A SunCam online continuing education course

Precast Segmental Bridge Construction
Precast Segment Manufacturing

by

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Introduction

The popularity of precast concrete segmental bridge construction has grown worldwide in the last few decades. A broader understanding of these structures and basic outline of the processes for Precast Manufacturing, Substructure Erection, Superstructure Erection – Span by Span Method, and Superstructure Erection – Balanced Cantilever Method are detailed in the SunCam course; ***Precast Segmental Bridge Construction – An Introduction***. This course gives a more specific look at Precast Segment

Manufacturing. Some of the material from the referenced Introduction course is repeated within this course as background information to allow this document to be read as an individual subject. However, as the subsequent courses are added (Precast Substructures, Span by Span Erection, Balanced Cantilever Erection, Stressing and Grouting, etc.), each one should be complementary to provide the full scope of this type of construction. The course will be broken down into four basic sections: Casting Equipment, Precast Segment Manufacturing, Storage, Stressing and Grouting, Loading and Transporting.

Precast Concrete Segmental 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.

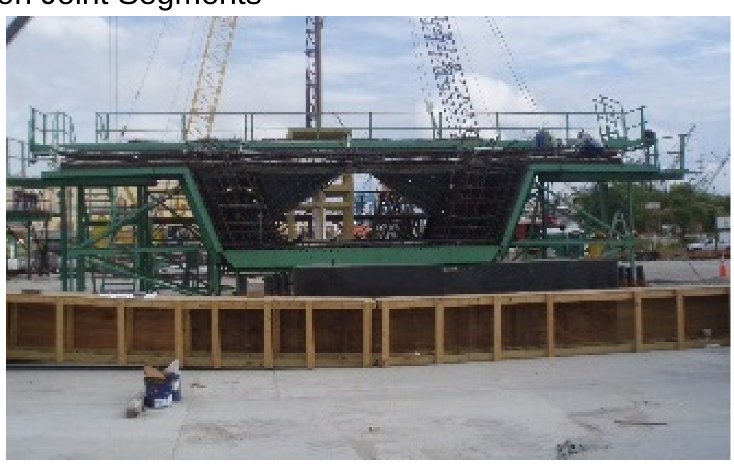
Casting Equipment

The Segment Casting operations should become a repetitive process to quickly produce a controlled quality product. This is accomplished with some very specialized manufacturing and handling equipment. The following items will be described further but the basic casting cells include the following:

Casting Cell Formwork
-Typical Segment

-Variable Depth Segment

-Pier and Expansion Joint Segments



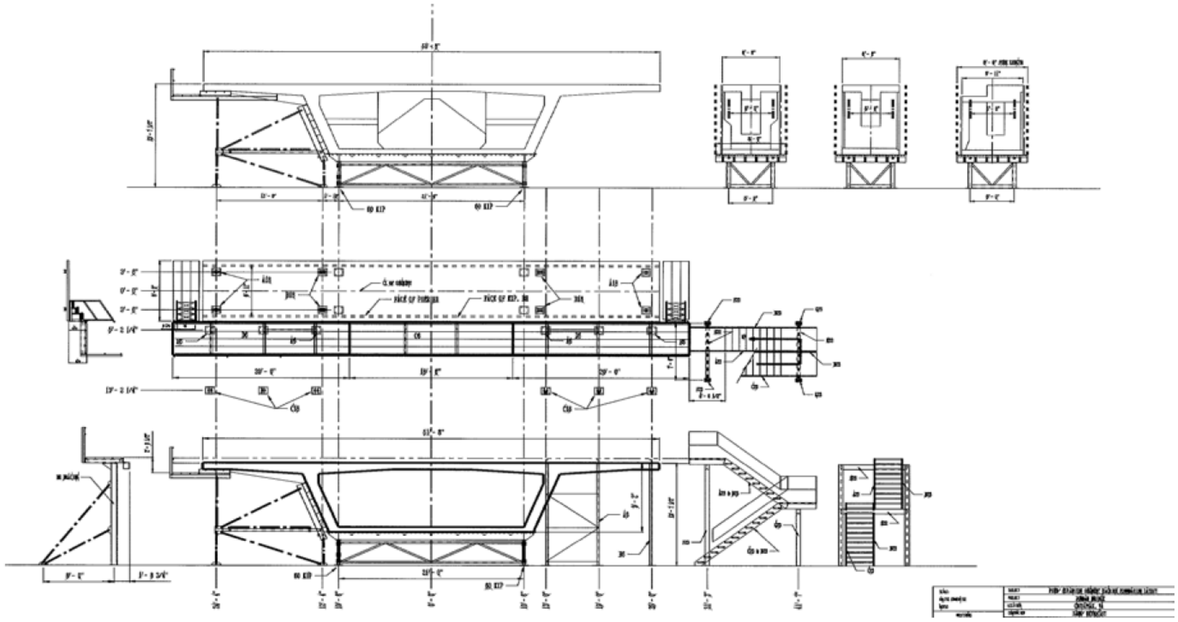
Rebar Jigs and Rebar Storage

Survey Towers

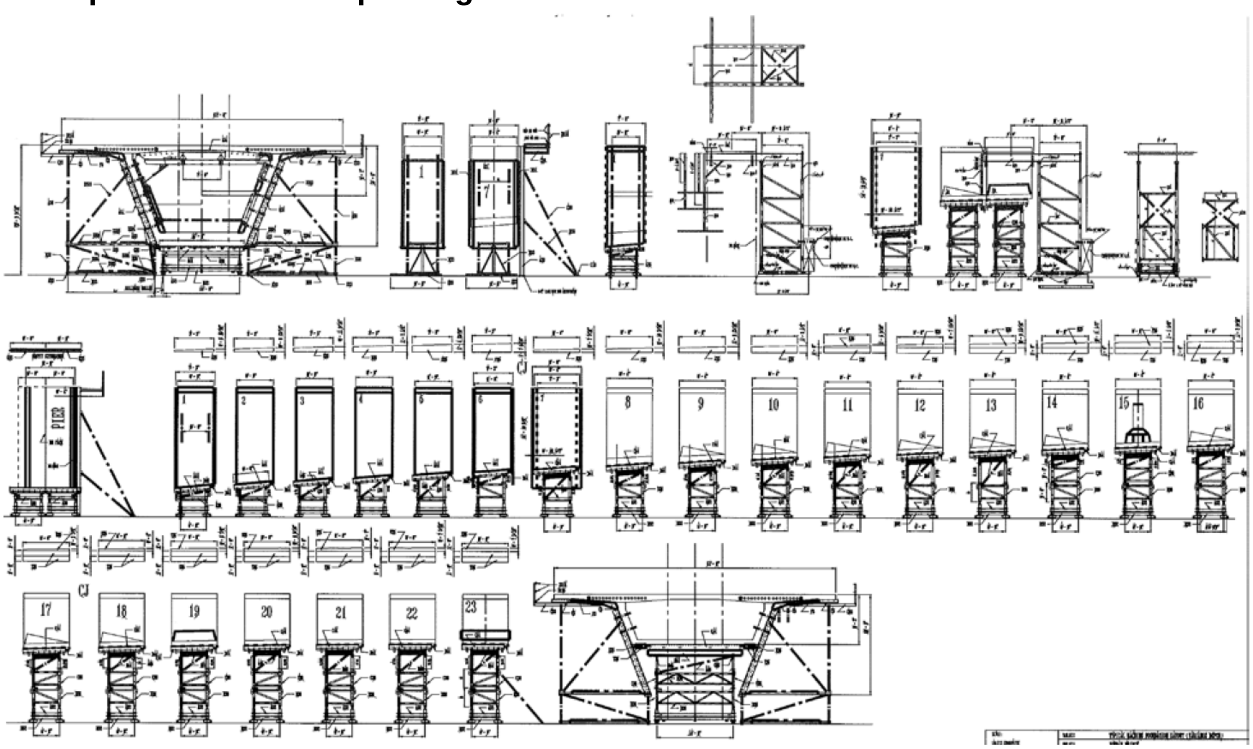
Concrete Plants

Protective Housing

Example of Pier or Expansion Segment Formwork Drawings



Example of Variable Depth Segment Formwork



Precast Segment Manufacturing

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 fundaments 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 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 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

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.

The foundation for the casting cell will need to support at least three segments (which can weigh around 100 tons each), the steel formwork for the segments, the handling equipment used to move the completed segments, and other live and dead loads. The picture above shows driven concrete piles and reinforcing steel for an example casting area. These foundations provide firm support and prevent settlement of the cells during production of the precast concrete segments. Throughout the project the foundation should be monitored by survey to determine if the foundations are settling. If settlement occurs, a correction may need to be applied to the castings to ensure the geometry is maintained.

After construction of the footings, the above picture shows casting cells in various stages of completion. The farthest cell is already in production with the straddle lifts moving the already cast segments, the next two cells are near completion with rebar jigs and formwork in place, the fourth cell has formwork and shoring being erected by crane, and the fifth cell's concrete working slab has just been placed and finished.

The basic form elements of the cell include:

Soffit Form

The soffit form provides the shape for the bottom slab of the segment and also serves as a means to move the segment after it has been cast. The soffit form needs to be designed to support the heaviest segment to be cast in that particular cell and needs to be placed upon a support system that can be moved after casting to serve as the next match-cast segment or to load out to storage. For variable depth segments, the soffit form needs to accommodate different widths and slopes for the bottom of the segment. Soffit forms, their support system, and the remainder of the casting cell forms will be supported by the previously described concrete foundations

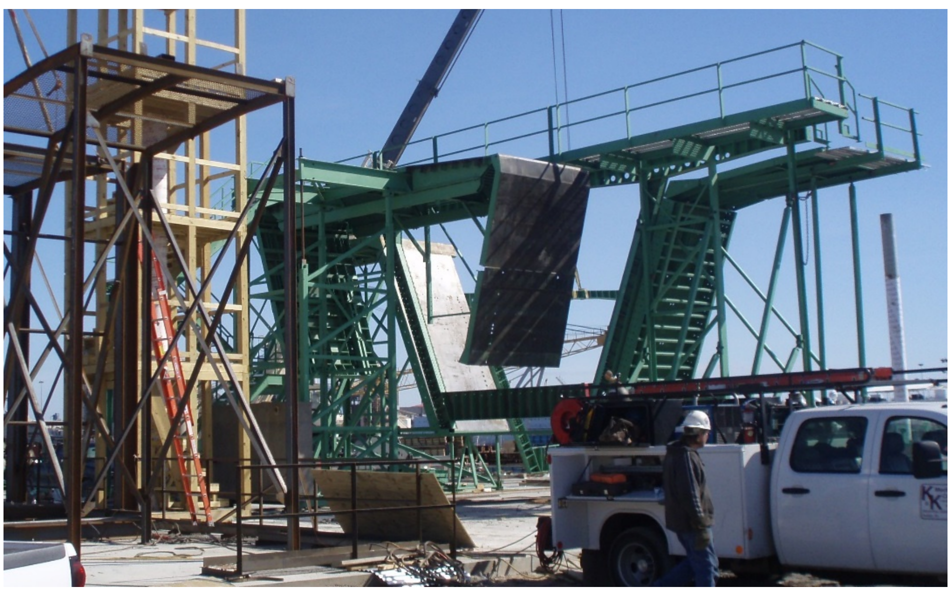
Bulkhead Forms

The bulkhead form provides the shape of the vertical face for the back edge of the cast segment. The bulkhead shape includes post-tensioning embeds, and shear and alignment keys. The bulkhead form's position is fixed; therefore any segment geometry (discussed later) is obtained by adjusting the position of the segment previously cast in the match-cast position. To accommodate the change in height of variable depth segments, the bottom of the bulkhead needs to be able to adjust vertically. Since the web slope for the segments are typically held constant, the remainder of the bulkhead does not need to be changed however, if segment cross slopes or shoulder breaks from changes in supelevations are needed, the bulkhead will need transition hinges.

Wing/Web Forms

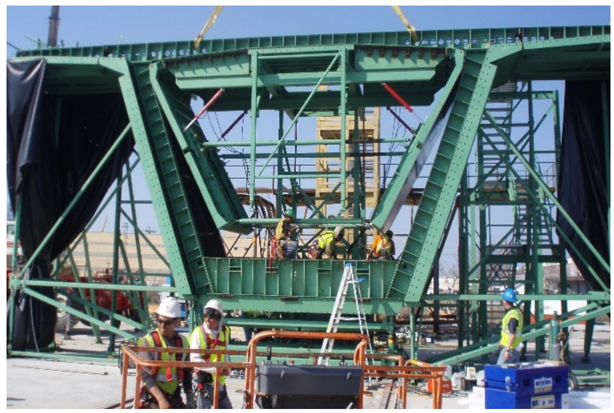
The wing and web forms provide the shape for the underside of the wing and the exterior of the web. The wing and web forms are normally supported by a frame connected to the casting cell foundation.

Core Form



The interior form, or core form, provides the interior opening within the segment. The form supports the segment's interior top slab and controls the concrete thickness in the webs. For ease of stripping the forms after segment casting, the form sides should collapse and the whole system needs to travel in and out of the cell. In order to travel in this manner, the forms are cantilevered off a frame that needs a concrete counterweight to maintain alignment.

Views of Completed Casting Cell Formwork for Variable Depth Segments



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 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.

Quality Control Technicians reviewing Slump and Air Content tests

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.

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 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.

Casting Geometry

Geometry Control for the segment casting process is necessary to ensure that the segments of the spans are oriented in the correct horizontal and vertical alignments, as well as, controlled for cross slope super-elevations, and camber. (In addition to the geometry control needed for the bridge design alignment, the balanced cantilever erection method requires additional geometry control to account for the temporary construction loads on the structure caused while the span is in the cantilevered condition so, additional camber must be built into these segments). Each segment has an (X), (Y), & (Z) which represents its small section of the bridge whether horizontally straight or curved, vertically constant slope or varying, and cross-sectional constant or varying (ex. Segments lying within a horizontal curve will be pie shaped with superelevated cross-slopes, whereas a straight alignment will have square shaped segments with a crowned cross-slope). Each segment represent such a small portion of the bridge alignment therefore the changes from segment to segment may be visually imperceptible but if deviations are not corrected they can cause major alignment issues during the erection process (a .25% change in vertical slope for a 10 foot segment is only ¼" but if uncorrected over a 150 ft bridge span it will create a 4 ½" bump in the road).

The previous section, **Concrete Placing and Curing,** gives an overview of the casting process and the relationship between the match-cast segment and the segment being produced. In addition to that summary, for geometry control, after casting a segment, the previous day's production is asbuilt by the survey crews to ensure the geometry was maintained while the concrete set. If the asbuilt survey shows any deviation from the plan geometry, adjustments will be made in the subsequent castings the correct the error (minor deviations can be corrected in the next segment while more severe differences may take several segments to span the adjustment or may ultimately result in rejection of the segment making a re-cast necessary). 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, embedded materials are placed, and the new geometry is surveyed to make the segment ready for 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. The as-cast survey is recorded to be given to the field surveyors at the erection site for controlling the erection alignment.

Since the formwork of the segment being produced is mostly in a fixed position, the adjustments from segment to segment are made by adjustments made to the position of the match-cast segment. If the bridge is in a constant alignment, the match-cast segment will be squared to the formwork of the new segment. If the bridge alignment is curved or varying, the match-cast segment will be skewed to the chord length and angle of deviation needed to produce the new segment in its required shape relative to its location. Every segment is produced relative to the successor and predecessor segments of its position.

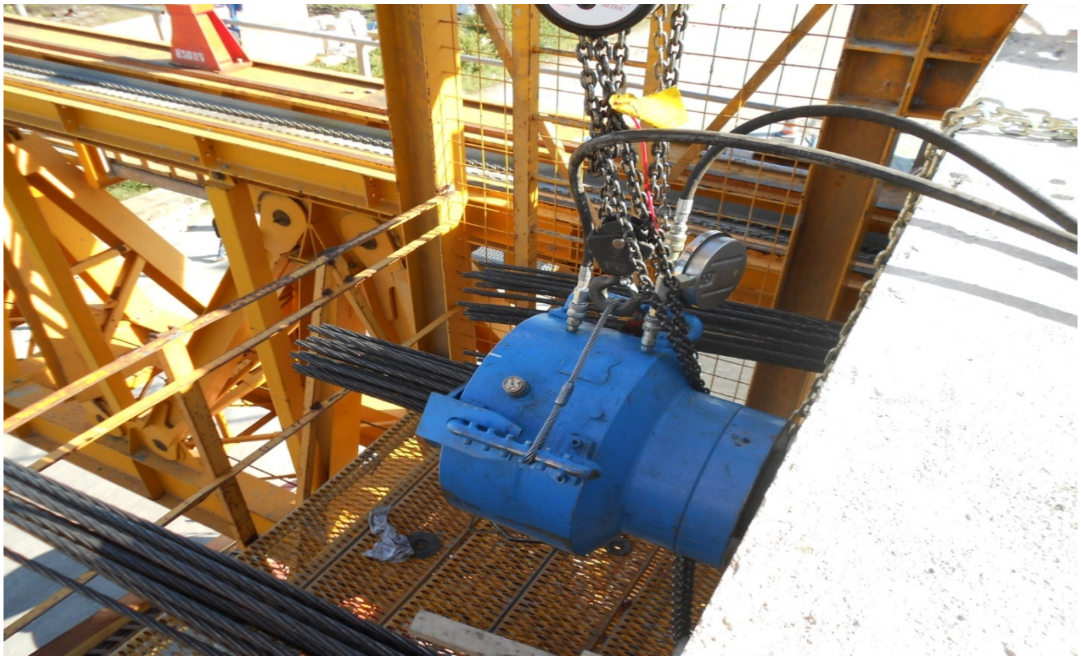
At erection the individual segments are surveyed as they are placed in position, then the deck is re-surveyed as a unit to confirm the alignment was maintained through the erection process. Utilizing the same survey control points cast into the segment, the first segment will be set in the required location and the following segments will be surveyed as they are placed to aid the "fitting up" of the matching pairs. The geometry will be monitored with each segment placed and compared to the recorded data from the casting. Through the erection process minor changes due to field tolerances will occur. This can be controlled by adding cast-in-place closure pours between segments (usually at planned locations at the beginning, end, and midpoint segments of the span but additional closures (designed condition or field condition) are possible). Since the closures are cast-in-place, the geometry can be adjusted horizontally and vertically to accommodate transverse and longitudinal changes (further options are discussed in other courses beyond this scope).

Stressing and Grouting

Post-tensioning of the bridge elements is mostly associated with the erection processes of precast segmental bridges but the casting locations and materials of the segment manufacturing are critical to the performance of post-tensioning operations. The high strength post-tensioning strands provide the longitudinal and transverse compressive forces in the segments that allow them to act as a single unit capable of carrying their intended loads. A more comprehensive detailing of the stressing and grouting operations is covered in the SunCam course ***Precast Segmental Bridge Construction***

- Stressing and Grouting, and the stressing and grouting operations for the erection process in ***Precast Segmental Bridge Construction - Span by Span Erection Method*** and ***Precast Segmental Bridge Construction - Balanced Cantilever Erection Method*** courses.

A brief summary of the stressing and grouting process:
After the setting and joining of a bridge span is complete, the post-tensioning operations will begin. Install permanent internal and external post-tensioning strand and rod longitudinally through the span. 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 ducts are then pressure grouted to both protect the strand from corrosion and to permanently contain the stresses from the jacks.

The precast segments of the bridge must have post-tensioning embeds cast into the segments in critical locations. The strands will be placed in plastic and steel ducts and the anchor devices will be formed into the faces of the segments.

The above completed pier segment show anchor heads and metal ductwork in the cross-section face of the segment and shows transverse strands extending out the wings for stressing

Transverse ductwork installed for a segment prior to placement of concrete in the cell

Vertical ductwork for a precast column segment prior to placing concrete in the cell

Steel Ducts stored for placement

Flexible Plastic duct stored for placement

Preassembling transverse post-tensioning duct & anchors for installation in forms

Stressing and grouting of the transverse strands is normally done in the storage yard prior to shipping for erection. The transverse tendons are usually single 7-strand wires (coated or uncoated) which are tensioned individually and then grouted in place.

Pressure grouting the ducts after post-tensioning the tendons locks the compressive forces into the segment and adds another element of corrosion protection.

Grout cubes and flow tests are performed by the QC department to ensure the grout meets the specifications and the operations are acceptable.

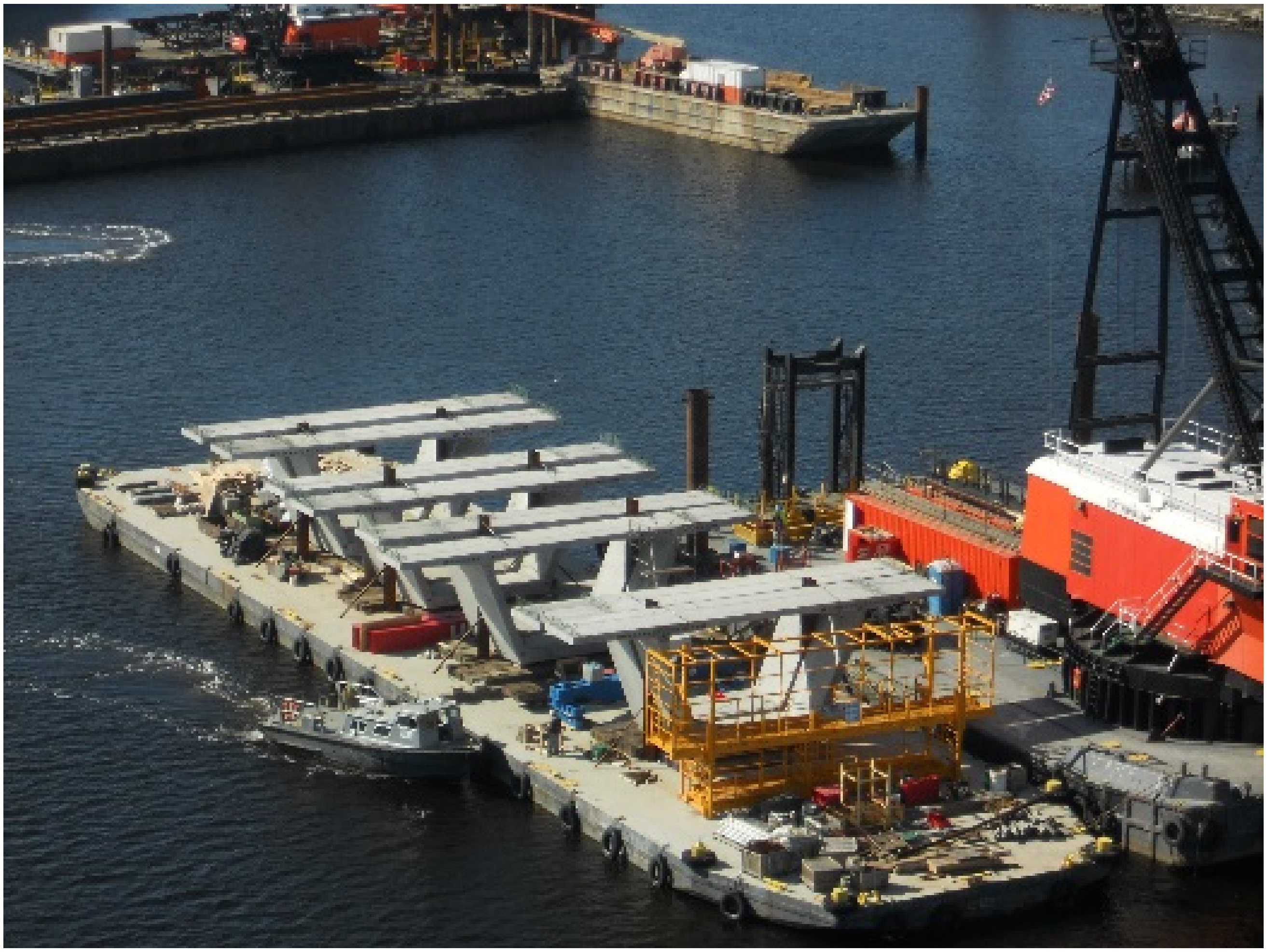
Loading and Transporting Segments

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.

Crane lifting segments using picking frames and picking beams with anchors or sleeves cast into the top deck of the segment

Gantries lifting segments using under wing straps with softeners at the concrete edges

Specialized multi-axle trailers will be needed for hauling the segments, as well as, a tractor with enough horse-power to tow the load. The above trailer is adequate for non-permit loads for hauling onsite or at the casting yard. Multi-axle dollies will be needed for legal permit loads on public roadways. If the trailers are used to deliver segments over the previously constructed portions of the bridge, the engineer will need to check that the wheel and axle loads are allowable. If manufacturing details for the tractor and trailer are available, the engineer can determine the optimal location for placing each segment on the trailer to distribute the loading acceptably to each axle. Alternately, portable truck scales can be used to measure the actual axle loads and through a series of “trial-and-error” segment placements, so an optimal location can also be determined.



A loading sequence will be developed for barging segments. If the barge is not uniformly loaded it can cause an unsafe condition which may damage the segments or jeopardize the entire load. Segments will be loaded and unloaded in a specific order and location to match the barge capacities and the erection sequencing. A deep water bulkhead will allow the crane to position as close as possible to the segments and minimize the lifting radius. Alternatively, a straddle lift can transport the segments on finger piers and place the segments on a barge positioned in the berth.

Conclusion

This course is gives a more specific look at precast segment manufacturing for precast segmental bridges, broader information can be found in the Suncam course ***Precast Segmental Bridge Construction – An Introduction***. 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 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.