Segmental Construction for Concrete and Steel Bridges That Incorporate Posttensioning

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An overview of recent segmental construction for concrete and steel bridges is presented. Particular emphasis is on bridges where posttensioning techniques have been used. Currently, segmental construction is perhaps the most predominately used method of systems construction for bridge structures. This paper describes the various types of segmental construction. The variables discussed are major materials employed, type or shape of segment used, structural systems incorporated, and construction methods employed.

This paper presents an overview of the recent segmental construction for concrete and steel bridges up to 1981 and places particular emphasis on those bridges where posttensioning techniques have been used. Currently, segmental construction is perhaps the most predominantly used method of that portion of what is called systems construction for bridge structures.

Systems construction of bridge structures may not have a strict definition, but it is generally believed that it includes repetitive use of designs, forms, plants, machinery, and equipment in the production and erection of bridge members. Segmental construction may be defined in different ways. In its narrower sense, segmental construction has come to refer only to bridges made of precast or cast-in-place concrete box sections. In its broader sense, any bridge construction that employs repetitive placement of segments in any material of whatever shape may be termed segmental construction. Many steel bridges of the box-girder type are erected in segments, and these bridges are certainly of the segmental type.

Because the main purpose of this paper is to describe the various types of segmental construction that have been or are being employed in this country and in other parts of the world, it will be interesting to describe the several variables involved in this construction, such as the following:

1. Major materials employed,
2. Type or shape of segments used,
3. Structural systems incorporated, and
4. Construction methods employed.

There can be various combinations of the above four variables. For example, a segmental bridge of steel construction can be built by using box-shaped segments to form a cable-stayed bridge built by the double-cantilever method of construction. We believe that with this approach, engineers will broaden their outlook of segmental construction and view it as consisting of different combinations of these variables applicable to various requirements for a project.

MAJOR STRUCTURAL MATERIALS

Most bridges that employ segmental-type construction are built by using concrete or structural steel. However, the segmental concept can also be applied to other materials, such as wood and masonry. Frequently, steel cables are either applied externally or internally to construct prestressed units or used as external supports to form cable-stayed structures. The combination of steel and concrete, which usually act together in composite action (with steel as the main carrying members and concrete for the bridge deck), is often used. Cable can be used to either posttension or pretension concrete decks. It can also be used to posttension the steel girders to reduce dead load moments that in turn reduce the weight of steel required. Thus, we can envision three major structural materials--concrete, structural steel, and steel cables--used alone or in combination for the purpose of achieving economical segmental construction.

TYPES OF SEGMENTS

Currently, the most popular type of segment is the transverse segmental type that normally comprises a box shape. The box shape has a special advantage in that it is a rugged section that can be easily transported and erected and forms a torsionally stiff section that adapts itself to both the positive and negative moments of the structural system employed. However, there are also some basic disadvantages for a box shape, as compared with other shapes, since it may require excessive material and labor. This is true for both concrete and steel box sections. As a result, boxes with orthotropic steel decks frequently have proved to be uneconomical. Concrete boxes may be uneconomical for short or medium spans or where the bottom soffit may not be required structurally. They also add weight and additional cost for labor, forming, transportation, and material.

Longitudinal precast segments, which use standard I-beams and T-beams and are precast and erected in parallel, have been another popular type of segmental construction for many years. They can be classified as longitudinal segments to distinguish them from the transverse segments described above. The immediate advantages in the use of such segments when constructed in elements of 120 ft are the simplicity of fabrication and the relative ease in transportation. Furthermore, in continuous systems they can be lengthened to 150 ft and perhaps beyond. These longitudinal sections are spaced sided by side with the concrete deck poured in place. This is often an expensive process, since such in-place concreting has not yet been highly mechanized. By using reinforced concrete decks, these segments are spaced somewhat close together. Then, by using transverse posttensioning of the deck, the spacing can be increased, thereby resulting in overall economy. Concrete T-beams of the longitudinal segmental type can simplify deck construction, but their spacing may be limited unless gaps are left between the T-beams.

Another longitudinal segmental type is the V-shape or inverted-Delta shape that was used for the Dumbarton Bridge. These V-beams are rugged and relatively stable for handling and can be joined to form longer spans. For example, the Dumbarton Bridge joined two 75-ft-long V-beams to form beams 150 ft long. When used for approach spans, their sloping sides blend well aesthetically with the longer main-span box girders (Figure 1).

Another interesting shape is the segmental waffle type. Precast waffle segments can be placed in a grid pattern on falsework supports to form bridges of varying width and curvature. Tendons are placed between the webs of the units and the space is filled with concrete that has a topping. The Hegenberger Bridge in Oakland, for example, was made of waffle segments 10 ft by 15 ft by 6 ft 2 in; the walls were only 3 in thick. These were precast at the site in the form of inverted bathtubs (Figure 2). Tendons were then placed within the troughs between these segments and integrated with poured-in-place concrete.

Another segmental construction technique is illustrated by the Rio Colorado Bridge in Costa Rica (Figure 3). Precast channel-shaped plate elements are supported on cables draped between abutments. These cables were then posttensioned to form a rigid lower platform from which the entire superstructure, also composed of precast column and beam elements, was erected.

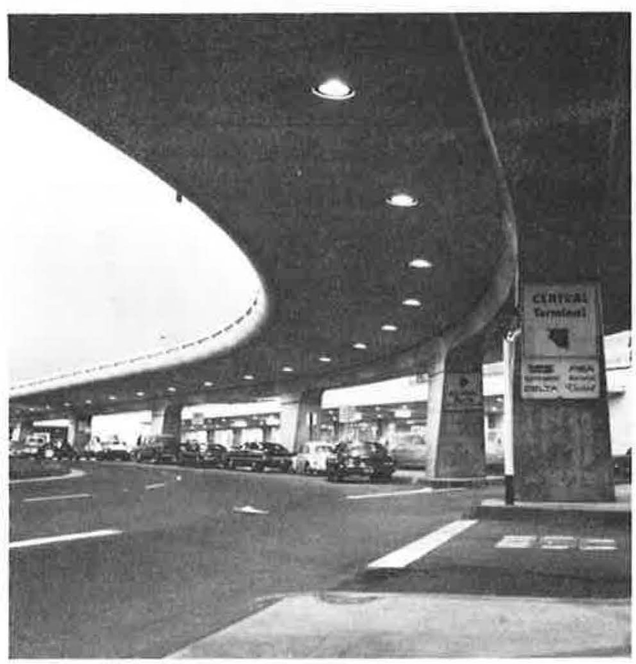
Wing-type segments were used for the San Francisco International Airport elevated roadway (Figure 4) and then again for six intersections in Bogota, Colombia (Figure 5). These wing-shell sections with transverse ribs were precast without match-casting and placed side by side on falsework with a 0.5-in gap in between. Epoxy is not used at the joint. Then in situ concrete is poured over the top to form the deck onto the spinal beam. Posttensioning is applied in the spinal beam to carry the load longitudinally, but the posttensioning forces are transmitted only through the in situ concrete. The wing elements are used to support the loads transversely. This is a very economical segmental construction when using concrete, but its span is probably limited to less than 200 ft. A combination of a steel spinal beam with composite concrete wings perhaps can prove to be a solution for longer spans.

Figure 1. Dumbarton Bridge.

Figure 2. Hegenberger Bridge.

Figure 3. Rio Colorado Bridge.

Figure 4. San Francisco International Airport elevated roadway.



STRUCTURAL SYSTEMS

The third variable in segmental bridge construction lies in the basic structural systems employed. Currently, the balanced double cantilever is the most frequently used system (Figure 6). However, the single cantilever, which has the other end anchored by counterweight, has also been built. In any case, cantilever construction is a natural solution when steel cables are posttensioned along the top of the section. Although this has been used only for concrete construction, it is envisioned that it can be used for steel bridges that incorporate composite concrete decks.

The second predominate type of segmental bridge construction is the cable-stayed bridge. For example, the Pasco-Kennewick Bridge used precast transverse sections in a cable-stayed bridge (Figure 7), while the Kwong Fu Bridge in Taiwan employed precast longitudinal sections (Figure 8). Other segmental bridges of the cable-stayed type could be built with travelers in cantilevering fashion, as was planned for the Ruck-A-Chucky Bridge.

Span-by-span erection seems to be a method for shorter spans. These simple spans can be made partly continuous for live load, such as was done for the Long Key Bridge in Florida (Figure 9).

Another approach is the use of continuous spans by using segmental construction (as was used for the San Francisco Airport elevated roadway). Expansion joints are placed either over the supports or at the point of inflection for every few spans. The Rio Colorado Bridge is an example of a suspension bridge that uses segmental construction for the lower suspended chord, columns, and deck system.

CONSTRUCTION METHOD

The construction method is a prime consideration in both the design and erection of segmental bridges,

Figure 5. Bogota, Colombia, intersection.

Figure 6. Rio Higuamo Bridge, San Pedro de Meloris, Dominican Republic.

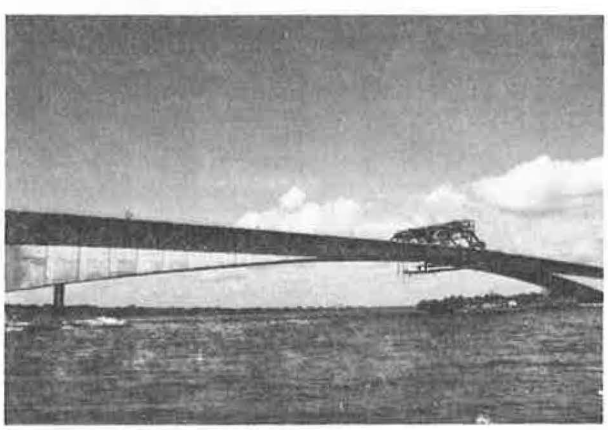


Figure 7. Pasco-Kennewick Bridge.

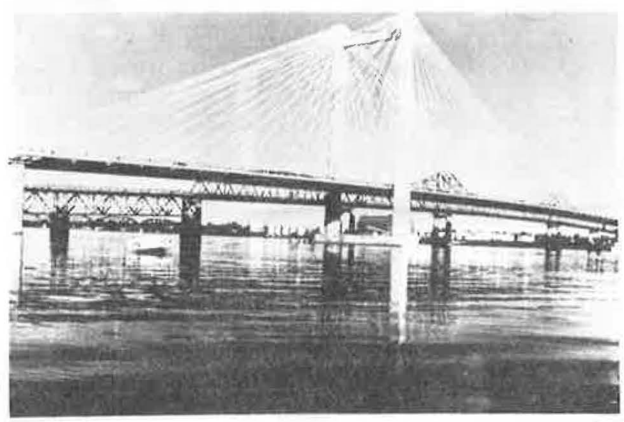
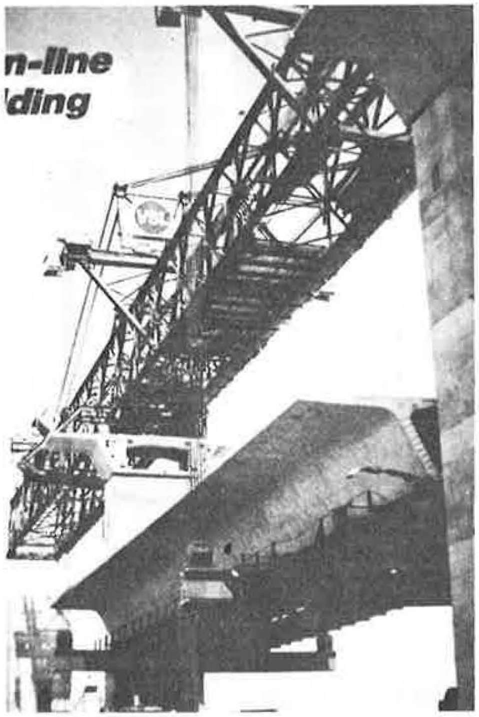


Figure 8. Kwong Fu Bridge.

Figure 9. Long Key Bridge.



particularly when incorporating posttensioning techniques. Speaking in general terms for both steel and concrete bridges as described above, there are essentially four general methods of construction.

The traditional method of construction is the use of falsework supported from the ground. Such falsework may have temporary supports at suitable and close intervals that are spanned with steel girders or trusses to form over traffic openings. The falsework provides a broad work platform that serves as a soffit form. This conventional method, which generally uses pipe scaffolding, can be very economical, especially if the structures are over land and not very high. It can also lead to economical steel erection by providing temporary supports for steel modules until permanent joints can be built.

Cantilevering or double cantilevering, which results in free-span construction, is very appealing and is becoming a popular method of construction. This method is generally used for concrete bridges up to about a 600-ft span but has also been used in certain cases for longer spans. The steel box-girder San Diego-Coronado Bay Bridge was erected by the double-cantilevering method for its 660-ft main span. For cable-stayed construction, both concrete and steel spans can employ cantilever construction.

The incremental-launching method has been used for many bridges in Europe and for at least one bridge in the United States. Although mainly done in concrete, they can also be done in steel. In fact, steel, being a material that can take both tension and compression, would suit itself very well to this method because of the fluctuating static system during construction. As domestic examples, the railroad bridge over the Arkansas River was constructed this way by using steel and the Wabash River Bridge in Indiana was launched by using a prestressed concrete structural system.

A fourth type is the use of launching trusses. Such trusses can be launched forward to provide a support for erecting the superstructure in steel or concrete. After the span is erected, the truss is advanced for the next span. When building over water, the truss can be lowered onto a barge and moved forward to the other spans. Whenever there are many repeated spans, this type of construction can be economical for steel and concrete segments and for precast or cast-in-place segments.

DESIGN OF SEGMENTS

The design of a segmental bridge involves many facets, starting with the layout of the bridge. There is, of course, the classical criterion that the cost of the superstructure and substructure should be proportioned to result in a minimum total cost. Although a designer should economize the substructure and the superstructure each by itself, he or she needs also to think of the two together so that the choice of type of segment or segmental construction may depend of the considerations discussed above.

Whether to use a single or multiple box, I-shape or T-shape, wing or waffle sections, or steel or concrete can be a major decision in the design of a segmental bridge. The location of hinges to relieve shrinkage, creep, and temperature stresses and their effects on maintenance and riding quality are other important considerations.

The posttensioning or cable stressing of steel bridges is of recent interest in reducing the cost of steel bridges. These are being developed for various crossings that range from slightly more than 150 ft and up to 600 ft or more. Some of these cables can be prefabricated, attached to the structural element, and then prestressed in the shop or yard under controlled conditions so that systems construction is applied. The art and technique of posttensioning tendons have now advanced to a high state of perfection when applied to concrete. There is every indication that it can be applied to steel with resulting economy. This is exemplified by the Bonners Ferry Bridge, which is now under final design.

JOINERY AND DETAILS

One important item in segmental construction is the joinery between sections. For steel construction, field joints should be limited to bolting and welding should be limited to the shop. For concrete construction, the use of epoxy has not always been successful. Perhaps wet or poured-in-place joints and other methods could be developed to become more economical, thereby incorporating the advantage of precast construction with the homogeneous quality of cast-in-place construction.

Posttensioning detailing has developed to the extent that numerous types of joinery are available to the designer. The use of posttensioning detailing in concrete construction is well known and, recently, the use of tendons and anchorages in steel construction has proved to be equally applicable.

Joints in steel segmental construction are usually made to provide continuity between the segments, thus allowing the use of specially designed segments that can be fabricated, transported, and lifted economically. Joints made in the field are made predominately with A325 high-strength bolts, but A490 bolts, which are of higher strength than the A325 bolts, offer potential savings because fewer bolts are required. At times, field joints are welded but are usually more expensive than bolted field joints because edge fit-up requires tight dimensional tolerances, the welding process demands close controls, and inspection is more difficult to perform outside of a shop environment.

The trend in steel segmental construction is to design continuous multiple spans that have few expansion joints in the deck. Continuous spans of more than 1000 ft are possible with only one joint at each end. Thermal movements at piers can be accommodated by using laminated neoprene pads for relatively short distances and confined neoprene in a "pot" bearing with teflon sliding surfaces for longer distances. The pot bearing offers an economical and compact way of transmitting medium to large loads to the substructure and also can be fixed to the piers to resist lateral forces. Thus, joints can be located to optimize the performance of the structure.

AESTHETICS

From an aesthetic point of view, segmental structures should be designed to possess a certain simplicity and elegance to fit well into the environment. In his or her quest for economy, the designer should not neglect the aesthetic appearance of the bridge. Segmental construction lends itself to repetitive modules placed in uniform configuration. This can produce a beauty of its own, such as the wing-type segment of the San Francisco Airport. But if care and concern for aesthetics are not exercised, it can produce a stiff rectangular post-and-lintel appearance. It behooves designers to be aware of the aesthetic limitations of segmental construction and consider carefully the details as well as the overall appearance of the structure. Some of the details of design that should be considered for their appearance are joints between segments, junction of piers and superstructure, mating of railing to deck, junction of superstructure to the abutments, and the sitting of the abutments into its surroundings.

The overall appearance should be checked for a smooth rising and falling grade line from abutment to abutment. A sagging or inch-worn effect may cost less but detracts so much from the appearance of the finished structure that it should never be used. Likewise, in the plan, the bridge should be straight or curved in one direction only. A double curve S-shape can be used if well proportioned. But a bridge that irregularly deviates from one point to another is very displeasing and should be avoided. Occasionally, the inside curve of superelevation transition will dip, thereby producing the appearance of a sag in the bridge that has irregular layouts.

ECONOMICS

Economics is often the central issue in segmental bridge design and construction. To reach an optimum solution, design must be tied in with construction. Items to be considered in segmental construction are source of material, method of fabrication, and location of the fabrication yard; mode of production; transportation; storage areas; and erection systems. Contractors who wish to bid competetively must have a design that considers all items. Competitive bidding often can be enhanced by preparing two comparative designs of different materials, type of segments, or, in some cases, structural systems.

Some segment systems are of such recent development that there is no measure for long-term performance. It would be difficult to arrive at a life-cycle cost comparison between alternative designs, and therefore it is not presented here. With our current knowledge of material durability, corrosion processes, fatigue and fracture mechanics, and the performance of bridge systems already built, it is possible to make an engineering projection of how these segmental designs will hold up. Of course, we are continuing to learn in these areas, and every case of distress adds to our knowledge. However, the long-term performance promises to be as good as or better than previous conventional construction. It is somewhat reassuring that economic comparison based on competitive bidding is currently our best approach.

Deck sections are usually integrated into the fabrication of some types of segments, such as the box and wing sections. Precast and prestressed deck sections placed on longitudinal systems (such as steel and concrete I-girders) have recently been used to advantage. Perhaps more attention will be devoted in the future to segmental deck construction. New innovations are being devised to lower costs of construction for other types of segmental construction.

Good management techniques by the owner are as important as good design and are a major factor to help achieve total economy. The management function involves decisions on the best approach for items such as method of bidding, controlling specifications, design alternatives, value engineering, construction management, time for construction, fast tracking, and other items that may affect the biddings.

A design and construction turnkey package, which is prevalent in Europe, has not been used to any extent in the United States. It may offer an economic advantage to segmental bridge construction. A construction management team that monitors and schedules construction is now being used for the construction of buildings. However, it has not been used to any extent on bridges. This could become an advantage as inflationary trends demand shorter construction time to avoid extra cost, particularly on large jobs constructed over a long period of time. Also, designs held on the shelf until money becomes available will have a greater cost than when first proposed.

CONCLUSION

It can be observed that segmental construction is fairly well developed, but improvements can always be made. Recent studies carried out on the standardization of box segmental construction indicate that standardization of segmental units can lead to economy just as standardization of I-girders has in the past. Most important is the recent development of steel segmental construction. Because steel is lighter and easier to lift, it can fit into much longer segments that require fewer joints, which opens up interesting possibilities. Further use of posttensioning has, in effect, reduced the required steel quantity, thereby allowing for an optimum and economical structure. Thus, the use of segmental construction in both concrete and steel bridges has developed in many different directions and will progress to newer developments as the future unfolds.

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