Construction Techniques for Segmental Concrete Bridges

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One of the primary advantages of segmental concrete bridge construction is the economics. In a large majority of cases, segmental construction has been the winner where alternate construction methods have been available to contractors at the time of bidding.

There are many reasons for this relatively new method of bridge construction in the United States competing so well in the 10 years since the European transfer technology was started. I believe, however, that the principle reason for the success of segmental concrete construction is the number of construction techniques available to build these bridges. Of approximately 35 to 40 such bridges either completed, under construction or in design in the United States, few have been or will be constructed in exactly the same manner. The multitude of choices available to contractors allows them to tailor each project to their manpower and equipment in the interest of maximizing efficiency and optimizing cost.

Segmental bridge construction is also revising the basic thinking of design engineers. Until recently, designers have concerned themselves mainly on how to build the project after preparing computations and plans. Segmental construction has revised this thinking. The first question asked about a project now is "What is the best and most economical way to build this project?" Once this question has been satisfactorily answered, the designer can proceed with a design based on the most efficient construction method.

In order to make intelligent decisions, both designers and contractors need to become familiar with the available

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Discusses the various segment casting methods and erection techniques for constructing segmental concrete bridges. Particular attention is paid to geometry control procedures.

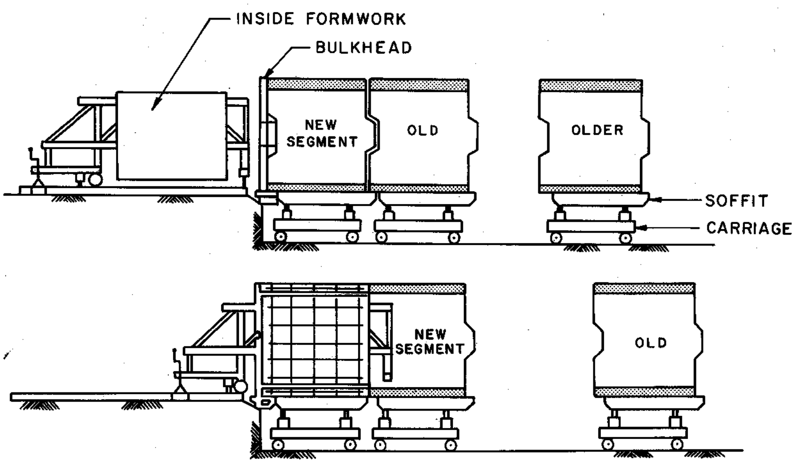

Fig. 1. Schematic of short line match casting system. The usual rate of production is four segments per week per set of forms.

methods of segmental construction. Not all methods are applicable to all projects but all should be considered for each job. There are several fundamental concepts relating to casting and erection of segments which could be considered for practically every bridge project. By no means should these basic concepts be the only ones considered. Segmental bridge construction was born out of innovation and will continue to grow through more innovation by both contractors and design engineers.

Precasting Techniques

Short line system—All the casting methods to be discussed utilize the concept of match casting. The basic premise of match casting is to cast the segments so their relative erected position is identical to their relative casting position. This requires a perfect fit between the ends of the segments and is accomplished by casting each segment directly against the face of the preceding one using a debonder to prevent bonding of the concrete. The segments are then erected in the same sequence they were cast.

The most common method for match casting segments is called the "short line" method. Fig. 1 shows a schematic of a short line match casting system.

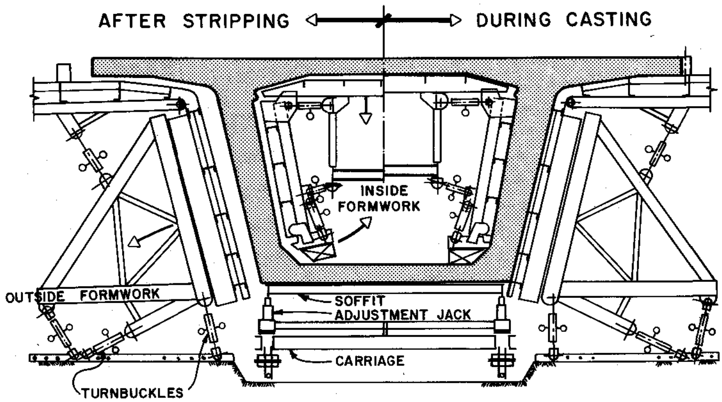

Fig. 2. Casting machines (forms) fold back hydraulically or with screw jacks to permit moving of segments.

With this system, the rate of segment production will approach one segment per line of forms per day. A good average to use for a project is four segments per line every 5 days.

For the sake of explaining the casting procedure, assume today is Wednesday. The older segment was cast on Monday and is now cured and ready for the storage yard. The old segment was cast yesterday or Tuesday and was match cast against Monday's segment. Today a new segment will be cast against Tuesday's segment.

Fig. 2 shows the form arrangement for short line match casting. The French call these forms casting machines. The appropriateness of this name will soon become apparent for they really are machines. The length of the side forms is equal to the length of the segment being cast plus 1 or 2 in. (25 or 51 mm) to seal around the match cast joint. The side forms have the capability of being folded back away from the segment to permit removal of the segment. This is done either with screw jacks or hydraulic rams. The collapsible inside formwork which forms the void of the box girder rolls on rails to allow removal of the form, enabling the segment to be lifted vertically.

When the workers arrive at the precasting yard on Wednesday morning, the side forms are closed, the inside form is rolled forward, Tuesday's segment is in the new segment position and Monday's segment is in the old segment position. The first operation is to determine the relative position as the segments actually were cast. This is done by shooting elevations and centerline with an accurate survey instrument. These shots are called "early morning shots." (Geometry control will be discussed in greater detail later.) Once the early morning shots are taken, the forms are released and Monday's segment is taken to the storage yard. Tuesday's segment is then moved from the new segment position to the old segment position.

All of the geometry of the bridge (horizontal or vertical curves and superelevation or transitions) is cast in by adjusting the old segment. The forms are never adjusted for geometry. Therefore, once Tuesday's segment is in the old segment position, its attitude is adjusted by screw jacks between the carriage and the soffit to provide the proper bridge geometry. A prefabricated reinforcing bar cage is then set in the new segment position. Once the side forms are closed

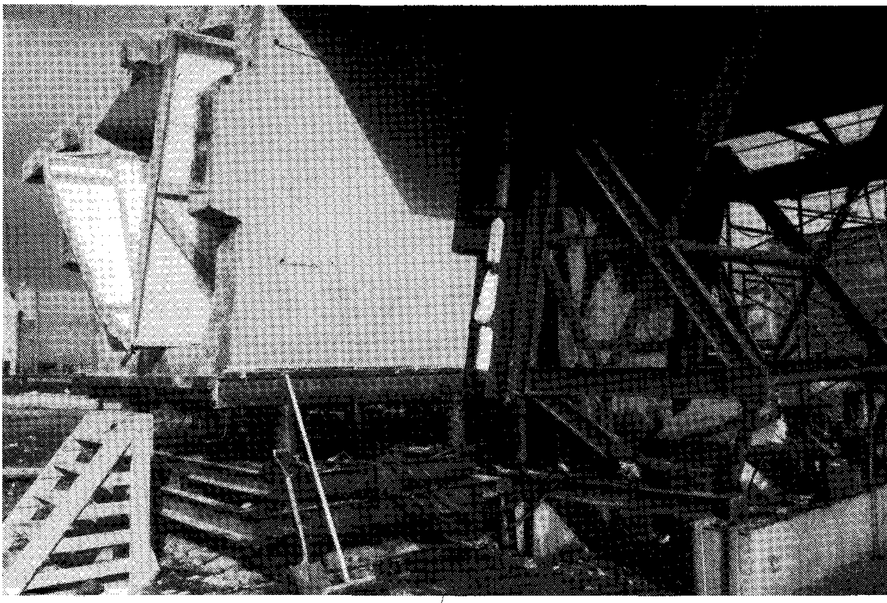
Fig. 3. Casting machine. Proper geometry is obtained by adjusting the alignment of the cast-against (concrete) segment with screw jacks under the supporting soffit.

and the inside form is rolled forward, the casting machine is ready for casting today's (Wednesday's) segment.

Fig. 3 shows a casting machine for a short line match cast system. Note the screw jacks for adjusting the attitude of the old segment.

Fig. 4 is a schematic of the geometry control layout for a short line casting method. The survey instrument is usu-

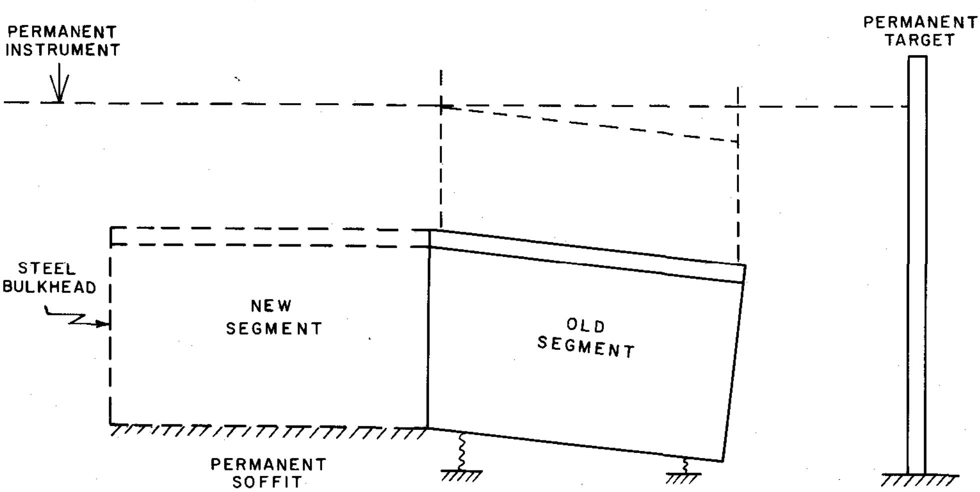

Fig. 4. Geometry control layout for short line system. The instrument support and target should be stationary and permanent.

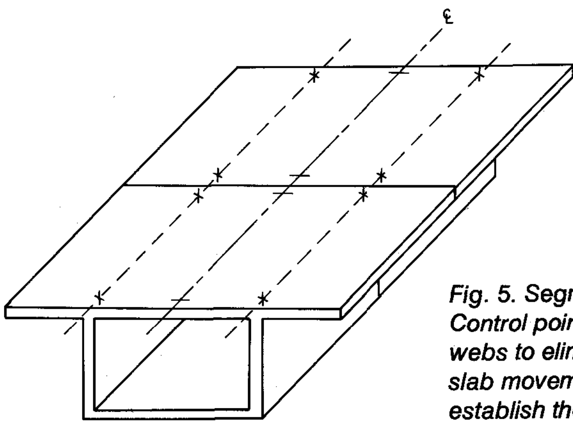

Fig. 5. Segment survey control points. Control points are located over the webs to eliminate any influence of top slab movements. The center points establish theoretical centerline.

ally a theodilite capable of measuring accurately to 1⁄32 of an inch (nearly 1 mm). The permanent target is generally a concrete pile driven into the ground and insulated to prevent bending due to the sun shining on one side. Elevations are shot using a survey rod. A metric rod may be more practical because the smallest graduations are approximately 1⁄32 of an inch which eliminates some of the guesswork involved when using rods marked in feet and inches. The data measured are elevation differences so the metric rod does not result in extensive unit conversion.

The segment survey control point positions are shown in Fig. 5. Each segment has six control points—four over the two webs and two on the centerline. Round-headed bolts placed 2 or 3 in. (51 or 76 mm) from the edge of segment are used for the elevation control points. They are assumed to be at the edge of the segment for computation purposes and should always be placed over the webs to eliminate any influence of top slab deflections. Since only relative positions of segments are of concern, these bolts do not have to be placed at any specific elevation but may be placed in the wet concrete so the bottom of the head is approximately at the concrete level. The early morning shots on these points establish the basis of relative positions.

The two centerline control points usually consist of U-shaped wires placed in the wet concrete after the top slab has

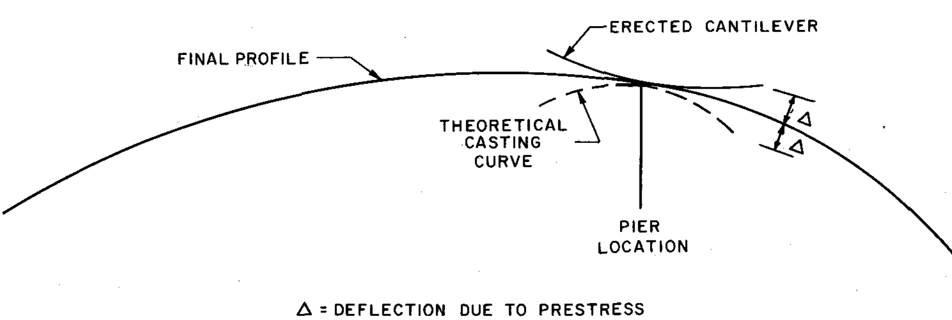

Fig. 6. Theoretical casting curve is drawn from data provided by the design engineer.

been finished. The theoretical centerline is established by notching these wires with a hammer and chisel during the early morning shots.

The designer of the bridge will provide information to develop a theoretical casting curve. The theoretical casting curve is a curve along which the segments should be cast so the final desired alignment will be achieved after all deformations. The computation of these deformations is quite intricate since most are time dependent and interdependent. Thus, a good computer program is needed for maximum accuracy. Among the causes of deformations are self weight of the structure, camber due to prestress, prestress losses, creep and shrinkage of the concrete and temperature variations.

For the sake of simplifying this discussion, let us consider the deformation of camber due to prestressing. Fig. 6 shows a crest vertical curve as a final desired alignment. Assuming balanced cantilever erection, the erected cantilever would deflect upward an amount Δ due to the prestressing as represented by the erected cantilever curve in Fig. 6. Therefore, it is obvious the segments must be cast with a downward deflection of Δ so when the camber occurs the proper alignment will be achieved. A curve depicting this downward deflection is the theoretical casting curve. In reality, when all the deformations are considered, the theoretical casting curve usually bends upward rather than downward.

Fig. 7 (top) shows the theoretical casting curve developed previously. Since segments cannot be cast curved, the curve is approximated by casting segments on the chords. This is the procedure followed whether the curve is horizontal or vertical. Therefore, chords equal to the length of the segments are laid out on the theoretical casting curve so a tangent to the curve can be drawn at the points of intersection of the chords. Angles B_1 and B_2 can then be measured from the local tangent defining the desired relative position of the segments as they are match cast and erected. This must then be related to the position of the casting machine.

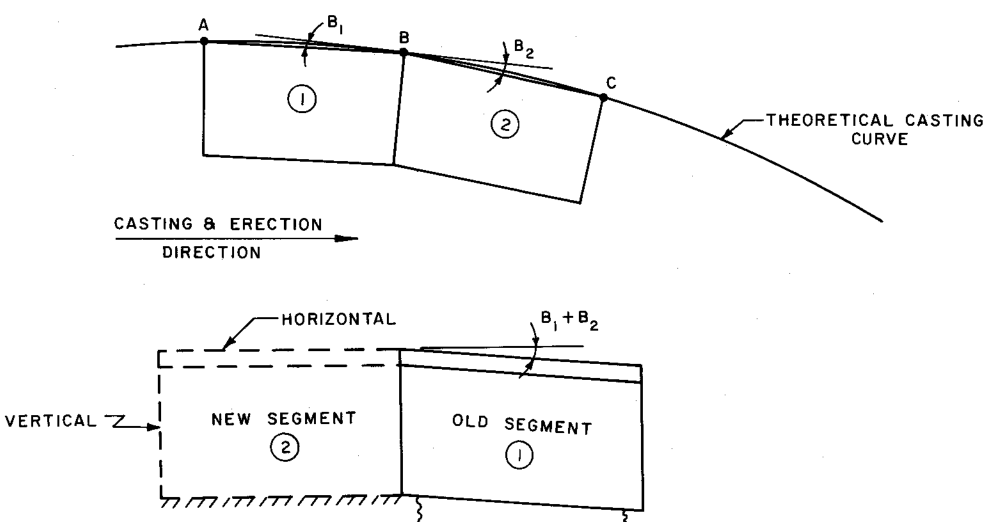

Fig. 7. General method for determining relative position of segments to obtain the desired geometry.

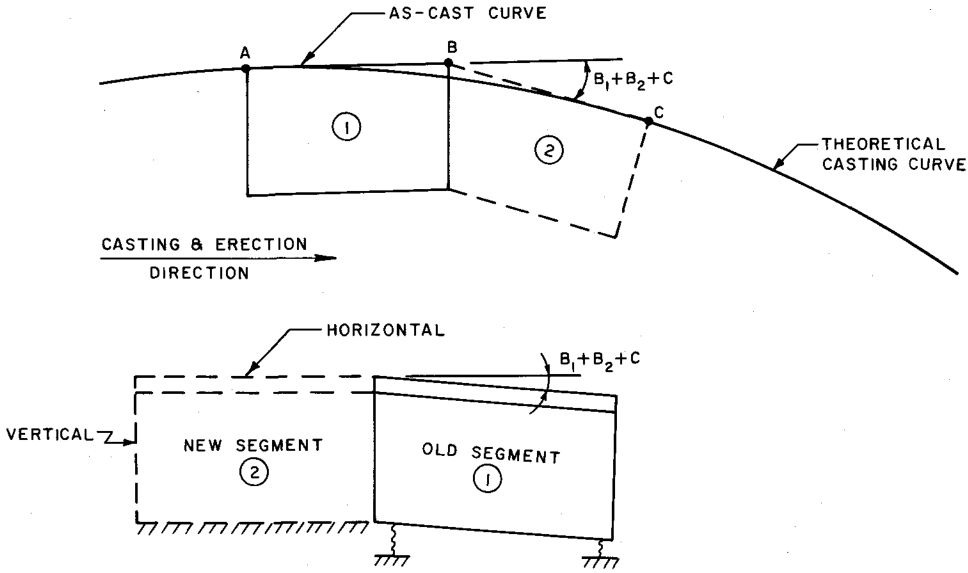

Fig. 8. Segments must be adjusted to compensate for casting errors.

Two assumptions relative to the casting machines must be made—the first can be controlled, the second cannot. The first assumption is that the steel bulkhead at the opposite end of the new segment from the cast-against segment is established and maintained absolutely vertical with the top being completely horizontal. In addition, the bottom soffit is established and remains absolutely horizontal. The second assumption is that the segment being cast is perfect. While this second assumption is not too important to this explanation, it is very significant when performing actual geometry control procedures.

To transfer the segment relationship from Fig. 7 (top) to the casting machine, one has to examine the direction of casting and erection. In this case Segment 1 is cast and erected before Segment 2. Therefore, on the casting machine Segment 1 is in the old position and Segment 2 is in the new segment position as shown by Fig. 7 (bottom). Remembering the steel bulkhead located on the left side of Fig. 7 (bottom) is always vertical and the soffit is always horizontal, one must adjust the attitude of Segment 1 to duplicate the segment relationship found in Fig. 7 (top). This is done simply by rotating Segment 1 by an angle equal to the summation of B_1 and B_2.

The procedure just described is theoretical and idealized. Now let's get practical. When we remember the segments weigh 40 to 50 tons or more and the concrete is steam cured, raising the temperature of the concrete and steel casting machine to 150 F (65 C), things are likely to move. In fact, they always do!

The purpose of the early morning shots is to determine the magnitude and direction of movement or casting error. These data are plotted directly on the theoretical casting curve as shown by Point B on Fig. 8 (top). In this case, the actual relationship between the two segments previously cast results in the end of Segment 1 being above the theoretical casting curve. However, it could just as well have been below it.

Therefore, to get back to the theoretical casting curve when casting Segment 2, assumed to be perfect, a correction must be included in the attitude of Segment 1 as it is placed in the old or cast-against position. Therefore, as shown by Fig. 8 (top and bottom) the proper angle of rotation of the segment is B_1 plus B_2 plus a correction C.

The curve generated by plotting all the early morning shot data is a curve which wiggles on either side of the theoretical casting curve. This curve is known as the "as-cast curve." If the as-cast curve starts deviating away from the theoretical casting curve, the engineer knows he has serious problems and can take corrective steps before the situation gets out of hand. The as-cast curve is also valuable information for the field engineer because it shows the actual relationship between the segments as they were cast. This relationship must be duplicated again when the segments are erected.

It is strongly recommended that all of the casting geometry control be set up graphically and drawn to the largest possible scale. This not only includes the two previously mentioned curves but the determination of rod readings to set the proper attitude of the cast-against segment. Also, a separate set of curves should be used for each line of control points even though two of them may be theoretically symmetrical. Frequently, the early morning data will not be symmetrical.

Of course, mathematical equations can be set up to calculate settings for all the points since all have a straight line geometrical relationship. However, these equations should only be used as an independent check of the graphics. It is much more difficult to determine tendencies and directions by examining sets of numbers than by examining graphical plots.

The short line system does offer some advantages. For example, the space required for set up is minimal resulting in a centralized operation. Any geometry desired can be obtained by twisting the position of the cast-against segment. The primary disadvantage of the method is the accuracy at which the cast-against segment must be set. Also, the casting machine must be flexible enough to conform to the twisted cast-against segment but rigid enough to adequately support the loads. This is particularly so when casting segments for a superelevation transition.

Long line system—An alternative to the previously discussed short line system is the long line system. The system is similar except that a continuous soffit the length of a cantilever is built. Figs. 9 and 10 show such an example. All the segments are cast in their correct relative position with the side forms moving down the line as each segment is cast. Geometry control is established by adjusting the side forms and soffit. Variable depth structures may be cast by varying the elevation of the soffit, i.e., curves are cast by curving the soffit.

A long line is easy to set up and to maintain control of the segments as they are cast. Also, the strength of the concrete is not as critical since the segments do not have to be moved immediately.

When considering a long line system several things must be taken into account. First of all, substantial space is required. The minimum length of soffit required is generally a little more than one-half the longest span of the structure. The foundation must be strong and relatively settlement free because the segment weight to be supported can be 5 tons per lineal foot or more. Any curing and handling equipment must be mobile since the side forms travel along the soffit. The contractor must set up a monitoring system and adjust the soffits periodically to correct for any settlement.

Fig. 11 shows the long line casting system used to cast the segments of the Kentucky River Bridge near Frankfort, Kentucky. This bridge was completed in

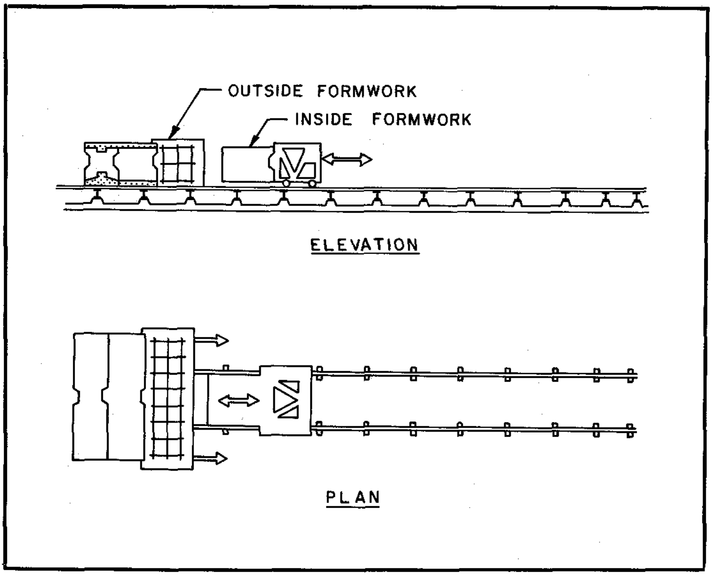

Fig. 9. Schematic of long line casting system. Side forms move along a permanent soffit to cast individual segments.

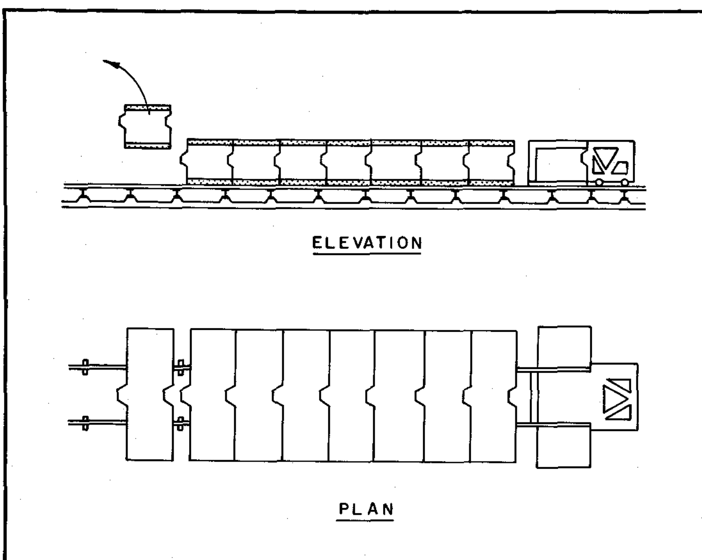

Fig. 10. As segments reach desired concrete strength, they can be removed to the storage yard. A second cantilever may be started with the addition of a second set of side forms.

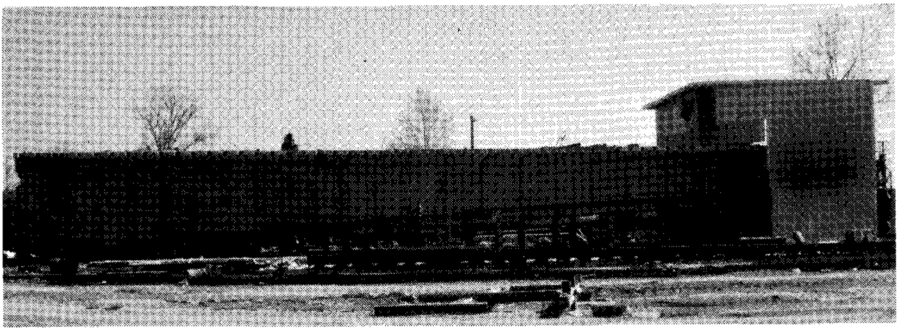

Fig. 11. Long line casting system used for Kentucky River Bridge, Frankfort, Kentucky. (Photo courtesy: Construction Products, Inc., Lafayette, Indiana.)

1979. Jack Kelly, manager of Construction Products, Inc., believes that this system proved easier and was more efficient for the variable depth segments.

Cast-in-Place Segments

Another alternative is to cast the segments in their final position on the structure. Numerous projects have been constructed in this manner across North America. The bridge located near Vail, Colorado (see Fig. 12) is one such example.

Cast-in-place construction proves to be very advantageous when large, very heavy segments are encountered. Instead of handling the segments, only materials have to be transported thus influencing the type and size of required equipment.

The commonly used method for casting segments in place is with the use of form travelers such as that shown in Fig. 12. Form travelers are moveable forms supported by steel cantilever trusses attached to previously completed seg-

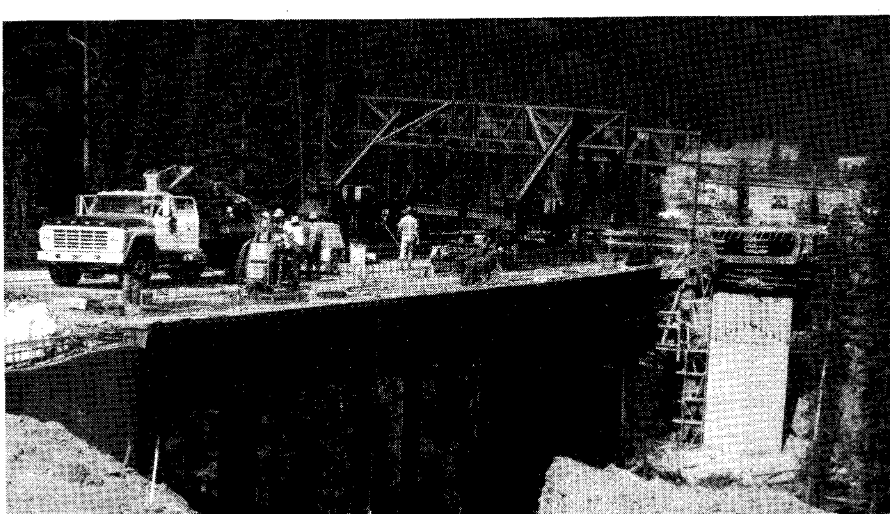

Fig. 12. Form traveler used on a segmental project near Vail, Colorado. The usual production rate for a form traveler is one segment every 3 to 5 days.

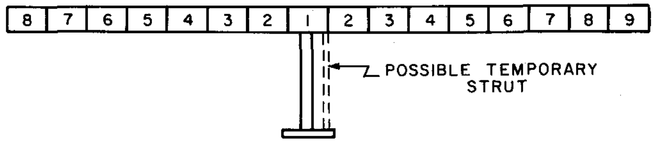

Fig. 13. Balanced cantilever erection will probably be the most commonly used method for constructing segmental bridges. It solves many problems such as environmental or existing traffic constraints.

ments. The forms themselves may be constructed of either wood or steel. When balanced cantilever erection is used, a minimum of two form travelers is required.

The segment production rate for form travelers is usually one segment every 5 days per traveler. Therefore, to approach the common precast segment production rate previously discussed, at least four travelers are required. The 5-day cycle time may be reduced with concrete admixtures to increase the early strength gain of concrete and by the application of partial post-tensioning. However, a practical minimum cycle time is around 3 days per traveler.

Alignment variations and corrections are more easily accommodated in cast-in-place construction; but more corrections will probably be necessary. The increase in alignment corrections for cast-in-place construction compared to precast construction relates directly to the age of the concrete when loaded. Generally, the concrete is much younger when loaded in cast-in-place construction.

The deformations due to creep and shrinkage vary logarithmically with the age of the concrete, with the values of the deformations decreasing as the age at loading increases. For instance, the ultimate creep deformation of concrete loaded at 7 days after casting will approach 1.5 times that for the same concrete when loaded 28 days after casting. Also, one has to remember the 5-day age difference for each segment results in a significant difference in the creep rate when an entire cantilever is analyzed. (This complexity is a further reason for using a computer in any bridge job.)

Erection Methods

Balanced cantilever—Balanced cantilever erection, as shown in Fig. 13, is quickly becoming the "classic" technique when considering segmental construction. This method solves a multitude of problems such as environmental restrictions, existing traffic problems, inaccessible terrain and many others. It can also be used readily with either precast or cast-in-place segments. However, the following discussion only relates to precast segments.

The general concept is to attach the segments in an alternate manner at opposite ends of cantilevers supported by piers. As the segments are attached the moment to be carried at the pier increases in a manner shown by Fig. 14. The hatched area represents the change in moment when attaching Segment 8.

The compressive stresses in the bottom of the concrete section at the pier build up similar to the moment variation. However, the theoretical tensile stresses occurring at the top of the same section are offset by the post-tensioning forces applied at a rate similar to the moment increase. It is important to remember that the top of the concrete section is essentially operating at capacity during the entire erection sequence. Therefore, the construction loads must not increase

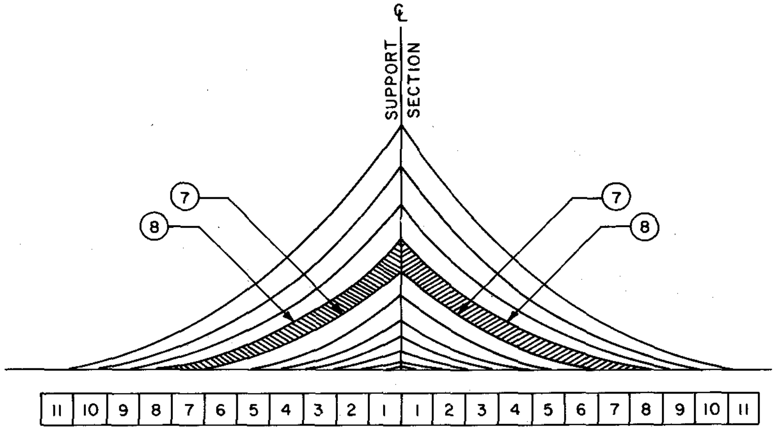

Fig. 14. As the length of the cantilever grows, the magnitude of moment at the pier increases. Since the post-tensioning tendons are also installed and stressed in increments as segments are attached, the top concrete stresses are close to the design limits at all times.

significantly over what has been assumed in the design.

As segments are attached to the cantilever ends one at a time, an overturning moment is created and must be resisted. This moment may be resisted by post-tensioning the pier segment down to the pier stem, providing temporary supports on either side of the pier or stabilizing the cantilevers with the erection equipment. The final choice belongs to the contractor but the designer must assume and detail a method for a stress evaluation and parameters for the contractor.

The segments may be delivered to the ends of the cantilevers by many means. The most economical and probably most commonly used method in the United States is lifting the segments with cranes. Crane erection will probably be more common in the United States than has been experienced in Europe because of the greater available capacity. Only restrictions which limit crane mobility make other methods more attractive. Fig. 15 shows segments being lifted by a barge crane.

Fig. 15. Crane erection is probably most economical in the United States due to crane availability. Access to the area under the bridge must be available.

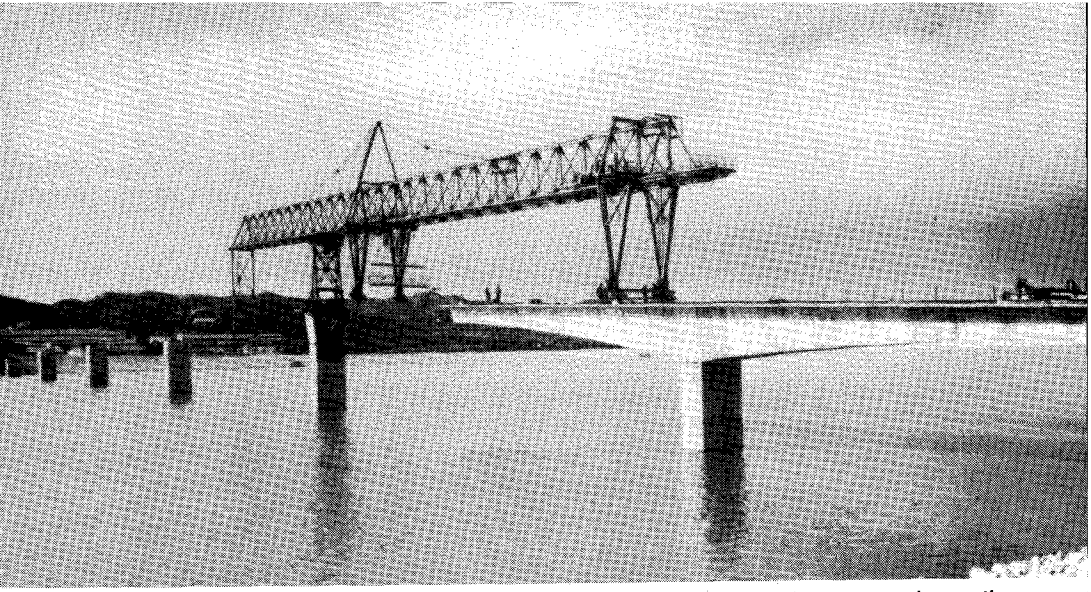

Fig. 16. The launching gantry eliminates the need for construction access beneath the structure. The gantry shown in this photo is in the process of moving to the next span to start a new cantilever.

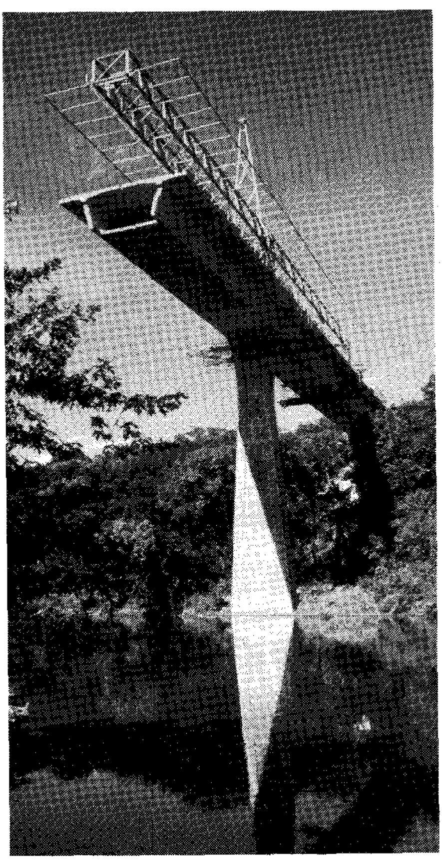

Fig. 16 shows a launching gantry placing segments for balanced cantilever erection. The launching gantry, developed by Jean Muller in France, is a machine capable of transporting a segment from a completed portion of the bridge or from below the bridge to either end of the cantilevers being erected. The first project in the United States to be erected with a launching gantry is the Kishwaukee River Bridge near Rockford, Illinois (see Fig. 17).

Launching gantries come in all sizes and shapes. They can vary from the large one shown in Fig. 16 to the small simple one shown in Fig. 18. Both serve identical functions; only the size of the spans and segments change. Most launching gantries have the capability to move themselves once a cantilever is completed and another is ready to

Fig. 17. This launching gantry is being used to erect the Kishwaukee River Bridge near Rockford, Illinois. This is the first such use of a launching gantry in the United States.

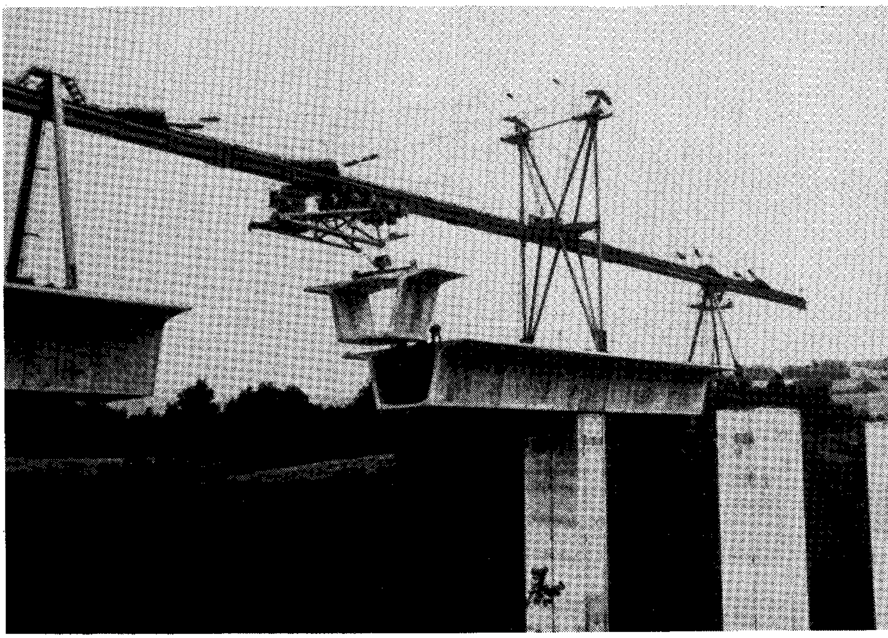

Fig. 18. Launching gantries may be very simple depending on project requirements. This gantry was used to erect high level viaducts in France.

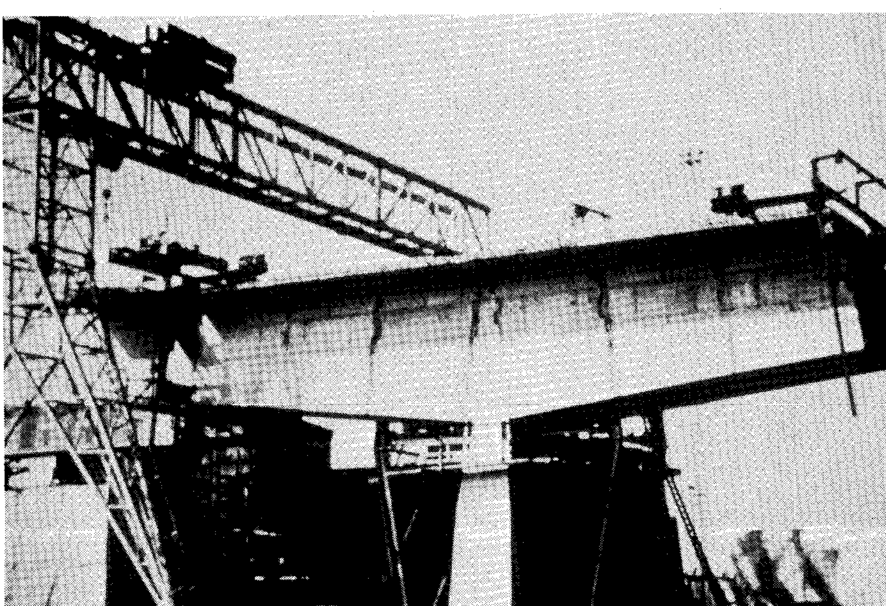

Fig. 19. Low level segmental bridges may be erected with gantry cranes similar to the one shown by this photo. The crane may be either rail mounted or be on rubber tires.

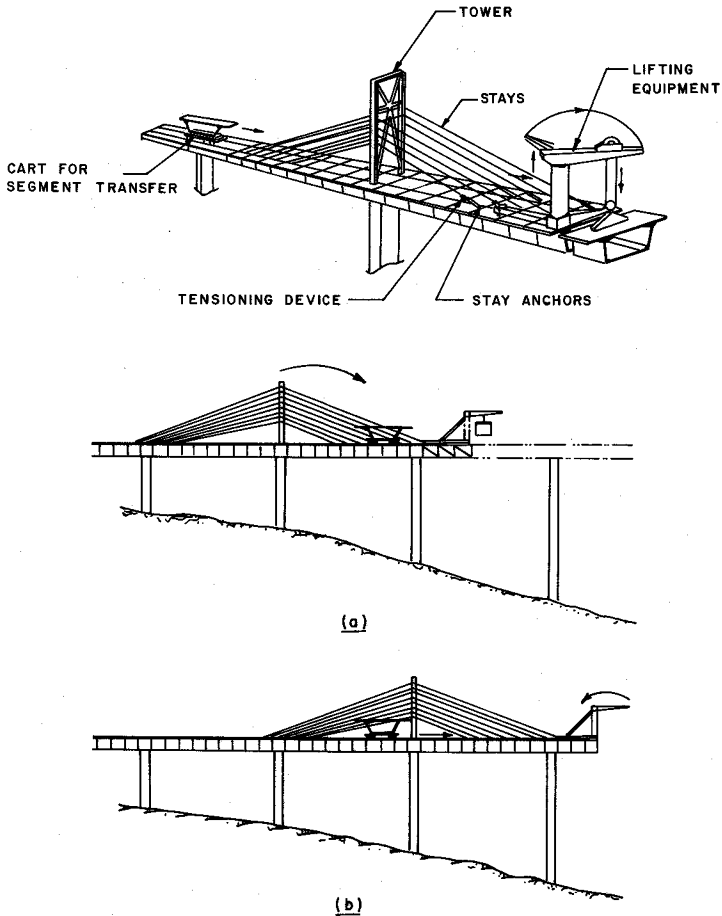

Fig. 20. A schematic of the progressive placing erection system. The system may prove valuable when the area is restricted for substructure construction such as the Linn Cove Viaduct in North Carolina (see Fig. 21 on opposite page).

begin. They may be equipped with two lifting devices enabling simultaneous attachment of segments minimizing required overturning moment provisions. The various details of the launching gantry depend on the size of structure and the economics involved.

Launching gantries are particularly advantageous when accessibility to the area beneath the structure is restricted by environmental consideration. By delivering segments across previously completed portions of the bridge, access to the area beneath is not required except to build the substructure. New bridges can be erected over existing traffic and/or buildings with minimal disturbance. This is a tremendous construction advantage in urban areas. Launching gantries can be used to erect curved bridges as well as straight ones. Accessibility to the structure is generally the overriding consideration for balanced cantilever erection with a launching gantry.

Gantry cranes similar to the one

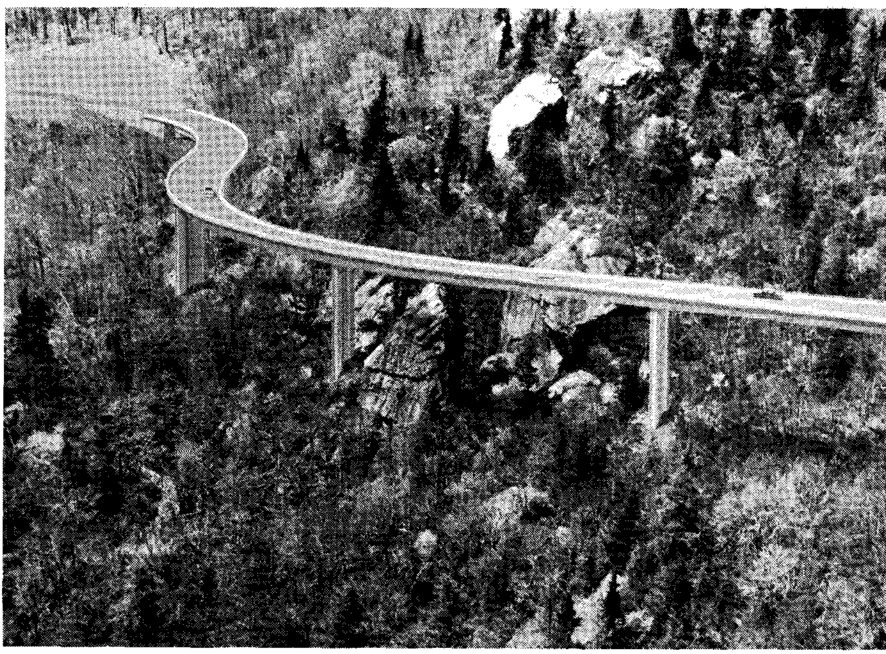

Fig. 21. A computer generated photo of the Linn Cove Viaduct. The bridge is being built from the top (including foundations) by the progressive placing concept. (Photo courtesy: Figg and Muller Engineers, Inc.)

shown in Fig. 19 may also be used to lift the segments. The gantry crane, whether mounted on rubber tires or rails, travels between the ends of the cantilevers to lift the segments. Obviously, the practicality of this type of equipment is limited to low level structures over land such as viaducts. But gantry cranes possess faster movement than track mounted cranes and may eliminate the need for a second large capacity crane on a project.

Progressive placing—Progressive placing is a modification of the balanced cantilever concept. Fig. 20 shows the basic concepts of progressive placing. Instead of starting erection at a pier and proceeding in two directions, progressive placing erects cantilevers in only one direction.

The equipment required is a crane capable of lifting a segment delivered along the previously completed portion of the bridge and swinging around and lowering the segment to be attached to the end of the cantilever. The crane shown in Fig. 20 (top) is a swivel crane available in Europe. A stiff leg derrick may also be used.

As the cantilever extenas in one direction, the capacity of the section located at the pier is soon exceeded. Therefore, a temporary support must be provided to prevent overstress. The method shown in Fig. 20 is a system of temporary cable stays which are moved from pier to pier as construction proceeds.

As shown in Fig. 20, hydraulic jacks can be attached to the stays to control the stay stresses and orientation of the cantilever. An alternate and maybe simpler method is to provide jacks beneath the legs of the vertical steel tower. Thus, the stress in the stays can be varied by raising or lowering the steel tower. The

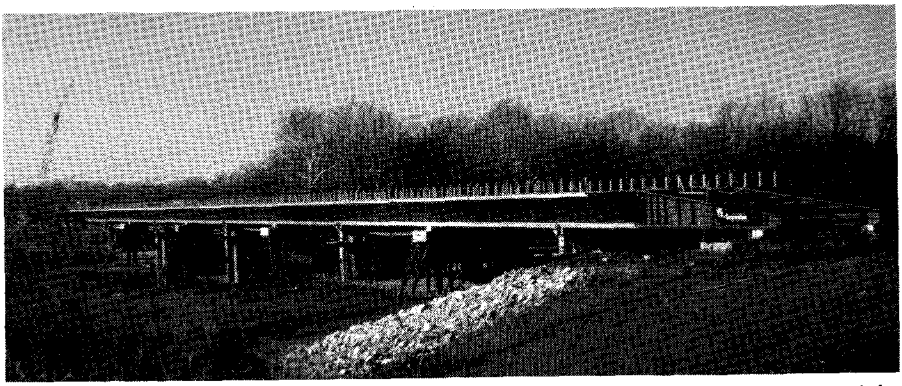

Fig. 22. Steel launching nose used to control erection stresses for the incremental launching concept. As the bridge moves across the supports, the concrete is subjected to both maximum positive and negative dead load moments.

primary advantage here is having only two jacks to control the operation.

Instead of the temporary cable stay system, a system of temporary bents may be provided beneath the structure. If permitted by the terrain, temporary bents may be a more economical and faster solution. Of course, each project must be evaluated separately.

Progressive placing not only provides an opportunity to construct the superstructure unhindered by obstacles but provides the ability to also build the piers from the top. A case in point is the Linn Cove Viaduct located near Grandfather Mountain in North Carolina. This project, representing the final link of the Blue Ridge Parkway, will take the parkway around a mountain in a scenic and environmentally sensitive area. In fact, the terrain is so rough, it is impossible to get heavy construction equipment to the pier sites without extensive damage. The National Park Service, owner of the bridge, stipulated a construction road could only extend from the abutment to the first pier. Fig. 21 shows a computer generated image of the completed project. Construction was started in 1979.

The Linn Cove viaduct is being erected by the progressive placing technique with temporary bents located at midspan between the permanent piers. Both the bents and piers are being constructed from the top with the stiff leg derrick used to place the precast segments. As the end of the cantilever approaches a pier location, the derrick lowers men and equipment to drill and cast 9-in. microshaft piles. The elliptical shaped footing is then cast with concrete delivered over the completed portion of the bridge and lowered with the derrick. The pier stems consist of precast segments delivered and placed in a similar manner. Once the vertical pier post-tensioning tendons are installed and stressed, the superstructure segment placing resumes until the next pier location is reached. Then the process is repeated.

Incremental launching—Incremental launching is a technique where segments are cast at the end of the crossing and pushed across by large hydraulic rams. This method is most useful when the piers can be easily located at regular intervals.

Temporary support bents may or may not be required at midspans depending on the span length. A steel launching nose is generally attached to the end of the segments, as shown by Fig. 22, to control erection stresses. The segments are usually 50 to 100 ft (15 to 30 m) in length.

Incremental launching is best adopted to bridge lengths of 1000 to 2000 ft (305 to 610 m) unless other considerations are involved. For instance, when the working area is severely restricted, bridges up to 4000 ft (1220 m) in length may be achieved by launching from both ends.

When considering incremental launching, one must consider some restrictions. The horizontal and vertical alignment must either be straight or of a constant radius of curvature; preferably 250 ft (76 m) or greater. In addition, the top slab must have a constant crown or constant superelevation without any transitions.

The Wabash River Bridge near Covington, Indiana, was the first incrementally launched bridge in the United States. This project (see Fig. 23) was completed in 1977. The original design plans and specifications were based on precast segmental construction erected by balanced cantilevers with cranes. The contractor exercised an option to alter the construction method with a reported savings to the State of Indiana.

It is believed precast segments may also be launched although the author is not presently aware of any projects using this method. Identical restrictions would probably apply but the basic principles could be used to launch precast segments to achieve a desired result.

Span by Span—Span by span erection may be the most economical technique for erecting segmental bridges in the medium span range [less than 250 ft (76 m)]. This method utilizes an assembly truss spanning between permanent piers to support precast segments prior to installation and stressing of post-tensioning tendons. Segments are placed on the assembly truss by a crane in approximately their final position. After all segments comprising a span are assembled, the post-tensioning

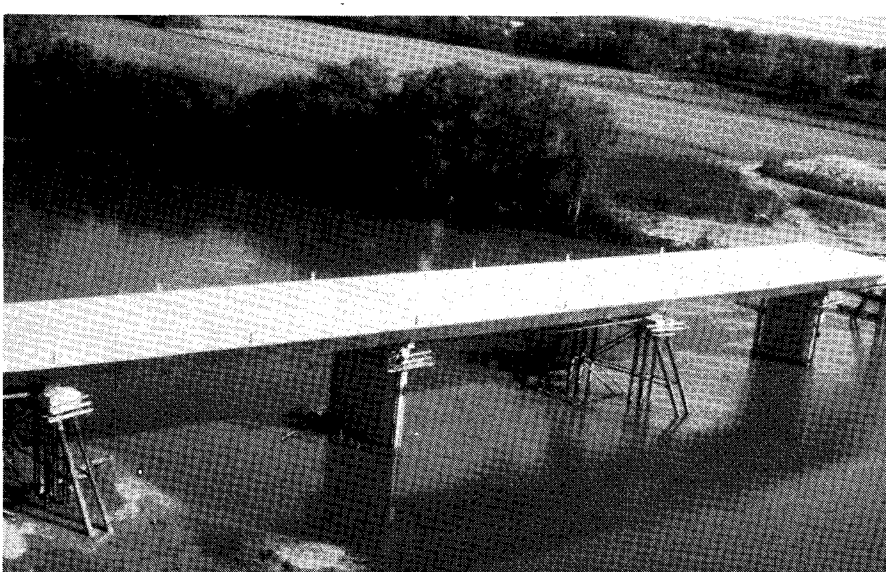

Fig. 23. The Wabash River Bridge near Covington, Indiana, was the first incrementally launched bridge in the United States. This photo shows the bridge approaching the opposite side of the river.

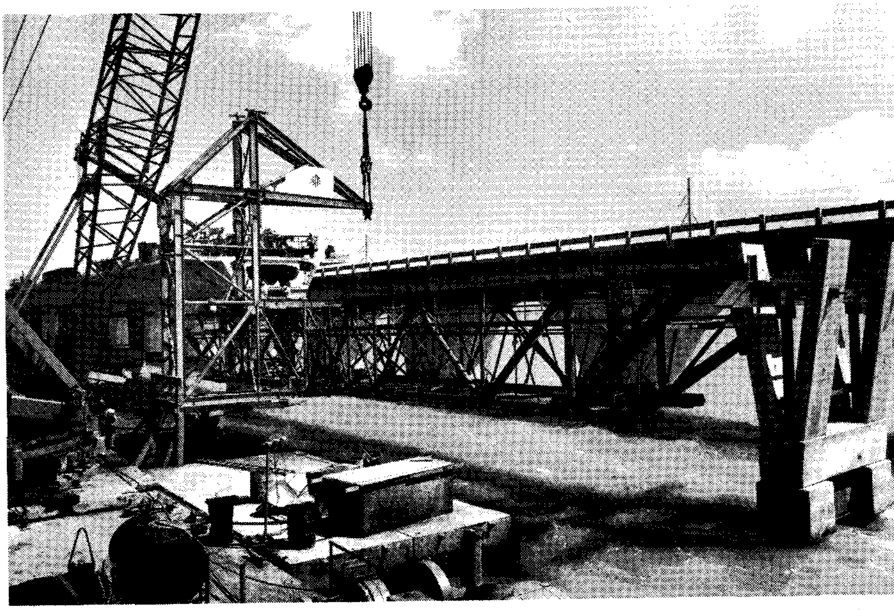

Fig. 24. The span by span erection scheme has proven to be very economical for shorter span segmental bridges. The method is applicable to both precast and cast-in-place segmental construction. (Courtesy: Figg & Muller Engineers, Inc.)

tendons are installed and stressed. Fig. 24 shows the basic system.

Jean Muller developed the span by span concept in an effort to Americanize segmental construction. The basic objectives were to simplify the system thereby reducing the number of operations required. Reduced labor requirements are not a significant factor because segmental construction in general is not labor intensive.

Span by span techniques allow additional modifications to the components of the structure. Primarily, the post-tensioning tendons may all be continuous for the total span length and may be located in a draped manner providing most efficient use of post-tensioning forces. Also, only one operation of installing and stressing tendons is required per span.

The Long Key Bridge in Florida is the first structure to be erected in this manner. The spans are 118 ft (33 m) in length. Fig. 25 shows the assembling of segments for one of the spans. The contractor has readily achieved an erection rate of three spans per week resulting in the essentially complete construction of 354 ft (108 m) of superstructure per week. Only the casting of the barrier curbs remains to complete the structure.

The span by span erection technique allowed two other modifications of normal segmental construction procedures. The Long Key Bridge is the first precast segmental bridge to be constructed with dry joints. Normal practice is to seal the joints with epoxy. However, dry joints are not recommended for bridges which may be subject to freeze-thaw conditions and deicing chemicals. Also the post-tensioning tendons are located in the void of the box girder as opposed to locating the tendons in the concrete walls of the sections. The tendons are protected with plastic conduits and grout. This tendon location simplifies the

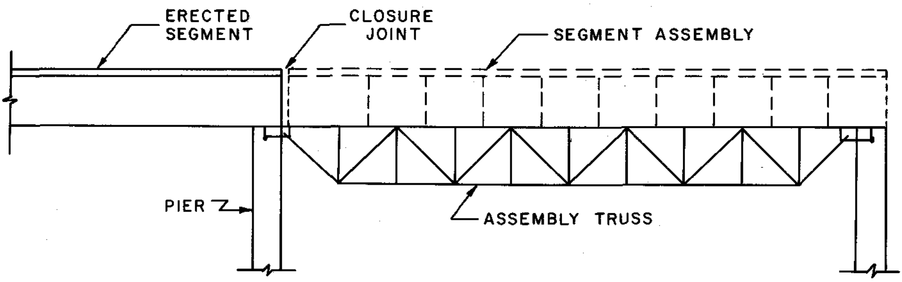

Fig. 25. Assembly truss being used to erect the Long Key Bridge in Florida. This photo shows the truss being installed between two piers. The contractor erected three 118-ft spans per week. (Courtesy: Figg and Muller Engineers, Inc.)

casting of the segments and eliminates any problems of tendon alignment at the segment joints.

The Seven Mile Bridge located near the Long Key Bridge in the Florida Keys (see Fig. 26) will also be erected span by span but the contractor has elected to assemble the segments on a barge and lift the entire 135 ft (41 m) span at one time. A temporary post-tensioning system and support frame will hold the segments together during the lift. The contractor hopes this modification will provide an even faster construction rate than achieved at Long Key.

Concluding Remarks

The bottom line when choosing a construction technique for a particular segmental bridge is economics—and correctly so. The prospective contractor should thoroughly investigate all systems complying with specified parameters and choose the one which provides the least cost. The casting method,

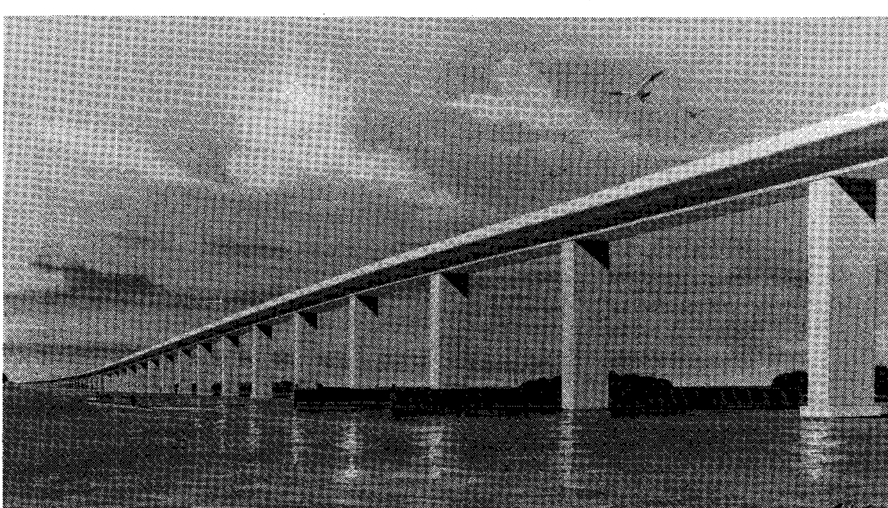

Fig. 26. Rendering of Seven Mile Bridge. (Courtesy: Figg & Muller Engineers, Inc.)

post-tensioning system or erection procedure cannot be evaluated separately for each is only a part of the entire construction technique to be used. All aspects of the project have to be considered together.

The design engineer should evaluate the parameters of the project and base the design on the most economical method. However, all other methods complying with the parameters should be allowed as contractor's options. There is essentially no difference in the final quality of the project.

Many different construction techniques have been discussed in this paper. However, it should not be inferred that these are the only techniques available. Time and space permitted the inclusion of only some of the most common construction methods. Engineers, whether contractors or designers, should use their ingenuity to use the common techniques and develop new techniques to reduce construction costs.

Geometry control techniques were discussed more extensively for short line match casting than for the other methods. This is because this geometry control is probably the most difficult to understand. With proper understanding and attention to details, the results will be excellent. For instance, the Long Key Bridge is being cast by the short line method and will not receive an additional wearing surface. The author has ridden on the completed portion of the bridge in a vehicle traveling at various highway speeds. The segment joints could neither be felt nor heard. This is a tribute to what can be accomplished.

Some contractors have expressed concern over the additional time and money required to evaluate the options before bidding projects. The days in which design engineers could tell contractors exactly what to do are quickly coming to an end. To create the most economical projects, competition between materials and the methods of using the materials must be encouraged. We in North America are not going to the design-build concepts prevalent in Europe, but are going to approach that idea and probably be somewhere in between. This is also a tendency in Europe.

In the future, projects and construction methods are going to be more engineering oriented requiring a cooperative effort between designers and contractors with a required increase in contractor engineering staffs. Also, there will be more competition between construction materials including the availability of two complete sets of plans based on different materials. The final result should be a much more economical use of construction resources.

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