns from the sides on the land.

4.2 Humber Suspension Bridge, UK

This Bridge in England was the longest suspension bridge in the world when opened in 1981, as it has a single suspended span of 1410 m and a bridge overall length of 2220 m. It remained the longest for 17 years however nowadays it is the seventh-longest suspension bridge in the world. Each of its two towers is made of a two hollow vertical concrete columns, each of them has a height of 155.5 m a squared base of 6 m x 6 m that tapers to reach 4.5 m × 4.75 m at the top. The bridge design criteria included tolerating a wind speed of 129 km/hr. The total length of the suspension cables strands is 71,000 km. The north tower is on the bank while the southern one is in the water. The middle span crosses the Humber (the river mouth formed by two rivers) between Barton-upon-Humber on the south side and Hessle on the north side. The project consultant was Freeman Fox & Partners (now named Hyder Consulting) while the main contractor constructing the superstructure was British Bridge Builders and the contractor doing the sub-structure was John Howard & Co Ltd. This project incurred a cost of £151 million upon its completion (Wikipedia, 2015).

4.2.1 Applied Method

After finishing the substructure and the towers construction in 130 days, the side anchorage points were constructed and the main suspension cables were placed in 670 days. These initial steps took long time due to the fact that constructing the side anchorage points involved complicated deep foundations due to the soil nature. Once the main cable was fully placed in position, the deck erection started. The deck consisted of 124 steel box girder deck segments. Each prefabricated steel segment was 18.1 m long, 4.5 m deep and 28.5 m wide. A 37 mm thick orthotropic plate constitutes the top of each section an on which asphalt cement concrete surfacing was to be laid afterwards. The main cables had a sagging of 115.5 m while the horizontal distance between the vertical cables was 22 m. The main cables were composed of 5 mm UTS wires of a tensile strength of 1.54 GPa grouped in strands. Each of the main cables had a cross-sectional area of 0.29 m^2. After the cable assembly two locomotives were placed on the two main cables in the middle span, each of these locomotives (that were movable within the middle span) carried a winch that carried each deck segment and placed it in position. This process started from the mid-span. Barges were used to transfer the prefabricated deck sections from the fabrication plant on land to the bridge location. After each segment was carried and connected to the corresponding vertical cables, the connections with the neighboring deck segments took place. Simultaneously, the transportation and assembly of the deck segments took place on the two side spans. However, for the northern side which was fully on the bank the segment transportation was done using large trucks. For both side (the southern and northern), the construction started from the anchorage points towards the towers not from the mid-span of each side. This was done to avoid using locomotives at these sides and to use cranes instead which made the process faster and more conventional. The same procedures of deck segment assembly and connections took place on the sides as the sequence done at the middle span. The assembly of the bridge decks on the sides started shortly after the beginning of the assembly of the decks located in the middle span. However, the side deck sections assembly was finished before the middle span deck assembly due to the shorter lengths of the northern and southern decks when compared to the middle span length. The whole deck assembly staged construction process was divided into 39 stages with each stage taking approximately 10 days hence the bridge deck was assembled in 390 days. Each of these stages was considered as a load case by itself during the design phase (Adanur, Günaydin, Altunisik, & Sevim, 2012).

4.2.2 Construction Method Evaluation

Due to the difficulty of using false work in the middle of the water, using conventional construction would have been nearly impossible for the deck construction within the middle span and northern side however it was possible to use the conventional erection method on the southern side which would have saved the cost and hassle of transporting and lifting large deck segments at that side. On the other hand starting the construction on the outer sides from the anchorage points was a correct decision as it saved the cost and time of installing locomotives supported on the main cables at these locations. On the other hand it was possible to assemble the deck in the middle span using the balanced cantilever method however this would have exerted additional moments on the towers and unbalanced tensile forces in the cables reflected to additional forces at the anchorage points as the middle span was 1410 m long while one of the outer spans was 280 m and the other was 530 m hence the load would have been eventually unbalanced in the later stages of deck assembly due to the large differences in spans causing additional stresses in the towers, the main cables and the anchorage points. Consequently, and according to the selection criteria developed in section 3, the choice of starting the deck assembly from the mid-span of the main bridge span was the most cost-saving option as it saved the cost of additionally stiffening the towers, cables and anchorage points.

5 CONCLUSIONS AND RECOMMENDATIONS.

When examining the methods applied in the two cases discussed in section 4 of this paper against the selection criteria developed in section 3, the selection criteria proved that it covered the different aspects governing the selection of the most suitable methods for different long-span bridge construction cases. The most governing factors of choice are the bridge type, length and location. The need for special design considerations, temporary supports, level of risk, time frame, resources (especially equipment), costs and constructability also affect the method selection. Hence, it is highly recommended when using the selection criteria matrix to take all the factors governing the method selection into account as neglecting some of them could cause serious problems that are difficult in fixing.

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