BRIDGE ERECTION MACHINES

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Contents

Summary

Bridge industry is moving to mechanized construction because this saves labor, shortens project duration and improves quality. This trend is evident in many countries and affects most construction methods. Mechanized bridge construction is based on the use of special machines.

New-generation bridge erection machines are complex and delicate structures. They handle heavy loads on long spans under the same constraints that the obstruction to overpass exerts onto the final structure. Safety of operations and quality of the final product depend on complex interactions between human decisions, structural, mechanical and electro-hydraulic components of machines, and the bridge being erected.

In spite of their complexity, the bridge erection machines must be as light as possible. Weight governs the initial investment, the cost of shipping and site assembly, and the launch stresses. Weight limitation dictates the use of high-strength steel and designing

for high stress levels in different load and support conditions, which makes these machines potentially prone to instability.

Bridge erection machines are assembled and dismantled many times, in different conditions and by different crews. They are modified and adapted to new work conditions. Structural nodes and field splices are subjected to hundreds of load reversals. The nature of loading is often highly dynamic and the machines may be exposed to impacts and strong wind. Loads and support reactions are applied eccentrically, the support sections are often devoid of diaphragms, and most machines have flexible support systems. Indeed such design conditions are almost inconceivable in permanent structures subjected to such loads.

The level of sophistication of new-generation bridge erection machines requires adequate technical culture. Long subcontracting chains may lead to loss of communication, the problems not dealt with during planning and design must be solved on the site, the risks of wrong operations are not always evident in so complex machines, and human error is the prime cause of accidents.

Experimenting new solutions without the due preparation may lead to catastrophic results. Several bridge erection machines collapsed in the years, with fatalities and huge delays in the project schedule. A level of technical culture adequate to the complexity of mechanized bridge construction would save human lives and would facilitate the decision-making processes with more appropriate risk evaluations.

1. Introduction to Bridge Construction Methods

Every bridge construction method has its own advantages and weak points. In the absence of particular requirements that make one solution immediately preferable to the others, the evaluation of the possible alternatives is always a difficult task.

Comparisons based on the quantities of structural materials may mislead. The technological costs of processing of raw materials (labor, investments for special equipment, shipping and site assembly of equipment, energy) and the indirect costs related to project duration often govern in industrialized countries. Higher quantities of raw materials due to efficient and rapid construction processes rarely make a solution anti-economical.

Low technological costs are the reason for the success of the incremental launching method for PC bridges. Compared to the use of ground falsework, launching diminishes the cost of labor with similar investments. Compared to the use of an MSS, launching diminishes the investments with similar labor costs. In both cases launching diminishes the technological costs of construction and even if the launch stresses may increase the quantities of raw materials, the balance is positive and the solution is cost effective.

The construction method that comes closest to incremental launching is segmental precasting. The labor costs are similar but the investments are higher and the break-even point shifts to longer bridges. Spans of 30-50m are erected span-by-span with overhead or underslung launching gantries. Longer spans are erected as balanced cantilevers: self-launching gantries reach 100-120m spans and lifting frames cover longer spans and curved bridges.

Heavy self-launching gantries are used for macro-segmental construction of 90-120m spans. Span-by-span erection of macro-segments requires props from foundations. Balanced cantilever erection involves casting long deck segments under the bridge for strand jacking into position. Both solutions require high investments.

On shorter bridges, prefabrication is limited to the girders and the deck slab is cast in-place. Precast beams are often erected with ground cranes. Sensitive environments, inaccessible sites, tall piers, steep slopes and inhabited areas often require assembly with beam launchers, and the technological costs increase.

LRT and HSR bridges with 30-40m spans may be erected by full-span precasting. The investment is so high that the break-even point is reached with hundreds of spans. The precasting plant delivers 2-4 spans per day for fast-track construction of large-scale projects. Optimized material and labor costs add to the high quality of factory production. Road carriers and ground cranes may erect four single-track U-girders (two LRT spans) every night. Heavy carriers with underbridge and gantries fed by SPMT's are the alternatives for ground delivery of HSR spans. Precast spans longer than 100m have been erected with floating cranes.

Medium-span PC bridges may also be cast in-place. For bridges with more than two or three spans it is convenient to advance in line by reusing the same formwork several times, and the deck is built span-by-span. Casting occurs in either fixed or movable formwork. The choice of equipment is governed by economic reasons as the labor cost associated with a fixed falsework and the investment requested for an MSS are both considerable.

Starting from the forties, the original wooden falsework has been replaced with modular steel framing systems. In spite of the refined support structures, labor may exceed 50% of the construction cost of the span. Casting on falsework is a viable solution only with inexpensive labor and small bridges. Obstruction of the area under the bridge is another limitation.

An MSS comprises a casting cell assembled onto a self-launching frame. MSS's are used for span-by-span casting of long bridges with 30-70m spans. If the piers are not tall and the area under the bridge is accessible, 90-120m spans can be cast with 45-60m MSS's supported onto a temporary pier in every span. Repetitive operations diminish the cost of labor, the quantities of raw materials are unaffected, and quality is higher than that achievable with a falsework.

Bridges crossing inaccessible sites with tall piers and spans up to 300m are cast in-place as balanced cantilevers. When the bridge is short or the spans exceed 100-120m the deck supports the form travelers. Overhead travelers are preferred in PC bridges while underslung machines are used in cable-stayed bridges and cable-supported arches. With long bridges and 90-120m spans, two longer casting cells may be suspended from a self-launching girder that also balances the cantilevers during construction.

2. Main Features of Bridge Erection Machines

The industry of bridge erection machines is a highly specialized niche. Every machine is initially conceived for a scope, every manufacturer has its own technological habits, and every contractor has preferences and reuse expectations. The country of fabrication also influences several aspects of design. Nevertheless, the conceptual schemes are not many.

Most beam launchers comprise two triangular trusses made of long welded modules. The diagonals may be bolted to the chords for easier shipping although site assembly is more expensive. Pins or longitudinal bolts are used for the field splices in the chords. New-generation single-girder machines allow robotized welding and have less support saddles and smaller winch-trolleys. 50m spans are rarely exceeded in precast beam bridges.

A launching gantry for span-by-span erection of precast segmental bridges also operates on 30-50m spans but the payload is much higher as the gantry supports the entire span during assembly. The payload of an MSS for in-place span-by-span casting is even higher as it also includes the casting cell, although the nature of loading is less dynamic.

Versatile twin-girder overhead machines comprise two trusses that suspend deck segments or the casting cell and carry runways for winch-trolleys or portal cranes. The field splices are designed for fast assembly and the modular nature of design permits alternative assembly configurations. These machines are easily reusable; however, their weight, labor demand and complexity of operations may suggest the use of more specialized machines on long bridges.

Lighter and more automated single-girder overhead machines are built around a central 3D truss or two braced I-girders. A light front extension controls overturning and a rear C-frame rolls along the completed bridge during launching. Single-girder overhead machines are compact and stable and require ground cranes only for site assembly. Telescopic configurations with a rear main girder and a front underbridge are also available for bridges with tight plan curves.

Underslung machines comprise two 3D trusses or pairs of braced I-girders supported onto pier brackets. Props from foundations may be used to increase the load capacity when the piers are short. A rear C-frame rolling over the completed bridge may be used to shorten the girders. Underslung machines offer a lower level of automation than the single-girder overhead machines and are affected by ground constraints and clearance requirements.

Span-by-span macro-segmental construction requires heavy twin-truss overhead gantries with a rear pendular leg that takes support onto the deck prior to segment lifting. Transverse joints at the span quarters and a longitudinal joint at bridge centerline divide 80-100m continuous spans into four segments. The segments are cast under the gantry with casting cells that roll along the completed bridge and are rotated and fed with the prefabricated cage at the abutment.

Overhead gantries for balanced cantilever erection of precast segments reach 100-120m spans. Compared to span-by-span erection, the payload is lower as no entire span is suspended from the gantry. The negative moment from the long front cantilever and the launch stresses on so long spans govern design. Varying-depth trusses are structurally more efficient while constant-depth trusses are easier to reuse on different span lengths. Stay cables are rarely used in new-generation machines.

Overhead MSS's for balanced cantilever bridges operate in a similar way. Two long casting cells suspended from a self-launching girder shift symmetrically from the pier toward midspan to cast the two cantilevers. After midspan closure and launching to the next pier, the casting cells are set close to each other to cast the new double pier-head segment. These machines can be easily modified for strand-jacking of macro-segments cast on the ground.

The bridge itself can support lifting frames for balanced cantilever erection of precast segments or form travelers for in-place casting. These light machines are used in short or curved bridges, PC spans up to 300m, and cable-stayed bridges. Lifting frames and form travelers permit erection of several hammers at once and different erection sequences than from abutment to abutment, but they require more prestressing and increase the demand for labor and ground cranes.

Carriers with underbridge and heavy gantries fed by SPMT's are used to erect precast spans. Spans are rarely longer than 40m in LRT and HSR bridges and 50m in highway bridges due to the prohibitive load on the carriers and the bridge. Longer spans have been handled with floating cranes when the bridge length permitted amortization of such investments.

3. Beam Launchers

The most common method for erecting precast beams is with ground cranes. Cranes usually give the simplest and most rapid erection procedures with the minimum of investment, and the deck may be built in several places at once. Good access is necessary along the entire length of the bridge to position the cranes and deliver the girders. Tall piers or steep slopes make crane erection expensive or prevent it at all.

The use of a beam launcher solves any difficulty. A beam launcher is a light self-launching machine comprising two triangular trusses. The truss length is about 2.3 times the typical span but this is rarely a problem as the gantry operates above the deck (Figure 1). Beam launchers easily cope with variations in span length and deck geometry, plan curvatures and ground constraints. Crossbeams support the gantry at the piers and allow transverse shifting to erect the edge beams and to traverse the gantry for launching along curves.

Two winch-trolleys span between the top chords of the trusses and lodge two winches each. The main winch suspends the beam and a translation winch acting on a capstan moves the trolley along the gantry. A third trolley carries an electric generator that feeds gantry operations. When the beams are delivered at the abutment and the vertical movements are therefore small, the main winches may be replaced with less expensive long-stroke hydraulic cylinders.

Figure 1. 102m, 90ton launcher for 45m, 120ton beams (Comtec)

A beam launcher operates in one of two ways depending on how the beams are delivered. If the beams are delivered on the ground, the launcher lifts them up to the deck level and places them onto the bearings. If the beams are delivered at the abutment, the launcher is moved back to the abutment and the winch-trolleys are moved to the rear end of the gantry. The front trolley picks up the front end of the beam and moves it forward with the rear end suspended from a straddle carrier. When the rear end of the beam reaches the rear winch-trolley, the trolley picks it up to release the carrier.

The longitudinal movement of the gantry is a two-step process. Automatic clamps block the trusses to the crossbeams and the winch-trolleys move the beam one span ahead; then the winch-trolleys are anchored to the crossbeams, the blocks are released and the translation winches push the trusses to the next span. Redundancy of anchorages is necessary in both phases for safe launching along inclined planes. The sequence can be repeated many times so when the beams are delivered at the abutment, the gantry can place them several spans ahead. When the bridge is long, moving the gantry over many spans slows the erection down and may be faster to cast the deck slab as soon as the beams are placed and to deliver the next beams along the completed bridge.

Truss deflections at landing at the piers are recovered with alignment wedges. The alignment force is small but the support saddles must be anchored to avoid displacements or overturning. Realignment may also be achieved with long-stroke cylinders that rotate arms pinned to the tip of the truss. Similar devices are also applied to the rear end of the gantry to release the support reaction when launching forward and to recover the deflection when launching backward.

New-generation single-girder launchers are based on two braced I-girders. The main girder is less expensive than two triangular trusses due to robotized welding, the winch-trolleys are smaller, the number of support saddles halves, and the crossbeams are shorter. Lightened launching noses may be attained with laser-cut windows in the webs to avoid hand welding. A C-frame supports the rear end of the gantry and allows the beams to pass through when delivered along the completed bridge. The C-frame is not necessary when the beams are delivered on the ground as the launcher lifts and shifts them into position within the same span (Figure 2).

Figure 2. 74m, 98ton single-girder shifter for 28m, 60ton beams (Deal)

Crossbeams anchored to the pier caps carry rails for lateral shifting of the gantry. The crossbeams have lateral overhangs for placement of the edge girders and to traverse the gantry for launching along curves. Adjustable support legs located so as not to interfere with the precast beams are used to set the crossbeams horizontal. Some launchers have light service cranes at the ends of the trusses to reposition the crossbeams without any need for ground cranes.

The support saddles comprise bottom rollers that shift laterally along the crossbeam and top rollers that support the truss. Equalizer beams allow the top rollers to cope with the flexural rotations in the truss and the gradient of the launch plane. A vertical pivot connects the two roll assemblies to allow rotations in the horizontal plane. Lateral shifting along the crossbeams is achieved with capstans or light long-stroke cylinders.

Automatic clamps block the trusses to the crossbeams during winch-trolley operations. Launching occurs along inclined planes and breaking of any component of the tow system would leave the gantry unrestrained on low-friction supports. Redundancy of tow systems involves oversizing and slow operations.

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Biographical Sketch

Marco Rosignoli received his Doctorate in Civil Engineering *cum laude* at the University of Ancona (Italy) in 1981. From 1982 to 1997 he served as construction manager, project manager, bridge department lead and technical director with prime European bridge contractors. From 1997 to 2006 he worked as an international free-lance consultant for the design and independent design checking of major bridges and bridge erection machines. He is serving as principal bridge engineer at HNTB Corp. since 2006. Assistant to bridge designers, contractors and owners in 21 countries and 4 continents, expert in bridge design and construction technologies, and international authority on the incremental launching of bridges, Dr. Rosignoli is author of 2 books and 80+ publications on mechanized bridge construction. Author of Chapter 6 of ASBI *Construction Practices Handbook* and member of ASBI Technical Advisory Committee, he has set up and is chairing IABSE working group WG-6 *Bridge Construction Equipment* for the 2009-2013 period.