Bridge Construction Methods

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Abstract
In Hong Kong, bridge is one of the main transportation accesses. Gammon has responded with resourcefulness, innovation and determination and constructed some of the major Hong Kong bridges that form key components of Hong Kong’s road and bridge infrastructure for over 30 years. The main component of the construction of bridge is the deck and there are different kind of method for building it, such as balanced cantilever travelling formwork and pre-cast I-beam construction.

Keywords
bridge, deck, cantilever, pre-cast, I-beam

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Mr. K F Tam is currently the Project Director of both the Reconstruction and Improvement of Tuen Mun Road Č Eastern Section project and the Widening of Tolo Highway/Fanling Highway Between Island House Interchange and Fanling (Stage 1-Between Ma Wo and Tai Hang). He has over 30 years construction experience involved in mega projects in Hong Kong, broad experience in the overall site management of large-scale civil engineering projects and supervision of site operation team to achieve construction targets. Project experience includes site formation, geotechnical and roadworks, construction of heavy civil structure and different types of elevated highway / viaducts.

1. Introduction
Hong Kong’s difficult terrain and dense urban environment pose a constant challenge to road builders. For over 30 years, Gammon has responded with resourcefulness, innovation and determination and constructed some of the major Hong Kong bridges that form key components of Hong Kong’s road and bridge infrastructure.
While traditional in-situ formwork method has been a norm practice in the industry for decades, Gammon is an early adopter and brought-in talent techniques like balanced cantilever travelling formwork as early as year 1971 at the Tsing Yi Bridge and then 1977 at Ap Lei Chau Bridge. Soon, the pre-cast construction technique Gammon used has demonstrated its strength in this area: the pre-cast I-beam construction in year 1973 for Waterloo Road Flyover & Argyle Street Flyover solved complicated logistics and access problem for carrying out a mega scale construction in the congested Kowloon urban area. The Lifting Frame, Goliath Gantry and Bogies used in the project were all in-house designed.
Since then, Gammon committed to delivery innovations in its projects. Gammon started to construct bridges by using launching girders for precast segments in constructing the viaducts for Route 3 in 1995 and Tsing Yi North Coastal Road in 1999. Many of these advanced techniques are still frequently employed in Gammon projects, for example, the Route 8 Ç Nam Wan Tunnels in 2003 (Lifting Frames), Deep Bay Link - Northern Section in 2003 (Launching Girder), Hong Kong-Shenzhen Western Corridor (Lifting Frames & Launching Girder), Castle Peak Road Improvement in 2004 (Travelling Formwork) and etc. Details of these bridge construction techniques commonly used are illustrated in the following sections.

1.1 Traditional Formwork/ Falsework
Formwork and falsework have been used in construction since ancient times, when Roman bridge builders erected their semicircular stone arches for bridges, aqueducts, and vaults on wooden centering. Falsework provides continuous support for the formwork that gives shape to the superstructure. In most cases formwork and falsework are used for cast-in-place concrete structures. They are frequently used for the bridges of complicated geometry with full of twists and turns or complex alignments of highway interchanges.

Western Harbour Crossing Approach Roads (1993-1997)

Formwork requires firm, relatively even ground, stable foundations and sufficient bracing on which it can be erected. They can be erected by less specialized workers to any desired shape. Use of modern standard elements of which the formwork and falsework are put together allows uncomplicated erection.

There are, however, several disadvantages. A lot of material is required for formwork and falsework set up, which requires much time and manual labor to be spent on its erection, in addition to the cost of purchasing or renting the materials themselves.

1.2 Balance Cantilever Construction
Balance cantilever construction denotes building a bridge superstructure from both sides of the pier table in a scales-like fashion. The pier segment, serving as a base from which cantilevering is begun. Balance cantilevering can be carried out with cast-in-place or precast segments.
1.2.1 Traveler Form, Balance Cantilever

As early as 1971, Gammon started to employ traveler form in the construction of Tsing Yi Bridge (1971-1974). For such cast-in-place balance cantilevering a set of two form travelers is required, one for each arm of the cantilever. For multi-span bridges the form travelers can be dismantled after finishing cantilevering from one pier and can be set up for new use on the next cantilever.

Cast-in-place cantilever construction requires formwork that is attached to the tip of the growing cantilever for casting. As the cantilever grows the forms travel are set forth in steps. These form travelers give shape to the segment, support the weight of the newly cast concrete until it has gained enough strength to be post-tensioned to the previous cantilever segments, and transfer the segment weight to the already existing superstructure.

Form travelers available in today’s construction industry are reusable and very flexible with respect to changing geometry of the bridge superstructure and its alignment, including camber. They can be enclosed in a heated tent to enable concrete placement and curing to proceed during adverse weather conditions, especially low temperatures. In comparison with a precasting yard, form travelers often offer the less costly solution, since transportation and storage of prefabricated segments is avoided, and they integrate all the functions of the precasting plant into a relatively small device. Suspended from the traveler are not only the adaptable forms for exterior and interior of the concrete segment, but also working platforms on different levels that can be accessed from above.
1.3 Incremental Launching
The incremental launching technique consists of casting a continuous chain of segments at one particular location on site and then pushing the growing superstructure out over site to be bridged. A casting bed with adjustable formwork for the superstructure segments is set up. This casting bed can also be enclosed in a heated tent so that controlled casting and curing conditions are achieved.
Two different techniques for launching the bridge superstructure from the casting bed exist. Hydraulic jacks can pull the superstructure with steel rods. The second, more common method is to employ a pair of hydraulic jacks acting vertically and horizontally. Continuous repetition of lifting the superstructure off the abutment and then pushing it forward as far as the jack allows will achieve the launching in incremental steps.
In front of the cantilevering superstructure a lightweight steel launching nose is attached with tendons that reaches the next support before the bridge superstructure itself arrives. Its purpose is to keep the bending moments in the superstructure smaller. Another way of reducing the bending moments is to implement temporary towers between the bridge piers. These towers need to be able to take the horizontal forces that arise from launching.
On top of all supports, including abutments, piers, and temporary towers temporary sliding bearings are installed during construction that will later be replaced with the permanent ones. Stainless steel plates are installed on the bearings. While the superstructure is advanced, Neoprene pads coated with Teflon and reinforced with steel plates are inserted between concrete and steel to reduce friction.
Several advantages make incremental launching a very competitive erection method. As with any cantilevering method, it leaves the site below completely unobstructed during construction. Only for very long spans temporary towers or cable stays from above as supports are needed. Except for these the equipment necessary is reduced to the jacking mechanism, the adjustable stationary casting bed, and temporary sliding bearings, all of which may possibly be reused, which reduces the capital investment considerably. Cost savings due to avoidance of segment transportation and heavy construction equipment. The controlled casting and curing conditions allow steady and quick construction progress. Bridges that are erected with the incremental launching method should have a constant cross-section, especially in depth, and have a straight superstructure. It is possible to accommodate small variations in alignment and horizontal and vertical curvatures provided that they have a constant radius. Close control of the bridge geometry during casting and launching is very important. This technique is rarely used in Hong Kong’s construction.

1.4 Precast Viaduct
Precast construction means that bridge members or segments are prefabricated at a location different that the site, transported to the site, and installed there.
Construction with precast segments has several advantages in comparison with cast-in-place segmental bridges. Casting of the segments can be performed under controlled, plant-like conditions at the precasting yard. This industrialized process allows easy quality control of segments prior to placement in the superstructure and saves money through reuse of the precasting formwork. Surface finishing works, such as texturing, sandblasting, painting, and coating can be performed on the ground level without scaffolding when the segments are still accessible from all sides prior to installation in the superstructure. Another major advantage mentioned by is that the complete casting of the superstructure can be removed from the critical path of the overall construction schedule, since superstructure segments can be precast during construction of the substructure. Assembly of the bridge superstructure takes much less time than cast-in-place construction, as precast segments do not need to cure on site before being prestressed together. Through the early casting of segments material properties are also influenced positively. As segments are usually stored at the precasting yard or on site for a while the concrete will have gained more strength until installation than cast-in-place elements have when being loaded. The time-dependent effects of concrete shrinkage and creep will occur with reduced extent because of the increase age of the concrete segments and will cause smaller deflections of the superstructure than with cast-in-place construction.

However, cost for the precasting yard, storage, transportation, and installation of precast segments needs to be evaluated in comparison with cost for the form travelers for cast-in-place construction to achieve an economical solution. The precasting yard requires investment in equipment. Adjustable formwork to form the bridge geometry and alignment needs to be installed. Lifting equipment is also required to put the segments into the storage area and later load them on truck to be hauled to the construction site.

1.4.1 Precast Sequence
Metal casting bed according to the shape and design of the bridge segment will be constructed at the precast factory. Reinforcement bars were preassembled into reinforcement cages and then put in the casting bed by lifting crane. Pre-tensioning strands are stressed prior to concrete placement. After concrete placement and consolidation with vibrators the segment was screeded and given a surface finish before the curing shed was set up over the casting bed. The freshly cast segments were steam cured in a movable shed covering the casting bed formwork. The pretensioning strands were released by cutting them, quality control and testing of concrete samples was performed, and internal formwork units were removed from the new segment. The new segment is then rolled out of the formwork. Cleaning of the casting bed and internal formwork will be done and the casting cycle of the next segment starts.
Launching Girder
Launching girders are widely used to place precast segments. Limited access under the cantilever and great height of bridge superstructures above ground are reasons why launching girders would be widely used. They are very feasible for bridges with several spans, as due to their length they can be advanced over gaps that are still to be bridged. During construction they are moved forward on rails whenever a major part of the bridge superstructure has been completed. Launching girders, also called launching gantries, are large trusses that are placed longitudinally on the bridge superstructure. One or more movable crane devices for transportation of the precast segments can be attached to them, running along the chords of the girders. Precast segments are delivered to the girder by special heavy-duty vehicles.

Launching girder trusses can have triangular or rectangular cross-sections and can be constant in depth or higher towards the middle. They can be disassembled into parts that are connected with high-strength friction bolts for transportation, very similar to tower crane booms. Most launching girders are overhead trusses that have three leg supports. The three legs are called rear, central, and guide leg. Some of these legs, often the guide leg, are not permanently fixed to the girder to allow the advancing movement as will be described below. Very often these legs form a bent above the superstructure, leaving space for the precast segments that are turned 90° sideward to be moved through the gap. Pivoting the whole launching girder around the rear support leg accommodates bridge superstructure curves in the horizontal plane.

1.5.1 Launching Girder, Balance Cantilever
Construction of the bridge superstructure with a launching girder by Balance Cantilever method is longer. Launching girder rests with its rear leg above a previous pier and with its central leg above a free pier. It is easily possible to also support it at the guide leg once the third pier segment has been placed. Placement of the segments will then proceed on both sides of the pier segment in the middle of the girder. To speed up construction, the girder can be equipped with two crane devices to place segments on both sides simultaneously. After the remaining gap in the superstructure has been closed and the cantilever has grown into the next span, the girder is advanced one complete span. Hence, in our construction, launching girder is mainly used in building bridges.
1.6 Lifting Frame, Balance Cantilever
Lifting frames are self-contained and incorporate safe unobstructed working platforms and accesses to all necessary locations. Lifting frames can operate independently. The frames usually provide both lifting and self-launching mechanisms. Lifting frames require relatively simple temporary works. They can lift large segments with very high rate of erection.
1.7 Crane, Balance Cantilever
Cranes and barges are also very commonly employed to place precast segments as they are generally readily available in the market. When site and ground conditions are suitable, this method of erection has proved highly effective and can facilitate considerable rates of work. In order to balance the weight of both arms of the cantilever superstructure the segments will be about equally placed at both ends. Actual placement of new segments will hardly proceed exactly at the same times. Therefore the pier can undergo overturning bending moments and needs to be designed accordingly. Temporary towers with vertical prestressing or counterweights can provide additional support.

Route 8 - Nam Wan Tunnel and West Tsing Yi Viaduct (2003-2008)

1.8 Launching Girder, Span-by-span
The span-by-span erection method is to assemble the segments for a span in a set, which is then aligned, stitched, and longitudinally post-tensioned together to make a complete span; all are assembled on the erection girder. The launching girder used is about a span long with two cross beams. After advancement, the girder rests with its rear cross beam on the previous pier and its fore cross beam on the next pier. Between these two piers, the superstructure segments of the midspan will be lifted and placed to filling up the before advancing the girder to the next pier. Afterwards, the construction process repeats for erecting the next span. Unlike span-by-span on falsework erection method, this method will not obstruct existing traffic condition.
1.9 Span-by-span on Falsework
The span-by-span on falsework erection method, on the contrary, is to assemble the segments for a span all are assembled on falseworks. The segments can be lifted in place by a heavy-duty crane. Finally, post-tensioning would be performed to link all the segments together to form a complete span. The structure became self-supporting after casting of the closure joints with the pier segments. However, the massive falseworks will obstruct activities and traffic underneath.

1.10 Launching Girder, Whole-span
Whole-span or full-span deployment is similar to the span-by-span method. The main difference is the whole span of segment is produced and prestressed in the production yard. Whole span will be transport to site and lifted in position in full. However, due to the limited traffic system in Hong Kong, whole span launching technique does not appear in Hong Kong construction.

1.11 Precast Beams
A beam bridge, in general, is a bridge built of beams placed on bridge abutments and foundation piers. In turn, a bridge deck is built on top of the beams in order to carry traffic. The concrete beams can be I-beam shape or U-beam shape. The concrete beams can be either prestressed cast concrete or post-tensioned, and be place in place by either launching girders or cranes using similar technique.
1.12  Stitching
Precast segments have joints that require special attention. An epoxy agent is usually applied to the joint faces shortly before putting a segment into its location in the superstructure. Joints are usually only a few millimeters thin. In the finished structure the hardened epoxy seals the joints against moisture and thus additionally protects the tendons in their ducts. Furthermore, the epoxy is able to transmit compressive forces and shear forces. The epoxy agent can reach a higher final strength than the concrete itself.
1.13 Stressing/Post-tensioning

Post-tensioning denotes the method of stressing the tendons only after the concrete has reached a specified strength. To allow for the necessary movement of the tendons inside the concrete they are installed in tendon ducts that are made from steel or polyethylene. The ducts need to be fixed to the normal reinforcement to prevent misalignment during casting. After post-tensioning the ducts are filled with cement grout under pressure for and protection against corrosion of the tendons. Grouting the ducts will introduce bond between the steel and the surrounding grout.