Self-launching erection machines for precast concrete bridges

Marco Rosignoli

The technological aspects of construction influence the modern bridge industry from the very first steps of design. Entire families of prestressed concrete bridges, such as launched bridges, span-by-span bridges, and balanced-cantilever bridges, take their names straight from the construction method.

Construction of precast concrete bridges with spans ranging from 100 ft (30 m) to more than 600 ft (180 m) is mostly based on the use of self-launching machines. The launching units are complex and delicate structures. They resist high loads on long spans under the same constraints that the obstruction to overpass exerts on the final structure. They are adaptable for reuse on different projects. They must be as light as possible, which involves designing for high stress levels in different load and support conditions, and they are assembled and dismantled many times and reused by different crews.

Little has been written on these machines in spite of their cost, complexity, and sophistication. The present work illustrates the main features of self-launching bridge erection machines and some lessons learned during 27 years of the author's practice in the bridge industry and as an independent design-checker of launching units.

Every construction method for precast concrete bridges has its own advantages and challenges. In the absence of particular requirements that make one solution immediately preferable to the others, the evaluation of the possible alternatives is a difficult task. Comparisons based on the quantities of materials consider only one of the components of the construction cost of a bridge. In industrialized countries, the cost of a bridge is more and more influenced by the processing costs of the materials, such as labor, investments for specialty equipment, delivery and assembly costs for the equipment, and energy.

Editor's quick points

- Precast concrete bridges are frequently built with self-launching erection machines.
- Little has been written about these machines despite their cost, complexity, and sophistication.
- This paper illustrates the main features of self-launching erection machines and presents some lessons learned.

Savings in materials lower the construction cost of a bridge only when they are not achieved with higher technological costs. In other words, greater quantities of materials do not necessarily make a solution uneconomical, provided that the construction process is able to generate low labor costs and to facilitate the amortization of specialty equipment.

A good balance of material costs and technological costs is the reason for the success of the incremental launching method in industrialized countries.[1] Compared with the use of ground falsework, bridge launching diminishes the cost of labor with similar investments in equipment. Compared with the use of self-launching erection machines, bridge launching diminishes the investments in equipment with similar labor costs. In both cases bridge launching diminishes the technological costs, and even if the launch stresses increase the cost of prestressing, the balance is positive and the solution is financially effective.

The construction method that comes closest to bridge launching is segmental precasting.[2] Hundreds of bridges have been built by segmental precasting even though the need for avoiding joint decompression increases the cost of prestressing. However, the investments in specialty equipment are also high, so segmental precasting is typically used for long bridges that allow amortization of precasting facilities and erection machines. On shorter bridges, prefabrication is limited to the concrete girders and the deck slab is cast in place.

Precast concrete segments or girders can be erected with ground cranes if the piers are not tall and the area under the bridge is accessible. Sensitive environments, valleys with steep slopes, tall piers, and inhabited areas often require assembly by launching gantry, and in this case the technological costs increase significantly.

Self-launching erection machines are complex and delicate machines. They resist huge loads on long spans, often the weight of an entire span. Deck erection and self-launching must be compatible with plan and vertical curvatures of the bridge, and the most advanced units are also able to transfer their support systems to avoid the use of ground cranes.

In spite of such complexity, the launching units must also be light. The weight governs the cost of the unit, the delivery and assembly costs, and the launch stresses. Weight limitation dictates the use of high-strength steel and designing for high stress levels under different load and support conditions.

The launching units are reused several times in different conditions and by different crews. The units are modified and adapted to new work conditions, field splices are assembled and dismantled many times, and structural nodes and splices are subjected to hundreds of load reversals. The nature of loading is often highly dynamic and the units may be exposed to impacts and strong wind. The support reactions are often applied eccentrically, the support sections are often devoid of diaphragms, and most units are supported on deformable brackets or cross beams.

Mechanical and hydraulic components interact with the structural components and often govern the stress distribution. The safety of the unit itself depends on complex interactions among mechanical, electrical, hydraulic, and structural components. Indeed, such design conditions are almost inconceivable in a permanent structure subjected to such loads.

Types and features of launching units

The industry of self-launching machines is a specialty niche. Every unit is originally conceived for a scope, every manufacturer has its own technological habits, every contractor has preferences and reuse expectations, and every bridge has its own technical requirements. The length of the bridge dictates the automation level of the equipment, and even the construction country of the unit affects some aspects of design. Nevertheless, there are not many conceptual schemes.

The launching gantries for precast concrete girders comprise two parallel 3-D trusses. Two winch trolleys run along the top chords with the girder suspended underneath, so no cross braces are typically installed between the trusses. The span is relatively short; 150 ft (45 m) spans are rarely exceeded in precast concrete–girder bridges, the design load of the unit is relatively low as the girder is just a small portion of the span, and the winch trolleys operate far from each other as the girder is suspended at the ends. Therefore, these units are light, deformable, and often comprise transportable modules with tubular diagonals welded to the chords and through pins at the field splices.

A launching gantry for span-by-span erection of precast concrete segmental box girders operates on similar spans, 130 ft to 170 ft (40 m to 50 m), but the design load is much higher because the unit supports the entire span during segment assembly and the application of prestress.

The most versatile overhead units comprise two parallel girders that suspend the deck segments and support the runways for one or two winch trolleys. The girders are supported by cross beams and are equipped with truss extensions that control overturning during launching. The winch trolleys operate along the entire unit so the main girders are braced to each other only at the ends. The girders comprise modules joined by pins or bolts, and the modular nature of design often permits different assembly configurations of chords and diagonals. These heavy workhorse units are expensive on long bridges because of their weight, the high labor demand, the complexity of operations, and the need for specific support structures.

Lighter and more automated, custom-designed, single-beam units are often preferred on long bridges. These units are based on one central beam; a light front extension controls overturning during launching, and a rear portal frame is supported by the new span. The front end of the main girder may also be supported by a self-launching beam, and the connection may be pivoted to fit tight plan curvatures. These units are lighter than the twin-upper-beam units and do not require cross beams at the piers; however, they are less versatile and adaptable. These units are also more stable and compact and typically have full self-launch capability.

Two parallel girders are also used in the underslung units. The girders are typically equipped with front and rear extensions that control overturning and are supported on pier brackets. The most advanced units are able to move the brackets to the new pier. Struts from foundations are also used to support the unit in bridges not very high above the ground. In this case, the bridge span can be longer.

A cross beam running along the new span may suspend the rear end of the unit. This diminishes the number of pier brackets needed and shortens the unit. The front ends of the main girders may also be connected with a cross beam sliding along a central self-launching support beam. These units are short and able to operate on tight plan curvatures.

Although the depth of the main girders may cause clearance problems at the abutments or when overpassing highways or railroads and their length is often a problem in curved bridges, the twin-lower-beam gantries for span-by-span precast concrete segmental erection are typically less expensive than the twin-upper-beam units.

The upper-beam units for precast concrete segmental balanced-cantilever erection can be operated on spans that often exceed 350 ft (100 m). Compared with the launching units for span-by-span construction, the design load is less because the segments are handled individually or in pairs and no entire span is suspended from the unit. Top-slab tendons in the deck resist the negative moment generated by the segment weight, and temporary pier locks resist the load imbalance when the deck is not continuous with the pier.

The design-governing load condition for the unit is typically the negative moment from the long front cantilever, so varying-depth trusses are sometimes preferred. Stay cables deviated by an extension tower of the main support frame solve the most critical cases. The load deflections are significant, but this is rarely a problem.

The bridge itself may support lifting frames for precast concrete segmental erection of balanced-cantilever bridges. These light units are cost-effective for short bridges and long spans, though they typically involve longer construction duration. Compared with a launching gantry, these units also permit contemporaneous erection of several hammers and erection sequences that do not require construction from abutment to abutment.

Purpose-designed, multiwheel carriers with self-launching support girders are used for transporting entire precast concrete spans from the casting yard to the assembly location along the completed bridge. The span length rarely exceeds 130 ft (40 m) because of the prohibitive design load for both the carrier and the bridge. Much longer precast concrete spans can be handled with floating cranes when the bridge dimensions permit amortization of such investments.

Launching gantries for precast concrete girders

The most common method for erecting precast concrete girders is with ground cranes. Cranes usually entail the simplest and most rapid erection procedures with the minimum of investment, and the deck may be built in several places at the same time. Good access is necessary along the entire length of the bridge to allow the cranes to be positioned and the girders to be transported and lifted into place, and the bridge should be low to the ground. In the presence of rivers, railroads, highways, or tall piers, crane erection may not be possible. Ground transportation and crane erection of precast concrete girders are often impossible in urban areas.

Ground gantries on tires or rails have been used to lift the girders where level access is available and the deck is very low to the ground. Less versatile than cranes, ground gantries are typically used for erecting long urban viaducts along existing roads. Paired gantries may be necessary for the longest girders to limit the negative moment from long-end cantilevers.

The use of a launching gantry often solves erection difficulties. A launching gantry for precast concrete girders is a light modular structure comprising two parallel trusses with triangular cross sections. The truss length is about 2.3 times the standard bridge span (**Fig. 1**). Light braced frames support the trusses at the piers and allow the longitudinal and transverse movements necessary to place the girders with the due eccentricity and to launch the gantry along curved alignments. The gantry operates without any contact with the deck so the girders for many spans can be placed before casting the deck slab.

Two winch trolleys run along the upper chords of the gantry and lodge two winches each. The main winch suspends the girder, and a smaller translation winch acting on an endless ring cable moves the trolley longitudinally along the gantry. The endless ring cable is anchored to the opposite ends of the unit and is kept in tension by lever counterweights. A third trolley often carries an electric generator that feeds gantry operations. Motorized wheels can also be used for translation. Vertical hydraulic cylinders may replace the main winches when the girders are delivered along the completed deck.

The gantry operates in one of two ways depending on how the girders are delivered. If the girders are delivered at the ground level, the gantry raises them to the deck level and places them onto the bearings. If the girders are delivered at the abutment, the gantry is moved back to the abutment and the winch trolleys are placed at the rear end of the unit. The front trolley lifts the front end of the girder and moves it forward along the unit with the rear end supported on the ground transportation unit. When the rear end of the girder reaches the rear winch trolley, the latter picks it up to release the ground transportation unit.

The longitudinal movement of the gantry is a two-phase process. Initially, the gantry is anchored to a pier and the winch trolleys move the girder one span ahead. Then the winch trolleys are anchored to the pier and their translation systems launch the trusses to the next span. This sequence can be repeated many times so that when the girders 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 down the erection and it may be faster to cast the deck slab as soon as the girders are placed and to deliver the next girders along the completed bridge.

The launching gantries for precast concrete girders are relatively inexpensive and easily adaptable in both length and spacing of the main trusses. They are flexible, so wedge sledges are necessary at the ends of the trusses to recover the elastic deflection during launching. These units are able to cope with variations in span length and deck geometry, and because they are located above the deck, they are generally unaffected by ground-level constraints and the plan curvature of the bridge.

Support frames anchored to the pier caps hold a rail for the lateral movements of the unit. The cross beam of the support frames typically comprises two I shapes connected by horizontal bracing and diaphragms. Box girders are also used in light applications. The cross beams have lateral overhangs to shift the gantry laterally for the placement of the edge girders and to launch the unit when the bridge is curved in plan (**Fig. 2**). The support legs of the pier frames are located so as not to interfere with the girders (Fig. 1). They are adjustable (typically, hydraulic cylinders for geometry adjustment and screw legs for the structural support) to set the transverse rail horizontal when the pier cap is inclined.

Figure 1. This light gantry is used for precast concrete girders. Photograph courtesy of Comtec.

The typical support block for the main trusses comprises a lower group of rolls or skids that move transversely along the support cross beam and an upper group of rolls that support the bottom chord of the truss. A transverse pin connects the two groups of rolls and allows the upper rolls to follow the rotations of the main trusses and the gradient of the launch plane. Some support blocks are equipped with lock systems for the main trusses to avoid involuntary movements of the unit. Most bridges have a longitudinal grade and the gantries are supported on low-friction inclined planes, so the lock systems are critical for the stability of the unit and safety of operations.

Launching gantries for span-by-span erection of precast concrete segmental box girders

Three different techniques can be used for erecting a precast segmental box girder:

- span-by-span assembly
- balanced-cantilever assembly
- progressive placement with the help of temporary stays or props

With the span-by-span method, all of the segments for a span are positioned before the prestressing tendons are installed, and the complete span is lowered onto the bearings. The balanced-cantilever method involves erecting the segments as a pair of cantilevers about each pier, and the segments are prestressed with deck slab tendons that cross the entire hammer. With the progressive placement, a lifting frame or ground crane raises and places the seg-

Figure 2. The edge girder is being placed. Photograph courtesy of Comtec.

ments in one direction from the starting point, passing over the piers in the process. The balanced-cantilever method is mostly used on long spans while long viaducts with shorter spans are better suited to the span-by-span method. Progressive placement is rarely adopted.

Span-by-span erection is used for both simply supported spans and continuous superstructures. The adjacent spans of continuous bridges are joined together with in-place stitches that avoid propagation of the geometry tolerances of short-line segmental match-casting. After the closure pour has hardened, continuity prestressing tendons are installed and tensioned. With span-by-span erection and epoxy joints, a typical 130 ft (40 m) span is usually erected every two or three days. With a twin-lower-beam gantry and dry joints, an erection rate of up to one span per day is achievable.

Span-by-span erection is typically used for spans shorter than 160 ft (48 m). For longer spans, balanced-cantilever erection is often more cost-effective because of the lower cost of the gantry. Progressive placement is usually the most time-consuming erection technique because of the single work location; however, the specialty equipment can be particularly inexpensive, especially when ground cranes can erect the segments along the entire length of the bridge.

Upper- or lower-beam gantries are used in the span-by-span erection to support a complete span of segments, which are pulled together by prestressing bars during gluing of the joints and then by the permanent tendons. The gantry then releases the span onto the bearings and launches itself forward to erect the next span.

A typical twin-upper-beam gantry comprises two parallel trusses or box girders supported on cross beams. The truss units are preferred in high-wind regions and are often lighter, while the box-girder units are more stable and solid. The twin-upper-beam units are easily adaptable to different span lengths, and they are able to cope with variations in deck geometry. Because the main girders are located above the deck, these units are less affected by ground constraints; however, they are more complex to design, assemble, and operate and the units are slower in erecting the segments than an underslung gantry.

Overturning during launching is typically controlled with extension trusses applied to the main girders. The total length of the unit thus becomes about 2.3 times the standard span of the bridge, but this is rarely a problem with overhead units. Cross beams anchored to the piers support the main girders with saddles that permit longitudinal launching and lateral movements of the unit. The support legs of the cross beams are adjustable to ensure that the frame is level. Hydraulic cylinders are used to adjust the elevation, and safety ring nuts lock the cylinders during operation and launching. The cross beams are anchored to the pier cap with prestressing bars that resist uplift forces. The cross beams have lateral overhangs to set the gantry with the appropriate eccentricity **(Fig. 3)** and to launch the unit on curved spans, so significant uplift forces may arise in the anchor systems.

The support rollers comprise a lower group of transverse rolls, which are supported on the cross beam, and an upper group of longitudinal rolls that support the bottom

Figure 3. This shows a twin-upper-beam gantry with support cross beams. Photograph courtesy of NRS.

chord. A transverse pin between the two roll assemblies makes the support adaptable to rotations in the main girders and to launching onto grades. Some support blocks lodge longitudinal lock systems for the unit, and all the support cross beams are typically equipped with transverse lock systems.

The overhead gantries operate in one of two ways depending on how the deck segments are delivered. If the segments are delivered along the completed deck, a winch trolley picks them up at the rear end of the gantry, moves them over the span until reaching the assembly location, and lowers them down to the deck level. If the segments are delivered at the ground level, the winch trolley raises them up to the deck level. Hangers are used to align and hold the segments in position during assembly. After reaching the assembly location, the segments are hung from the main girders and the winch trolley is released for a new cycle. To avoid interference with the hangers of the previously placed segments, the segments are moved out with the long side in the longitudinal plane of the bridge. The segments are rotated 90 deg just before suspension with a special hook that is able to hydraulically turn the segment.

Typically, all of the segments for the span are suspended from the gantry before the joints are glued so that no additional truss deflections can occur. Epoxy is applied to groups of segments that are then pressed together with temporary clamping bars. The permanent tendons are usually tensioned from a stressing platform attached to the front segment.

The lightest gantries may be launched with winches, such as those units for precast concrete girders. Typically, however, long-stroke hydraulic cylinders lodged into the support saddles and acting against racks anchored to the main girders are used to push the unit forward. Twin cylinders are often used so that one cylinder anchors the unit during repositioning of the adjacent cylinder. **Figure 4** shows the launch cylinders of a twin-lower-beam gantry in the raised configuration for segment assembly. Lowering the support jacks releases the span onto the launch bearings in one operation.

Single-upper-beam gantries may also be used for span-by-span precast concrete segmental erection. In these units, the carrying structure is a longitudinal girder that is supported at the front pier of the span to be erected and at the rear pier (in the case of simply supported spans) or on the front overhang of the completed deck (in the case of a continuous bridge). The main girder may comprise two braced trusses or plate girders, or it may be a triangular truss with one upper chord and two bottom chords. A winch trolley runs along the unit and moves the deck segments to the assembly locations.

Figure 4. The launch cylinders of a twin-lower-beam gantry are shown in the raised configuration for segment assembly.

A light front extension typically controls overturning during launching. The rear end of the unit is supported by the completed span. No rear nose is necessary, so these units are shorter than a typical twin-upper-beam gantry and are more adaptable to curvatures in the bridge. The main girder is stiffer than two parallel trusses, and its support systems are also stiffer.

Lateral bracing connects the trusses or plate girders along their entire length (**Fig. 5**). Lateral bracing typically includes cross beams between the flanges or chords, connections designed to minimize displacement-induced fatigue, and sufficient flexural stiffness to resist vibration stresses. Cross frames connected to the flanges or chords at the same locations of lateral bracing distribute torsion and provide transverse rigidity. Connections are often designed to develop member strength.

The gantry supports an entire span, so the main girder is heavily stressed. The units for the heaviest spans are sometimes equipped with prestressing or stay cables, though this complicates and slows the operations and increases labor demand. Truss gantries are preferred in this case for better control of buckling and simpler structural nodes at the anchor points of stay cables.

Figure 5. Lateral bracing of a single-upper-beam gantry in a movable scaffolding system configuration connects the plate girders along their entire length.

Special support devices are necessary to launch the unit when the front support frame is integral with the main girder. Launching is typically achieved by friction, taking advantage of the support reaction that the main girder applies to the launcher. **Figure 6** shows a typical friction launcher assembled onto a support tower. A support box is located underneath each bottom flange or chord of the main girder. A hydraulic cylinder moves the box longitudinally along the low-friction surface of a pivoted arm, and two jacks at the opposite ends of the arm lift and lower the main girder. The working sequence is as follows:

1. The vertical jacks lower the unit onto the support boxes.

2. The thrust cylinders push the support boxes forward, and the thrust force is transferred to the main girder by friction.

3. When the launch cylinders reach the limit stop, the jacks lift the unit and the support boxes may return idle to the initial position to start this cycle again.

The friction launchers are typically pinned to the support towers to allow rotations when launching along curved alignments. Low-friction surfaces between the support tower and the base frame also allow lateral shifting (Fig. 6). These geometry-control systems are equipped with sliding clamps so that the entire assembly can be suspended from the main girder (**Fig. 7**). Figure 7 shows the two friction launchers of the unit suspended from the front overhang. The rear support of the gantry is an adjustable frame that runs along the completed span. Horizontal hydraulic cylinders control the transverse alignment of the frame when launching along curved spans, and vertical cylinders control the support reaction that the frame transfers to the deck.

Upon completion of span erection, the rear launcher is moved backward to the front pier or overhang. In the first phase of launching, the unit is typically supported at the rear launcher and at the rear support frame. When the front end of the unit reaches the next pier, the pier-cap segment and the front launcher are positioned for launch completion. A front support leg typically controls overturning during this operation. At the end of launching, the two launchers are suspended from the front overhang and a new span can be erected with the unit supported at the main frame and the rear portal frame.

Refined single-upper-beam machines have been designed for erecting precast concrete segmental box girders with tight plan curvatures. In the unit of **Fig. 8**, the winch trolley is suspended from the bottom flanges and the deck segments are delivered on the ground or along the completed deck through the rear support frame. To accommodate tight plan curvatures, the gantry comprises two elements: a rear main girder and a front support beam. A turntable with hydraulic controls for translation and vertical and horizontal rotations connects the main girder to the support beam. During launching, the turntable pulls the main girder along the support beam. When the front support frame has reached the front pier, the support beam is launched forward to clear the area under the main girder for assembly of the new span.

Many precast concrete segmental bridges have also been erected with underslung gantries. These units are positioned beneath the deck with the two trusses or box girders on opposite sides of the pier, and the gantry supports the segments under the lateral overhangs. The unit is typically supported on pier brackets or props from foundations. When the deck is low to the ground, midspan props may be used to increase the operating span of the unit.

When overturning is controlled with front and rear extensions, the length of the unit is more than twice the typical span length. A central front launching beam may be used in curved bridges to support the main girders in combination with a rear support frame running on the completed deck. This type of gantry is a telescopic assembly of a central support beam and two lateral girders that support the segments. This solution requires a particular design of the pier head to create the launch clearance for the support beam.

The segments are placed onto the gantry with a crane or lifting frame. When the segments are delivered through the completed deck, the lifter is placed at the rear end of the gantry. When the segments are delivered on the ground, the crane is placed at the front end of the gantry. The segments are placed onto the gantry close to the lifter and are moved along the gantry to the assembly position with rollers. Upon completion of assembly and application of prestress, the gantry lowers the span onto the bearings.

Underslung gantries are simple to design, assemble, and operate. Segment erection is fast, and props can be used to extend the operating span when working low to the ground. However, these units are not suitable for decks on a tight horizontal curve. Vertical hinges in the main girders have been used though the joints are heavily stressed and the units are more complex to operate.

The underslung gantries also project beneath the deck, which may cause clearance problems when passing over existing roads or railroads and difficulties in the end spans because the abutment walls are broader than the piers. This problem is typically solved by assembling the rear launching noses after erecting the first span and launching the unit to the second span. The front nose is also dismantled before launching the unit to the last span. The abutment walls must also be taller than the total depth of the unit so as not to prevent operations in the first and last span.

Figure 6. A friction launcher is assembled onto a support tower.

The length and weight of the precast concrete segments for box-girder bridges are usually governed by handling and transportation requirements. Lengths up to 12 ft (3.6 m) are often transportable on public roads without excessive restrictions. If the precasting plant is close to the erection site and no transportation restrictions exist, the segments are made as long as practical, but they rarely exceed lengths of about 14 ft (4.3 m).

To further increase the segment dimensions, a box girder may be divided transversely into two halves to be joined with in-place stitches in the two slabs. The girder may also be divided into a pier-cap segment and a midspan segment

Figure 7. The friction launchers are suspended from the main girder.

Figure 8. This is the pivoted single-upper-beam gantry for curved precast concrete segmental bridges. Photograph courtesy of Deal.

Figure 9. This heavy twin-upper-truss unit is for precast concrete macrosegmental erection.

with in-place stitches at the span quarters. A macrosegmental span thus typically comprises four precast concrete segments.

The macrosegments are transported longitudinally. The segment length rarely exceeds 150 ft (45 m), so the maximum span length of the span-by-span macrosegmental bridges is about 300 ft (90 m). In this case, the deck typically has varying depth. The segment weight is excessive for ground cranes and also for most gantries for balanced-cantilever construction, so special twin-upper-beam units are used for macrosegmental erection (**Fig. 9**).

The segments are transported along the completed deck. The length and weight of the segments are such that the gantry cannot rotate them, so the segments are delivered with their final alignment. The complexity of the operations and the cost of gantry are such that macrosegmental construction is typically used for long parallel bridges low to the ground. The four macrosegments for a span can thus be supported on temporary towers at the front span quarter before stitching and completion of prestressing. The rear ends of the midspan segments are typically suspended from the front overhang of the completed deck.

The launching gantries for macrosegmental construction are subjected to specific design constraints. The segments are very heavy, with the pier-cap segment typically heavier than the midspan segment, and their weight may exceed 1500 kip (6.5 MN). The length and weight of segments prevent their being picked up from cantilever sections of the gantry. Therefore, a rear pivoted leg is necessary. Compared with a gantry for balanced-cantilever construction, however, the front cantilever is shorter, so the total length of the unit is similar. The pier-cap segments are inserted longitudinally between the pier and the front support cross beam, so the latter is supported on tall braced columns (Fig. 9). The segments are also moved laterally, which requires shifting the gantry along the support cross beams and also shifting the winch blocks along the winch-trolley cross beams to reach the maximum eccentricity. Overloading the main trusses is increased further in curved bridges.

The design-governing loading condition typically occurs during handling of the pier-cap segment. This segment is heavier and it is suspended at the center because it is designed for negative moment, so the two winch trolleys work closely to each other and loading of the main trusses is localized (Fig. 9). The segment weight is also unevenly distributed between the winch trolleys to control overturning during insertion under the front support cross beam. The lighter midspan segments are suspended at the ends so that the winch trolleys work far from each other, and the load displacement along the gantry is also shorter.

The main trusses and the support cross beams are heavy, so the launch stresses are also demanding on such long spans. The weight of cross beams discourages crane erection, and the gantry is typically able to reposition its supporting systems. In this case, the unit has four support points:

- two main cross beams
- a front arm used during transfer of the front cross beam to the next pier
- the pivoted rear leg, which is lowered behind the macrosegment after its insertion under the gantry

The cross beams are moved forward with the winch trolleys. Both cross beams usually lodge hydraulic cylinders for the launch of the main trusses. The launch of a twin-upper-beam gantry for macrosegmental construction is a complex operation because these units are heaviest and the load that they transfer to the bridge requires precise support locations. Control of overturning may require placing the winch trolleys at the rear end of the unit and suspending counterweights, which further increases the launch stresses and generates specific conditions of out-of-plane buckling.

Figure 10. This long twin-upper-beam gantry is used for balanced-cantilever erection. Photograph courtesy of HNTB archive.

Launching gantries for balanced-cantilever construction

Balanced-cantilever erection is a construction method well suited to precast concrete segmental bridges. The deck is erected from each side of the pier in a balanced sequence to minimize the load imbalance on the pier. This method is particularly advantageous on long spans and where access beneath the deck is difficult.

Segment assembly with ground cranes or lifting frames permits free erection sequences, while the use of a launching gantry requires that the deck be erected from one abutment toward the opposite one; however, this permits delivering the segments along the completed deck and does not require having access to the area under the bridge.

Balanced-cantilever bridges usually have box-girder sections.[3] Ribbed slabs have also been built in the past; nowadays they are used almost only for cable-stayed bridges, where most of the negative moment is resisted by the stay cables. The deck can have constant or varying depth. Constant-depth decks are easier to build, but they are competitive in a narrower range of spans, 200 ft to 230 ft (60 m to 70 m). It is possible to erect a 130 ft (40 m) precast concrete segmental span with epoxy joints in 3 days, while spans of 330 ft (100 m) typically take from 7 to 12 days to erect.

In a precast concrete segmental bridge, the pier-head segment should have the same weight as the other segments so as not to require special lifting devices. The segment contains a thick support diaphragm (the bearings are usually eccentric with respect to the webs because of their dimensions) and the bottom slab is also thick because of the longitudinal compression forces from the cantilevers, so the pier-head segment is usually very short. This also facilitates its placement because the gantry also must be supported at the pier. Sometimes it is necessary to transfer some bending to the piers by means of two parallel lines of bearings. Full continuity can also be achieved by casting the pier-head segment in-place with through reinforcement from the pier.

The most common methods for precast concrete segmental balanced-cantilever erection are with ground cranes or launching gantries. Ground cranes require access to the deck along the entire length of the bridge. Ground improvement may also be necessary. Cranes usually give the simplest and most rapid erection procedures with the minimum of temporary works. Cranes are also readily available, and multiple cantilevers can be erected at once. The main constraint on crane erection is access because balanced-cantilever bridges are often selected in response to inaccessible terrain.

Lifting frames operating on the deck are sometimes used on tall piers or cable-stayed bridges. They are also selected to use over water, where a custom-built system can accommodate heavier segments. The pier-head segment is cast in place to establish a platform on which one or two lifting frames are secured. An auxiliary frame may also be used to lift the pier-head segment and then the main lifting frame. When a single lifting frame is used, the unit is moved from one side of the pier to the other to lift the segments in turn. Some lifting frames are able to pick up the segment at the base of the pier and to move it along the cantilever. Using a pair of lifting frames, one on each cantilever, simplifies the erection process. Unless the bridge is very high off the ground, lifting frames are used less than ground cranes because of their cost and relative slowness and the disruption when moving to the next pier.

Launching gantries can speed erection rates, and when the segments are delivered along the deck, site disruption beneath the deck is minimized. They are suited to building over rivers or other obstructions, though they are limited to erecting the deck in a sequential manner and are delayed if problems occur at any pier or span. Both single- and twin-upper-beam units can be used. The gantry takes support at the front pier of the span to be erected and on the front overhang of the completed deck (**Fig. 10**).

The earliest gantries were slightly longer than the span to be erected. The length was sufficient to span between the front overhang of the completed deck and the next pier, and minimizing the distance between the supports resulted in a lighter gantry. Disadvantages of short gantries include overloading the front deck overhang and the complexity of placement of the pier-head segment and of the launching operations. The length of the most recent gantries is typically twice the span length. These units take support onto the piers, and the higher cost of the gantry is offset by less reinforcement and prestressing along the entire length of the bridge. Placement of the pier-head segment and launching are also simplified.

One or two winch trolleys transport the segments to the assembly location. If the segments are delivered along the completed deck, the winch trolley picks them up at the rear end of the gantry and moves them out over the span. If the segments are delivered at the ground level or on barges, the winch trolley raises them up to the deck level.

A typical sequence for gantry erection is as follows:

1. The gantry places the pier-head segment onto the next pier. At this stage, the front support frame of the gantry is on the pier and the central and rear support cross beams are on the completed deck.

Figure 11. This single-upper-truss gantry is equipped with a deviation tower. Photograph courtesy of HNTB archive.

2. The gantry moves its central support cross beam forward onto the pier-cap segment.

3. The gantry is launched forward until it is sitting symmetrically above the pier.

4. After the gantry is anchored, the deck segments are picked up and moved into position. New segments are placed on either side of the pier and fixed with epoxy, temporary joint clamping bars, and top-slab tendons.

5. When the two cantilevers are completed, aligned, and locked to each other, a 1 ft to 2 ft (0.3 m to 0.6 m) in-place closure segment is cast at midspan. Bottom-slab tendons are installed across the joint to complete the connection.

The pier-head segment is typically placed on temporary supports while it is set to the correct alignment. When the deck is supported on one line of bearings, the cantilevers are stabilized with temporary lock systems. Props and tie-downs from foundations are used with short piers. For taller piers, stability is achieved with brackets or tie-down arrangements comprising hydraulic jacks and vertical prestressing bars. The temporary pier-head lock systems are typically designed for a maximum of one segment out of balance. Sometimes two segments are erected simultaneously on either side of the pier to reduce the load imbalance, though this requires gantries equipped with two winch trolleys. In some cases the gantry itself has been used to stabilize the cantilevers.

Single-upper-truss gantries are sometimes equipped with a deviation tower at the central support and symmetrical stays that relieve the stresses in the truss (**Fig. 11**). The rear support leg is typically close to the rear pier to diminish the stresses in the front deck overhang. This solution is sometimes also adopted for span-by-span erection. In this case, the deviation tower is placed at the rear pier and the cable-stayed truss suspends the entire span.

The deviation tower is integral to the main support legs and the truss. In the transverse plane, the tower is an A-frame with the anchor section of stay cables at the top, the truss at the middle, and two support legs that allow the precast concrete segments to pass through. A base cross beam often resists the horizontal forces generated by the leg inclination. Truss towers and legs may be used to enhance rigidity.

A single plane of cables is generally preferred. The use of numerous small cables facilitates their anchoring, and a fan layout simplifies pull adjustment from a work platform. A single support plane results in high torsion in the main truss, however, so a few cables may be anchored to the bottom chords to provide a torsional restraint. The winch trolleys are typically suspended from the bottom chords; H-shapes are used for the chords, and the wheels run onto the bottom flange. The field splices in the chords are arranged with longitudinal bolts above the upper flange and below the bottom flange to permit the wheels to pass through.

Figure 12. Strand-jack lifting of macrosegments is used for balanced-cantilever construction. Photograph courtesy of Thyssenkrupp.

Macrosegmental construction is also compatible with balanced-cantilever erection of long deck segments delivered on the ground. The weight of segments suggests strand jacking for lifting as in **Fig. 12**. The segments are connected with in-place stitches with through reinforcement, and after application of prestressing the two segments are released and the unit is ready for lifting another pair of segments. This type of launching units can easily be adapted to in-place casting (the lifting platforms are replaced with shifting casting cells) and vice-versa.

The use of these heavy lifting units is suitable for spans up to 350 ft to 400 ft (100 m to 120 m) and rectilinear or slightly curved bridges of adequate length. The length of the girders is about 1.3 times the maximum span length. Despite their cost, these units offer many advantages. The girder provides easy access to the work locations from the completed deck for workers and materials. If the deck is supported onto bearings, the girder balances the cantilevers without the deck being temporarily anchored to the pier. This balancing action is also useful when the deck is continuous with the piers and the piers are tall and slender.

Wheeled carriers for full-span precasting

Several major bridges have been built with concrete spans entirely cast off-site and transported into place. Box girders are well suited to highway and railroad bridges, while U-girders are used only for railroad bridges, where they meet structural and noise-containment requirements. Truss box girders with one or two railroad tracks on the bottom slab and a roadway on the top slab have also been entirely precast.

Full-span precasting results in rapid bridge construction and repetitive casting processes in factory conditions. The precast concrete units may be longer than 330 ft (100 m) when floating cranes are used for placement. Ground transportation is rarely adopted for spans longer than 170 ft (50 m).

The precasting plant is usually located near the bridge site to facilitate the transfer of the units. The units are removed from the forms as soon as the concrete has reached the required strength and are stored on temporary foundations for completion of prestressing, application of bearings, and finishing. The units are moved around the precasting plant and storage areas with heavy gantries or wheeled carriers. Rail-mounted gantries are often simpler to operate, while wheeled carriers provide more flexibility. The reinforcement cage is typically prefabricated complete with bulkheads and inserted into the casting cell by the heavy lifters (**Fig. 13**).

For viaducts over land, the spans are transported along the completed deck with special multiwheel carriers. The carrier of **Fig. 14** was custom designed for erecting 755 spans. After transporting the 1660 kip (7.4 MN), 103 ft (31.5 m) span to the front end of the bridge, the front trolley of the carrier moves forward along the 250 ft (76 m) support beam until reaching the lowering position. The support beam is then launched forward to the next span to clear the area under the carrier for lowering the span.

The precast concrete spans are usually placed on bearings to simplify the erection process, but they may be made integral with the piers with in-place concrete connections. The units can also be joined together with in-place concrete stitches to form a continuous structure.

Design loads

The load combinations used in the design of self-launching bridge erection machines are complex because of the dynamic nature of loading. Because most units are designed in Europe, the discussion that follows is based on the FEM-1.001 standard for heavy lifters.[4] The load classifications and combinations can easily be adapted to different standards.

The heavy lifters are grouped into classes in relation to the tasks they perform during their service life. The classifica-

Figure 13. The prefabricated cage for the entire span is being inserted into the casting cell.

Figure 14. This wheeled span carrier has a self-launching support beam for high-speed railway projects.

tion determines the load-amplification factor to be used for the design of the structural components, which varies from γ_C = 1.00 for A1-class units to γ_C = 1.20 for A8-class units. The class of a unit is determined by the expected number of load cycles and the loading level. A load spectrum relates the entity of loading to the number of cycles, and since most load cycles of these units take place at or near the load capacity, the spectral factor is typically high. However, the number of cycles is low, so these machines are often designed as A2-class units with load factor γ_C = 1.02.

A similar classification applies for the mechanical components. The load-amplification factor varies from γ_M = 1.00 for M1-class units to γ_M = 1.30 for M8-class units, and the bridge erection machines are often designed as M2- or M3-class units with γ_M = 1.04 and γ_M = 1.08, respectively. In both cases, the amplification factors are applied to the individual loads, and the results are then processed with the load factors for limit-state assessment prescribed by the design standard.

The structural components are designed for static stresses in the least favorable load conditions, inertial forces generated by vertical and horizontal movements of the load or the unit, and meteorological loads. The design loads are divided into four groups:

- forces that act regularly during the normal operations of the unit
- forces that arise occasionally in the unit in service
- exceptional forces in service and out-of-service conditions
- forces that arise during assembly and dismantling

The regular forces include self-weight, service load, and inertial forces generated by load movements. The structural weight resulting from cross-sectional areas is typically increased by 30% to 40% to account for attached components, such as stiffeners and connections. The accuracy of correction may be checked by weighting modules of the machine during assembly. Concentrated loads represent specific components, such as rollers and electric generators.

Service load includes lifted accessories, such as a gin block, hook, positioning transoms, and suspension bars. Vertical inertial forces derive from the sudden application or removal of the load and from the positive or negative accelerations during the vertical movements. The intervention of the emergency brakes in the case of an electrical blackout may be analyzed with dynamic analysis and assessed like any other service-limit-state (SLS) condition, though the elasticity of such demultiplied ropes diminishes the dynamic response significantly. The longitudinal inertial forces derive from the accelerations or decelerations of the winch trolleys along the runways.

The occasional forces are impacts of the wheels of the winch trolleys against the runways, wind, snow, ice, and thermal differences. The impacts along the runways are often disregarded when the field splices in the rails are welded and grinded away at dismantling. Snow and ice are often disregarded in ordinary weather. FEM-1.001 requires designing the erection machines for temperatures from -4 °F to 113 °F (-20 °C to 45 °C).[4]

The exceptional forces are out-of-service wind, load testing, impacts against end-of-stroke buffers or fixed obstacles, and the design earthquake. Impacts against buffers at the ends of the winch-trolley runways are often disregarded for translation velocity lower than 2.3 ft/sec (0.7 m/sec), provided that the runways are equipped with end-of-stroke switches. The effects are computed in relation to the deceleration imposed on the winch trolley. The static stresses are often increased 25% for linear-spring buffers and 60% for constant-force hydraulic buffers.

The design loads are grouped into three load conditions. Load condition 1 is the normal operational condition, which combines self-weight, superimposed dead load, service load inclusive of vertical dynamic amplification, and service load plus weight of winch trolley multiplied by the longitudinal-dynamic-amplification factor. All of these loads are then multiplied by the load-amplification factor resulting from the classification of the unit. Load condition 2 is the operational condition in the presence of occasional forces. It combines the actions of condition 1 with wind in service, snow and ice, and thermal differences. In the case of strong design wind, the longitudinal dynamic amplification can be different from the value for condition 1 because the action of wind can affect the starting and braking times of the winch trolleys. Load condition 3 is the action of exceptional loads. It considers the following combinations:

- self-weight, superimposed dead load and out-of-service wind
- self-weight, superimposed dead load, service load, and impacts against the end-of-stroke buffers
- self-weight, superimposed dead load, service load and design earthquake
- self-weight, superimposed dead load, wind in service, and assembly and dismantling operations

Although conceptually similar to assembly and dismantling, self-launching is typically assessed in the more demanding condition 2 because of the higher frequency of these operations. Load testing typically requires specific checks when the static test load is greater than 140% of the design load or the dynamic test load is greater than 120%.

Both SLSs and ultimate limit states (ULSs) are assessed. SLSs correspond to the loss of functionality of the unit and are related to internal displacements of components or rotations of slip-critical connections. Unit load factors are applied to the three load conditions, and the resistance factors are prescribed by the steel design standard. The ULSs correspond to critical conditions, such as rigid equilibrium, rupture of connections, yielding of structural elements, and local buckling. The three load conditions are handled with progressively lower load factors. According to CNR-10021,[5] for example, it is $\gamma_{LC-1} = 1.50$, $\gamma_{LC-2} = 1.34$, and $\gamma_{LC-3} = 1.20$.

Most design standards do not distinguish between local and global (out-of-plane) buckling, and both conditions may be assessed like any other ULS condition. However, out-of-plane buckling of long sections of compression chords is a riskier event than local buckling of a web panel or a secondary compression member. No post-critical domain exists in most cases, and the critical load is influenced by geometry imperfections that are difficult to detect. It is therefore common practice to assess out-of-plane buckling with higher load factors, $\gamma_{LC-1} = \gamma_{LC-3} \approx 2.5$.

Modeling and analysis

The optimum level of detail for the finite-element (FE) model of a launching unit is always a major concern. The more refined the model, the more accurate the results of analysis. Alternatively, the number of load and support conditions to analyze suggests using simple models to rapidly investigate all of the possible combinations. Simple beam models facilitate the research of the design-governing load conditions and provide the stress magnitude to be expected from more refined analyses as well as the boundary conditions to assign to local models. Afterward, however, the different types of bridge erection machines require specific approaches to FE modeling and analysis.

The twin-lower-girder units are typically supported on stiff pier brackets, and simple beam models often suffice.

Twin-lower-truss units are more complex, and 3-D models are recommended when the pier brackets are flexible or only some of the trusses support the deck segments. Modeling the support structures is also necessary when the unit is supported onto permanent piers and temporary props from foundations as the different flexibility and thermal inertia of supports affect load distribution and buckling factors.

In a single-upper-beam gantry, the front support legs are close to each other to be supported by the pier while the rear legs are distant to feed the assembly area with precast concrete segments through the completed deck. In the presence of so many technological requirements, the structural nodes are so complex **(Fig. 15)** that local 3-D solid models are often necessary. Simple beam models are used to analyze span erection, the deck-gantry interaction at the application of prestress, and self-launching.

When a twin-upper-truss unit is supported by deformable cross beams, analyzing the unit as a single 3-D truss on rigid supports leads to imprecise results. Modeling the entire unit allows for evaluation of the effects of cross-beam deflections.

An ideal truss should fulfill three basic conditions. The members of diagonals and chords are perfectly hinged at the truss nodes. This condition is never respected in a launching unit. The truss nodes are continuous, and when the unit is provided with assembly pins, these are typically located far from the nodes. The loads are applied at the truss nodes. Also this condition is never respected. Technological requirements dictate the location of the suspension points of segments, and the load applied by winch trolleys and support rollers migrates along the chords. The gravity axes of all members converging into a node cross at the geometric panel node. This condition could actually be met, though in most cases the convergence points of the diagonals onto the chords are eccentric to simplify the design of nodes.

Depicting the stresses resulting from these geometry imperfections requires accurate modeling. The model should describe the entire unit—3-D trusses, support cross beams, and support towers. Out-of-node eccentricities and steps in the bending plane at the changes of cross section should be considered, and end offsets should be used to account for the finite size of diagonal and chord intersections.

The reliability of internal releases of degrees of freedom should be critically reviewed. The twin-upper-beam units are often supported on cross beams that are held up by steel towers. The main tower provides the longitudinal restraint, and the secondary tower may be equipped with sliding bearings. Before overcoming breakaway friction, the sliding bearings do not slide at all and thermal expansion of the main girders generates horizontal bending in the cross beams and *P*-delta effects in the support towers. It is therefore necessary to check that the longitudinal stiffness of the support points of the main girders is higher than the breakaway friction of sliding bearings.

Instability of main trusses

Among the factors influencing the stability of a freestanding truss are the degree of fixity at the supports, a support condition prompting the truss to twist as it deflects laterally, the lateral restraint exerted by the inclined diagonals on the compression chords, the location of concentrated loads, and the level of imperfections in the initial geometry of the truss.

In the twin-truss units, these factors coexist and coalesce. The degree of fixity at the supports is low, the truss being supported at the bottom chords on flexible brackets or cross beams with out-of-node eccentricity and without cross diaphragms. The truss bends laterally and twists because of the deflections in the support cross beams, and the height of the truss amplifies the lateral displacements of the upper chord. The truss is typically high and narrow, so the lateral restraint that the inclined diagonals exert onto the upper chord is poor. The winch trolleys run along the upper chord, so the load is applied above the center of shear. Finally, the geometric imperfections may be significant because of the high number of field splices and the tolerances accumulated in second-hand equipment.

The design standards normally recognize two types of instability; the first type is related to the overall sway of the structure (out-of-plane buckling) and the second type is related to deformations of a compression member between its end nodes (local buckling). Out-of-plane buckling can rarely be assessed with bibliographic values of the critical elastic moment in such complex structures. Investigating many buckling modes with complex numerical models involves long computational times, so only the first modes of out-of-plane buckling are typically analyzed numerically, and the local modes are checked with the load-magnification factors prescribed by the design standard.[6]

Linear buckling analysis investigates the stability of a structure under a specified set of loads. The buckling modes depend on the load, and instability must therefore be assessed for different load conditions—that is, by reproducing the placement of the design-governing deck segments. The inertial load amplification also affects the buckling factor during the vertical and lateral movements of load.

Excessive confidence with a launching gantry as a result of having already handled similar loads in the past may be a serious mistake. The stability of a gantry does not only depend on the entity of the load but also on how the load is applied to the unit. When a gantry handles a long precast concrete girder, the winch trolleys are at the girder ends

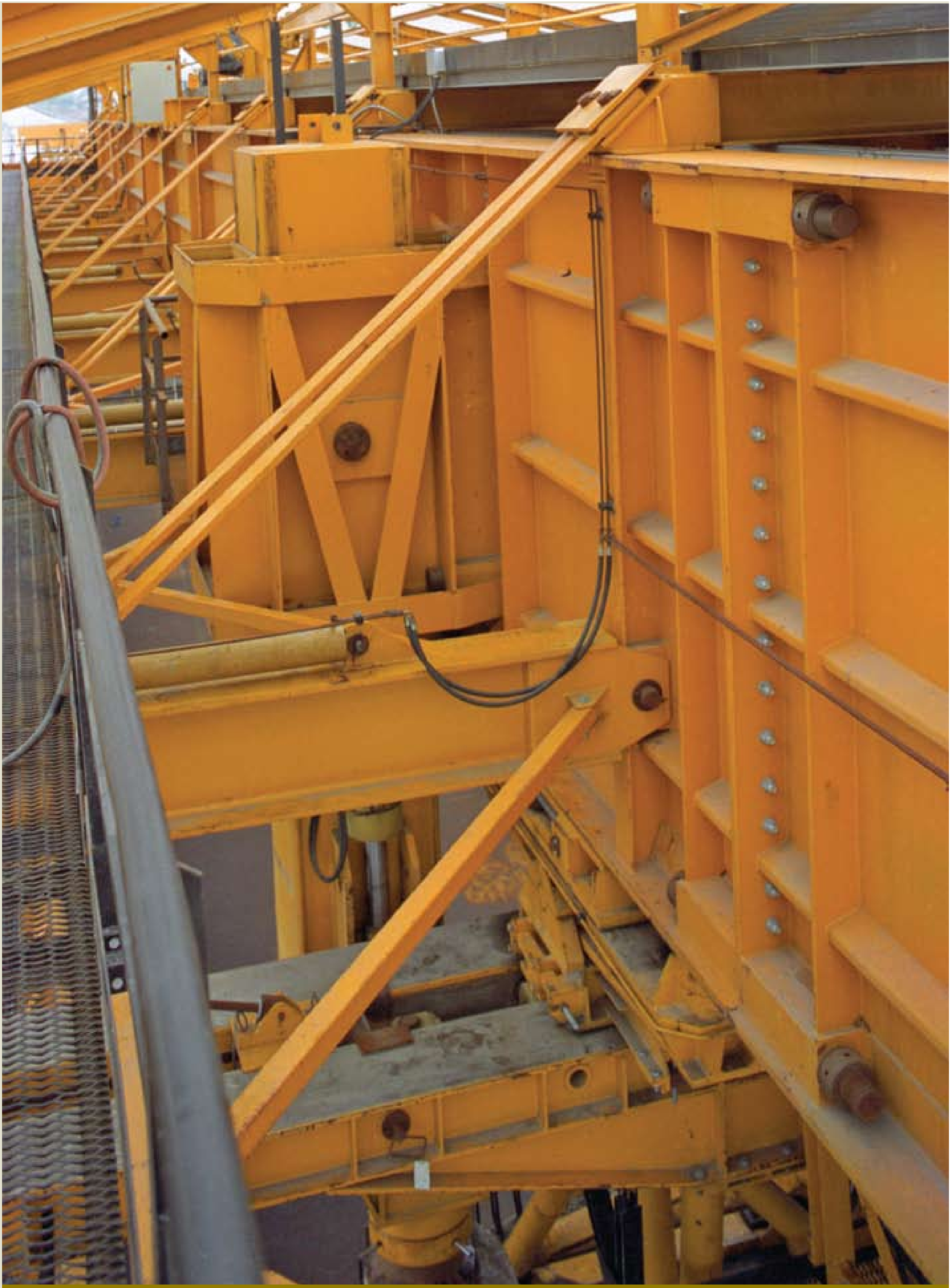

Figure 15. This shows the main structural node of an overhead gantry.

Figure 16. The buckling of the compression flange at the supports is due to the wrong operation.

and the load that they apply is one-half of the total weight. When the winch trolleys operate near each other (for example, in a heavy pier-cap segment), the total load may be similar but the stresses in the compression diagonals may be much higher.

Overloaded members may buckle suddenly, so careful inspections are necessary during assembly and at regular intervals during the use of a launching unit. Damaged diagonals must be reinforced or replaced even when they apparently are in noncritical locations because the load conditions are so varying that they might become the critical element of the structure. The cross diaphragms should also be inspected frequently.

The stability of a launching gantry depends on the stability of members against local failure and on the unit response to local failure. Local buckling of a primary load-carrying member is often critical in the support towers, while stable alternate load paths often exist in such redundant trusses; however, local buckling may trigger a chain reaction of failures causing progressive collapse. The simplest approach to ensure the robustness of a launching gantry and to reduce the risk of progressive collapse is to require insensitivity to local failure. In other words, local buckling of a primary load-carrying member must not cause collapse of the gantry or of a major part of it.

Although the structural damage induced by local buckling is limited, the sudden stress redistribution generated by the loss of carrying capacity of a member is a highly dynamic process that requires analysis in the time domain.[6] The resulting stresses can be assessed like any other ULS condition. Dynamic amplification is often low thanks to the flexibility of these units, and because the support rollers are long, several pairs of diagonals are typically involved in the load path at supports.

Local buckling in the compression flange can trigger critical situations in the box-girder units because during launching the support sections are devoid of stiffeners and diaphragms. In the unit in **Fig. 16**, the left girder (on the right side in the photograph) was slightly misaligned leftward so that when the front overhang was already 157 ft (48 m) long, the operator of the unit decided to realign it. A cross beam was placed near the front support saddle to

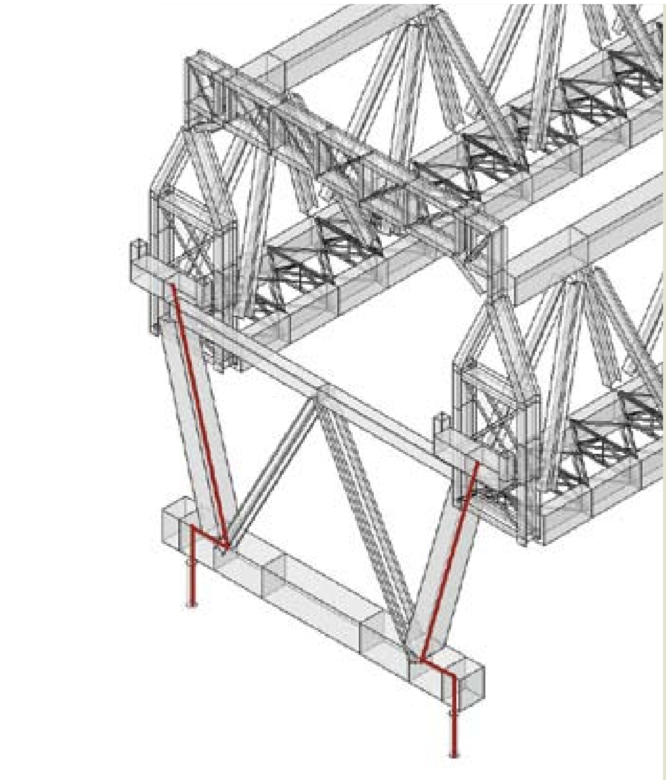

Figure 17. This figure shows a rear portal frame with shifting support pistons.

support two flat jacks on PTFE plates. The jacks were to be inserted under the box-girder webs to then pull the jacks and box girder rightward along the low-friction contact. However, the procedure was misunderstood and after raising the box girder with the flat jacks, the PTFE plates were inserted between the box girder and the main support jacks.

In the initial stage of realignment, the box girder resisted the transverse bending generated by the increasing eccentricity in the support reactions. Eventually, the outer flange and the central flange panel buckled upward. This generated two low-friction inclined planes that gave rise to uncontrolled rightward sliding of the box girder. Flange buckling further increased, and both webs also buckled. Collapse was avoided because the end block of the cross beam stopped the box-girder stroke when the left jack (on the right in the photograph) was already almost disengaged.

Support member instability

The weight of the gantry and the service load are transferred to the bridge foundations through complex load paths that typically include adjustable components, hydraulic systems, and pivoted legs. These support systems are affected by specific forms of instability. The pivoted support legs, in particular, are among the most delicate components of a launching gantry.

A gantry had a pivoted W-shaped rear support frame, where the base cross beam originally had a box section over the entire width. Reusing the gantry on a curved alignment required lateral shifting of the base hydraulic cylinders of the support frame to align them with the bridge webs, so the cross beam was windowed in its end sections. As a result, the torsion constant in the two 12 ft (3.6 m) windowed portions of the cross beam became about one-thousandth of the original box-section constant.

When the support cylinders are at the ends of the cross beam, the two vertical load paths are three-aligned-hinge schemes where the central cylindrical hinge has minimal rotational stiffness because of the low torsion constant of the windowed section **(Fig. 17)**. The scheme is more stable when the support cylinders are under the inclined legs of the W-frame, so buckling was likely to occur only in curved bridges. The buckling factor was as low as γ_{LC-1} = 0.6, and triangular box stiffeners were applied to increase the torsional constant and stabilize the frame.

The design of connections has a fundamental influence on the strength and stability of the support towers. When the legs are always compressed and the contact between column and end plate is machined, the welds at the ends of the module are subjected to minimal stresses. In the case of load reversal, therefore, the end welds are often designed for tension and the much higher compression force is resisted by the machined contact. In the case of roughly machined contacts, however, the weld can break under the compression force, and at load reversal, the column can detach from the end plate.

Launch and lock systems

In light units such as lifting frames, the launch stresses are relatively low and the operations are simple and intuitive. In heavy units such as long gantries, the launch stresses are so great that they often govern the design of primary components of the unit. The launch stresses depend on the launch procedures, and launching heavy units involves sequences of operations that are typically more complex the heavier the unit is.

Light gantries for erection of precast concrete girders and many heavy units use assemblies of cast-iron rolls on rocking arms for the launch bearings. The number of rolls depends on the load and the diameter. It is usually two, four, or eight, with progressively higher costs. Lateral guide may be ensured with rolls acting against the bottom flange or a steel rail welded under the web.

The use of cable bearings is less frequent. The support reaction is distributed by a tensioned ring cable that directly supports the rolls, so these bearings are thinner and more stable than the roll bearings with rocking arm. When the launch occurs along a curve, cable bearings may be combined with orientation ball-plate bearings and shifting bearings, which respectively orient and align the rolls under the webs. Cable bearings may also be placed onto hydraulic jacks for accurate distribution of the support reactions and the creation of torsional hinges.

Sliding bearings may also be based on polytetrafluoroethylene (PTFE) skids. The bottom flange typically slides along lubricated PTFE surfaces without interposition of stainless-steel sheets. Dispersal of the support reaction into the webs may be facilitated with multilayered elastomeric blocks covered with a dimpled PTFE plate. These blocks are aligned in rocking frames on ball-and-socket articulations or transverse pins. At the current state of practice, roll bearings and sliding bearings are complementary. Sliding bearings are fit for slow launching of high loads, while roll bearings are fit for medium loads and high launch velocities.

The launch and lock systems have a substantial impact on the stability and safety of a launching gantry. Launching is achieved with one of three methods. In the simplest and oldest units, a winch trolley is anchored to a pier and its translation winch moves the main trusses to the next span. In more recent units, long-stroke hydraulic cylinders lodged into the support saddles push the unit forward by acting against racks fixed to the bottom flanges. In the most advanced units, the thrust force is transferred by friction using hydraulic launchers that directly support the girders.

The light gantries for precast concrete girders are usually moved with winches, though this solution presents some disadvantages, especially when launching along inclined planes. The longitudinal grade of many bridges is close to the friction coefficient of the rollers, so when launching occurs with new or well-greased rollers it can be necessary to brake the unit to prevent uncontrolled sliding. Braking of any component of the tow system also leaves the unit unrestrained on low-friction supports. This requires design precautions and the adoption of higher safety factors, which involves oversizing equipment and operating more slowly.

Higher thrust forces require mechanical transmission by means of launch cylinders acting against racks fixed to the bottom chords, as in Fig. 4. These launch systems are very efficient in the case of horizontal launching, and they also permit backward pulling of the unit. When launching up grade, the unit must be locked during the return stroke of the launch cylinders to avoid uncontrolled backward sliding. Two adjacent launch cylinders are used in this case.

In the more refined units, the launch force is transferred by friction (Fig. 6). For the unit to be trailed, it is necessary that the ratio of the thrust force to the support reaction onto the launcher be smaller than the friction coefficient between the two steel surfaces. The support reaction varies during launching, so two synchronized launchers are generally used. Friction launchers offer high intrinsic safety because the worst consequence of hydraulic faults is halt of the launch. Therefore, the equipment can be designed for the launch loads and overloaded without excessive worries if necessary. The electronic control of the hydraulic plant permits synchronization of launchers and the ability to set limit pressures avoids overloading. Launch-cycle automation with end-of-stroke switches facilitates the operations and increases the launch speed.

When approaching the pier, the front end of the gantry is deflected downward. In the lightest gantries, the front deflection is recovered by inclining the bottom flanges to force progressive realignment (Fig. 2). The alignment force rarely overloads the support cross beams, but the launch bearings must be anchored to avoid displacement or overturning. The launch bearings must also be articulated to accommodate large rotations. Realignment may also be achieved with long-stroke hydraulic cylinders that move steel arms hinged to the nose tip. When the lifting arm reaches the pier, it is lowered down and forced until recovery of the elastic deflection. Hybrid solutions are also possible where the bottom chords are rounded and a front hydraulic cylinder recovers only a portion of the cantilever deflection.

Several overhead gantries are designed for launching their own support systems. In this case, the front tip is often equipped with a vertical arm that during launching takes support at the front pier to stabilize overturning. After forcing the front arm, the winch trolley places the pier cap segment and then advances the front support cross beam and places it onto the segment, and the launch can restart.

Load testing

Bridge erection machines are typically load tested upon completion of the first assembly. New load tests and comparisons with previous tests should also follow every major reassembly of the unit.

Launching gantries are subjected to static and dynamic tests. The static test load is 10% to 40% higher than the design load of the unit. Load testing takes place in the absence of wind and consists of slowly lifting a progressively increasing load until reaching the full test load. The load is lifted at different locations to reach full design stresses in the critical components of the unit, the deflections are compared with the theoretical values, and deflection recovery is also checked. The dynamic test load is typically 10% to 20% higher than the design load. The movements of the gantry are tested individually at increasing velocities until they reach the maximum values. Blackout tests can also be performed to measure the dynamic response to the intervention of the emergency brakes.

Conclusion

The bridge industry has seen unbelievable progress in the past decades. New means of analysis and a better knowledge of mechanics of materials have permitted new structural solutions and are at the basis of architectural wonders that will represent our legacy, as a bridge community, to the next generations. Such progress, however, is also the result of the technological advance in the erection methods for precast concrete bridges.

The technological aspects of erection will have a more and more marked influence on the modern bridge industry, and construction of precast concrete bridges is mostly based on the use of self-launching machines. In spite of the technical skill and the quality-assurance and quality-control processes of many manufacturers of launching units, accurate custom-written technical specifications and independent checking of design may be precious tools in making better and more circumstantiated decisions and dodging avoidable mistakes.

References

1. Rosignoli, M. 2002. *Bridge Launching*. London, UK: Thomas Telford.

2. American Segmental Bridge Institute (ASBI). 2008. *Construction Practices Handbook for Concrete Segmental and Cable-Supported Bridges*. Phoenix, AZ: ASBI.

3. Hewson, N. 2003. *Prestressed Concrete Bridges: Design and Construction.* London, U.K.: Thomas Telford.

4. Federation Europeenne de la Manutention FEM 1.001. 1987. *Règles pour le Calcul des Appareils de Levage*. [In French.]

5. CNR 10021. 1985. *Strutture di Acciaio per Apparecchi di Sollevamento. Istruzioni per il Calcolo, l'Esecuzione, il Collaudo e la Manutenzione*. [In Italian.]

6. Rosignoli, M. 2007. Robustness and Stability of Launching Gantries and Movable Shuttering Systems—Lessons Learned. *Structural Engineering International,* 02/2007: pp. 133–140.

About the author

Marco Rosignoli, Dr.Ing., P.E., has 27 years of experience in bridge design and construction. For 15 years he has served as construction manager, project manager, and bridge-department lead for prime European bridge contractors. After assisting contractors on complex bridge projects in 19 countries and 4 continents for 9 additional years, he has served as chief bridge engineer at HNTB Corp. since 2006.

Rosignoli has been the independent design checker of many self-launching bridge-erection machines. Expert in bridge construction technologies, he has written two books and more than 60 publications. He is currently chairing the working group WG-6, Bridge Construction Equipment, of the International Association for Bridge and Structural Engineering.

Synopsis

Launching units are complex and delicate structures. They resist high loads on long spans under the same constraints that the obstruction to overpass exerts onto the final structure. They are adaptable for reuse on different projects. They must be as light as possible, which involves designing for high stress levels in different load and support conditions, and they are assembled and dismantled many times and reused by different crews.

For all of these reasons, self-launching bridge erection machines are typically purchased or leased based on purpose-written technical specifications, their design is subjected to independent checking, load testing is frequent at the end of assembly, and the operations are ruled by written procedures.

Little has been written on these machines in spite of their cost, complexity, and sophistication. This article illustrates the main features of self-launching bridge erection machines and includes some lessons learned.

Keywords

Bridge, girder, launching gantry.

Review policy

This paper was reviewed in accordance with the Precast/Prestressed Concrete Institute's peer-review process.

Reader comments

Please address any reader comments to *PCI Journal* editor-in-chief Emily Lorenz at elorenz@pci.org or Precast/Prestressed Concrete Institute, c/o *PCI Journal*, 209 W. Jackson Blvd., Suite 500, Chicago, IL 60606.