An Overview of Precast Prestressed Segmental Bridges

Walter Podolny, Jr.
Bridge Division
Office of Engineering
Federal Highway Administration
U.S. Department of Transportation
Washington, D.C.

The seventies will be recorded by engineering historians as the decade in which prestressed concrete segmental bridge construction came of age in North America. Segmental box girder bridges have attracted the attention and captured the imagination of bridge engineers and designers across the continent.

Because of practical limitations of handling and shipping, the precast prestressed I-girder type of bridge construction is limited to an approximate range of 120 to 150-ft (37 to 46 m) spans. Beyond this range of span, post-tensioned cast-in-place box girders on falsework are more attractive. However, in certain instances the extensive use of falsework can prove to be an economic disadvantage. Where deep ravines or navigable waterways must be crossed, extensive formwork may be impractical.

Construction in this manner may also have a serious impact upon environment and ecology. Prestressed segmental construction has extended the practical span of concrete bridges to approximately 800 ft (244 m). Where segmental construction is used in conjunction with the cable-stay bridge concept, the span range can be extended to 1300 ft (400 m) and perhaps longer.[1]

Because construction of the superstructure is executed from above, i.e., at deck level, the use of extensive falsework is avoided. Thus, there is no effect upon navigation clearance from falsework during construction and the cost of extensive formwork is eliminated. Segmental viaduct type bridges provide a method whereby the impact of highway construction through environmentally sensitive areas can be minimized.

Discusses the evolution and advantages of precast segmental bridge construction. The technology for constructing segmental bridges has rapidly advanced in the last decade. There are currently four techniques for constructing this type of bridge.

Precast segments can be incorporated into a variety of bridge types such as cable-stay, arches and rigid frames as well as the girder type bridge. The potential of this type of bridge construction is only limited by the innovation and imagination of the designer and contractor.

Utilization of an elevated viaduct type structure requires only a relatively narrow path along the alignment to provide access for pier construction. Once the piers have been constructed, all construction activity is from above. Thus, the impact on the environment is minimized. Also, because the structure is elevated, as opposed to an at-grade highway, there is no interference with wild life migratory habits.

Prestressed concrete segmental bridges have proven to be esthetically appealing and, because various construction methods can be used, the structures are cost effective and environmentally adaptable.

Evolution of Segmental Bridges

Before discussing the various facets and variants of precast segmental box girder bridges, it may enhance the understanding of this type of construction to briefly trace the historical evolution of prestressed concrete bridges to this point in the state-of-the-art and to present a few basic definitions.

Precasting of elements or members of a structure implies that the concrete is cast in forms at some location other than the final position of the member. The member may be cast at a permanent precasting plant at some location other than the construction site; then transported by truck, rail, or barge to the site; and eventually erected to its final position. The member may also be cast at some location in close proximity to the construction site eliminating the transportation from precasting plant to construction site. In either situation the member is cast at a location other than its final position in the structure.

Segmental construction has been defined as "... a method of construction ... in which primary load carrying members are composed of individual segments post-tensioned together."[2]

As early as 1948, Eugene Freyssi-

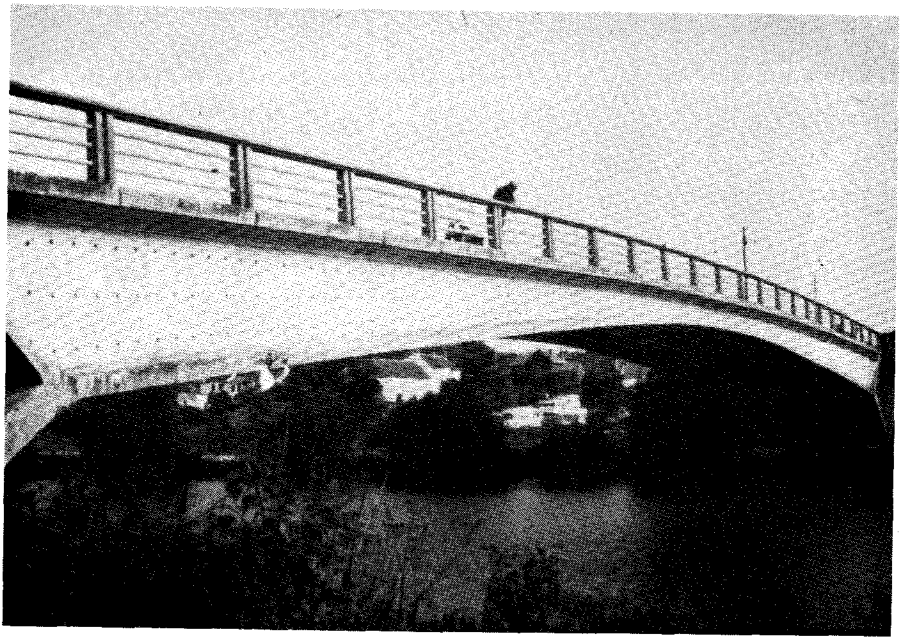


Fig. 1. Marne River Bridge near Paris, France. (Courtesy: Figg and Muller Engineers, Inc., Tallahassee, Florida.)

net, the great French prestressing pioneer, used prestressed concrete for the construction of five bridges over the Marne River near Paris, with spans of 240 ft (73 m) having an exceptionally light appearance (Fig. 1). Construction of these bridges, as indicated in Fig. 2, utilized precast segments which were post-tensioned together. Thus, by definition, these five structures can be called precast prestressed segmental bridges.

Prestressing of bridges in North America did not start until about 1949.* The first prestressed bridge in the United States was built in Madison County, Tennessee. This bridge was made using a series of machine-made blocks (strung like beads on a string) which were prestressed together to form a beam.

The construction method (although very crude by modern standards) is similar, in principle at least, to today's precast prestressed segmental bridges.

The Tennessee prestressed block beam bridge was followed very shortly by the famed Walnut Lane Bridge in Philadelphia, Pennsylvania, in 1950. The 160-ft (48.8 m) long beams were cast-in-place and post-tensioned.

Soon thereafter, precast pretensioned bridge girders evolved resulting from inherent economies and quality control of plant fabricated elements. With few exceptions, during the fifties and early sixties, most multi-span precast prestressed bridges built in the United States were designed as a series of simple spans.

*An interesting historical account of the early prestressed bridges in America is given by Charles C. Zollman in "Reflections on the Beginnings of Prestressed Concrete in America—Part 1: Magnel's Impact on the Advent of Prestressed Concrete; Part 2: Dynamic American Engineers Sustain Magnel's Momentum," PCI JOURNAL, V. 23, Nos. 3 and 4, May-June and July-August 1978, pp. 22-48 and pp. 30-67. See also Ross Bryan's article on "Prestressed Concrete Innovations in Tennessee," published in the current PCI JOURNAL, pp. 14-31.

They were designed with standard AASHTO-PCI girders of various cross sections in spans ranging up to about 100 ft (30.5 m), but more commonly for spans of 40 to 80 ft (12 to 24 m). The advantages of a continuous cast-in-place structure were abandoned in favor of the more economical construction offered by plant produced standardized units.

During the middle sixties a growing concern with regard for safety of the highways asserted itself. An AASHTO Traffic Safety Committee report in 1967[3] called for:

> "Adoption and use of two-span bridges for overpasses crossing divided highways . . . to eliminate the bridge piers normally placed adjacent to the shoulders."

It soon became apparent that the conventional precast pretensioned AASHTO-PCI girders were limited by their transportable length and weight. Transportation over the highways limits the precast girder to a range of 100 to 120 ft (30.5 to 36.6 m) in length depending upon local regulations.

As a result of longer span requirements, a study was conducted by the Prestressed Concrete Institute in cooperation with the Portland Cement Association.[4] This study proposed simple spans up to 140 ft (42.7 m) and continuous spans up to 160 ft (48.8 m) be constructed of standard precast girders up to 80 ft (24 m) in length joined together by splicing and post-tensioning. To obtain longer spans the use of inclined or haunched piers was proposed. In general, these concepts utilized precast I- or box girders with field splices and post-tensioning for continuity.

This type of construction, using long standard precast prestressed units never quite achieved the popularity that it merited. Despite some limitations, the method is adaptable for spans up to 200 ft (61 m).

The concepts developed by the PCI-PCA studies fall into the defini-

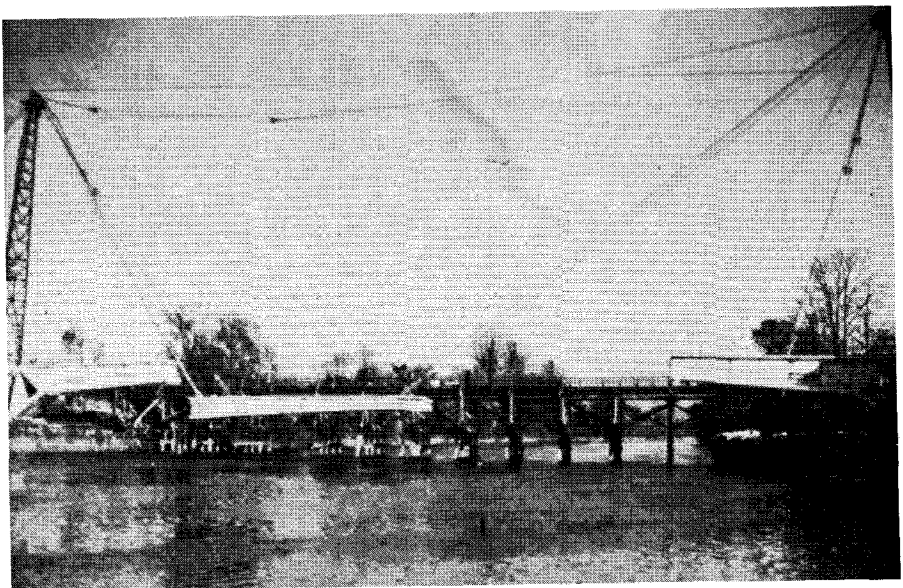


Fig. 2. Marne River Bridge near Paris, France. (Courtesy: Figg and Muller Engineers, Inc., Tallahassee, Florida.)

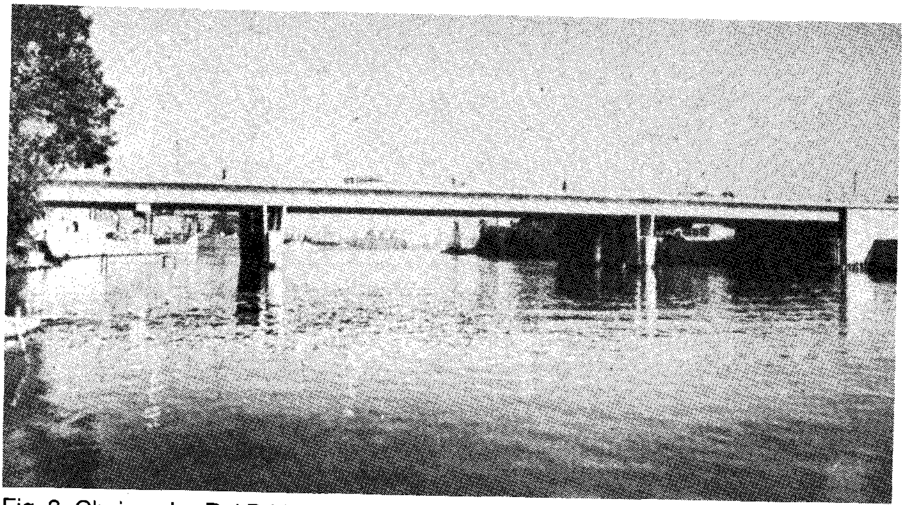


Fig. 3. Choisey-Le-Roi Bridge over the Seine River south of Paris, France. (Courtesy: Figg and Muller Engineers, Inc., Tallahassee, Florida.)

tion of precast segmental construction and might be described as "longitudinal" segmental construction. The individual elements are long with respect to their width.

As spans increased, designers turned toward utilization of post-tensioned cast-in-place box girder construction. The Division of Highways, State of California, including several other states, have been quite successful using cast-in-place, multi-cell, post-tensioned box girder construction for multi-span structures with spans of 300 ft (91.5 m) and longer. However, this type of construction has its disadvantages; it requires extensive formwork during casting with its undesirable impact upon the environment and/or ecology.

Meanwhile in Europe, segmental construction proceeded slightly differently in conjunction with box girder design. Segments were cast-in-place or precast in relatively short lengths, providing full roadway width and depth. Today, "segmental construction" is generally recognized as having been pioneered in Europe.

Ulrich Finsterwalder, in 1950, was the first to apply cast-in-place segmental prestressed construction in a balanced sequence to a bridge crossing the Lahn River at Balduinstein, Germany. This system of cantilever segmental construction rapidly gained acceptance in Germany, especially after the successful completion of a bridge crossing the Rhine River at Worms in 1952.[5] Since then, the concept has spread across the entire world.

Concurrently, precast segmental construction was evolving during this period. In 1952, a single span county bridge located near Sheldon, New York, was designed by the Freyssinet Company. Although this bridge was constructed using longitudinal segments, rather than transverse segments, as was being done in Europe, the structure represents the first practical application of match casting. This technique has become an important development in precast segmental construction.

The bridge girders were divided into three longitudinal segments that were cast end to end. The center segment was cast first and the end seg-

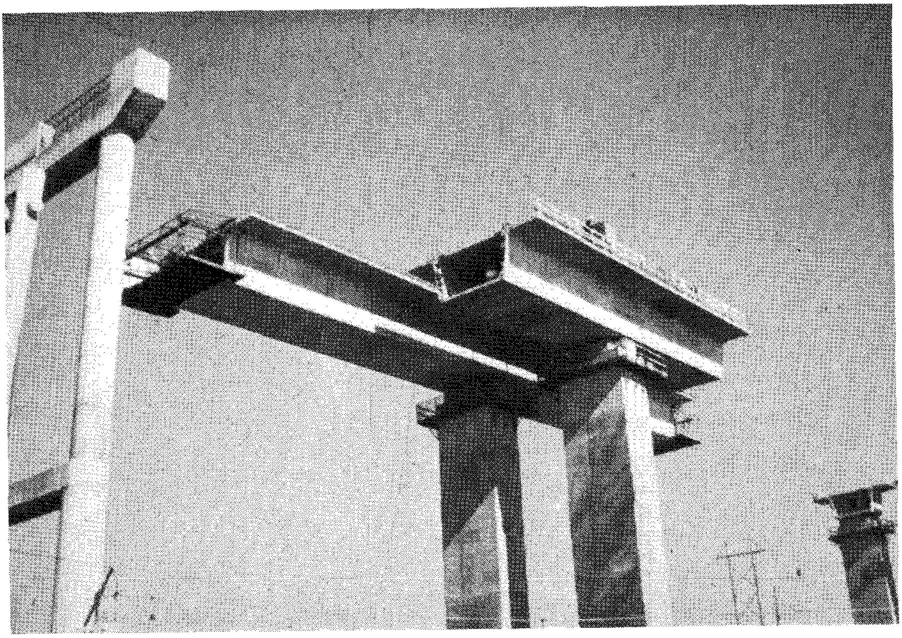


Fig. 4. JFK Memorial Causeway, Corpus Christi, Texas.

ments were cast directly against the center segment. Keys were cast at the joints so that the three precast elements could be joined together at the site in the same position they had in the precasting yard. Upon shipment to the job site, the three elements of a girder were post-tensioned together with cold joints.[6,7]

The first major application of match cast, precast, segmental construction was not realized until 10 years later, in 1962, in France. This structure, designed by Jean Muller,* was the Choisy-Le-Roi Bridge located south of Paris crossing the Seine River (Fig. 3). Since then the concept has been refined and has spread from France to many other countries.

The first precast segmental bridge to be built in North America was the Lievre River Bridge located on Highway 35, 8 miles (13 km) north of Notre Dame du Laus, Quebec. The bridge, which had a center span of 260 ft (79.2 m) and end spans of 130 ft (39.6 m), was built in 1967. The Bear River Bridge, Digby, Nova Scotia, followed in 1972 with six interior spans of 265 ft (80.8 m) and end spans of 203.75 ft (62.1 m).

The JFK Memorial Causeway, Corpus Christi, Texas (Fig. 4) represents the first precast prestressed segmental bridge completed in the United States. It was opened to traffic in 1973. Designed by the Bridge Division of the Texas Highway Department, this structure has a center span of 200 ft (61 m) with end spans of 100 ft (30.5 m).

In the United States, currently (1979), the author is aware of at least 24 precast segmental bridge projects that are either completed, in construction, or in design and planning stages (see Table 1). There are undoubtedly many more.

*Jean Muller, formerly chief engineer with Entreprises Campenon Bernard, Paris, France, is currently in partnership with Figg and Muller Engineers, Inc., with offices in Tallahassee, Florida, Washington, D.C., and Paris, France.

Table 1. Precast Segmental Concrete Bridges in North America.

Name and Location	Date of Construction	Method of Construction	Span Lengths ft (m)
Lievre River Notre Dame du Laus, Quebec	1967	Balanced Cantilever	130-260-130 (39.6-79.2-39.6)
Bear River Digby, Nova Scotia	1972	Balanced Cantilever	203.75-6 @ 265-203.75 (62.1-6 @ 80.77-62.1)
JFK Memorial Causeway Corpus Christi, Texas	1973	Balanced Cantilever	100-200-100 (30.5-61-30.5)
Muscatuck River U.S. 50 North Vernon, Indiana	1975	Balanced Cantilever	95-190-95 (29-58-29)
Sugar Creek, State Route 1620 Parke County, Indiana	1976	Balanced Cantilever	90.5-180.5-90.5 (27.6-55-27.6)
Vail Pass, I-70 West of Denver, Colorado (four bridges)	1977	Balanced Cantilever	134-200-200-134 (40.8-61-61-40.8) 134-200-200-145 (40.8-61-61-44) 151-155-210-210-154 (46-47.2-64-64-47) 153-210-210-154 (46.6-64-64-47)
Penn DOT Test Track Bridge Penn State University, State College, Pennsylvania	1977	On Falsework	124 (37.8)
Turkey Run State Park Parke County, Indiana	1977	Balanced Cantilever	180-180 (54.9-54.9)
Pasco-Kennewick, Columbia River between Pasco and Kennewick, Washington (cable-stay spans)	1978	Balanced Cantilever	406.5-981-406.5 (124-299-124)
Wabash River U.S. 136 Covington, Indiana	1978	Incremental Launching	93.5-4 @ 187-93.5 (28.5-4 @ 57-28.5)
Kishwaukee River Winnebago Co. near Rockford, Illinois (dual structure)	1979	Incremental Launching	170-3 @ 250-170 (51.8-3 @ 76.2-51.8)
Islington Avenue Extension Toronto, Ontario	1979	Incremental Launching	2 @ 161-200-5 @ 272 (2 @ 49-61-5 @ 83)
Kentucky River Frankfort, Kentucky (dual structure)	1979	Balanced Cantilever	228.5-320-228.5 (69.6-97.5-69.6)
Long Key, Florida (contract let late 1978)	—	Span-by-Span	113-101 @ 118-113 (34.4-101 @ 36-34.4)
Linn Cove, Blue Ridge Parkway North Carolina (contract let late 1978)	—	Progressive Placing	98.5-163-4 @ 180-163-98.5 (30-49.7-4 @ 54.9-49.7-30)
Zillwaukee, Michigan (dual structure) (bids opened late 1978)	—	Balanced Cantilever	26 north bound spans, total length 8087.5 (2465) 25 south bound spans, total length 8057.5 (2456)

Advantages of Precast Segmental Construction

In many instances where prestressed concrete segmental bridge design alternates have competed against structural steel designs they have proven to be cost effective. As previously indicated, when compared to more conventional methods of concrete construction, prestressed concrete segmental construction has extended the span range for concrete bridges and is competitive in the intermediate and long span range. The method eliminates the need for costly falsework and minimizes its impact on the environment.

In general, the economic feasibility of cast-in-place or precast segments will be determined by site conditions, site accessibility, available erection equipment, time to construct and/or erect the segments, and the relative economic trade-off in transporting a finished segment as opposed to transporting constituent materials.

Advantages

The often cited advantages of precast segmental construction are:

- Fabrication of the segments can be accomplished while the substructure is under construction, and thus, erection of the superstructure is speeded up.
- By virtue of precasting and maturity of the concrete at the time of erection, the time required for strength gain of the concrete is removed from the construction critical path.
- As a result of the maturity of the concrete at the time of erection, the effects of concrete shrinkage and creep are minimized.
- Quality control of factory produced precast concrete.

Disadvantages

The disadvantages of precast segmental construction are:

- Necessity for a high degree of geometry control during fabrication and erection of segments.
- Temperature and weather limitations regarding mixing and placing epoxy joint material.
- Lack of mild steel reinforcement across the joint and therefore a limitation of tension stress across the joint.

It should be noted that for large-sized projects, it is no longer difficult to set-up fully mechanized concrete site mixing equipment. With today's technology, it is possible to produce a high quality concrete at the site. Therefore, for large projects, it is doubtful whether factory produced concrete has an advantage over site produced concrete except for the important aspect that loads and prestressing forces are applied at a later age on a more mature concrete.

Types of Precast Segmental Construction

It has been observed[1] that the technology for constructing segmental bridges has rapidly advanced in the last decade. During the initial development of segmental bridges they were constructed by the balanced cantilever method.

Currently, such techniques as span-by-span construction, incremental launching, and progressive placing are also being utilized. Thus, there are now a variety of design concepts and construction methods which may be used to economically produce segmental bridges for almost all site conditions.

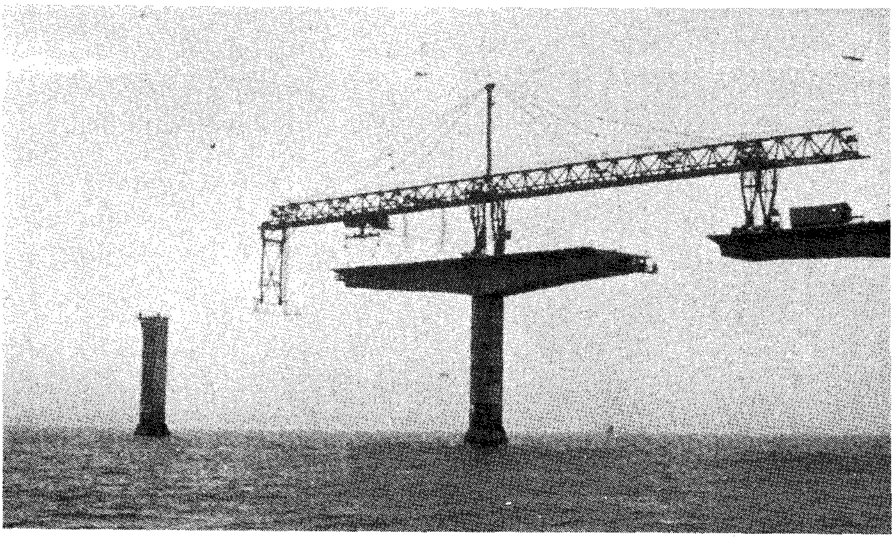


Fig. 5. Sallingsund Bridge, Denmark, showing balanced cantilever construction.

Balanced Cantilever Construction

The balanced cantilever method of construction, sometimes referred to as the free cantilever method, was developed out of a need to eliminate falsework. Not only is falsework expensive, but it is a temporary structure and, as such, is designed with small margins of safety, as has been indicated by some falsework failures.

In waterways that are subject to spring flash floods, falsework can be washed away resulting in potential damage to the structure, lost construction time, and possible financial ruin. In navigable waterways, falsework is either not allowed or is severely restricted. With cantilever construction, falsework is eliminated because precast segments are erected and supported from the pier or the already completed portion of the structure.

In this method of construction segments are simply cantilevered from the preceding pier in a balanced sequence on each side until midspan is reached. Then a closure placement is made with a previous half-span cantilever from the preceding pier (Fig. 5). This procedure is then repeated until the structure is completed.[1,9]

Unless symmetrical segments are simultaneously erected, the pier will be out of balance by one segment. The moment caused by this imbalance can be accommodated by a moment resistant pier. Where the pier is not monolithic with the superstructure, a temporary moment resistance may be provided by temporarily "clamping" the superstructure to the pier, provided the pier is designed to take the temporary moment. Where feasible, temporary bracing may be provided (Fig. 6). Obviously, the imbalance must be maintained on the side of the pier where the bracing is located.

This concept utilizes a dual system of prestressing tendons. Cantilever (negative moment) tendons are required at the top of the segments for dead load cantilever stresses [Fig. 7(a)] and then after closure, at midspan, continuity (positive moment) tendons [Fig. 7(b)] are installed to accommodate the positive moment in the continuous structure. Because of the high cantilever moments during construction, which are reduced by moment redistribution in the final structure, a slightly larger amount of prestressing is required compared to a structure supported on falsework.

In continuous structures the final stresses in the completed structure are substantially different from what they were initially during cantilever construction. However, subsequent concrete creep and steel relaxation will tend to make the initial and final stresses approach each other. This means that there will be a redistribution in the moments and stresses of the structure. In general, the negative moments over the piers will decrease while the positive moments at midspan will increase by a corresponding amount. This redistribution of moments must be accommodated in the design.

Normally in precast balanced can-

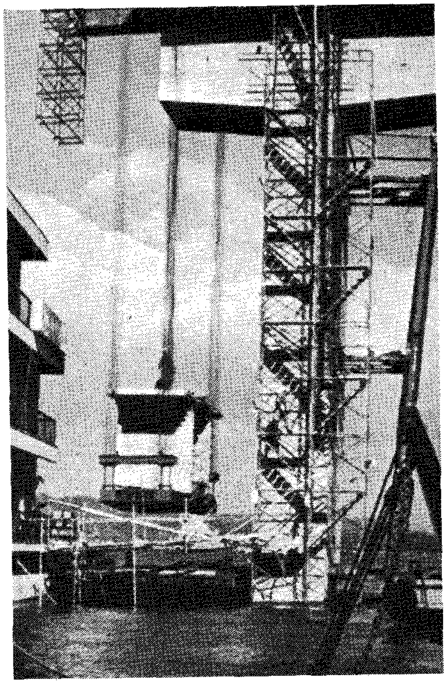


Fig. 6. Konoshima Ohashi Bridge, Japan.

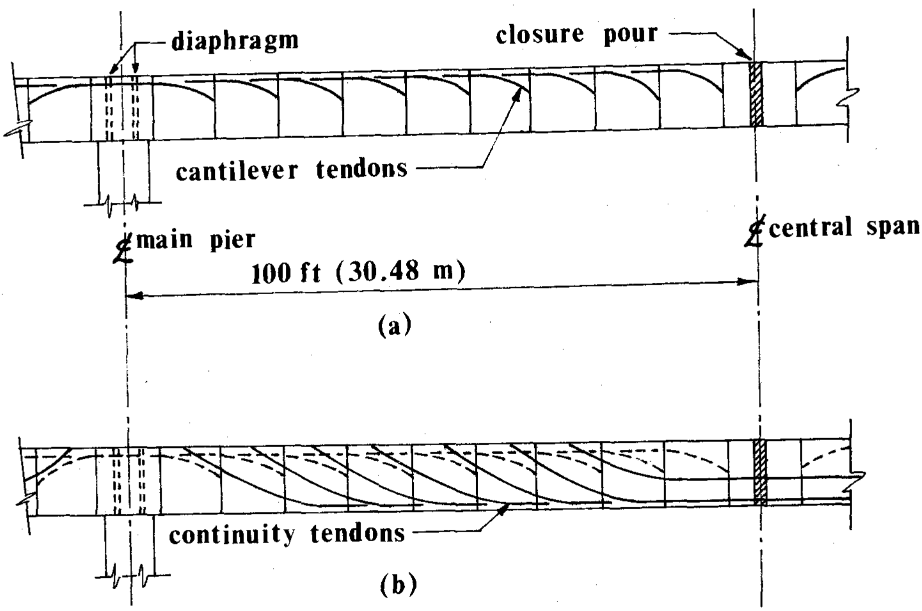


Fig. 7. Balanced cantilever method, system of prestressing tendons (JFK Memorial Causeway, Corpus Christi, Texas).

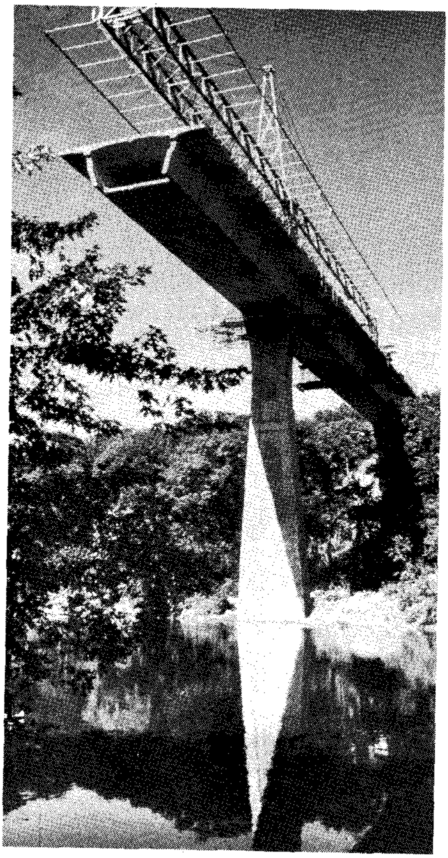


Fig. 8a. Kishwaukee River Bridge near Rockford, Illinois.

tilever construction, tendons are of the strand type. However, in the Kishwaukee Bridge (Figs. 8a and 8b) located near Rockford, Illinois, tendons were of the Dywidag thread bar type. In so far as the author is aware, this is the first time that Dywidag bars have been used in conjunction with precast segmental construction. The bar type tendon was allowed in the specifications issued by the Illinois Department of Transportation to encourage competition.

Span-by-Span Construction

The balanced cantilever construction method was developed primarily for long spans, such that construction activity for the superstructure could be accomplished at deck level without the use of extensive falsework. A similar need exists for long viaduct structures with relatively shorter spans. The German firm of Dyckerhoff & Widmann pioneered the development of a system whereby the superstructure is executed in one direction, span-by-span, by means of a moveable form carrier.

Although the span-by-span method has been used for cast-in-place construction, a method for precast span-

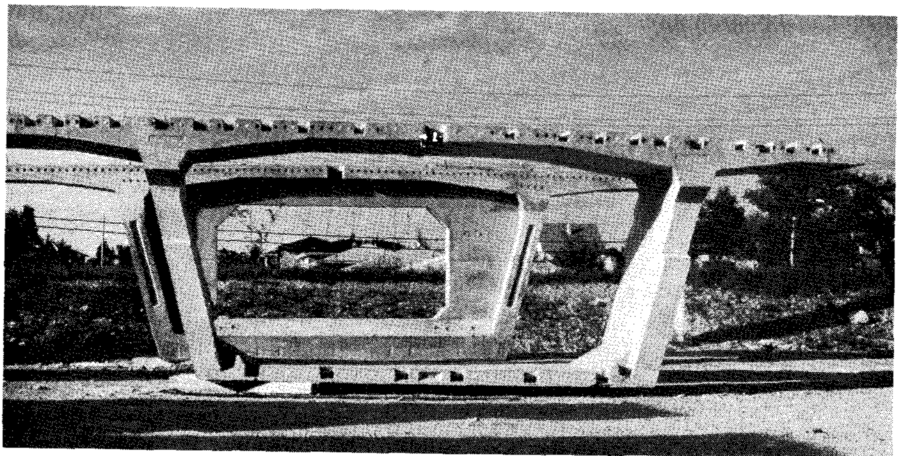


Fig. 8b. Precast segments for Kishwaukee River Bridge near Rockford, Illinois.

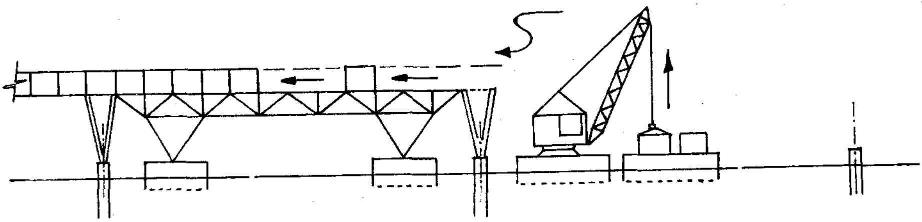


Fig. 9. Span-by-span erection (Long Key Bridge, Florida).

by-span construction has been proposed as a successful alternative for the Long Key Bridge project (currently being built in the State of Florida). A structural steel trusswork (Fig. 9) is used to support the precast segments which are installed progressively from one end of the structure to the other in span increments.

The steel trusswork has a length equivalent to the span of each identical interior span. It is placed by the same floating crane that handles all precast segments and further adjusted by a system of hydraulic jacks with regard to the piers. Upon completion of a span, the trusswork is released and moved over to the next span to start a new cycle of operations. As a consequence, in this method of construction prestressing requirements are very similar to those of a cast-in-place structure.

Interesting variations from normal precast segmental construction on the Long Key project are that dry joints will be used between the segments, i.e., no epoxy; and the longitudinal prestressing tendons are external, namely, inside the box.

Progressive Placing

Progressive placing is similar to the span-by-span method described above whereby construction starts at one end of the structure and proceeds continuously to the other end of the structure. The progressive placing method derives its origin from the balanced cantilever concept. In this method the precast segments are placed continuously from one end of the structure to the other in successive cantilevers on the same side of the various piers rather than by balanced cantilevers on each side of the pier.

Currently, this construction method appears to be practical in span ranges from 100 to 200 ft (30 to 60 m).[7] Because of the length of cantilever (one span) in relation to construction depth, the stresses become excessive and a moveable temporary stay arrangement must be used to limit the cantilever stresses to a reasonable level.

The erection procedure is illustrated in Fig. 10. Segments are transported over the completed portion of the deck to the tip of the cantilever span under construction where they are positioned by a swivel crane that proceeds from one segment to the next. Approximately one-third of the span from the pier may be erected by the free cantilever method, the segments being held in position by exterior ties and final prestressing cables.

In the balance of the span, each segment is temporarily held in position by external temporary ties and by two stays from a moveable tower located over the preceding pier. The two stays are continuous through the tower and anchored in the previously completed span deck. The stays are anchored to the top flange of the box

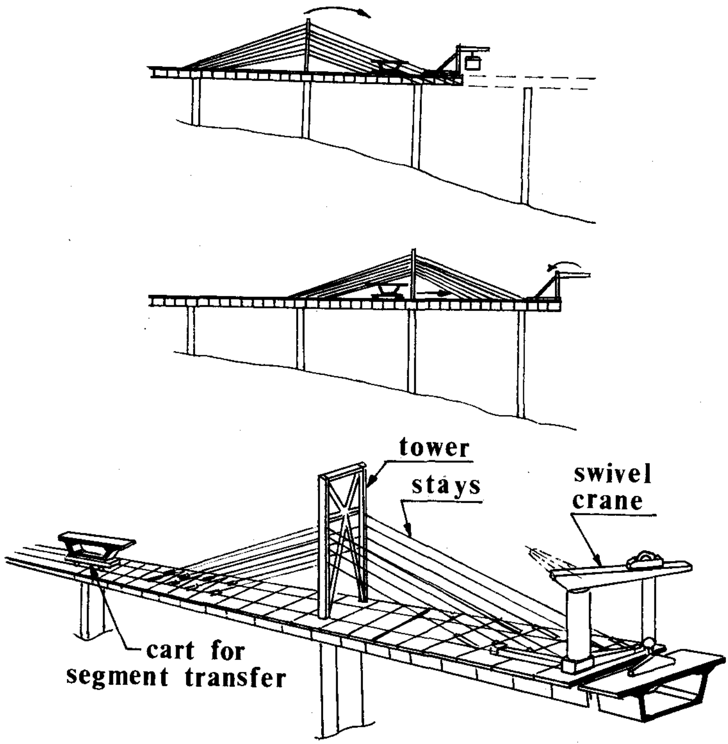
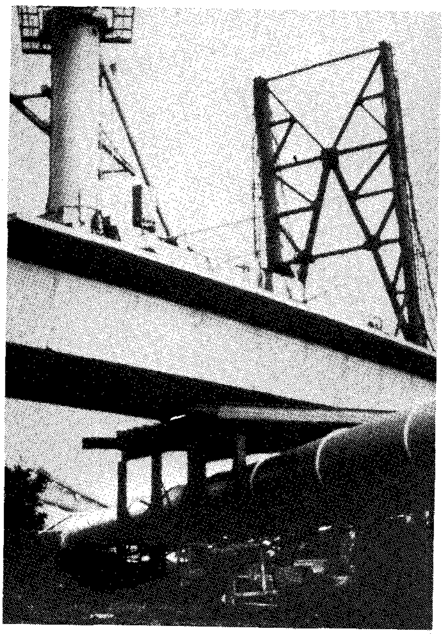


Fig. 10. Progressive placing erection (Reference 7).



girder segments such that the tendons in the stays can be adjusted by light jacks.

This type of construction has been used for the Rombas Viaduct (Fig. 11) constructed by Campenon Bernard in eastern France. The bridge, located in an urban area, is a dual structure of nine continuous spans ranging from 82 to 148 ft (25 to 45 m) in length. The single cell box sections have a constant depth of 8.2 ft (2.5 m). A view of the swivel crane picking up the segments from the transport dolly is shown in Fig. 12.

Fig. 11. Rombas Viaduct under construction in eastern France. (Courtesy: Figg and Muller Engineers, Inc., Tallahassee, Florida.)

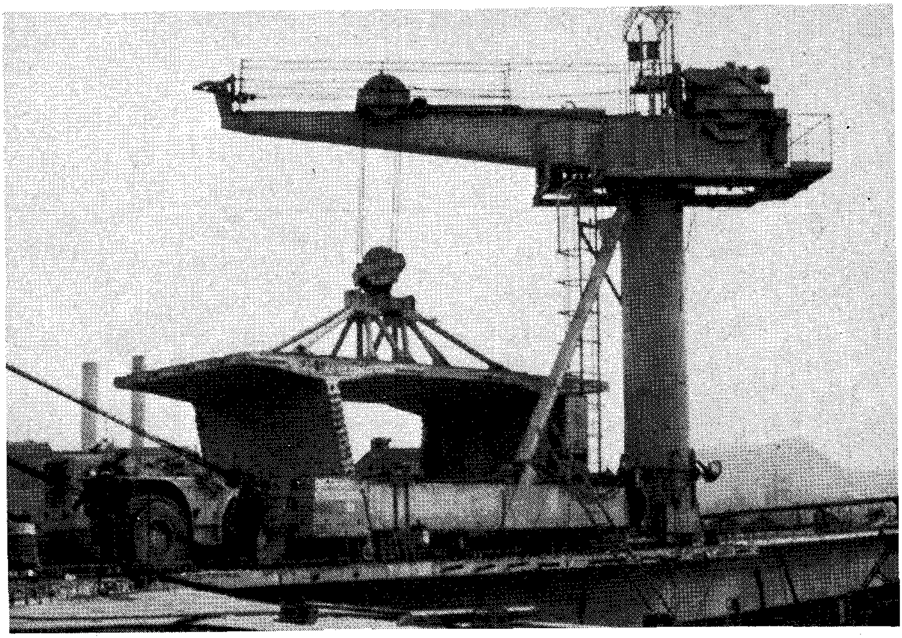


Fig. 12. Lifting of precast segment for Rombas Viaduct in eastern France. (Courtesy: Figg and Muller Engineers, Inc., Tallahassee, Florida.)

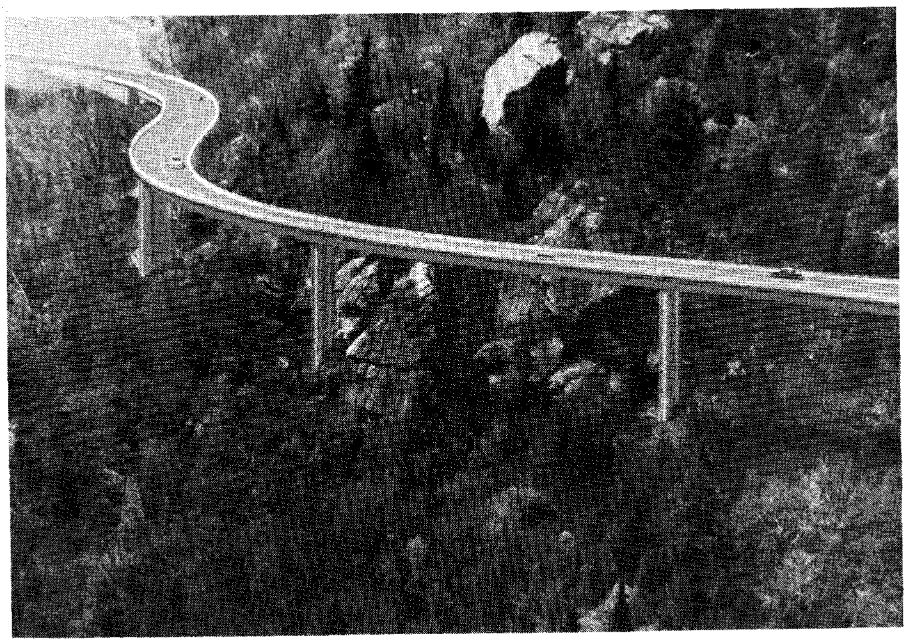


Fig. 13. Photomontage of the Linn Cove Viaduct at Blue Ridge Parkway, North Carolina. (Courtesy of Region 15, Federal Highway Administration.)

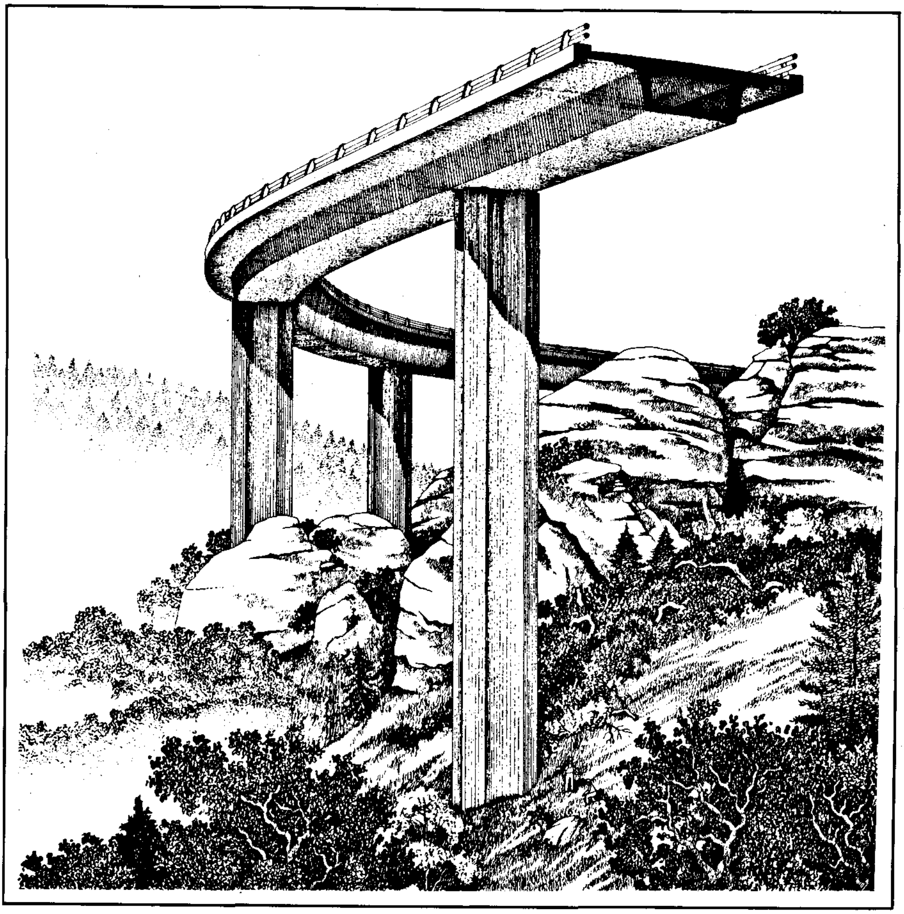


Fig. 14. Rendering of the Linn Cove Viaduct at Blue Ridge Parkway, North Carolina. (Courtesy: Figg and Muller Engineers, Inc., Tallahassee, Florida.)

A progressive placing scheme is proposed for the Linn Cove Viaduct on the Blue Ridge Parkway in North Carolina (Figs. 13-14). Because of the environmental sensitivity of the area, access to some of the piers is not available. Therefore, the piers will be constructed from the tip of a cantilever span, with men and equipment being lowered down to construct the foundation and pier. The piers are precast segments stacked vertically and post-tensioned to the foundation.

Because of the extreme curvature of the alignment, the use of temporary stays was impractical. Temporary bents at midspan will be used to reduce cantilever and torsional stresses during construction to acceptable levels. Erection of the temporary bents will be accomplished in the same manner as the permanent piers, utilizing the swivel crane at the end of the completed cantilevered portions of the structure. When temporary bents are no longer required, they will be dismantled and removed by equipment located on the completed portion of the bridge deck. Consulting Engineers for this structure are Figg

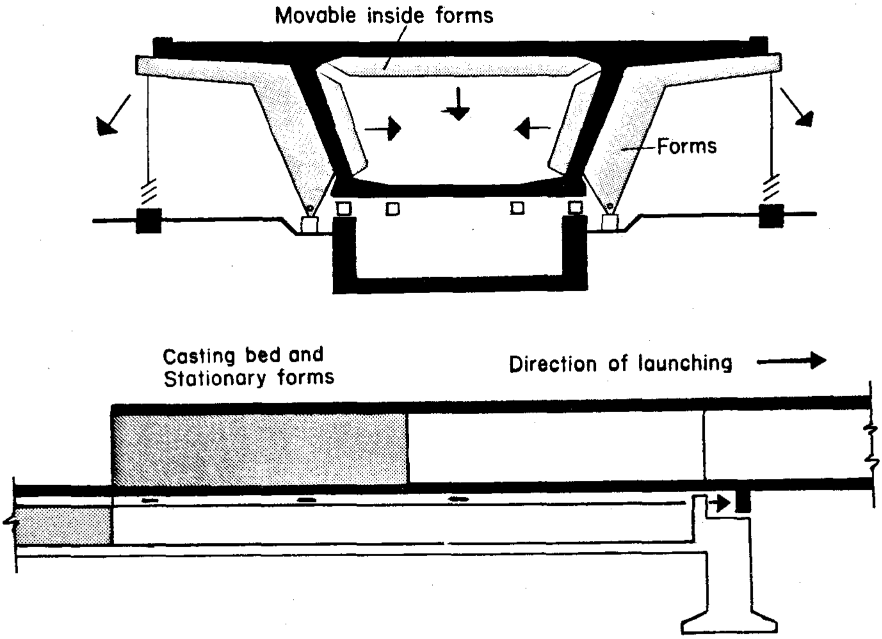


Fig. 15. Incremental launching, casting bed and launching arrangement. (Courtesy: Fritz Leonhardt, Stuttgart, West Germany.)

and Muller Engineers, Inc., working for Region 15 of the Federal Highway Administration and the Park Services.

Incremental Launching

Another variant of the segmental concept, which is new to American bridge engineers and contractors, has evolved in Germany and is called "Taktschiebeverfahren." Literally translated taktschiebeverfahren means "phased shoving concept." In North America it is refered to as incremental launching or push-out construction. This concept was first implemented in 1962/63 on the Rio Caroni Bridge in Venezuela, built by its originators Willi Baur and Dr. Fritz Leonhardt of the consulting firm Leonhardt and Adra, Stuttgart, West Germany.[10, 11]

The bridge superstructure is constructed in an on-site factory in stationary forms behind the abutment in lengths of 33 to 100 ft (10 to 30 m) (Fig. 15). After a segment reaches sufficient strength, it is post-tensioned to the previous segment and the entire superstructure is pushed out longitudinally one increment length. The succeeding segment is then cast against its predecessor. Normally, a work cycle of one week is required to cast and launch a segment, irrespective of its length. Operations are scheduled such that the concrete can attain sufficient strength over a weekend to allow launching at the beginning of the next week (Fig. 16).

Bridge alignment in this type of construction is either straight or on a curve; however, the curve must be of constant radius. This requirement of constant rate of curvature applies to both horizontal and vertical curvature. The Val Ristel Bridge in Italy which was incrementally launched on a radius of 500 ft (150 m) is illustrated in

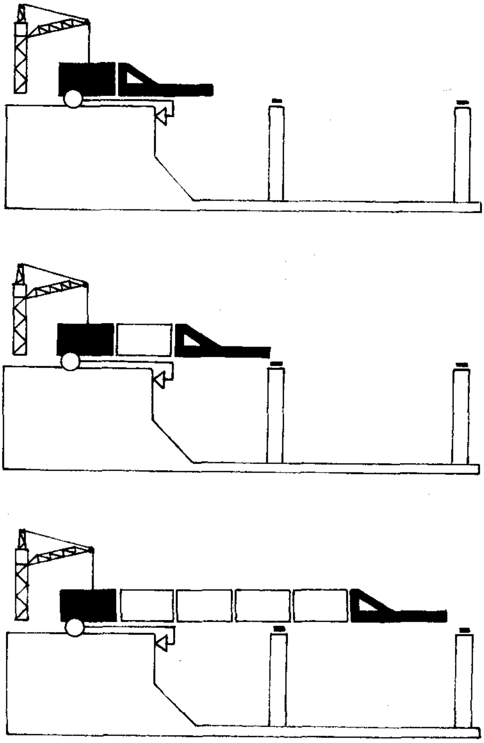


Fig. 16. Schematic drawing of incremental launching sequence. (Courtesy: Fritz Leonhardt, Stuttgart, West Germany.)

Fig. 17. This then implies that roadway geometry is dictated by construction rather than the present practice in the United States, where geometry dictates construction.

To counteract the varying bending moments that occur during the launching operation, the superstructure is concentrically prestressed. In addition, a launching nose (Fig. 16) is provided in order to preclude the development of excessively large bending moments during launching.

The concentrically prestressed superstructure is pushed forward longitudinally in successive increments by means of hydraulic jacks. To accommodate the movements of the superstructure, temporary sliding bearings are installed on the piers. These bearings are made of teflon (PTFE) faced steel-reinforced neoprene pads which slide on polished stainless steel plates (Fig. 18).

There are two methods of launching. The method used on the Rio Caroni Bridge has the jack bearing on an abutment face and pulling on a steel rod, which is attached to the last segment cast by launching shoes. The second and more current method consists of a horizontal and vertical jack (Fig. 19).

The vertical jack slides with a teflon plate at its base on a stainless steel plate and has a friction element at the top to engage the superstructure. The vertical jack lifts the superstructure approximately $^{3}/_{16}$ in. (5 mm) for launching. The horizontal jack then moves the superstructure longitudinally. After the vertical jack has

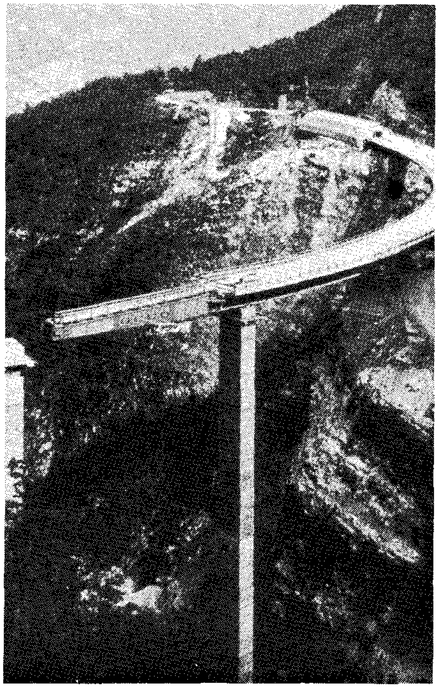


Fig. 17. Val Ristel Bridge, Italy. (Courtesy: Fritz Leonhardt, Stuttgart, West Germany.)

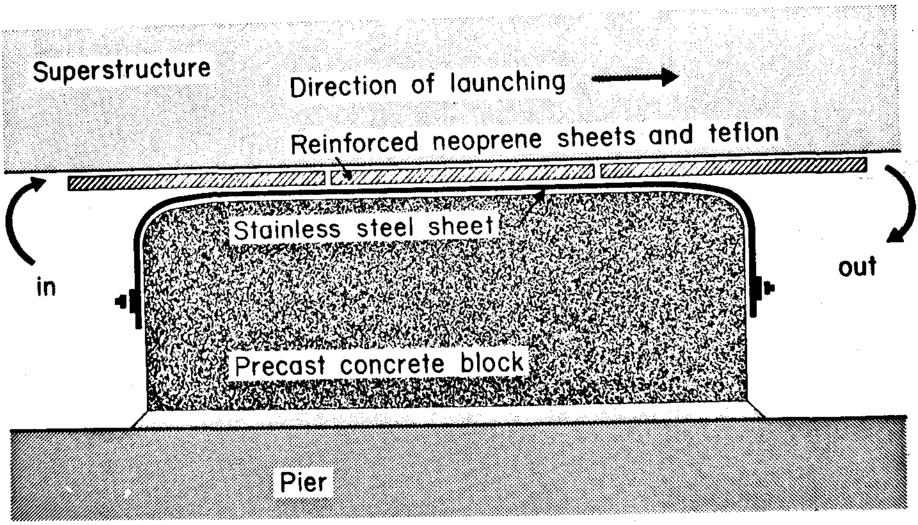


Fig. 18. Temporary sliding bearing. (Courtesy: Arvid Grant, Olympia, Washington.)

moved forward one stroke of the horizontal jack, the vertical jack is lowered and the horizontal jack is retracted to restart the cycle.[11]

After launching is completed, when the opposite abutment has been reached, additional prestressing is added to accommodate moments in the final structure. The original concentric prestress must resist the varying moments which occur as the superstructure is pushed over the piers to its final position.

The incremental launching technique has been used for spans up to 200 ft (60 m) without the use of temporary falsework bents. Spans up to 330 ft (100 m) have been built

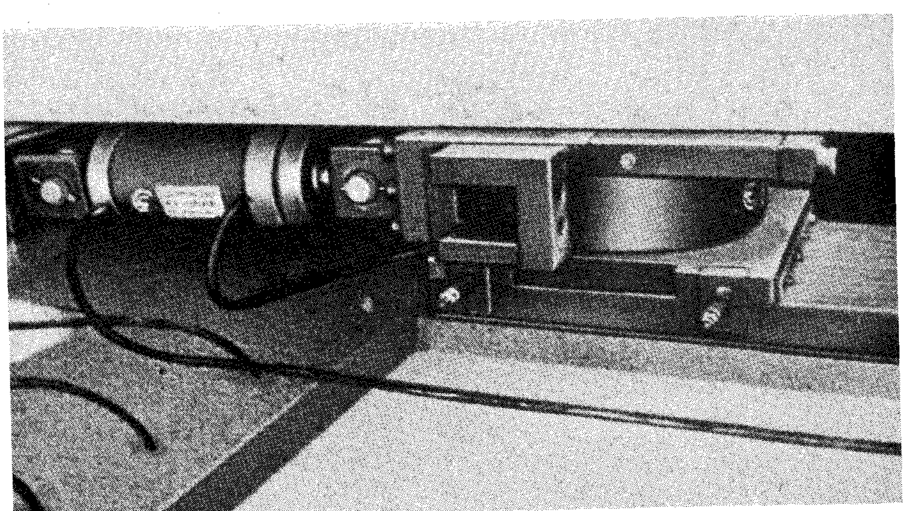


Fig. 19. Jacking mechanism. (Courtesy: Fritz Leonhardt, Stuttgart, West Germany.)

utilizing temporary supporting bents. Girders are of a constant depth and usually with a depth of 1/12 to 1/16 of the longest span. This construction technique has been used for the first time in the United States for constructing the Wabash River Bridge at Covington, Indiana.

Since the segments are cast behind the abutments and relocated in the final structure, this construction method, by definition, may be classified as precast. Most precast producers would consider this to be a fine line of distinction; however, depending upon constraints at a particular site, the segments could be precast and match-cast at a precasting plant, transported to the site, positioned, post-tensioned, and launched. There would have to be some modification in design to accommodate the lack of mild steel reinforcement continuity across the joint.

Construction on Falsework

Segmental construction on falsework, although negating a major advantage of segmental construction, under certain circumstances is advantageous. Generally, the end span of a bridge will be slightly longer than half the span of the first interior span. Thus, there will be a short length of end span near the abutment that will not be accommodated by the balanced cantilever concept. Segments in this short portion of the structure will generally be placed on falsework supported at grade.

Where simple span structures are contemplated or where the height of the bridge from existing terrain is not excessive and falsework is not environmentally objectionable, it is doubtful whether segmental construction would be economically competitive with conventional in-situ type of construction, unless it were a long viaduct type structure. The only segmental bridge constructed entirely on falsework that the author is aware of is the Pennsylvania DOT test structure constructed at the Pennsylvania State University test track facility; however, this structure was specifically specified as precast segmental for research purposes.

The Long Key Bridge in Florida might be considered as segmental on falsework; however, in this case the falsework is portable, i.e., mounted on barges and relocated from span to span and therefore is not falsework in the conventional sense.

Segment Erection

The method of erecting precast segments is dependent upon a number of parameters. The size and weight of the unit will determine, or be determined by, the erection equipment available. The height of the bridge above existing terrain, or navigational clearance, will determine if the units can be erected by truck, crawler, or barge mounted cranes.

In some instances, precast units may be lifted up from a barge or truck by a jacking mechanism located on the pier or completed portion of the structure (Fig. 6). On the other hand, if the height of the structure is such that truck or barge cranes are not practicable, if access for trucks at existing grade is not feasible, or if the structure is a long viaduct, a moveable launching gantry such as that shown in Fig. 5, or a swivel crane (Fig. 12), may be necessary and economically justifiable.

The moveable launching gantry can be more readily justified economically for a long viaduct. Usually, launching gantries are used for the balanced cantilever type of construction and only require repositioning upon completion of two half-span cantilevers.

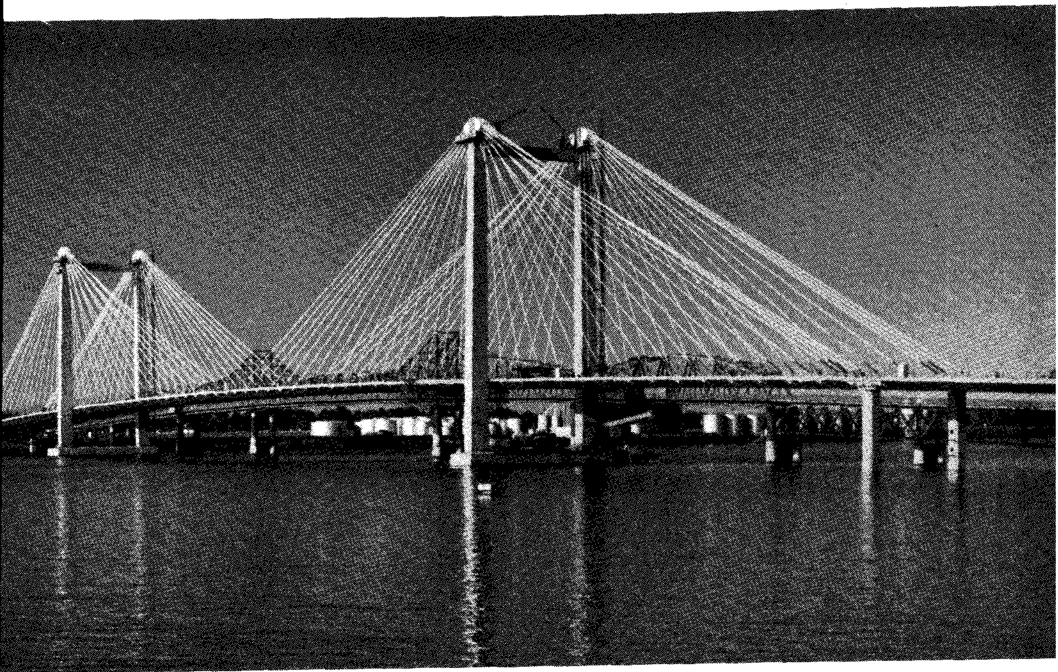


Fig. 20. Pasco-Kennewick Bridge over Columbia River in the State of Washington nearing completion. (Courtesy: Arvid Grant, Olympia, Washington.)

Swivel cranes have only been used, thus far, for the progressive placing method of construction and require relocation for erection of each segment.

Types of Segmental Bridges

Up to this point the documentation of prestressed concrete segmental bridges has been concerned with what might be classified as girder type bridges. However, segmental construction is a versatile type of construction applicable to other types of bridge construction and as such should not be stereotyped to girder bridges only. As with any new concept the innovative engineer should be able to apply the concept to other types of construction.

The material presented herein indicates only the adaptation of segmental construction; it is not within the scope of this paper to present specific design considerations for the various types of bridges. The reader should consult other literature* for design information relative to a specific type of structure.

Cable-Stayed Bridges

The first cable-stayed bridge with a segmental concrete superstructure to be built in the United States is the Pasco-Kennewick Intercity Bridge crossing the Columbia River in the State of Washington (Fig. 20). The overall length of this structure is 2503 ft (763 m). The center cable-stay span

*An informative design manual on segmental construction titled *Precast Segmental Box Girder Bridge Manual* (1978) is available from the Prestressed Concrete Institute, Chicago, Illinois.

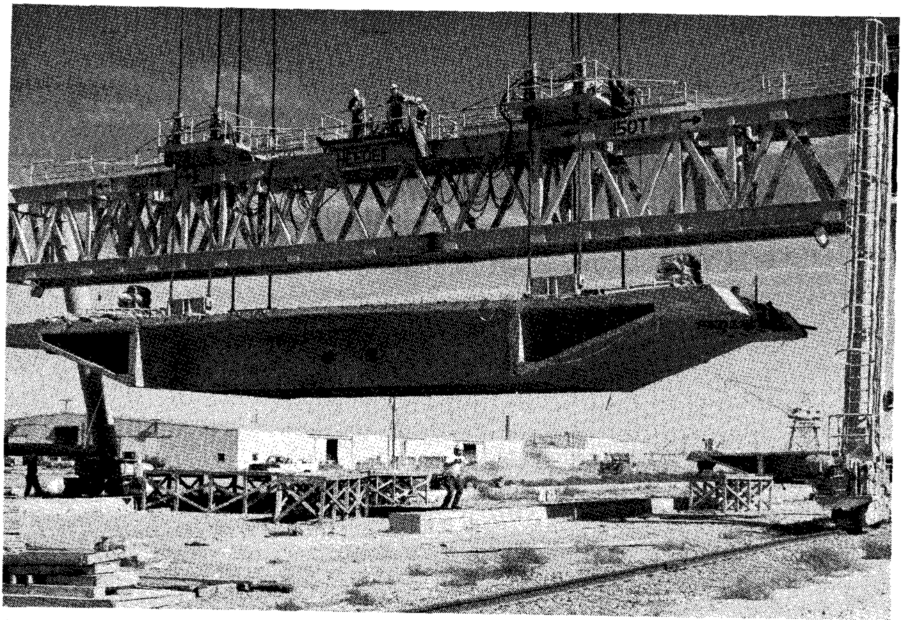


Fig. 21. Giant precast segment in casting yard for Pasco-Kennewick Bridge over Columbia River in the State of Washington. (Courtesy: Arvid Grant, Olympia, Washington.)

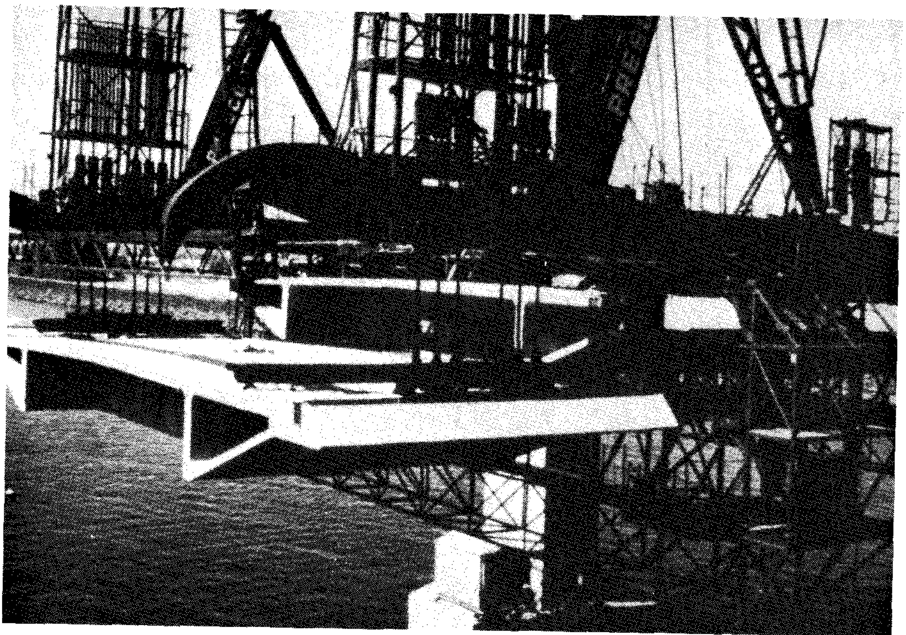


Fig. 22. Precast segment erection of Pasco-Kennewick Bridge over Columbia River in the State of Washington. (Courtesy: Arvid Grant, Olympia, Washington.)

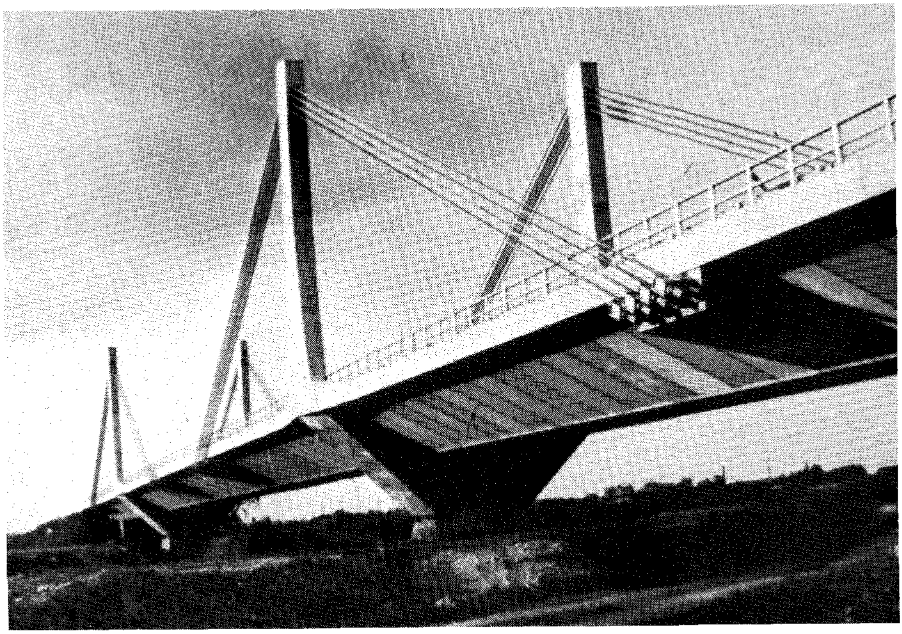


Fig. 23. Danube Canal Bridge on Vienna Airport Motorway in Austria. (Courtesy: Figg and Muller Engineers, Inc., Tallahassee, Florida.)

is 981 ft (299 m) and the stayed flanking spans are 406.5 ft (124 m). The three main spans are assembled from precast prestressed concrete segments, while the approach spans are cast-in-place on falsework.

The segments are precast about 1 mile (1.6 km) downstream from the bridge site (Fig. 21). Each segment is 27 ft (8.2 m) long and consists of three transverse girders and a roadway slab joined along the segment edges with a hollow triangular box and weighs about 300 tons (272 mt). The segment has a constant depth of 7 ft (2 m) and is 79 ft 10 in. (24.3 m) wide.

Segments are barged directly beneath their place in the bridge and hoisted into position (Fig. 22). It requires approximately 6 hours to lift each segment into position. Fifty-eight precast, transversely prestressed concrete bridge girder segments are required. The segments are match-cast, prestressed, cured and then transferred to the bridge, and erected symmetrically about the two main bridge towers, epoxy joined, longitudinally prestressed against the previously erected ones, and suspended to the bridge stays. A large part of the longitudinal prestressing force is provided by the compression resulting from the horizontal component of stay-cable forces.

Another interesting cable-stay structure is the Danube Canal Bridge located on the Vienna Airport Motorway and crossing the Danube Canal at an angle of 45 deg. It has a 390-ft (119 m) center span with 182.7-ft (55.7 m) side spans (Fig. 23). The structure is unique insofar as its construction technique is concerned. Because construction was not allowed to interfere with navigation on the canal, the

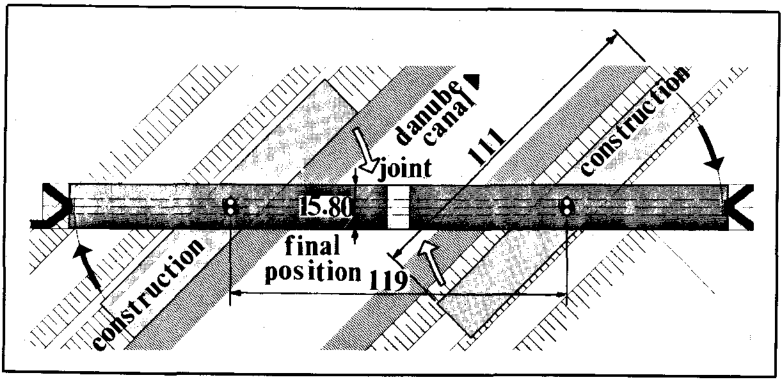


Fig. 24. Plan for Danube Canal Bridge on Vienna Airport Motorway in Austria.

structure was built in two 364-ft (111 m) halves on each bank and parallel to the canal (Fig. 24).

Upon completion, the two halves of the span were swung into final position and a cast-in-place closure joint was made. In other words, each half was constructed as a one-time swing span.[12]

The bridge superstructure is a 51.8-ft (15.8 m) wide trapezoidal three-cell box girder. An interesting variation in this structure is that the

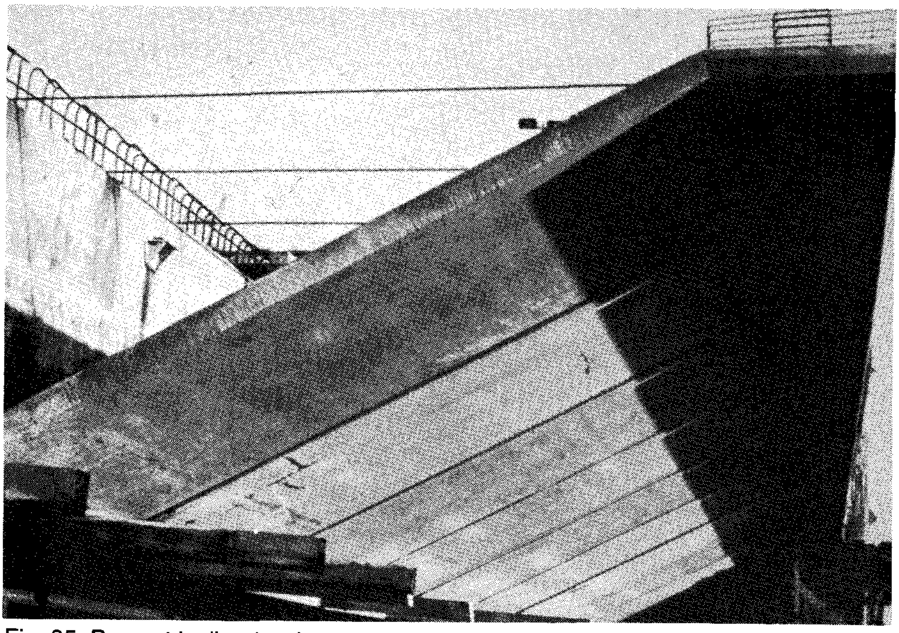


Fig. 25. Precast inclined web segments for Danube Canal Bridge on Vienna Airport Motorway in Austria. (Courtesy: Figg and Muller Engineers, Inc., Tallahassee, Florida.)

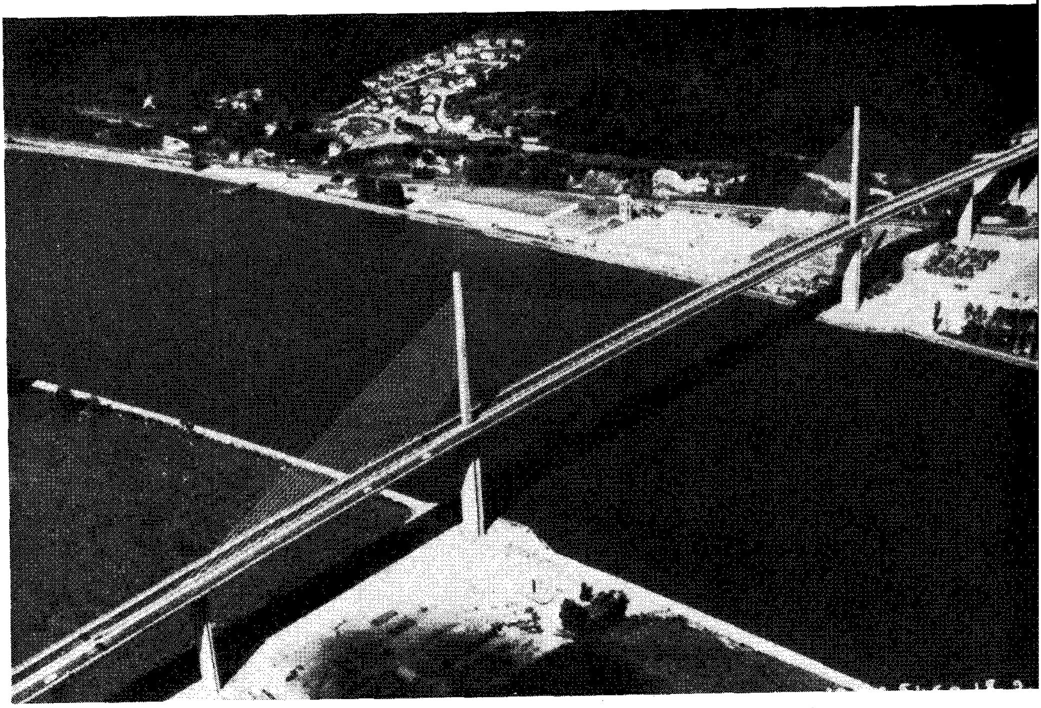


Fig. 26. Aerial view of Pont de Brotonne near Rouen, France (Reference 13).

central box is cast in 25-ft (7.6 m) long segments on falsework; after the precast inclined web segments are placed, the top slab is cast (Fig. 25). Thus, the system uses a combination of both precast and cast-in-place segmental construction.

The Brotonne Bridge crosses the Seine River downstream from Rouen in France. An aerial view (Fig. 26) shows the general configuration of the bridge. Fig. 27 shows an isometric view of a segment and the orientation of prestressing and stay.[13]

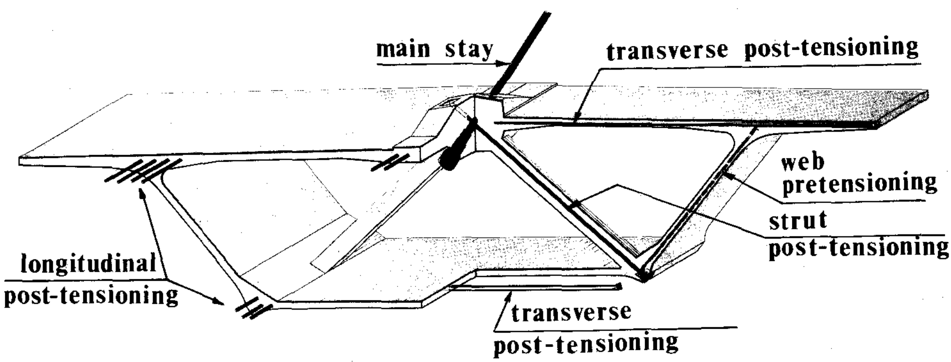


Fig. 27. Isometric view of precast segment of Pont de Brotonne near Rouen, France. (Courtesy: Figg and Muller Engineers, Inc., Tallahassee, Florida.)

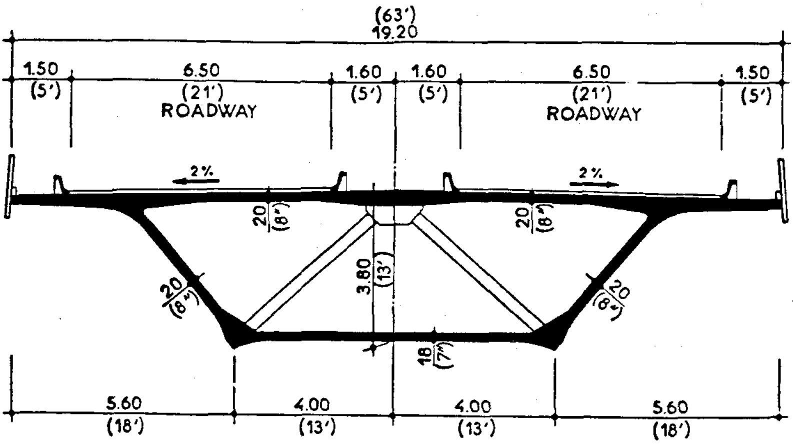


Fig. 28. Deck cross section of Pont de Brotonne near Rouen, France (Reference 13).

The total length of the structure is 4194 ft (1278 m). The central river crossing includes a 1050-ft (320 m) center span and 471-ft (143.5 m) side spans. At present, this structure holds the record length for a cable-stayed bridge of prestressed concrete and for any type of concrete span.

The main deck structure is a built-in balanced cantilever out from the pylon piers. Dimensions of the deck segments are, top flange 63 ft (19.2 m) wide, bottom flange 26 ft (8 m) wide, and a constant depth of 12.5 ft (3.8 m) as shown in Fig. 28. Each segment is 9.8 ft (3 m) long.

Similar to the Danube Canal Bridge, the only parts of the trapezoidal box girder that are precast are its sloping webs. The 9.8-ft (3 m) long, 13-ft (4 m) wide precast web elements are precast at the site. The balance of the cross section, including top and bottom flanges and its interior stiffening struts, is cast-in-place.

Final support for the deck units is provided by 21 stays continuous through the pylon which lie in a vertical plane along the longitudinal axis of the structure. Spacing of the stays at deck level is 19.6 ft (6 m); thus, every other segment has a stay anchor.

Fig. 29 shows the arrangement of the stays and the underside of the segments of the Pont de Brotonne (looking up the pylon piers).

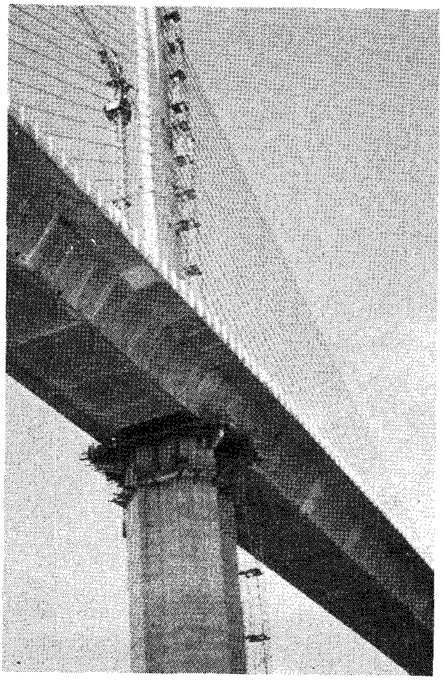


Fig. 29. Bottom view of deck segments of Pont de Brotonne near Rouen, France.

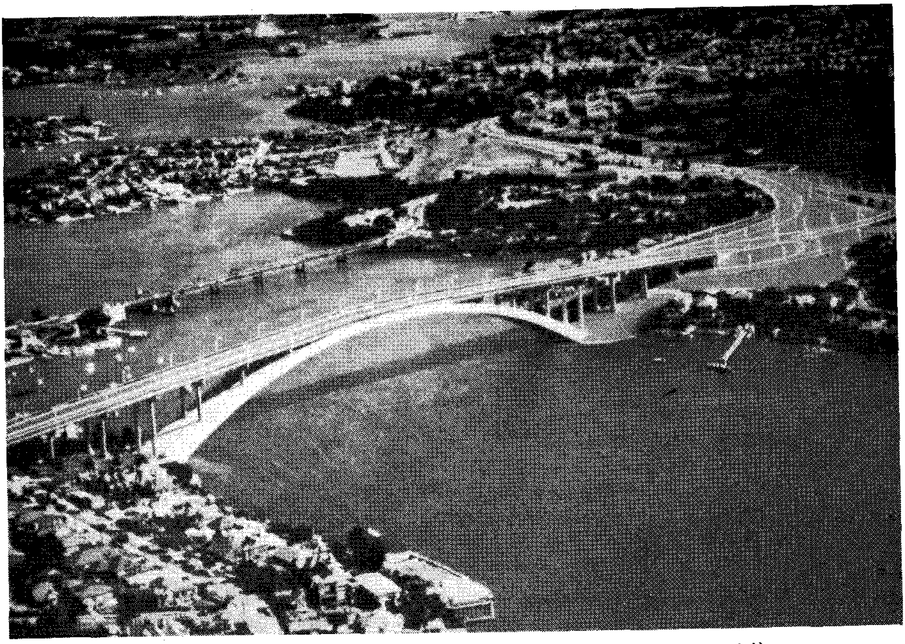


Fig. 30. Aerial view of Gladesville Arch Bridge, Australia (Reference 14).

Arch Bridges

The Gladesville Bridge in Australia, completed in 1964, is a precast segmental arch bridge (Fig. 30). The arch has a clear span of 1000 ft (305 m) and consists of four arch ribs. The hollow box units and diaphragms were cast 3 miles (4.8 km) downstream from the bridge site. The casting yard was laid out such that the manufacture of one arch rib could be accommodated at one time.

Each arch rib consists of 108 box units and 19 diaphragms. Each box unit is 20 ft (6 m) wide with depths decreasing from 23 ft (7 m) at the thrust block to 14 ft (4.3 m) at the crown of the arch, measured at right angles to the axis of the arch. The length of the box units along the arch varies from 7 ft 9 in. (2.4 m) to 9 ft 3 in. (2.8 m).

After the box units were manufactured, they were loaded on barges and transported to the bridge site. The box units and diaphragms were lifted from the barges to the crown of the arch falsework and winched down to their proper position (Fig. 31).[14]

Diaphragms are spaced at intervals of 50 ft (15.2 m) to serve not only as supports for the slender columns which support the roadway above, but also to tie the four arch ribs together.

When the units were located in position on the falsework a 3-in. (76 mm) joint between the precast units was cast-in-place. At two points, in each rib, four layers of Freyssinet flat jacks were inserted, with 56 jacks in each layer. The rib was then jacked longitudinally by inflating the jacks with oil one layer at a time, the oil being replaced by grout and allowed to set before the next layer was inflated.

Inflation of the jacks increased the distance between the edges of the units adjacent to the jacks and thus the overall length of the arch along its center line. In this manner a camber was induced into the arch rib causing it to lift off the supporting falsework.

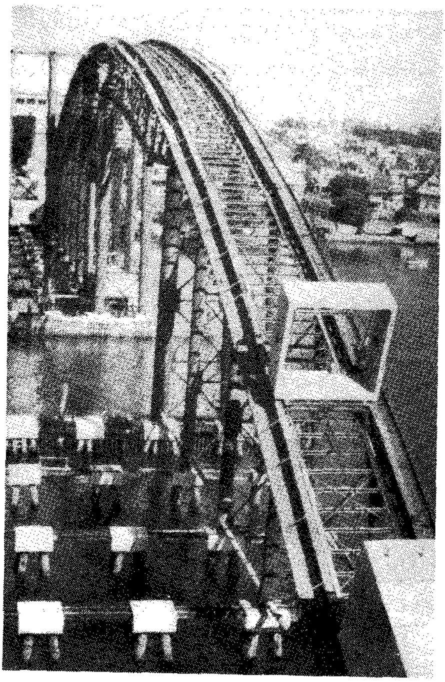


Fig. 31. Erection of precast segments of Gladesville Arch Bridge, Australia (Reference 14).

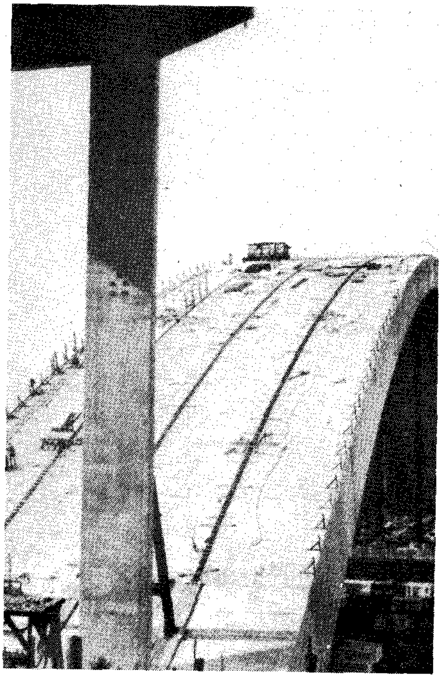


Fig. 32. Completed four arch ribs of Gladesville Arch Bridge, Australia (Reference 14).

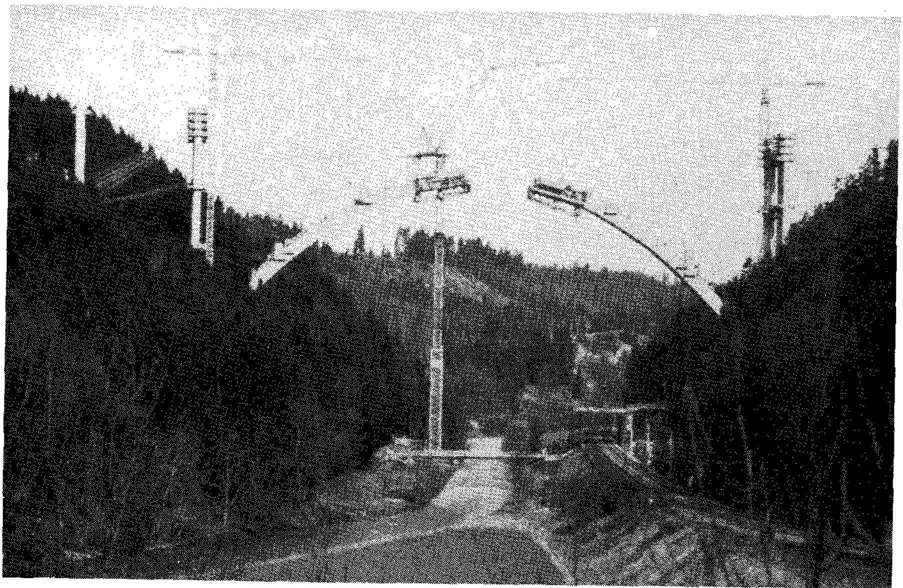


Fig. 33. Arch just before closure section of Talbrücke Rottweill-Neckarburg Bridge southwest of Stuttgart, West Germany. (Courtesy: W. Zellner.)

The falsework was then shifted laterally into position to support the adjacent arch rib and repeat the cycle. A view of the completed four arch ribs is shown in Fig. 32.

A unique segmental arch bridge is the Talbrücke Rottweill-Neckarburg located 50 miles (80 km) southwest of Stuttgart, West Germany, and crosses the Neckar River (Fig. 33). Although the structure is constructed utilizing a cast-in-place segmental technique, it could, with some modification in design, be constructed with precast segments.

The roadway of this 1197-ft (365 m) long structure is approximately 310 ft (95 m) above the river. The 507-ft (154 m) arch span has a rise of 164 ft (50 m). Roadway width is 102 ft (31 m). The entire structure is actually constructed in two independent longitudinal halves, which are joined together along the abutting edges of the roadway trapezoidal box girder flanges.

Each independent arch rib is a two-cell box. The ribs are constructed in symmetrical cantilever halves (Fig. 34) by the cast-in-place segmental method. As each rib is cantilevered out from its foundation, it is temporarily tied back to rock anchors with Dywidag bars. The roadway for this structure is composed of parallel single-cell box girders which are constructed by the incremental launching method (see Fig. 35 on next page).

With some modification in design, an arch bridge of this type could be constructed with precast arch rib segments. The segments could be positioned perhaps with the assistance of a high-line, held in position with temporary prestressing until permanent prestressing is installed and supported by the back stays until closure.

Rigid Frame Bridges

The Brielse Maas Bridge, near Rotterdam, Holland, is a distinctive

Fig. 34. Cantilever construction of Talbrücke Rottweill-Neckarburg Bridge, southwest of Stuttgart, West Germany. (Courtesy: W. Zellner.)

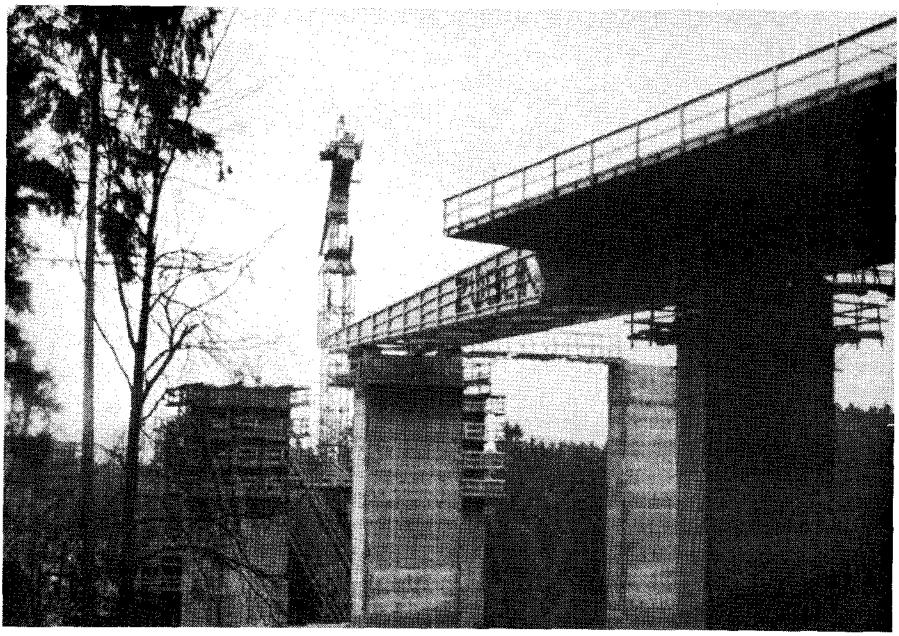


Fig. 35. Incremental launching of deck box girder of Talbrücke Rottweill-Neckarburg Bridge, southwest of Stuttgart, West Germany. (Courtesy: W. Zellner.)

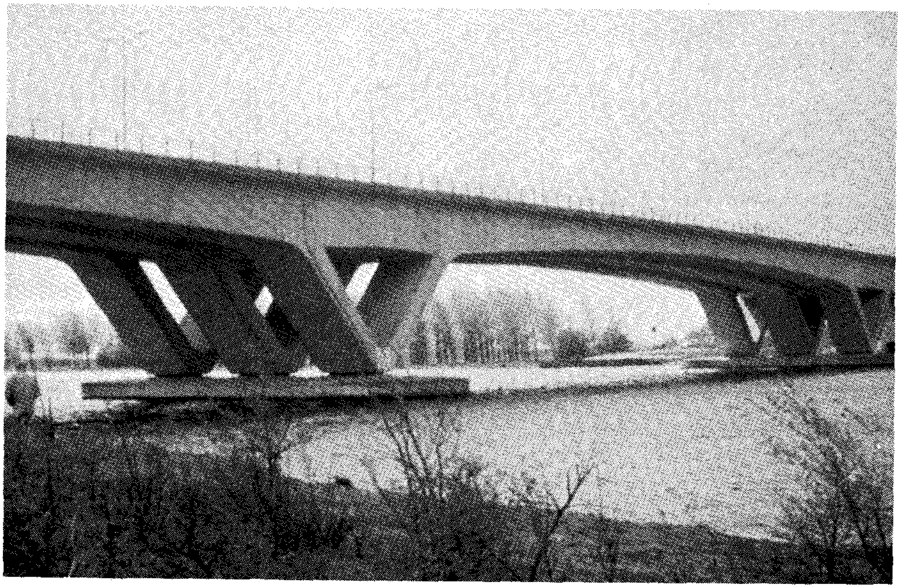


Fig. 36. General view of Brielse Maas Bridge near Rotterdam, Holland. (Courtesy: Brice Bender, BVN/STS.)

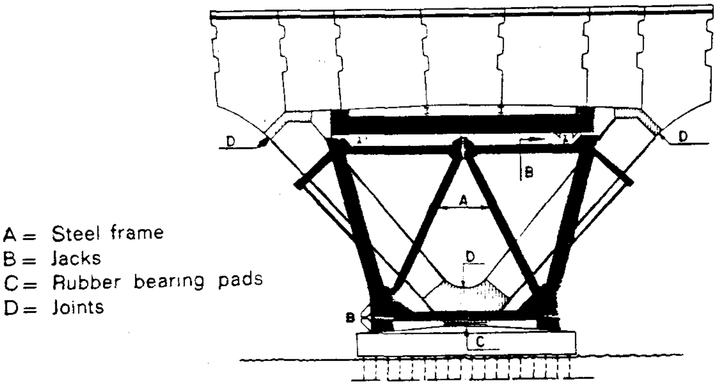


Fig. 37. Erection frame for Brielse Maas Bridge near Rotterdam, Holland. (Courtesy: Brice Bender, BVN/STS.)

structure with its V-shaped piers (Fig. 36). Transversely the structure is made up of three precast single-cell boxes which are joined together at their flange tips with a longitudinal closure placement and are transversely prestressed.

A special structural steel frame was used to position the inclined precast hollow box legs of the piers and to support the seven precast roadway girder segments prior to casting the joints at the corners of the delta pier portion of the structure. This frame is also utilized to balance the pier during erection of the balance of the roadway girder segments and to adjust, by means of jacks, the loads in the inclined legs of the pier during various erection stages (Fig. 37). The inclined legs are connected to the deck structure by post-tensioning and the V-pier is supported at its base through neoprene bearing pads on piers founded on piles (Fig. 37).

The Bonhomme Bridge over the Blavet River in Morbihan, France, is a slant leg rigid frame of cast-in-place segments (Fig. 38). The span between the foundations of the slant legs is 611 ft (186.25 m). A tubular steel falsework was used to temporarily support the slant legs until closure at midspan.

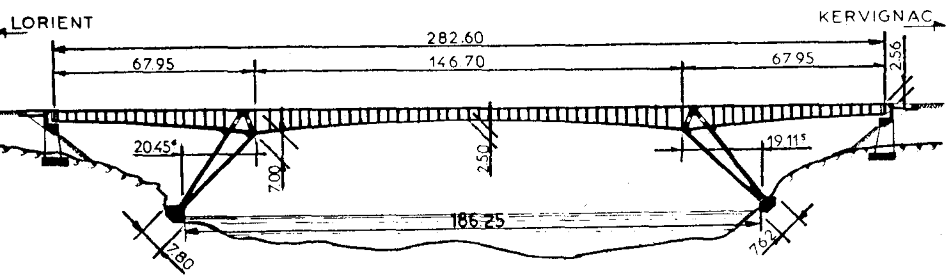


Fig. 38. Bonhomme Bridge, Morbihan, France. (Courtesy: Figg and Muller Engineers, Inc., Tallahassee, Florida.)

Closing Remarks

Precast prestressed concrete segmental bridges have extended the practical and competitive economic span range of concrete bridges. They are adaptable to almost any conceivable site condition. This method can reduce environmental impact from that of conventional cast-in-place and falsework type concrete construction.

It is apparent that there are many ways in which segmental prestressed concrete bridges may be constructed, using any of the four construction methods discussed in this paper. Precast concrete segments may be lifted by truck, crawler, or barge-mounted cranes or hoists secured on the top of previously placed segments. Giant gantry cranes may be used to span between bridge piers to erect the segments. Precast segments can be incorporated into a variety of bridge types such as cable-stay, arches and rigid frames as well as the girder type bridge. Examples of many of these construction procedures and equipment and bridge types have been described in this paper.

The designer of a segmental bridge must have detailed knowledge of the various alternatives, construction and prestressing equipment, and site conditions. The designer must establish all major aspects of how the structure will be constructed. Construction procedures can no longer be isolated from design and vice versa. Although most aspects of construction are fixed, there is still leeway for both innovation and error in judgment. Since the success of segmental construction is dependent upon agreement between the design assumptions and the construction methods, it is essential that designers and contractors interact during the design and construction phases of the project.

Segmental construction is a design concept that arose out of a need to overcome construction difficulties. Therefore, as a concept, segmental construction's potential in general and applicability to a specific project is only limited by the innovation and imagination of the designer and contractor.

Discussion of this paper is invited. Please forward your comments to PCI Headquarters by July 1, 1979.

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