

Full-span precasting for light-rail transit and high-speed railway bridges

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Numerous major bridges have been built for high-speed railway projects. The 113 km (70.2 mi) Beijing-Tianjin route in China includes 100 km (62 mi) of bridges (88%), the 1318 km (819 mi) Beijing-Shanghai route includes 1140 km (708 mi) of bridges (86%), the 904 km (562 mi) Harbin-Dalian route includes 663 km (412 mi) of bridges (73%), and the 995 km (618 mi) Wuhan-Guangzhou route includes 402 km (250 mi) of bridges (41%). More than 35,000 spans for high-speed railway bridges have been built in China, and large investments in high-speed railway infrastructure have also been made in Europe, Japan, Korea, and Taiwan.

The cost of track infrastructure and systems diminishes the share of the supporting structures of the total cost of the project. The cost of embankments with transition wedges at abutments and box culverts, the disruption of traffic in case of track geometry defects or settlement, and restraints on the vertical alignment all favor the use of long prestressed concrete bridges, while control of train-induced vibrations necessitates short spans. The combination of long bridges and short spans makes for hundreds of spans, justifying the investment needed to set up large precasting facilities and to provide special means of transport and placement. Full-span precasting of high-speed railway bridges accelerates construction, minimizes labor, improves quality, and further increases the competitiveness of prestressed concrete bridges over embankments.¹

- Full-span precasting offers rapid construction; repetitive, high-quality casting processes in factorylike conditions; and year-round erection in almost any weather conditions.
- This paper examines the organization of full-span precasting facilities for light-rail transit and high-speed railway beams.
- The loading, kinematics, support and launch systems, performance, productivity, and structure-equipment interaction of the different types of special equipment used for transportation and placement of full-span precast concrete beams are also described.

Several recent light-rail transit projects include miles of prestressed concrete elevated guideway. The light-rail transit spans are short to facilitate control of train-induced resonant vibrations; thus the large number of spans lends itself to full-span precasting in this application as well.

Many high-speed railway bridges and some light-rail transit bridges have been built with full-length precast concrete beams transported into place and erected span by span.² Single-cell and twin prestressed concrete box girders are well suited for dual-track bridges, while single-track U beams offer the additional advantages of noise reduction, train containment in case of derailment, optimum integration with the environment, and easier handling because of the lighter weight.^{2,3}

Full-span precasting offers rapid construction; repetitive, high-quality casting processes in factorylike conditions; and year-round erection in almost any weather conditions. The maximum span length depends on the capacity of the erection equipment. In large-scale projects where this construction method is used, it is common to build custom equipment for the length and weight of the beams to be handled.⁴ Ground transport of single-track, light-rail transit U beams and delivery of light-rail transit and high-speed railway beams on the completed deck are rarely used for spans longer than 30 to 35 m (98 to 115 ft) due to the cost of the erection equipment and the loads applied to the deck. Minimal gradients on bridges and access routes are also important for beam delivery on the deck.

Full-span precasting of single-track U beams for light-rail transit bridges

High-speed railway bridges are typically built in rural environments and light-rail transit bridges in urban environments. Dual-track precast concrete segmental box girders have been used extensively for light-rail transit bridges; the use of full-length precast concrete single-track U beams is becoming more frequent because of their high quality and fast erection. Dual-track U beams are typically precast segmentally and erected span by span with overhead self-launching gantries^{2,5} because they are too wide for ground transport.^{2,3}

Single-track U beams include two edge girders and a central bottom slab. The track can be ballasted or fastened to the slab (direct fixation). The top flange of the edge girders can be used as a walkway for passenger evacuation, and the combined lateral stiffness of web and top flange is often enough to keep the train on the bridge in case of derailment. The elevated guideway is often uninterrupted throughout aerial stations, and the need for access to passenger platforms limits the depth of the webs.

Single- and dual-track U beams span 30 to 35 m (98 to

115 ft), while stiffer dual-track box girders can be used for 40 to 45 m (131 to 148 ft) of simply supported spans. Longer spans would offer the advantage of fewer columns and foundations in an urban environment, but train-induced resonant vibrations and the visual appearance of a deep superstructure limit the span to 40 to 45 m in most cases. Two-span continuous beams may have longer spans but are complex and expensive to erect and are therefore mostly used only for special crossings.

Compared with span-by-span launching-gantry erection of precast concrete segmental dual-track box girders,⁶ full-span precasting of two single-track U beams offers several advantages:³

- Simple forming and casting: Two 35 m (115 ft) U beams are cast in one operation while a precast concrete segmental box girder requires match casting of 11 to 13 segments.⁷ Geometry control is also much simpler.²
- Rapid and inexpensive delivery and erection: Single-track precast concrete beams may be transported on public roads overnight,³ and two ground cranes typically erect four U beams (two full dual-track bridge spans) per night; a gantry takes two to three days to erect a precast concrete segmental box girder.⁸ Gantry erection is also a linear process, while precast concrete beams may be erected according to pier availability. However, twin single-track U beams require wide and expensive pier caps, the precasting facility must be designed for such productions, and ground crane erection requires accessible areas and short piers over the length of the bridge.
- Optimal integration with the urban environment: They are less conspicuous, the inner faces of the edge girders act as built-in sound barriers, they provide built-in cable support and system functions, and they provide integral walkways for passenger evacuation.^{2,3}
- Built-in structural elements capable of maintaining the train on the bridge in case of derailment: Transverse spacing of beam bearings controls uplift during derailment without the need for tie-downs.
- Possibility of lowering the vertical profile of the track by 1.5 to 2.0 m (5 to 6.6 ft): A lower center of mass diminishes the seismic demand on the columns, and escalators can sometimes be avoided at passenger platforms of aerial stations.³

A single-track U beam is 4.5 to 5.5 m (15 to 18 ft) wide, may weigh from 1500 kN (337 kip) for 25 m (82 ft) spans to 2000 to 2200 kN (450 to 495 kip) for 35 m (115 ft) spans and can often be transported on the ground with trucks and rear-steering trolleys. The weight of a 9 to 11 m

(30 to 36 ft) wide dual-track U beam ranges from 4000 to 5500 kN (899 to 1236 kip); the beam is too wide for ground delivery. Dual-track beams can be lifted with portal cranes and delivered onto the deck with tire trolleys or portal carriers² in most cases; however, the dual-track U beams are made with match-cast precast concrete segments glued with epoxy and erected with an overhead gantry.⁹

Different proportions of pre- and posttensioning are possible with full-span precasting. Pretensioning simplifies forming, improves durability, and minimizes the cost of labor and prestressing.¹⁰ Pretensioning, however, requires the investment for anchor blocks and reaction beams designed for the force of many strands. Self-stressing formwork is rarely used in full-span precasting because of cost.¹¹

The strand anchor blocks are located at the ends of casting lines comprising multiple casting beds (**Fig. 1**). Pretensioning requires an organization of the precasting facility so that all the beams in a casting line are the same age at transfer of prestressing.^{2,3} Pretensioning designed for beam lifting and transport to storage may be combined with integrative posttensioning applied before final delivery to minimize the cost of anchor blocks and reaction beams and to increase the efficiency of prestressing by using some parabolic tendons.

The cross section can be posttensioned transversely. Replaceable mono-strand anchored at the top of the edge girders and crossing webs and bottom slab increases the flexural capacity of the bottom slab, the shear capacity of the webs, and the train confinement capability in case of derailment.

The plinths for direct track fixation are cast in two phases: the base is cast in the precasting facility while the beam is curing, and the top adjustment layer is cast in place after beam placement and final leveling. The slab is typically devoid of crossfall: rainfall flows longitudinally among the plinths and is collected and drained at the piers.

The precasting facility is located near the bridge site to minimize ground transport. The steel cages may be fabricated by different methods.² When the cages are assembled on the casting beds, each casting line includes two to six beds where the beams are cast at once. Beam erection with ground cranes typically requires six-day cycles; delivery of four beams every night therefore requires six casting lines with four beds each. The cycle time depends on materials and fabrication procedures and can be shorter than six days, and the number of casting lines will diminish accordingly.² The fabrication process must be consistent with the productivity of delivery and erection.

The precasting facility is set up as a rectangular array of casting beds. The number of casting lines corresponds to the cycle time for a beam, and the number of casting beds



Figure 1. Four-bed casting line. *Courtesy of Systra.*

in each line corresponds to the daily number of beams for just-in-time delivery. Storage for curing completion is necessary only when the beams are delivered on the deck. Ground transport and crane erection require only two- to three-day curing because the beams are not loaded immediately after placement and can finish curing on the piers.

With a six-day cycle, one casting line contains beams ready for overnight delivery, a second line is being cleaned and prepared for cage assembly, a third is occupied by the ironworkers for cage fabrication and pretensioning, a fourth is being cast, and the remaining two are occupied by beams being cured. The curing days may be used to cast the plinths of the rail fasteners.

Portal cranes move full-length web forms from line to line. The web forms are rectilinear, the end bulkheads are rotated to the design plan radius, and the curved alignment of the rail fasteners is achieved by shifting the plinths laterally on the bottom slab.

A few platforms for beam storage provide flexibility in case of delivery delays or a defective beam (**Fig. 2**). In optimal conditions, the beams are lifted from the casting bed and loaded onto the truck for delivery. Large-scale storage is necessary only when the beams are delivered on the deck because the transportation means for the next beams load the beam immediately after placement (**Fig. 3**).

Full-span precasting of high-speed railway bridges

Precasting facilities for high-speed railway beams are organized in a different way. Because the beams are too heavy



Figure 2. Beam stacking on support frames. *Courtesy of Sysra.*

for ground transportation and crane lifting, they are delivered on the deck and positioned with dedicated machines. Immediately after placement of a beam, the transporters must transit over the new span to deliver the subsequent beams; thus the curing time of the beams is longer. The productivity of the precasting facility is calibrated to that of the erection lines, and the number of storage platforms is chosen based on the curing time required for delivery, which depends on the type of transporter.

The portal carriers spread the load to two spans. The beams may require 7 to 8 days' curing; each casting line therefore requires 7 to 8 storage platforms. Because tire trolleys do not spread the load, the beams often need a full 28-day cure to resist the load, necessitating 28 storage platforms for each casting line. Three casting lines would require 84 storage platforms. With additional platforms for emergencies and atypical spans, there could be 100 platforms or more, and the dimensions of the storage facility grow to the point where stacking becomes indispensable.

Constraints on time and availability of heavy lifters in the precasting facility call for cage prefabrication in full-span reinforcing bar jigs (**Fig. 4**). Reinforcing bar jigs add flexibility to the organization of the casting lines; the number of jigs and casting beds can be calibrated to the different productivity of the two working areas.^{2,4}

The beams are often designed for posttensioning to facili-



Figure 4. Reinforcing bar jig for full-span cage prefabrication of a single-track U beam.

tate cage handling and to shorten the curing time within the casting bed. The end bulkheads are attached to the reinforcing bar jig according to beam geometry, the tendon anchorages are attached to the bulkheads, the outer grid of the cage is fabricated, watertight plastic ducts are fabricated and tested, the rest of the cage is assembled, and all the embedded items are fixed to the cage. Strand is inserted into the ducts during casting and curing to lighten the cage during transfer into the casting bed and to remove activities from the critical path. A stiffening truss is attached to the cage prior to lifting to avoid distorting the cage (**Fig. 5**).

Combinations of pre- and posttensioning are also possible. Rectilinear pretensioned strands can be used in the bottom slab, with anchorages and parabolic ducts embedded in the webs for posttensioning during storage. Hydraulic jacks are used at one end of the casting line for initial pretensioning and transfer of prestress. Reinforced-concrete reaction beams and dead anchor blocks resist the forces of so many strands and stiffen the foundations of the casting beds (**Fig. 6**). The forming systems are designed in accordance with conventional criteria.

The number of reinforcing bar jigs in a casting line is determined by the productivity of casting beds and reinforcing bar jigs. Typically a casting line produces a



Figure 3. Large-scale storage of single-track U beams. *Courtesy of Sysra.*



Figure 5. Cage delivery.

beam per day on a two- or three-day cycle, depending on span dimensions and type of cross section. If a casting bed produces a beam every three days, three casting beds are needed. If a reinforcing bar jig produces a cage every four days, four jigs are needed in the casting line. Reinforcing bar jigs require additional investment, but different cycle times for casting beds and reinforcing bar jigs provide flexibility in beam production and minimize interference among carpenters, ironworkers, and prestressing crews. If necessary, additional jigs can be installed.²

Partial posttensioning is applied after 12- to 18 hours' curing to make the beam self-supporting for transfer to the storage platform; transfer of pretensioning typically requires longer curing. Parallel casting lines are separated by runways for delivery of the steel cages and removal of the beams. Three casting beds may be used in the casting lines for single-track U beams in combination with an inner portal form that rolls on rails to serve the entire casting line. The casting beds are complete enclosures; only the top of the webs is hand finished. After cage delivery, the inner form is moved over the casting bed to close the mold. The runways of the inner portal shutter may be extended at one end of the casting line to create a maintenance area.⁴

The inner tunnel forms for single- and dual-track box girders are more complex to operate and to remove from the beam. The form includes multiple hydraulic systems to drive the support truss longitudinally, to collapse the form modules for stripping, and to clear the pier diaphragm during extraction. When the beams are not pretensioned, the inner tunnel form may be stored between two casting beds to serve them alternately; each casting line therefore includes two or four casting beds. Casting and handling equipment for dual-track box girders is more expensive than for single-track U beams due to the weight and complexity of the precast concrete units, but only half as many units are needed, reducing construction duration and/or the number of casting beds and erection lines.

Concrete is pumped from the batch plant to the casting beds through underground pipelines for unrestricted mobility at the casting platform level. Each feeding line includes mixer, agitator, pump, hydraulic switches at the nodes of the pipeline network to multiple casting beds, and a tower-mounted distribution arm. Two feeding lines may be used for each casting bed to accelerate filling. One batch plant may be enough for two casting lines for single-track beams, while two plants are used for multiple casting lines and dual-track beams. The beams are usually cast monolithically to shorten the cycle and enhance quality.

Portal cranes on rails or steering wheels are used to move the beams around the precasting facility. Wheeled cranes are more complex to design, operate, and maintain but offer unrivalled flexibility of operations. Portal cranes with transverse tractors and steering wheels facilitate access



Figure 6. Casting cell for combined pre- and posttensioning. *Courtesy of VSL.*

to casting beds and storage platforms; portal tractors also allow longitudinal access (**Fig. 7**). These cranes are stable when handling stacked beams, and computerized steering allows crab movement,² but wide transport routes diminish the volumetric efficiency of the storage area. Portal cranes with pivoted tractors are used within the precasting facility and also for delivery and placement of the beams in combination with an underbridge (**Fig. 8**).

The bearings for the beam are positioned over the support blocks of the storage platform before lowering the beam onto them. Good ground conditions are required at the precasting facility to support the beams. Pile foundations may be necessary for casting beds and storage platforms to prevent the beams from twisting. Two to three days of storage are necessary to complete posttensioning and finishing; the rest of the curing time is dictated by strength requirements at beam delivery.

The beams are transported on the deck using portal carriers or tire trolleys. The portal carriers position the beams with the help of self-launching underbridges, while the tire trolleys feed special beam launchers for placement.²



Figure 7. A 9000 kN (2020 kip) dual-track box girder handled with a 64-wheel portal crane. *Courtesy of BWM.*



Figure 8. Beam transfer to the storage platform with a portal carrier with pivoted tractors.

Tire trolleys and beam launchers

Special tire trolleys are used to transport the beams along the access embankment and completed deck to the rear end of the launcher. The tire trolleys have 6000 to 9000 kN (1350 to 2020 kip) capacity, and the operating speed varies significantly from machine to machine.

The tire trolleys are monolithic machines comprising a full-length main beam and multiple cantilever beams on either side. Each cantilever beam carries a vertical pivot for 360-degree rotation of two paired wheels. Long cantilever beams ensure lateral stability and align the wheels with the deck webs to minimize transverse bending in the completed deck during span transport. Steering computers control wheel alignment, the wheel load is equalized hydraulically or electronically, and position sensors keep the wheels aligned with the deck webs during automatic drive along the bridge.

An articulated extraction saddle rolls on multiwheel bogies along the main beam for the entire length of the trolley. The saddle supports the rear end of the beam under the



Figure 9. Extraction saddle of a tire trolley for 4000 kN (900 kip) single-track box girders. Courtesy of BWM.

webs. The articulation allows three-dimensional rotations so that the saddle works like a spherical hinge during beam transport and removal (**Fig. 9**). Two fixed blocks support the front end of the beam during transport and provide torsional restraint.

Several configurations of beam launchers have been tried, not always with satisfactory results. Single-girder 2.3-span launchers (as long as 2.3 times the typical span) and without a central support frame are tall, expensive, and complex to operate. Twin-girder 2.3-span launchers with a central support frame are used to erect twin single-track box girders, but only infrequently because this type of superstructure is unusual in high-speed rail (**Fig. 10**).

A twin-girder telescopic launcher comprises a rear main frame for beam placement and a front 1.2-span under-bridge for launching. The underbridge is supported at the leading pier of the span to erect and at the next pier. The



Figure 10. Twin-girder 2.3-span launcher for 32.7 m (107 ft), 4000 kN (900 kip) single-track box girders. Courtesy of BWM.

front end of the main frame is supported on the under-bridge during launch and on the front half of the leading pier cap during beam placement. A trapezoidal C-frame supports the rear end of the main frame from the completed deck and allows the new precast concrete beam to pass through.

The main frame comprises two overhead box girders connected by a front crossbeam at the root of the front nose. The main girders cantilever out behind the rear C frame to store two winch trolleys during removal of the beam from the tire trolley. A rear platform connects the main girders at the end of the rear overhang (**Fig. 11**). Stiffening frames designed to allow the winch trolleys to pass through connect the main girders at midspan, at the C frame, and along the rear overhang. A closed rear C frame enhances the torsional rigidity of the assembly. Box sections are used in all main structural members, and braced I-girders are used only for the front nose.

The front nose carries an auxiliary hoist to reposition the underbridge after launch of the main frame. A full two-span self-launching underbridge may be used to avoid the need for a front nose in the main frame² (Fig. 12). When the rear C frame is equipped with foldable legs, the main frame and underbridge can be redeployed with the tire trolley used for beam delivery with minor dismantling.¹² At the completion of the bridge, the underbridge is launched over the trolley, the main frame is moved over the underbridge, and the rear C frame is retracted and folded (Fig. 13).

Two winch trolleys span between the main girders to handle the precast concrete beam. The winch trolleys spread the load over long sections of the main girders, and the rear overhang of the main frame is therefore long to store two trolleys before loading the beam. The winch trolleys pick up the beam at the rear C frame to diminish negative bending in the main frame and to control overturning.

The main girders are far from each other to enhance stability and diminish transverse bending in the rear C frame. The crane bridges of the winch trolleys are long and heavy, and translation bogies, hoist crabs, reeved hoisting ropes, sheave blocks, and lifting beams are also heavy. The hoist winches are often applied to the rear platform of the main frame to lighten the winch trolleys and to reduce the need for clearance at the stiffening frames.² Hydraulic motors or capstans drive the trolleys along the main frame and oppose the line pull in the hoisting ropes.

Enclosed fan-cooled industrial generators energize double axial displacement pumps that supply open-loop high-flow-rate hydraulic systems, allowing most functions to be operated simultaneously. Power-pack units and fluid tanks are applied to the rear platform of the main frame to diminish the load applied to the underbridge during launch and to increase the support reaction at the rear C frame for enhanced stability to lateral wind loads. Hydraulic launch motors are applied to the bogies of the rear C frame for enhanced traction and simple connection to the main hydraulic systems on the rear platform.

The front support leg of the main frame rolls along the underbridge during launch and takes support on the front half of the leading pier cap for beam placement. Long-stroke double-acting support cylinders are used for geometry adjustment and disengagement of the underbridge. The underbridge has a box section and closely spaced diaphragms to control torsion and distortion. Short 1.2-span and full two-span underbridges can be interchanged on the same machine.

Short 1.2-span underbridges are not self-launching and must be repositioned with the main frame. After launching the main frame, the front winch trolley picks up the rear end of the underbridge, an auxiliary hoist rolling along the front nose lifts the underbridge at midspan, and the two



Figure 11. Telescopic beam launcher for 32.7 m (107 ft), 9000 kN (2020 kip) dual-track box girders. Courtesy of BWM.

hoists move the underbridge to the next span to clear the area under the main frame for placement of a new beam.

Short 1.2-span underbridges have two support frames: the rear leg is braced to the underbridge to resist the longitudinal loads applied by the main frame during launching, and a front pendular leg slides along the underbridge to adjust the support geometry to the span length. Long-stroke double-acting support cylinders are used in both legs for vertical adjustment.

Full two-span underbridges are not prone to overturning during launch and are rolled forward with capstans or hydraulic motors. Three pier towers support the underbridge during launch and operations with multiwheel articulated bogies. The pier towers may be suspended from the underbridge to be repositioned with motorized wheels without the need for ground cranes.

Loading, kinematics, typical features

Loading a beam launcher is conceptually simple. The tire trolley is driven under the rear overhang of the main frame to bring the front lifting point of the beam as close as possible to the rear C frame. The operator cab is often placed at the rear of the tire trolley for faster drive back to the precasting facility and so as not to interfere with beam removal.



Figure 12. Short launcher with two-span underbridge for 32.7 m (107 ft), 9000 kN (2020 kip) dual-track box girders. Courtesy of BWM.



Figure 13. Main frame and two-span underbridge repositioned with the tire trolley. *Courtesy of BWM.*

The front winch trolley picks up the front end of the beam and moves forward, and the extraction saddle of the tire trolley supports the rear of the beam and rolls along the trolley. When the saddle reaches the front end of the tire trolley, the rear winch trolley picks up the rear of the beam to release the transporter.

The beam is moved out and lowered to the deck level. Load cells and stainless steel shims are used to adjust the support reactions. Placing the beam takes two to three hours, and repositioning the launcher takes another two to three hours, so two to three beams can be placed every day when there are crossover embankments along the delivery route and the precasting facility is designed for such production.

Spreader beams are applied to the precast concrete beam with through-threaded bars. The lifting beams are permanently connected to the hoists. Two interconnected lifting points are used at the rear hoist to replicate the torsional hinge provided by the extraction saddle of the tire trolley. Independent lifting points at the front winch trolley provide the torsional restraint during beam extraction and placement.

Although large-scale high-speed rail projects are designed for a typical span, some shorter spans are unavoidable. The distance between the hoists is not restrained, and the front support legs of main frame and underbridge slide longitudinally for geometry adjustment. Walkways are applied to main frame, rear platform, winch trolleys, and underbridge to facilitate access, maintenance, and inspection.

The rear C frame is wider than the beam to allow the latter to pass through. The frame provides most of the torsional stiffness of the launcher and transfers the weight of main frame, rear platform, hoists, and precast concrete beam. Support cylinders and launch bogies at the base of the frame are located over the webs of the completed deck for direct load transfer.

Picking up a high-speed railway beam from a tire trolley requires ample vertical clearance under the rear platform

of the launcher. The box girders of the main frame are also tall, and the height of these machines may pose problems of lateral stability during beam placement and launch. Multiple stressed bars are used to anchor the main frame and underbridge to provide stability and to resist lateral loads from wind and operations.

Support and launch systems

The main frame of most telescopic launchers is structurally continuous with the rear C frame and is supported on a lighter mobile front leg. The rear C frame rolls on the new beam during launching and typically does not rotate about the vertical axis due to the large plan radii of high-speed railway bridges. The front leg rolls along the underbridge during launching and is supported on the leading pier cap during beam placement. The hoists run along the main frame from the rear platform to a front crossbeam beyond the front leg.

During beam placement, the front leg of the main frame and the rear leg of the underbridge are both supported on the front half of the leading pier cap to lower the beam into position without conflicts with the support systems of the launcher. The front support leg rotates about the vertical axis and slides along the main frame; the same set of longitudinal double-acting cylinders drives both movements. Long-stroke double-acting support cylinders with mechanical locknut are lodged within the rear C frame and the front leg to set the main frame horizontal for beam placement and to lower the launch bogies on deck and underbridge for launching.

Hydraulic motors at the launch bogies of the rear C frame push the launcher over the underbridge in the first phase of launching. Vertical cylinders at the launch bogies provide adjustment of the support geometry. Displacement sensors and pressure valves provide feedback to the launch computer for monitoring of operations with programmable logical controllers. After anchoring the front support leg to the new pier cap, the front winch trolley and the auxiliary hoist are used to reposition the 1.2-span underbridge. Full two-span underbridges are typically self-launching.

Performance and productivity

Placing a precast concrete beam takes two to three hours. Repositioning the launcher takes another two to three hours, and three beams per day have been erected with one launcher. The productivity of the erection line, however, depends on factors such as productivity of the precasting facility, number and speed of the tire trolleys, length of the bridge and the delivery route, and availability of crossover embankments that allow the loaded trolley to move forward ahead of the empty trolley. The beam launcher is the last link of the delivery chain; its productivity rarely governs the erection rate.

The beams are delivered and placed as soon as they can resist the load applied by the tire trolley for placement of the subsequent beam. The load allowed on the beam determines the curing time and the number of storage platforms. Tall portal cranes are used in the precasting facility to stack the beams and move them over curing beams to load the tire trolleys. The erection lines are designed for just-in-time delivery, and the storage platforms are designed for the curing time and not to provide a buffer to the production of the precasting facility.

The speed of the tire trolleys may govern the erection rate of long bridges without crossover embankments.² A tire trolley is typically faster than a portal carrier because the machine is lighter, the beam is supported instead of suspended and does not oscillate, and the trolley has a short interaction time with the beam launcher. After beam delivery, the trolley is driven back to the precasting facility during beam placement, and the cycle is shorter. Without crossover embankments, multiple trolleys cannot shorten the time from having access to the bridge to leaving the bridge for access of the next trolley.

Beam launchers fed by tire trolleys are preferred for long bridges because the launcher is not used for beam transportation and the trolleys are stable and fast. Multiple shorter bridges are better handled with portal carriers because the carriers pick up the underbridge from the landing embankment and transport it to the next bridge. No dismantling is necessary to reposition the erection line, and immediate restart of beam delivery minimizes disruption of a precasting facility designed for just-in-time delivery.

Finally, beam delivery with tire trolleys precludes the presence of other machines on the deck, which may delay the finishing work or increase its cost.

Structure-equipment interaction

Structure-equipment interaction is relatively simple with such sophisticated machines.² The beam is supported at the ends during transport and suspended at the ends during placement, which avoids negative bending regardless of the flexibility of tire trolley, bridge, and beam. A torsional hinge at the rear of the beam avoids twisting during transportation and placement, and the dynamic load amplification is typically low with such slow machines on regular support surfaces.

The load on the axle lines is equalized electronically. The weight of beam and trolley is not spread along the bridge, and although a tire trolley is lighter than a portal carrier, localized loading necessitates longer curing of the beams. Position sensors control the wheel alignment to load the deck over the webs. Some trolleys are fully automated and run along the bridge without a driver.

The front pier diaphragm of every beam is detailed for the loads applied by the rear C frame of the launcher and includes tie-downs for anchoring. The loads applied by launcher and tire trolley rarely govern the design of piers and foundations of bridges designed for high-speed railway loads.

The rear C frame rolls on the new beam during repositioning of the launcher. The main frame is simply supported, and the rear support reaction is predicted accurately. The positive moment in the new beam is typically smaller than the moment generated by the tire trolleys, but the localized load may result in higher shear. The rear support reaction may be diminished by moving the winch trolleys forward during launching, though this operation increases the load applied to the underbridge.

Portal carriers with underbridge

A portal carrier for precast concrete beams comprises two wheeled tractors connected by a box girder that supports two hoists. The tractors have motorized steering wheels controlled by computers. In some machines the tractors rotate by ± 90 degrees for the lateral movements of the carrier; in other machines the wheels turn by ± 90 degrees individually. Both types of carrier are used in combination with two-span underbridges for beam erection. Power-pack units, hydraulic systems, fluid tanks, and hoist winches are applied to the rear end of the carrier to lighten the front tractor during operations on the underbridge (**Fig. 14**).

Picking up the beam from the casting bed involves a complex sequence of operations. The carrier is moved alongside the beam, and the tractors are lifted and rotated by 90 degrees on hydraulic props. The tractors are rotated individually to ensure lateral stability; rotation is not necessary when the carrier has ± 90 -degree steering wheels. The carrier moves laterally over the beam, lifts the beam from the casting bed, moves back to the transportation route, and is realigned with an inverse sequence of operations. The same operations are repeated to release the beam on the storage platform and to pick it up for final delivery.



Figure 14. A 58 m (190 ft), 3200 kN (720 kip) portal carrier with pivoted tractors for placement of 31.5 m (103 ft), 7400 kN (1660 kip) single-track U beams.



Figure 15. Motorized saddle on the rear overhang of the underbridge.

Automatic drive systems govern the movements of the carrier over the webs of the deck or within single-track U beams. The carrier spreads its weight and the weight of the precast concrete beam over two spans of the bridge. The load on the axle lines is equalized to compensate for beam deflections. At the leading end of the erection line, the front tractor of the carrier reaches the rear end of a full two-span underbridge.

The underbridge is a stiff box girder supported on adjustable pier frames at the leading pier of the span to erect and at the next pier. Long stroke cylinders or framed legs support the rear end of the underbridge at the rear pier. The pier frames lodge support cylinders for geometry adjustment and carry articulated support saddles. Double-acting cylinders shift the saddles laterally to align the rear end of the underbridge with the front tractor of the carrier. The pier frames are suspended from the underbridge for self-repositioning without the use of ground cranes.

A motorized saddle rolls along the underbridge and contains vertical support cylinders for the front tractor of the carrier. The underbridge has a rear overhang, and the saddle is moved backward over the leading span of the completed bridge to receive the tractor (**Fig. 15**). The saddle carries a power-pack unit and hydraulic systems for independent operation; linear displacement sensors monitor the position of the saddle along the underbridge.

The carrier is driven forward to place the front tractor over the saddle, and the vertical cylinders of the saddle are extended to lift the wheels from the deck. The hydraulic motors of support saddle and rear tractor are synchronized to move the carrier along the underbridge until the front tractor is beyond the leading pier (**Fig. 16**).

After reaching the beam-lowering position, the support bogies of the underbridge are unlocked and the motors of the saddle are inverted to push the underbridge forward until the area under the carrier is cleared. The rear tractor

provides longitudinal restraint during repositioning of the underbridge (**Fig. 17**). A full two-span underbridge is necessary to reposition the pier frames during this operation. The power-pack unit of the motorized saddle supplies the hydraulic systems of the pier frames for repositioning and alignment.

The bottom counter-plates of the bridge bearings are installed during pier erection. Three plates are set at the right elevation, and the fourth is set 4 to 5 mm (0.16 to 0.20 in.) lower. The beam is lowered onto four load cells placed on the counter plates. After adjusting the support reactions with stainless-steel shims, the beam is lifted, the load cells are removed, and the beam is lowered into position. Finally, the motorized saddle moves the underbridge backward to release the front tractor on the new beam for a new placement cycle.

Operating the underbridge requires a tall, wide clearance between the wheel groups of the tractors. This requirement is one of the advantages of portal carriers over tire trolleys. Tire trolleys apply the load over the deck webs, but the taller clearance of the carriers permits the presence of finishing equipment on the deck provided that the machines are parked at deck centerline at the arrival of the carrier.

Loading, kinematics, typical features

Four articulated lifting beams are applied to the precast concrete beam with through bolts anchored at the bottom surface. The lifting beams at one end of the beam are interconnected to create a torsional hinge, while the other two lifting beams are independent to provide torsional restraint.

The portal carriers are equipped with two hoists: one is fixed; the other may be shifted along the main girder to cope with shorter spans. A power-pack unit, fluid tanks, and hoist winches are applied to the rear of the carrier to diminish the load applied to the underbridge. The carriers



Figure 16. Portal carrier positioned for beam lowering.



Figure 17. Repositioning the underbridge.

move the beams within the precasting facility and on long delivery routes. The structural and mechanical components are fully loaded for long periods, and high quality is essential in these machines.

The portal carriers are taller than the beam launchers. Underbridge and motorized saddle are taller than a tire trolley, and the main girder is also taller due to the longer span. The precast concrete beam is kept close to the main girder to prevent oscillations, and the combined center of gravity of carrier and beam is high on the ground. The wheels of the tractors are aligned with the deck webs, and the narrow support base may cause problems of lateral stability. Stability is more critical with single-track U beams because the two lines of wheels are closely spaced to run within the U section. Wheel flexibility further lowers the first lateral frequency.

Most high-speed rail bridges have symmetrical crossfall and provide flat delivery routes for the carriers. The delivery routes within the precasting facility and along access embankments and crossover areas are leveled and maintained to minimize crossfall.

The support systems of the underbridge are designed for maximum stiffness. The pier frames for dual-track box girders are taller and stiffer than those for single-track U beams (**Fig. 18**). Anchoring the rear of the underbridge to the completed deck provides additional stability when necessary.

Lateral stability and limited span length are the weak points of these machines. The length of the beams delivered with tire trolleys is limited only by the load capacity of the deck and the launcher. With the portal carriers, longer beams require taller underbridges, and a higher center of gravity soon leads to potentially unstable delivery conditions. Tall pier frames for the underbridge are also less stable, and longer launch bogies complicate supporting the rear end of the underbridge on the front half of the leading pier cap during beam lowering.

Support and launch systems

Hydraulic motors drive both tractors. The rear tractor is synchronized with the motorized saddle of the underbridge to minimize longitudinal load unbalance. Pressure valves and full-length linear displacement sensors along the underbridge provide feedback to the launch computer for programmable logic-controlled operations.

Because of its primary role in ensuring torsional stiffness, the underbridge has a box section and closely spaced diaphragms to control distortion.¹¹ The underbridge is supported on inverted roll assemblies on equalizing beams.² The central pier frame is the most loaded support and is anchored to the front half of the leading pier cap. During beam lowering, the load of the front tractor is mostly transferred throughout the central pier frame. Front pier brackets may be necessary to support the front legs of the central pier frame when the piers are slender.

A full two-span underbridge equipped with a front support leg is necessary to reposition the pier frames without ground cranes. Hydraulic motors or capstans drive the pier frames along the underbridge, and vertical support cylinders and lateral shift cylinders provide geometry adjustment. The power-pack unit of the motorized saddle energizes most operations. The pier frames are anchored to the pier caps with stressed bars to prevent uplift.

The motorized saddle shuttles along the underbridge by means of four articulated assemblies of cast-iron wheels and balancing bogies under the power-pack unit. The support cylinders for the tractor of the carrier are located over the bogies for direct load transfer. Several wheels are motorized to avoid slippage under uphill traction.

Performance and productivity

Most of the service life of a portal carrier is spent transporting beams. Beam lifting takes one to two hours, placement takes three to four hours, and transport may take an entire day when the delivery route is long. The unloaded speed of the carrier is often doubled to maintain daily



Figure 18. Stiff pier frames for dual-track box girders. *Courtesy of VSL.*



Figure 19. Four-beam assembly platform for elevated erection line. Photo courtesy of Struktur.

cycles on long routes. Faster machines are expensive and may be unsafe due to load oscillations.

When the precasting facility has two casting lines, each carrier serves one casting line. Two carriers and two underbridges may be used to erect two bridges simultaneously. Two carriers may also work with a common underbridge to double the erection rate of one bridge when there are crossover embankments along the delivery route. Daily operations include filling the oil tanks, moving a fresh beam from the casting bed to the storage platform, and then picking up a beam from a storage platform and leaving for the delivery route.

Portal carriers are the first-choice solution for construction of multiple bridges separated by embankments or tunnels. The carrier picks up the underbridge from the landing embankment and moves it to the next abutment without any need for dismantling or ground cranes. Immediate restart of beam placement minimizes disruption of precasting facilities designed for just-in-time delivery.

The tractors may have single or paired wheels. Single wheels require large-diameter tires, and wheel spacing increases the axle load. In the transverse direction, however, single wheels maximize the central clearance for easier storage of machinery and materials on the deck during beam delivery. Both types of wheels may be designed for ± 90 -degree independent steering or for a smaller steering angle combined with 90-degree rotation of the tractor.

In most cases the portal carriers do not require heavy lifters in the precasting facility; the number of storage platforms is also smaller due to the more favorable load distribution on the completed bridge. Operations require minimal crossfall and smooth grades for equilibrium and power reasons. The large steering radius of carriers with pivoted tractors requires a radial distribution of the storage platforms in lieu of the typical matrix distribution of precasting facilities served by tire trolleys.

When access to the abutment is impossible or the precasting facility is at a lower elevation, twin portal cranes may

be used to lift the beams onto the deck (**Fig. 19**). In this case tire trolleys are the preferred delivery means. Four beams are lifted into position to establish a working platform for assembly of beam launcher and tire trolley. The tire trolley shuttles back and forth along the bridge to feed the launcher at the leading end of the erection line. Multiple tire trolleys may be used if crossover embankments exist along the delivery route.

Structure-equipment interaction

A portal carrier suspends the beam at the ends during transport and placement. This avoids negative bending regardless of the flexibility of carrier, deck, and underbridge. A torsional hinge at one end of the beam prevents twisting, and dynamic load amplification is typically low with such slow machines on regular support surfaces.

The load applied by the carrier rarely governs the design of piers and foundations of high-speed railway bridges, and structure-equipment interaction is mainly related to the load applied to the deck. The tractors are far from each other, and although a carrier is heavier than a tire trolley, the weight of beam and carrier is spread over two spans of the bridge. The length of the tractors is designed to meet the deck capacity at the given curing time, and equalization of the axle loads by programmable logical controllers avoids peaks due to deck flexibility.

Sensors control the lateral position of the wheels to align them with the deck webs. Some carriers are fully automated and run along the deck without a driver. The portal carriers are prone to wind-induced oscillations, and beam delivery is interrupted by high winds.

Structure-equipment interaction may also derive from adjacent structures. In mountainous areas with steep valleys, bridge abutments are often incorporated within tunnel portals. Special carriers designed for moving fully loaded throughout tunnels may seat on the motorized saddle of the underbridge by means of underslung platforms applied to the underbridge.¹²

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About the author



In 32 years of professional practice, Marco Rosignoli, DrIng, PE, has assisted bridge designers, contractors, and owners in 21 countries on 4 continents. He has designed or reviewed 50 km (30 mi) of light-rail transit and high-speed railway bridges and numerous bridge erection machines.

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Abstract

Full-span precasting is a consolidated construction method for large-scale light-rail transit and high-speed railway prestressed concrete bridges. Full-span precasting offers rapid construction; repetitive, high-quality casting; and year-round erection. The paper examines the organization of full-span precasting

facilities for light-rail transit and high-speed railway beams as well as the loading, kinematics, support and launch systems, performance, productivity, and structure-equipment interaction of the equipment used for transport and placement of full-span precast concrete beams.

Keywords

Bridge, full-span precasting, rail, transportation, underbridges.

Review policy

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