7. Design that uses prefabricated forms if possible; and
8. Use of specifications and specialized materials that can result in time savings and improve the quality of construction (e.g., superplasticizers that help reduce water content and simplify placement and finishing of concrete).

Scheduling of Construction Operations

The systems concept of optimization is widely used in the scheduling of operations in cast-in-place concrete construction. Objectives in the use of optimization techniques are reduction of on-site labor, materials, and equipment costs, as well as savings in overall construction time.

Construction scheduling essentially consists of arranging several construction operations in such a sequence that the project is completed in the least possible time while using the available resources in the best possible way. Incorporated in such a schedule is a thorough understanding and knowledge of how long each construction operation would take; lead-time requirements for labor, materials, and equipment; time required to prepare and obtain approvals of shop drawings; and subsequent delivery of materials. Extensive use of the critical path method (CPM) and the program evaluation and review technique (PERT) of similar methods is currently being made for scheduling construction of cast-in-place superstructures.

Applications to Superstructure Rehabilitation

Use of systems concepts in cast-in-place concrete superstructure rehabilitation has currently been somewhat limited. Precast concrete form panels, corrugated-metal deck forms, and slipforming are commonly being used to accomplish reduction in time and costs related to falsework and formwork. Construction scheduling is the other area where systems concepts are effectively employed.

CONCLUSION

This paper has reviewed the current practices in system construction and rehabilitation of precast and cast-in-place concrete superstructures. On the basis of this review, the following conclusions can be made:

1. Use of standardized sections has been effective in reducing on-site construction labor costs and time while providing reliable measures of strict quality control. Current trends indicate future innovations in standardized sections to further reduce on-site labor costs and time.
2. Use of standardized techniques has made a simplified application of sophisticated techniques feasible and practical.
3. Use of standardized procedures has ensured optimal use of on-site labor, equipment, and materials.
4. Innovative use of systems concepts to rehabilitation of concrete superstructures is becoming more common. It has effected very valuable savings in construction time as well as traffic-detour-related and other costs, especially in urban areas.

REFERENCES

1. C.A. Ballinger, W. Poldony, Jr., and M.J. Abrahamson. A Report on the Design and Construction of Segmental Prestressed Concrete Bridges in Western Europe, 1977. FHWA, U.S. Department of Transportation, 1978.
2. G.H. Brameld. Segmental and Stage Construction of Prestressed Concrete Box-Girder Bridges. TRB, Transportation Research Record 665, 1978, pp. 192-199.
3. B.E. Diaz. The Technique of Glueing Precast Elements of the Rio-Niteroi Bridge. Material in Construction, Vol. 8, 1975, pp. 43-50.
4. Systems Building for Bridges. HRB, Special Rept. 132, 1971.
5. M.K. Hurd. Denny Creek Bridge: A Concrete Answer to Environmental Challenges. Concrete International, Nov. 1980, pp. 16-24.
6. M.M. Sprinkle. Systems Construction Techniques for Short-Span Concrete Bridges. TRB, Transportation Research Record 665, 1978, pp. 222-227.
7. R. Tokerud. Economical Structures for Low-Volume Roads. TRB, Transportation Research Record 665, 1978, pp. 214-221.

Publication of this paper sponsored by Committee on General Structures and Committee on Construction of Bridges and Structures.

System Construction of Medium-Span Bridges in Prestressed Concrete

MAN-CHUNG TANG

The system-construction method has been applied widely in the construction of medium-span bridges in the United States in recent years. The advantage of achieving efficiency through repetition of work becomes obvious. The most commonly used schemes are put into four groups: incremental launching, cantilevering, span by span, and stage construction. Both precast and cast-in-place applications are discussed.

Medium-span prestressed concrete bridges have undergone significant development in North America in the past decade. The developments can be grouped in three areas: (a) code modifications, (b) more advanced methods of analysis, and (c) innovative construction techniques.

There have been many changes and modifications in the design codes to accommodate and facilitate the use of modern prestressed concrete. They encouraged transverse posttensioning and eliminated costly intermediate diaphragms for box girders. Many codes also provide a more realistic assessment of prestressed losses and the time-dependent behavior of concrete.

More clearly defined and simpler methods of anal-

Figure 1. Schematic sequence of incremental launching of box girders.

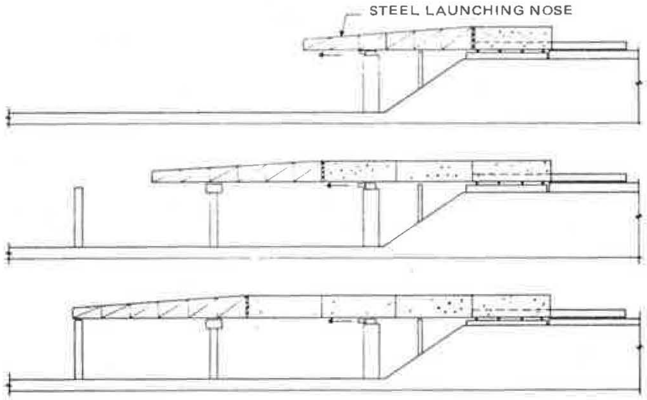


Figure 2. Incremental launching.

ysis are now available. More sophisticated computer programs have made it possible to analyze bridges that have complicated configurations and construction stages.

Many cast-in-place and precast methods have achieved further development to make them suitable for medium-span bridges. Besides classical cantilever construction, bridges have been built by span-by-span segmental construction, with overhead or underrunning trusses, by stage construction, by incremental launching, and by many other techniques.

GENERAL

Many new and efficient construction methods have been introduced to the U.S. building industry over the past decade for the construction of concrete bridges. Besides the cantilever method, which has made possible the construction of large spans such as the 790-ft Koror Bridge and the 640-ft Perrotts Ferry Bridge, other construction techniques for medium-span concrete bridges have been used very successfully. These new techniques have made construction of concrete bridges more efficient and, consequently, more competitive.

This paper reports only on those construction methods that are suitable for medium-span lengths, i.e., 120-350 ft. It also includes those methods that have not been used in the United States but have been applied successfully elsewhere in the world. In most cases, the efficiency is a product of repetition, i.e., system construction.

INCREMENTAL LAUNCHING

Although incremental launching was developed more than a decade ago, this method had been applied only once in the United States. This method was used on the Warren County Bridge in Indiana.

The principle of incremental launching is quite simple. It involves using a stationary casting bed at one end of the bridge. The girder is cast in segments of between 30 and 80 ft in length. After each segment has been cast and posttensioned, the girder is pushed out from the casting bed incrementally. To facilitate launching, or the pushing operation, sliding blocks are installed on top of the piers. These sliding blocks have a stainless-steel skin. Teflon-coated pads are fitted in between the girder soffit, and the sliding blocks thus reduce friction to as low as 1.5-2 percent of the vertical reaction. A launching nose, usually made of steel, is attached to the leading edge of the bridge girder to reduce the cantilever bending moment (Figures 1 and 2).

Depending on the size of the segments, each stage of construction can be completed in a oneto two-week cycle. For small bridge girders, the segments may be cast in one operation. For large bridge girders, the usual procedure is to cast the bottom slab first and then the webs and top slab in a second casting operation. Thus, the length of the casting bed is equal to the length of two segments, so that the bottom slab will be cast at the end of the casting bed simultaneously with the casting of the webs and top slab of the previous segment. This system is especially advantageous for union labor in the United States, where the work of various trades may not be interchanged; therefore, having two working locations can accommodate the even distribution of the labor forces.

The advantage of this method is that the casting bed, which is sometimes called the factory, is stationary. The major part of the work force is employed in repetitive work every working cycle and in the same location. In addition, the logistics of material transportation and accessibility is greatly simplified. One major drawback with this method occurs during the launching operation. Usually, the launching of each segment will last only about 3 h. However, one worker is required to be at each location where a sliding support is used. This will require additional workers, who are all needed at the same time, for a short period during the launching operation.

Because the bridge is cast at one end and advanced until it reaches the opposite abutment, certain geometric restrictions exist. Generally, only straight bridges or bridges with uniform curvature (a circular arc in either the horizontal or vertical direction) can be built by this method. This is not a serious restriction for a bridge structure. However, this method has to be incorporated into the design before the geometry of the bridge has been established. Because this construction method poses these restrictions in the geometry of the bridge, many highway engineers will not attempt to accommodate such a geometric layout. If the bridge is on a nonuniform curve, this construction method cannot be used. This is probably the major reason this method has not been used more widely in the United States.

SPAN-BY-SPAN CONSTRUCTION

In lieu of a stationary casting bed or factory at the abutment from where the bridge girder is sequen-

tially pushed from one abutment to the other, it is also possible to build the bridge span by span by using a casting factory that can span from pier to pier and cast the bridge girder either in segments within a span or cast a span in a single operation. There are many alternatives to this type of construction.

Elz Valley System

The Elz Valley system was first applied to the construction of the Elz Valley Bridge in West Germany (Figure 3). Although the early bridges built this way usually had spans of about 120 ft, it is possible to build this type of bridge with spans up to 200 ft. This construction method employs a steel form carriage that is one span in length and is designed to support the weight of the total span. The form carriage has a launching nose that can be used to move the carriage from span to span or, more correctly, from pier to pier. Instead of building spans from pier to pier with construction joints close to the piers, it is more economical to locate the construction joints at inflection points or, usually, just at the fifth point of the span. Expansion joints can also be located at these construction joints if they are required. Construction of the superstructure can be accomplished without interfering with ground traffic or navigation. It is, therefore, very suitable for high-level bridges where material supply from below is difficult or costly. Because the superstructure is continuously built from one end to the other, construction material can be supplied across the completed deck to the span under construction.

There are variations of this system. Instead of using a complete carriage as one unit, separate underdeck trusses have been found very economical (Figure 4). These are trusses that span from pier to pier and can also be moved forward.

Although this construction method was originally developed for solid girder bridges and for mushroom-type (variable-depth slab) superstructures, it has been applied to box girders in recent years (Figure 5). The result has been quite successful. The construction time for each span usually takes between two to three weeks after the crew has acquainted themselves with the construction method. For bridges that have longer spans or wider decks, the segments can be reduced to 50- to 70-ft lengths. This is economical, especially if the total length of the bridge is not great and, by subdividing the span into smaller segments, the required formwork will be less and the form will be used over a larger area, thereby reducing costs.

Figure 3. Elz Valley method.

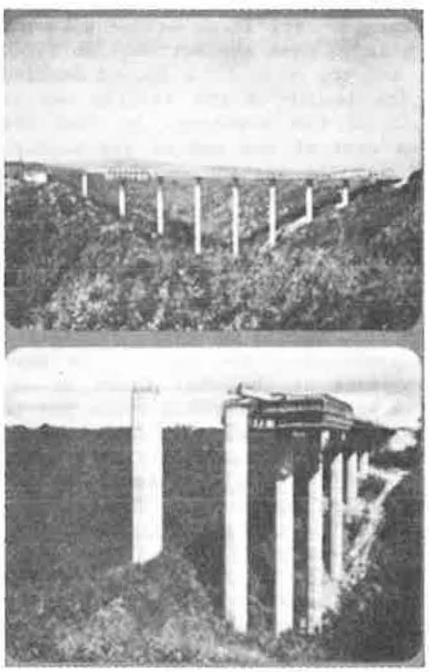
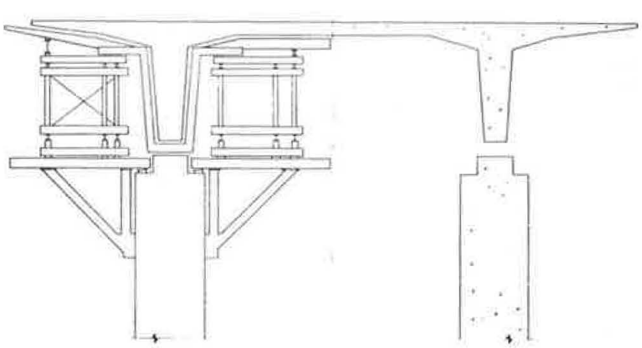


Figure 4. Span-by-span T-girder construction with below-deck erection trusses.



Eel River Method

If the total length of the bridge is not long and the investment in a span-by-span form carriage is not economically warranted, it is possible to use a variation of this span-by-span method, as in the case of the Eel River Bridge (Figure 6). The principle is the same as the Elz Valley method except, instead of a form carriage, falsework will be used

Figure 5. Span-by-span box-girder construction with below-deck erection trusses.

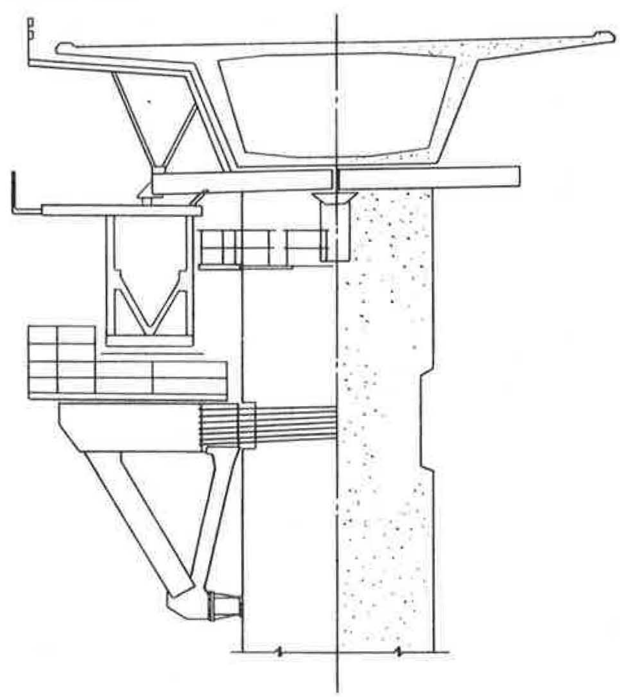


Figure 6. Eel River Bridge.

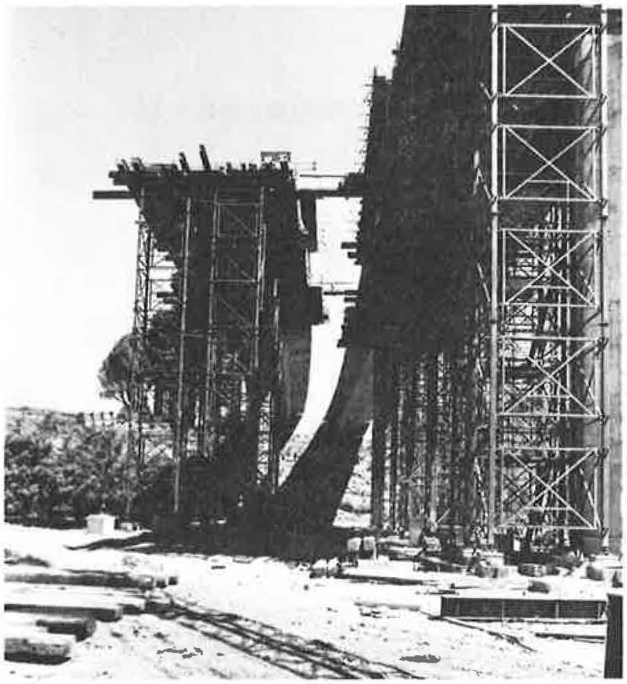
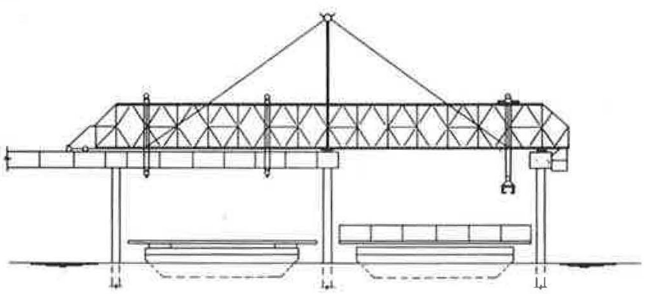


Figure 7. Seven Mile Bridge: span-by-span (over water) precast concrete box-girder construction with overhead trusses.



that is supported from the ground and provides a platform for the formwork of the superstructure. The falsework is about one span long, which is similar to the length of the form carriage. The bridge superstructure can then be divided into smaller segments (about 40 ft), as in the case of the Eel River Bridge. The formwork can be slid on top of the falsework platform. After each segment is completed, these forms can be simply lowered and slid into position for the next segment in a matter of 1-2 h. Again, due to the repetitious cycling of the work, the labor force becomes very efficient after a few cycles of operation.

Long Key Method

Precast segments were used in the construction of the Long Key Bridge, which is about 12 000 ft long and has typical spans of 118 ft. A steel truss is used to support the precast segments. These segments are transported to the job site from the precasting yard and then assembled on the steel truss. The completed span is then posttensioned together, and the steel truss is lowered and moved forward to the next span.

A variation of this method was used for the construction of the Seven Mile Bridge in Florida (Figure 7). This bridge has a total length of about 35 900 ft and typical spans of 135 ft. The segments are transported by barge to the bridge site and assembled on a barge-mounted truss. This barge is then placed between the piers. The pier segment is erected separately by means of an overhead truss. After the erection of the pier segment, the overhead truss is then used to raise the whole span. A closure pour is then made between the new span and the previous span while the new segments are supported by the overhead truss. The superstructure is then posttensioned after the closure-pour concrete has gained sufficient strength. The newly erected span is self-supporting after posttensioning; the supporting truss is then released and the cycle is repeated at the next span.

Two features have made this method very efficient. The first is the use of dry joints between the precast segments, i.e., without epoxy or any other bonding agent. This allows for easy assembly of the segments on the truss because, without any bonding agent between the joints, the segments are not sus- ceptible to deformations of the truss. The second feature is the use of internal-suspension-type ten- dons. These tendons are not bonded to the concrete structure but only suspended at the high point at the piers and the low point at locations inside the box girder. They are protected by grouting the plastic conduits for the tendons. These internal tendons will eliminate some tolerance problems in duct alignment that occur when tendons are embedded in the concrete section. When using a very high early-strength concrete for the closure pour, this erection method has achieved a construction speed of one span per day.

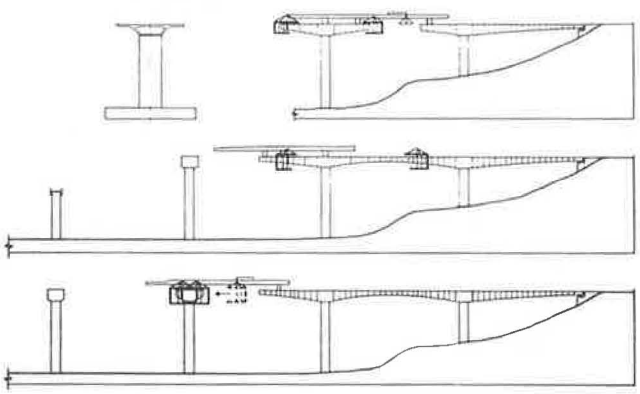
CANTILEVER CONSTRUCTION

For medium-span bridges, cantilever construction can be competitive by using overhead trusses or erection cranes. If an overhead launching truss is used, the bridge is usually constructed in a balanced-cantilever pattern from atop the piers and proceeds in one direction to the completion of the bridge. The truss will span from the finished part of the bridge to the next pier where the new cantilevers are to be started. Precast segments are transported to the end of the truss. The hoisting equipment at the truss will pick up this segment and transfer it across the open span to the ends of the cantilever, where it is tied to the previously erected segments by posttensioning. A closure pour will then be made in the middle of the following span. The launching truss is then advanced after the concrete at the closure pour has attained sufficient strength and posttensioning of the continuity tendons in completed. It is also possible to connect the cantilevers at the closure joint by means of local steel clamps so that the launching truss may be moved to the next span without having to wait until the closure pour is completed. However, certain precautions are necessary to avoid disturbance of the concrete closure pour when the concrete is still young. The first cantilever bridge in the United States that used an overhead truss is the Kishwaukee Bridge (Figure 8).

This method can also be used for cast-in-place cantilevers (Figure 9). The first use of this method was at the Siegtal Bridge in Germany. Instead of transporting the precast segments, the overhead truss is used to transfer form travelers from one pier to the next pier. It also serves as a walkway for personnel and for the transportation of construction materials.

Figure 8. Kishwaukee River Bridge: cantilever with overhead truss.

Figure 9. Cantilever construction method with launching truss.



Two recent applications of this concept are the Vejle Fjord Bridge (Figure 10) in Denmark, which used cast-in-place construction, and the St. Catharine's Bridge in Canada, which used precast segments.

For the construction of the Linn Cove Bridge in North Carolina, another variation occurs. In order to avoid disturbing the local environment, no access roads are allowed to the intermediate piers. A stiffleg is used to reach to the next support from the finished portion of the bridge. A stiffleg crane is used to erect segments from the advancing edge of the bridge. Temporary supports are provided at the midspan so that the superstructure will cantilever only half of the span each time to the next pier. A closure pour is provided in each span to eliminate any tolerance problem within this span.

STAGE CONSTRUCTION

Stage construction is similar to span-by-span construction, except that the cross section of the bridge is subdivided into longitudinal slices.

One example of this type of construction is the Denny Creek Bridge in the State of Washington (Figure 11). The cross section of this bridge is subdivided into three parts. The first is a U-shaped section that consists of the bottom slab and the two webs. The second is the top slab between the webs, and the third part is the cantilever slab at both sides of the cross section. The first and second parts are cast in lengths of one span, while the third part of the cross section can be divided again into two or more segments per span.

Figure 10. Vejle Fjord Bridge.

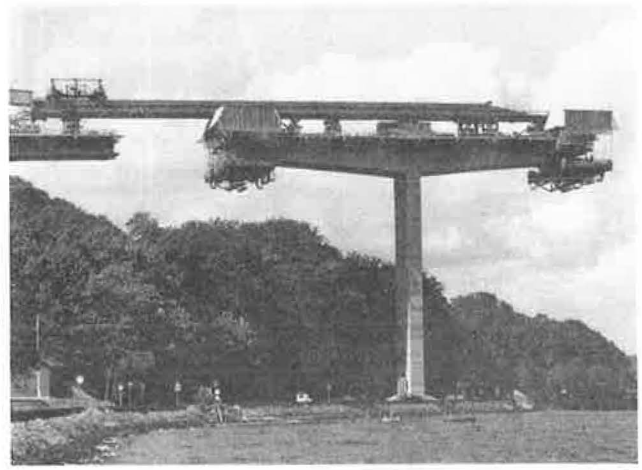
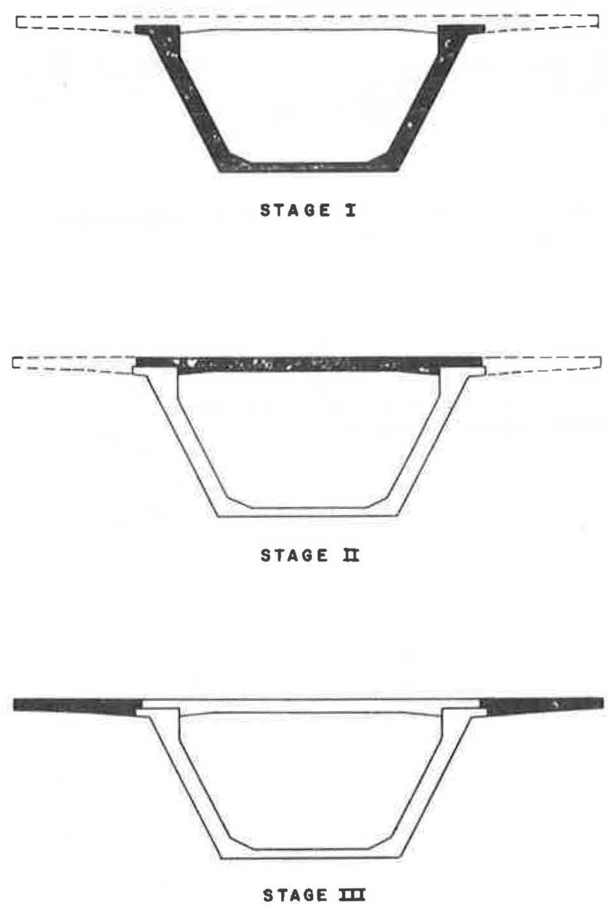


Figure 11. Span-by-span stage construction method (Denny Creek).



The bridge is designed in such a way that the first portion is cast by means of a launching truss supported by the piers, which is very similar to the span-by-span construction described previously. This U-shaped girder, after posttensioning, is self-supporting. It is also strong enough to support additional formwork for the middle part of the top slab plus the weight of the top slab. After the U-shaped girder is posttensioned, the supporting

Figure 12. Cantilever and stage construction combination (Kochertal Bridge).

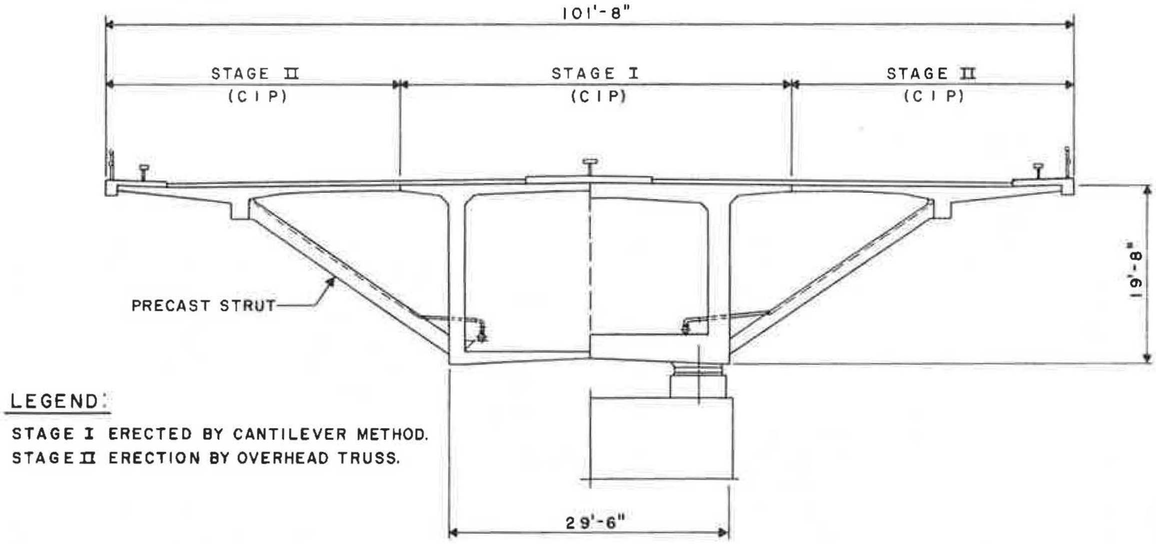
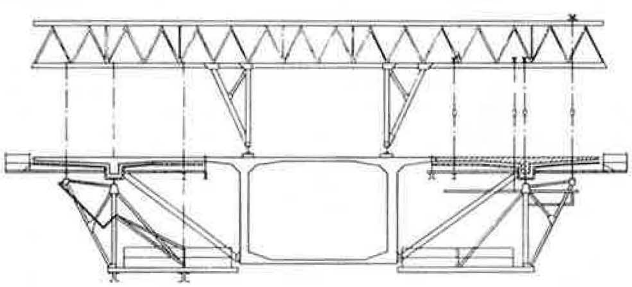


Figure 13. Cantilever and stage construction combination for casting wing slabs (phase 2).



truss can be moved ahead for the construction of the next span. The third portion of the cross section, the wing slabs, are cast by using formwork supported by an afterrunner.

The advantage of this system is that the supporting truss that spans from pier to pier carries only the weight of the U-shaped girder, whereas with span-by-span construction the truss has to carry the total weight of the girder. The savings in the weight of the truss are manifold. Moreover, this method allows the construction work to be spread out into three separate stages; therefore, cycling of the labor force is more efficiently distributed.

Similar methods have been applied to other bridges in Europe. One method employs an underslung truss to support the total weight of the span but, during construction, it is separated into two stages: first, the bottom slab and a small part of the web, then, in a second stage, the remainder of the webs and the top slab in one piece. It is reported that an average two-week cycle was quickly achieved.

By using precast girders, span by span with cast-in-place top slabs could also be defined as stage construction. This is a very common construction method for shorter spans. However, by using box-shaped girders similar to the construction of the Dumbarton Bridge in San Francisco, the span of the bridge can be extended to 150-160 ft.

A combination method uses precast girders that have relatively smooth top surfaces erected on hammerhead piers. The top slab is cast by a stationary form at one end of the bridge and then pushed out segmentally, which is similar to the incremental-launching method. The top slab can then be connected either by shear studs that are cast into preformed holes in the slab or by welding together steel plates that are separately cast in the girder and the top slab, respectively. Depending on the size and geometry of the bridge, this combination method can be competitive. Other combinations, such as that of the Kochertal Bridge (Figures 12 and 13), can also be very efficient.

SUMMARY

The purpose of system construction is to apply the principle of mass production to achieve efficiency and economy by the cycling of repetitive operations. Standard American Association of State Highway and Transportation Officials (AASHTO) girders have been used widely in the United States. Post-tensioning has provided bridge engineers another excellent tool in developing new construction techniques. It is very encouraging to see that many contractors are receptive to this type of construction. As a matter of fact, many contractors have even developed some new construction ideas to achieve efficiency and economy by themselves.

Unlike long-span concrete bridges, which up to now could only be built practically by free cantilevering or cable-stayed free-cantilever methods, medium-span bridges can be built in a wide variety of ways. The various alternatives grouped under the subtitles of incremental launching, span by span, cantilevering, and stage construction are some basic examples of how those bridges can be built. With imagination, many more variations on these systems can be created.

Publication of this paper sponsored by Committee on Construction of Bridges and Structures.