



Precast Segmental Bridge Construction – An Introduction

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# Precast Segmental Bridge Construction Part 1 - An Introduction

by

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### **Introduction**

The popularity of precast concrete segmental bridge construction has grown worldwide in the last few decades. These types of bridges offer many benefits to owners like reduced costs, reduced construction time, reduced environmental impacts, and reduced maintenance of traffic. These benefits can be achieved while utilizing local labor and materials, better means of quality control, and with minimum requirements for future maintenance. They also offer additional structural advantages of durability, fire resistance, deflection control, better rider serviceability, insensitivity to fatigue, and other redundancies. These bridges can accommodate highways, railways, and rapid transit, in both urban and rural environments. They can be straight or curved alignments, and can provide long spans for difficult obstructions and terrain.



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Segmental Bridges are varied in types such as: incrementally launched, long line castings, cable stayed, precast segmental progressive placement, arches, cast-in-place segmental, short line match cast precast segmental construction, etc. This course will consider Precast Segmental substructures and superstructures utilizing short line match casting of precast elements and both span by span, and balanced cantilever methods of erection. The course will be broken down into four basic sections: Precast Manufacturing, Substructure Erection, Superstructure Erection – Span by Span Method, and Superstructure Erection – Balanced Cantilever Method. Each section will be further broken down by: set up and staging, construction, stressing and grouting, and completion.

### **Precast Segment Manufacturing**







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The basic building blocks for the Precast Segmental Bridge are the Precast Concrete Segment Elements – superstructure or substructure. There are different means of casting these segments. This course will only consider short line match-casting. The production of these segments is critical to the success of the project. The segments are a major controlling factor in the quality, schedule, and profitability of the bridge and therefore require a well prepared plan to fabricate, store, and transport. The next five sections: Site Selection and Preparation, Casting Cell Construction, Concrete Placing and Curing, Storage and Finishing, and Loading and Transporting will outline the fundamentals for a manufacturing plan.

### **Site Selection and Preparation**



1. There are many decisions to be made when considering the segment casting site. Probably the most significant is whether to choose an already functioning pre-cast



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facility or to set-up and run your own. Although there will usually be several local pre-casters, their facilities and experience history may not be in manufacturing segmental bridge elements. The site preparation details should be similar whether outsourcing or self-performing, so what factors influence the choice?

Certainly past history of similar structures would be an important factor. These sites would have the specialized equipment, trained personnel, and permitting needs for a quick start up and timely production. Secondly, distance and transportation considerations (local to highways, railways, or waterways) would be evaluated. Lastly, budget issues including tax-implications will affect the decision process (the most experienced supplier may not be cost effective).

2. Once the decision of “who” is producing the segments is decided, the “how” to produce the segments is next. For simplicity of writing we will assume the decision is to







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self-perform. The first decisions would be site selection. Factors that would influence this decision would include: Availability of Concrete (transit-mix delivered from an existing supplier or self-production from a mobile batch plant), distance to the erection site and available transportation methods for delivery (railways, waterways, and highways), Permitting and Zoning, Adequate Storage Area, Environmental and Geotechnical Design Criteria, Proximity to a Skilled Workforce, etc...

### **Casting Cell Construction**





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The site should be arranged in an efficient organized manner for producing the precast segments. The number of casting cells constructed is directly related to the scheduling needs of the project. Fast paced schedules will need additional cells to achieve production requirements. Each casting cell requires a sizable investment in time, property, and money; this must be balanced against the schedule to determine the most efficient project course. At a minimum, a bridge will require cells for the pier columns (if precast substructures are being used), cells for typical superstructure segments and a cell for the pier and expansion segments (span-by-span method of erection), and a cell for variable depth superstructure segments (balanced cantilever method of erection).

An engineer should design the casting cells and should consider; geotechnical data for foundation type (each cell will need to support three segments plus formwork and equipment), reinforced concrete design for the base slab of the cell, formwork design (falsework, framing, and concrete forms), walkways and access scaffolds, shelters, and miscellaneous electrical/mechanical.

Major components of a casting cell: Base slab and foundation, forming system, rebar jig, survey towers and sites, and shelters. Specialized and general equipment: Steam generators, chillers, straddle lifts, man lifts, gantries, conveyors, forklifts, RT cranes, welders, generators, winches, survey equipment, etc. Some miscellaneous materials would include: dunnage, grout, form release, curing compound, bond breakers, epoxy, etc.



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### Concrete Placing and Curing



For this course the precast segments will be short-line match-cast. This means the segments are cast sequentially in a single stationary form system where subsequent segments are cast against their predecessor creating a matching pair. The exact bridge geometry is established between the matched pairs such that the segment is unique to a singular place in the structure. The controlled setting of the precast yard allows production similar to an assembly line environment with the goal of completing a segment each day per cell.

The first station in the assembly line is the Rebar Jig. A plywood or steel replica of the form machine is erected at the casting cell for pre-tying the rebar cage. The rebar is





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delivered and tied in the jig. Embed items such as post-tensioning ducts and anchors are also rough installed. The cage is lifted out of the jig to be placed in the forms for concrete placement. Standees and chairs are pre-attached to the cage to insure proper clearance and alignment when set in the form.

The second station is the casting form. The previous day's production is asbuilt by the survey crews to ensure the geometry was maintained while the concrete set. Concrete cylinders are broke to determine the concrete strength and if acceptable, the formwork is lowered; the segment is rolled out of the forms and then set in the match-cast position for the next placement. The forms are tightened around the match-cast segment, form oil is applied to the forms and a bond breaker is applied to the match surface. The rebar cage is lowered into the forms and the core is slid into place. After post-tensioning and embeds are secured, final survey and quality control checks are performed, and the segment is ready for concrete.

The third station is placing, finishing, and curing the segment. Before placing the concrete, quality control tests must be performed both at the plant for production and at the placement. Air content, temperature, and slump testing, plus the casting of concrete cylinders for compressive strength testing are the minimum tests needed to ensure a quality cast. The concrete for the bottom slab is tremied through the core, then a stiff mix is placed down the walls (care must be made to consolidate the mix without it "sloughing" down and out of the form to the bottom slab). Lastly, the top deck is placed (care to consolidate around post-tensioning ducts and anchors). The deck is usually finished with a roller screed and hand tools (usually a post-erection deck treatment is applied for rideability, if so applied, the surface can be left somewhat rough) and geometry control markers are set. The segment is then cured overnight, steam and heat curing may be necessary to accelerate the initial strengthening of the concrete.

The procedure is repeated with the match-cast segment rolled out to storage, the casting rolled out to be the new match-cast, and the cell prepared for a new casting. Precast substructure piers are cast in a similar manner only the cells are oriented vertically.



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### Storage and Finishing



After a day's production, the previous day's match cast segment is ready to be finished and set for storage. Depending on the design, some segments can be lifted and placed in storage prior to any post-tensioning. This will be a factor of strength gained during the initial cure of the segment and the dimensional properties of the bridge. Otherwise some design post-tensioning will be needed in the casting cell prior to load out.

An organized storage plan must be formulated early in the casting process. Not only should the location of each segment be established in an orderly manner for storage, but also for documenting the various stages of completion and acceptance, as well as, availability to deliver the segments to the bridge site when needed. Time and efficiency



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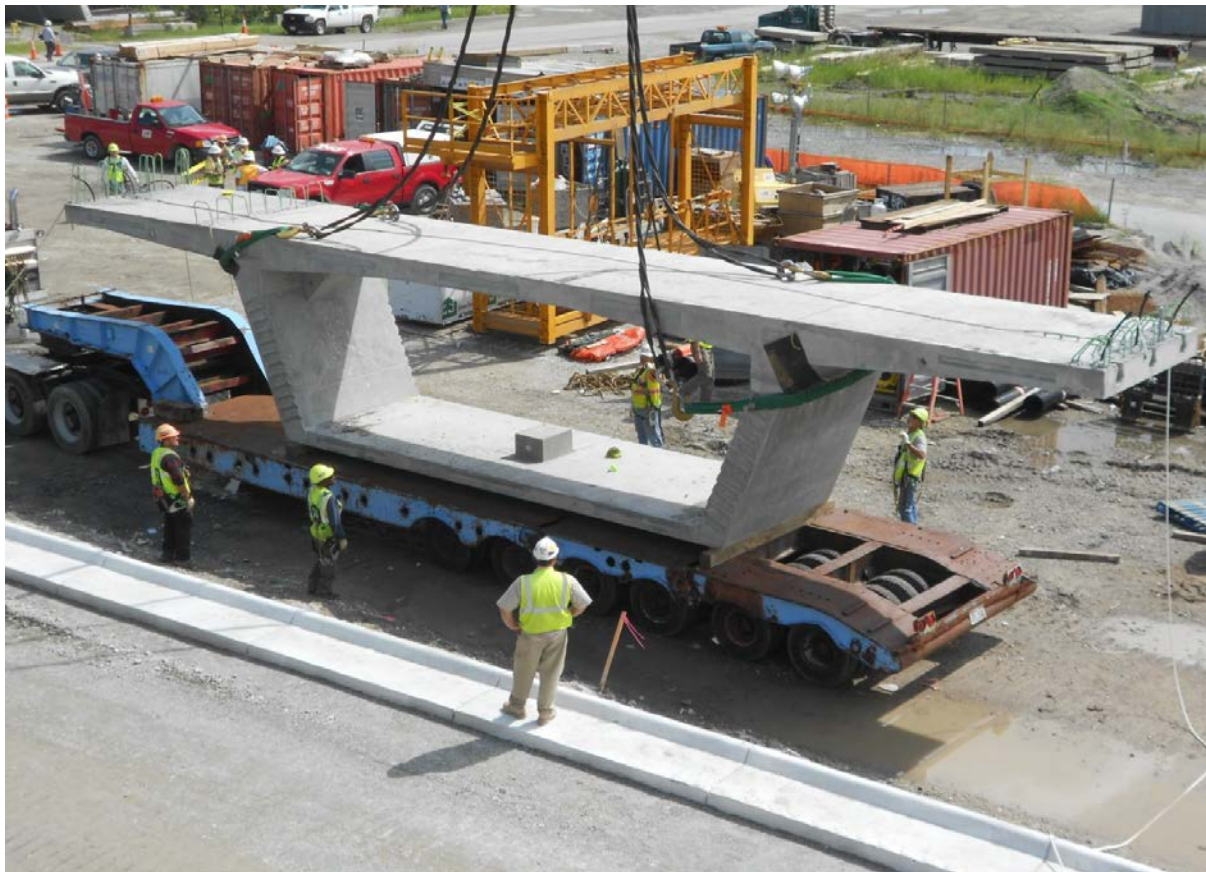
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losses caused by searching for segments will add up quickly especially if multiple movements are needed for access.

While in storage any pointing, patching, and architectural finishes can be applied (care must be taken when any repairs are made to the match-cast face to ensure the fit is not jeopardized). The post-tensioning rods and strands are stressed, anchored, and grouted. The Anchorages are sealed and poured back with like concrete. Any bond-breaking agents applied during casting must be power-washed off and the match face must be clean.

Note: The segment should be stored on stabilized grade using dunnage placed in a three point pattern to ensure the segment will not rack and lose shape.

### **Loading and Transporting.**







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Depending on the location of the storage area to the bridge erection site, the method of transportation will differ. Whether it is by trucks (on and off road), rail, or barge, several factors apply to all: hauling restrictions – time and weight, permits, environmental and noise ordinances, and distance. The most direct routes might not be the most cost effective or available. A necessary decision will also include whether to purchase, rent, or subcontract the loading and transporting. The lifting and handling of these large castings is specialized work and any errors can be catastrophic therefore, the services of professionally experienced subcontractors are advised.

Note: the segments must be transported to the bridge for erection in the same relation as they were cast.

### **Substructure Erection – Precast Columns**





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Precast match-cast structures are usually associated with superstructure elements in bridge construction but where economy of scale, scheduling, and access issues support the use, this method of construction is very effective for substructure pier elements. The construction for piers is very similar to the deck except the segments are stacked vertically then anchored to each other and the foundation with a vertical post-tensioning system.



Although they are usually cast-in-place and not precast, the erection process begins with the pier footings. Ductwork and anchors must be cast in the footing for the post-tensioning system. High strength rods are used in the “epoxy squeeze” activities and draped tendons (high-strength steel cables or “strands”) are used for the permanent compressive loads required to join the individual segments together in order to act as a single pier unit. Finally, a keyway is recessed in the top of the footing to receive the first or “base” segment.



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The base segment is set in the recess of the footing, and shimmed to line and grade. The post-tensioning ductwork and embeds from the footing are lined-up through the recess continuing into the segment with a grout tight connection. Lastly, the rest of the recess void is filled with grout, then the grout is allowed to set, and when strength is approved, erection is continued with subsequent segments.

After the grout has achieved the required strength, the intermediate segments can be erected with the following procedure: 1. Place epoxy on match-cast faces (epoxy acts as a lubricant and sealer to facilitate a tight fit between segments), 2. Connect high strength rods between segments, 3. Lower the segment onto the top of the previous segment, 4. Stress rods to provide “epoxy squeeze” to seat the segments to their match-cast (this step is performed every one to three segments placed), 5. Check survey control for line and grade on multiple faces to control plumbness and rotation, 6. If survey shows any signs of deviation from the as-cast geometry the next segment will





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need shimming to correct the error, 7. Repeat procedure to cap segment. Any epoxy that oozes or drips out during the squeeze will need to be cleaned (check the post-tensioning ductwork for epoxy that squeezes into the duct and restricts the diameter). The ducts for the rods can be grouted as the erection proceeds but this is a time consuming step. Most times access is provided to grout the rods once fully erected. Production rates of six segments per day can be regularly achieved; this is dependent on shimming and other quality control issues.



The last steps are the erection of the pier cap section, permanent post-tensioning, and setting of bearing pads. Setting the pier cap segment is very similar to the intermediate segments. Steps 1 through 5 above are followed with any survey deviations accounted with revised bearing pad locations. Since the cap contains the anchorages for the post-tensioning tendons and is the seat to support the spans, it must be a massive segment in proportion to the other segments of the pier. This means it will be the heaviest and



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tallest pick of the pier and therefore the most difficult to set. Once the segment is set, the post-tensioning strand can be installed. The strand is threaded through the ducts making a loop down the pier through the footing and back up the pier. Depending on the design, the number of strands per duct and the number of ducts per pier will vary and a stressing sequence will be provided in order to transfer a uniform load. The strand is stressed using high strength hydraulic jacks. When the jacks reach the required pressure (compressive loads will be calculated in terms of hydraulic pressure in the jacks) the strands will be anchored in places with wedges to retain the loaded energy. The stresses applied to the strand will stretch the steel. Elongations will be measured to ensure the stresses occurred over the entire length of the strand (a shortened elongation will mean the strand is pinched somewhere along its length and repairs may be necessary). The ducts are then pressure grouted to both protect the strand from corrosion and to permanently contain the stresses from the jacks. Concrete is then poured around the anchor blocks for further corrosion protection. Lastly, a final survey is performed and the bearing pads are set per the asbuilts.

Other precast concrete items found in bridge substructures include: concrete piling, precast cofferdams, pile cap soffits, and pier bent headers or caps.







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### **Superstructure Erection – Span by Span Method**



Span by span superstructure erection is a method of construction where the span elements are temporarily held in place until they are self-supporting and once capable of self-support the erection procedure advances to the subsequent span. The completion of one span at a time is the defining character for which the name “span-by-span” is derived from. This method is very repetitive and can be economical for spans ranging from 80 to 180 feet (150 ft spans are generally accepted as the most economical span length based on typical substructure types vs. typical truss). As with the previous sections of the course, efficiency is gained due to the repetitive assembly line nature of the work. Items that can affect productivity include: variations in span





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length and especially span height, the terrain being spanned (land vs. water, urban or industrial vs. open areas), and changes in alignment (curves and transitions).



In order to make this erection method as efficient as the name “span by span” would imply, the operations have been simplified to become repetitive. This however is aided/accomplished with some very specialized equipment. First the segments of the span must be temporarily held in place until they are self-supporting. Common temporary structures used for this function are: individual shoring towers, underslung carrying devices like trusses or box beams (these can support the segments under the soffit or under the wing (only if the segments are designed with a cantilever wing support condition)), the trusses can be supported from erected towers or brackets at the piers, or an overhead gantry can hang the segments from above. Second the segments must be lifted into position on the temporary supports. Where access permits, ground



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based or barged cranes can be used to lift the segments. Excessive heights or height restrictions may limit the use of cranes so specialized gantry transports have also been used. Lastly, rollers, jacks, winches, cable pushers and tuggers, stressing platforms, and C-brackets are a partial listing of miscellaneous equipment and fabrications that need to be procured prior to beginning the erection.

To begin erection, the support structures must be erected. If individual shoring towers are used, the ground must have a suitable bearing capacity, if not, stabilize with stone and/or use crane mats. If an underslung truss or overhead gantry is used, erect supports at piers and place truss to the correct line and grade off the pier supports. The length of the underslung or overhead trusses will need to be twice the structure's span length if they are to be self-launching, otherwise they can be shorter if a crane will be used to pick and set them in place at each span.



The procedures for the end spans are slightly different because of the location of the abutment stem and backwall, but for typical mid-spans the first step is to load segments





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on to the supports (assume underslung truss for narrative) starting from one location and launch them longitudinally to their approximate location. Typically the segments are set from the downstation end and are rolled up the truss (using Hillman rollers or alternate methods of launching) so the span segments need to be delivered in reverse order (last span segment first...first span segment last). Fully load the truss with all of the span segments prior to surveying to allow the truss deflection to occur. Survey and align segments for line and grade making sure chord offsets are correct for curved structures.



Next the segments will be aligned to the bridge geometry and joined. Sometimes it is helpful to dry fit the segments together before epoxy joining, especially if the epoxy is a rapid set type. This is usually an unnecessary step if adequate survey control was used in the casting yard during the match casting. A gap should be left between segments over the piers and the mid segments of the span. This gap will be closed with cast-in-

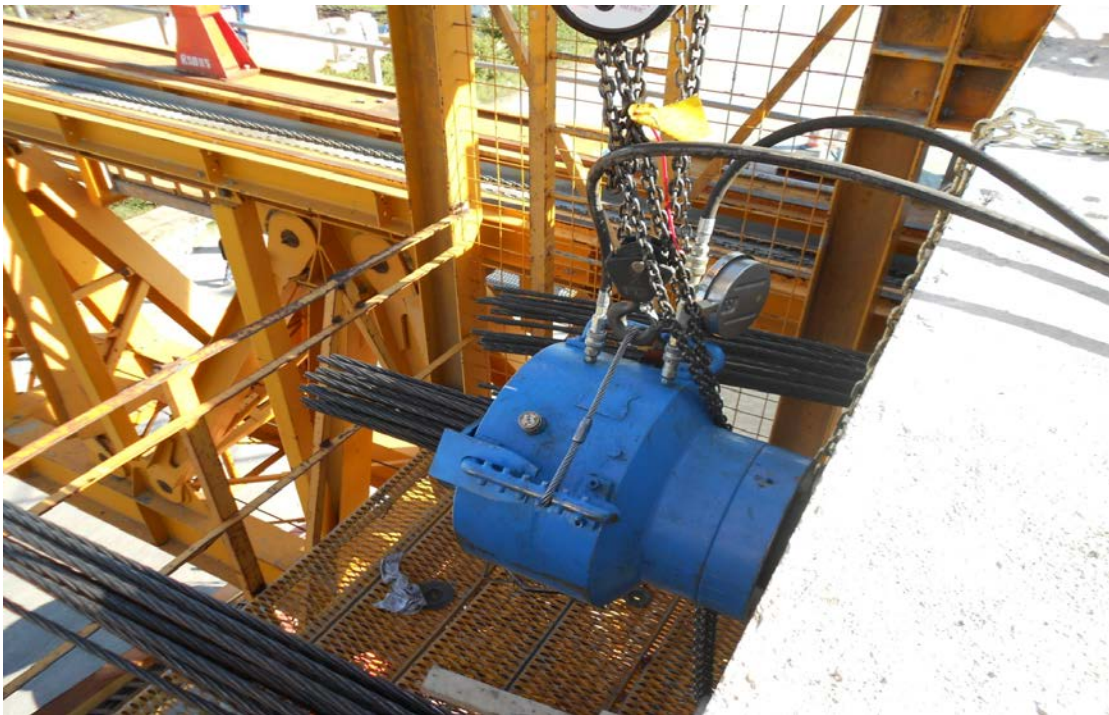


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place concrete as a closure pour to correct any unaccounted field conditions. This will help ensure that errors won't be cumulative through the structure but rather each span will start as corrected to the proper line and grade. After epoxy is applied to the match cast faces, apply pressure with temporary high strength rods for an "epoxy squeeze" to seal the joints (the epoxy is used as a lubricant/sealant to aid construction and increase long term durability of the structure). Last complete the closure pours to make the span continuous.

After the setting and joining of the span is complete, the post-tensioning operations will begin. Install permanent internal and external post-tensioning strand and rod



longitudinally through the span. Similar to the post-tensioning of the previous section (horizontal post-tensioning rather than vertical), the number of strands per duct and the number of ducts per span will vary and a stressing sequence will be provided in order to transfer a uniform load. The strand is stressed using high strength hydraulic jacks. When the jacks reach the required pressure (compressive loads will be calculated in terms of hydraulic pressure in the jacks) the strands will be anchored in places with





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wedges to retain the loaded energy. The stresses applied to the strand will stretch the steel. Elongations will be measured to ensure the stresses occurred over the entire length of the strand (a shortened elongation will mean the strand is pinched somewhere along its length and repairs may be necessary). The ducts are then pressure grouted to both protect the strand from corrosion and to permanently contain the stresses from the jacks. Concrete is then poured around the anchor blocks for further corrosion protection.

After post-tensioning, the span is self-supportive and complete. The trusses and other support devices are advanced to the next span to be erected and the process is repeated. Trusses can be advanced with cranes using a “pick, move, & place” method or can be self-launching using a “launch, slide, & pivot” method. Note: Design and maneuvering of trusses through curved spans takes tremendous consideration and potential losses in time and efficiency are significant if not properly planned.





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### **Superstructure Erection – Balanced Cantilever Method**



Balanced cantilever superstructure erection is a method of construction where span elements are erected in their permanent location starting at a central point and working cantilevered incrementally both up-station and down-station in a self-supporting balanced state. The segments can be placed individually alternating temporarily unbalanced to balanced conditions (the designer will specify how many elements out of balance can be erected – usually no more than one) or lifted in pairs, one over each end. This method is also repetitive and is useful for longer spans that can't be constructed by the span by span method. This method is used for precast segmental bridge spans ranging from 150 to 500 ft. As with the previous sections of the course, efficiency is gained due to the repetitive assembly line nature of the work but, this





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method of erection is more adaptable than the span by span method. Although variations in span length and span height, the terrain being spanned, and changes in alignment will be less efficient than straight, constant, and accessible designs, balanced cantilever spans are well suited for curved alignments, congested project sites, rough and water terrain, rail crossings, and environmentally sensitive areas.



Similar to span by span erection, specialized equipment will be needed to accomplish the erection. The first starter segments over the pier, commonly referred to as the “table-top”, will need to be supported. If the segments are on bearings, shoring towers will need to be erected along both the up-station and down-station sides of the pier column to temporarily hold the span against overturning until complete. If the segments are fixed to the columns, a frame will be needed to hold the segments in place until



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post-tensioning can be installed to integrate the superstructure and substructure units. If access allows, suitable cranes (200 to 300 ton crawlers usually) can lift the segments into place from below. Ground mounted cranes do not add any additional loads to the cantilevered structure but this method will be hard to coordinate in sensitive areas or where heights and weights are excessive but. Alternatively, beam and winch systems, fixed or travelers, can be used to hoist the segments into position from above. These systems are usually slower than cranes, custom built for single use (scheduling and cost considerations), and impart very heavy eccentric equipment loads to the structure. With either crane or winch methods, the segments will be lifted with a specialized



picking beam capable of holding the segments in the various longitudinal and transverse orientations (usually through hydraulic adjustments). Lastly, stair towers





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and stressing platforms will be needed to provide personnel access to the top and interior of the structure.

To begin erection, set starter segments, “table-top”, on the pier column with frames or supports per the previous paragraph and align for geometry. Closure pours may be needed periodically through the erection to correct any unaccounted field conditions. Similar to span by span, this will help ensure errors won’t be cumulative through the structure. If line can be maintained through minor shimming these intermediate closures will not be necessary and can be closed with the end pours of the span. If the table-top is aligned within tolerances, start erecting subsequent segments otherwise, use a closure pour at this point to make corrections (this is the easiest point to make corrections to project the correct line and grade through the span). Closure pours will





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require a means to temporarily hang the segments in place until cast in place concrete can be formed and poured in the closure. Once all adjustments are made for line and grade, typical erection can proceed.

As with all of the previous sections, the typical segment erection is a repetitive process that gains efficiency with experience and scale. The process is a combination of both the substructure and span by span erection procedures where the process includes both interior and exterior post-tensioning elements, except that the segments are hung horizontally without temporary supports. This makes the installation of the post-tensioning rod and the “epoxy squeeze” steps a structural process. For erecting the individual elements of the span, alternating from upstation to downstation: 1. Place epoxy on match-cast faces (epoxy acts as a lubricant and sealer to facilitate a tight fit between segments), 2. Raise balanced segments along respective sides of previous segments, 3. Connect high strength rods between segments, 4. Stress rods to provide







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“epoxy squeeze” to seat the segments to their match-cast (any epoxy that oozes or drips out during the squeeze will need to be cleaned (check the post-tensioning ductwork for epoxy that squeezes into the duct and restricts the diameter) at the end of this step the segments are self-supporting, 5. Install cantilever post-tensioning tendons in the internal ductwork of the balanced segment pair’s top slab (post-tensioning for cantilevered state are in top slab, continuity tendons for span completion are in the bottom slab), 6. Stress tendons and measure elongations (similar to previous sections), 7. At this time the ducts for the rods and tendons can be grouted but this is a time consuming step and may cause problems if the grout leaks over into future ductwork. Access should be provided to grout the post-tensioning elements once the span is fully erected, 8. Check survey control for line and grade to control plumbness and rotation (geometry programs should account for erection cambers cast into the segments for cantilever), 9. If survey shows any signs of deviation from the as-cast geometry the next segment will need shimming to correct the error, 10. Repeat procedure to complete the cantilever span, 11. Cast closure pours at mainspan and backspan connections, 12. Install, stress, and grout interior and exterior continuity post-tensionings. At this point the span will no longer be cantilevered and will be a continuous span through supports.

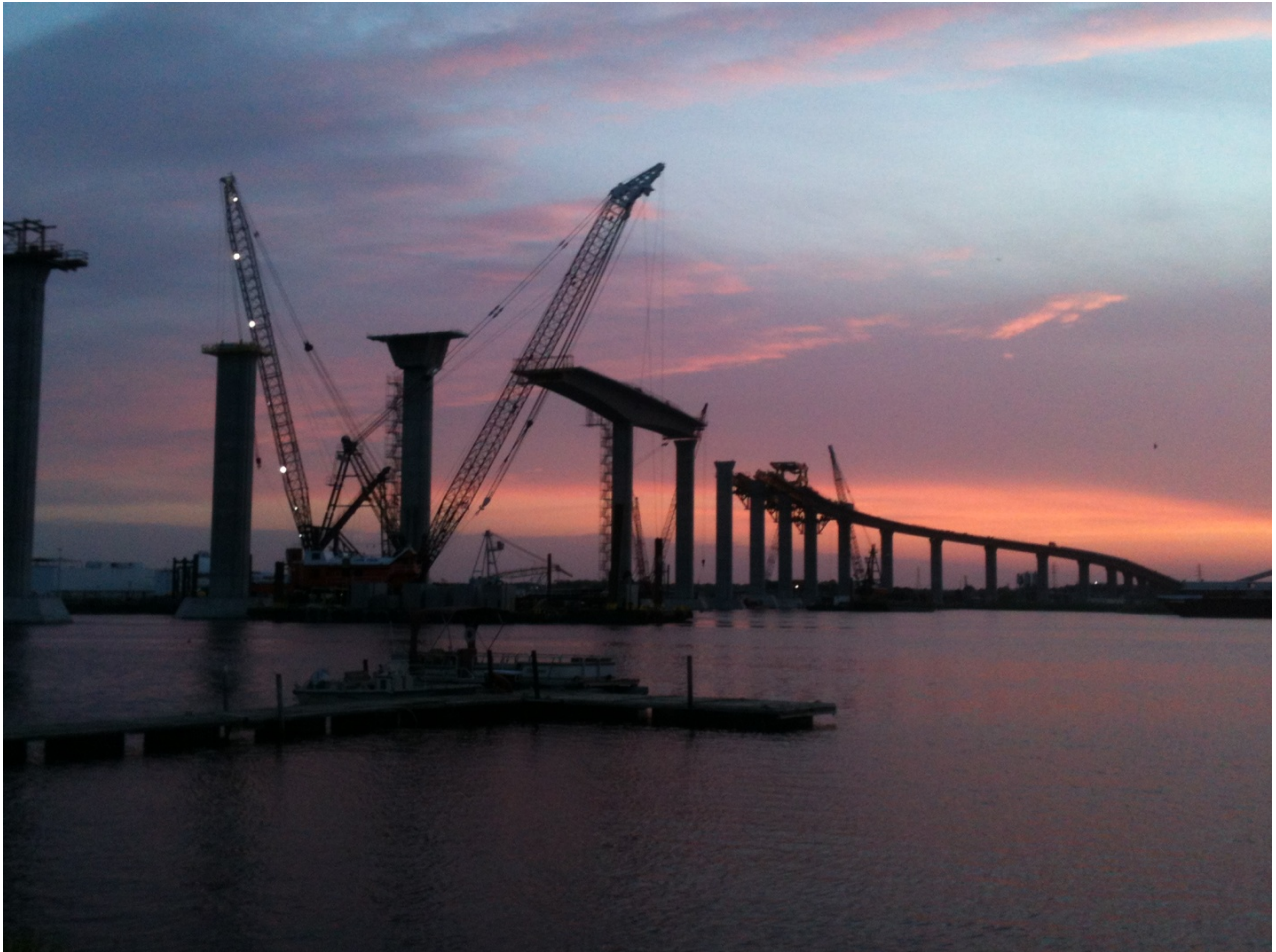
Prior to making the final closure pours (both midspan and backspan) alignment issues can develop that cannot be corrected by shimming. In this case the cantilever tips will need to be secured and brought into alignment using strongbacks. The strongbacks are used to stabilize the cantilever ends, hang formwork and access scaffolding, and vertically align the tips. For horizontal corrections cross chains and come-alongs can bring the tips into alignment (cantilevers on bearings will correct easier than fixed column types) but remember twists in one direction will cause an equal and opposite twist at the balanced end of the cantilever.



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### **Conclusion**



This introduction is a brief overview of the operations for precast segmental bridge construction, future courses will be written specific to each section of this course to provide a more in-depth review of each type of operation. This construction is very specialized and no matter how in-depth the courses are written there is no substitute for experience. Many specialty subcontractors and suppliers offer onsite consulting services as a supplement to the construction staffing. To organize a new construction project, managers should strongly consider these additions as well as the support of an experienced construction engineering firm. The consulting experience will help train the project personnel, troubleshoot problems, and give confidence to the owner. Additionally, a well structured quality control program is a must. From design to casting





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to erection, unaccounted errors can have significant impacts to cost, schedule, and **SAFETY**.

Lastly, safety must be a constant focus of every operation. Because of the versatility of these bridges (mostly described in the opening paragraphs of the course) they are often chosen to be constructed in some of the most adverse and inaccessible areas imaginable. Working with extreme weights at excessive heights requires safety diligence from every stakeholder. A comment from a past superintendent demanding patience about an operation; “we’re not just throwing pillows around”, sounds lighthearted considering the critical nature of these operations but served as a rallying cry for the safety of an entire project that completed without any OSHA recordable or lost-time incidents. Please be safe.





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### **Fun Facts From The Internet**

The first segmental concrete bridge, built in 1950, was cast-in-place across the Lahn River in Balduinstein, Germany.

The first precast segmental concrete bridge, built in 1962, crossed the Seine River in France

Eugène Freyssinet (13 July 1879 – 8 June 1962) was a French structural and civil engineer and was the major pioneer of prestressed concrete

Hoover Dam Bypass has the world's tallest precast columns

Longest Cable Stayed Bridge Span in the world is the Sutong Bridge in China - 3,570 ft, Longest in United States is the John James Audubon Bridge – 1,583 ft

Highest Cable Stayed Bridge – Baluarte Mexico – 1,321 ft in height