Current Practices in Systems Construction of Concrete Bridge Structures

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The current practices in systems construction of precast and cast-in-place concrete superstructures are reviewed. The paper covers a wide range of bridges from shorter single-span to longer multispan bridges. It discusses currently used standard sections, their economic and operational efficiencies, as well as their limitations. It describes effective use of systems techniques that can optimize costs related to formwork, on- or off-site labor, materials, equipment, time, transportation, and traffic detours. Systems techniques that can make superstructure rehabilitation alternatives for deficient bridges economically feasible are also given.

The construction practices for concrete bridge superstructures have undergone very significant and innovative changes during the past 20 years. The major thrust of these changes has been toward systems construction in order to accomplish overall savings of time and money while maintaining or improving the quality of construction.

Systems construction can be described as a clearly defined and well-coordinated sequence of construction activities to accomplish economically and operationally efficient construction. Applications of systems concepts to the construction of concrete bridge superstructures has resulted in the development of standardized sections, techniques, and procedures in precast as well as in cast-in-place concrete superstructures. The standardized sections include single, double, bulb, and quad tees; flat or voided-slab and rib-deck panels; single or multicell box girders; precast arch segments; and precast railings. Standardized techniques of methods include use of standardized sections in the construction of continuous spans, form-traveler, balanced cantilever, launching girder, incremental launching, and optimal scheduling. Standard procedures include standardization in design, specifications, and details; multiple-use forms; use of precast concrete or corrugated steel stay-in-place forms; and slip forming. Current practices in the systems construction of concrete bridge superstructures are discussed in the following sequence: basic systems concepts, precast concrete superstructures, and cast-in-place concrete superstructures.

BASIC SYSTEMS CONCEPTS

Basic systems concepts currently used in the construction of concrete bridge superstructures are discussed below.

Standardization

Standardization can be defined as a process of bringing repeatedly used similar components, steps, and operations into conformity with substantially uniform and well-established components, methods, procedures, or techniques. Use of standardization is beneficial when a number of dimensionally similar sections, details, or repeated construction operations are involved. Resulting benefits are stricter quality control, increased speed of construction, and reduced overall on-site labor, material, and equipment costs.

Use of standardization is limited to situations that have a large number of similar operations or sections of similar geometry. Other limitations include location-related constraints; availability of required skilled labor, materials, and equipment; as well as reduced flexibility in design. In certain situations, environmental, aesthetical, and other considerations may also limit the usable standardization options.

Optimization

Optimization can be defined as a process of organizing a group of interrelated components, activities, or operations into a system that is as economically and/or operationally efficient as possible. It provides the best compromise solution in terms of use of available resources and yields the best overall benefit/cost ratio possible.

The concept of optimization is being used widely in construction scheduling. Construction scheduling essentially consists of arranging the construction operations in such a sequence that the project is completed with optimal use of available resources and in the least amount of time. Frequent revision of schedules during construction keeps them current and facilitates prompt corrective actions.

PRECAST CONCRETE SUPERSTRUCTURES

Standardized Sections

Figure 1 shows the different types of currently used standard precast concrete sections. It also indicates the ranges of section depths, widths, span lengths, weights, and current costs. Precast concrete sections such as these are very widely used and have proved to be very competitive with rolled and built-up structural steel sections. Many states and fabricators have developed their own standard sections and have promoted their use. This has resulted in cheaper superstructure components and total bridge systems that require minimum material and on-site labor.

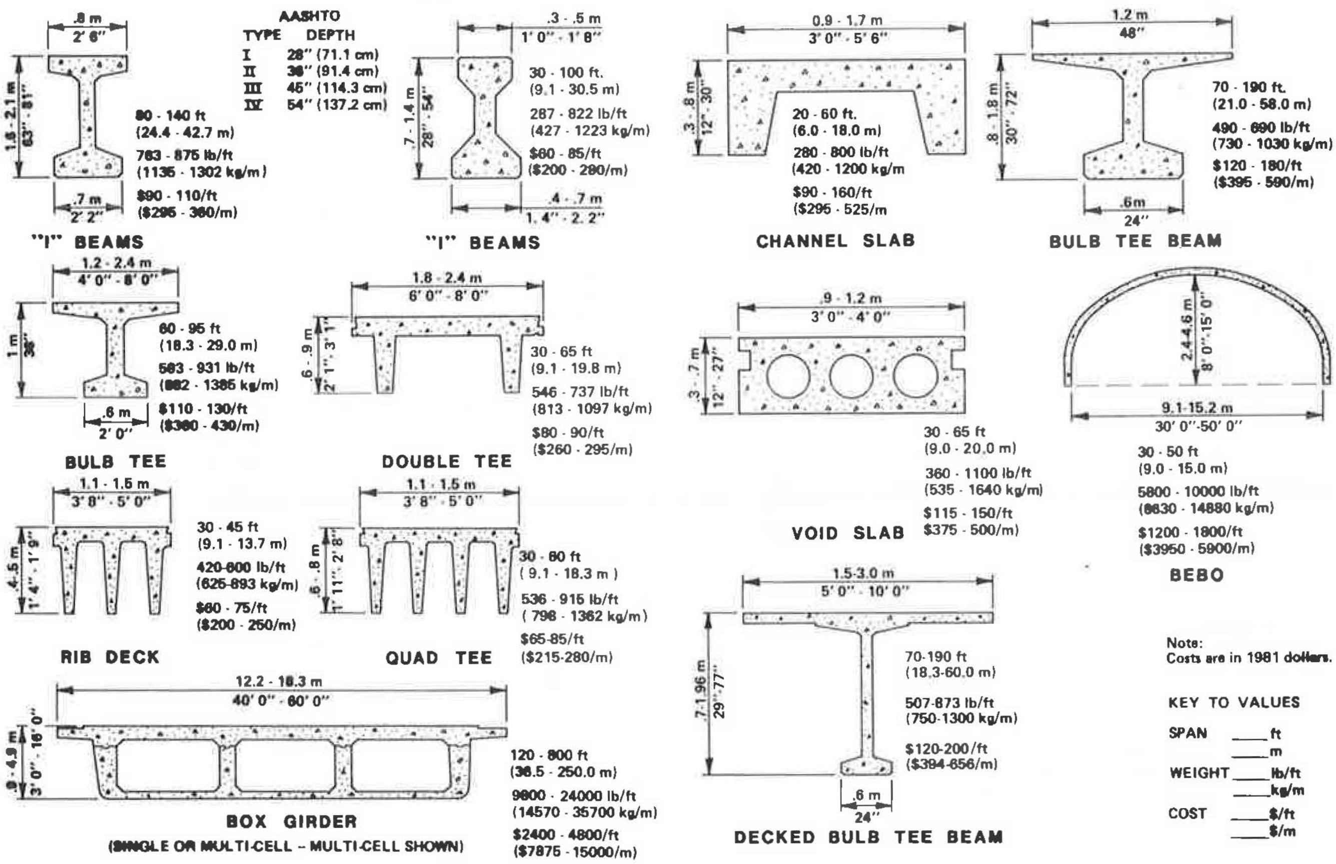
Use of standard sections has proved to be economically and operationally efficient where precast concrete plants are in the proximity and transportation as well as erection equipment are available at a reasonable cost. Current trends indicate increasing applications of segmental construction technology in the construction of precast concrete superstructures.

Standardized Techniques and Procedures

Standardized techniques and procedures that are currently used for the construction of precast concrete bridge superstructures include segmental construction, progressive placing, cable-stayed spans, and Benton Bogen (BEBO) concrete arch.

Segmental construction (1) is a construction that is put together segment by segment, then erected, glued together with epoxy, and finally posttensioned. Segmental posttensioned box-girder bridges, which originated in Europe, are being constructed in the United States in increasing numbers. Maximum spans in excess of 750 ft (230 m) (2,3) have been attained by using this technique. In a balanced-cantilever segmental system, construction proceeds by cantilevering segments from a pier in a balanced

Figure 1. Currently used standard precast concrete sections.



fashion on each side until midspan is reached from both sides, and then a closure section is poured. This procedure is repeated until the entire structure is completed. Where symmetrical sections cannot be erected simultaneously, a temporary bracing or falsework is necessary. Span lengths to 300 ft (92 m) have been common. Segmental technology offers the benefits of all seasons and, therefore, shorter-duration construction; partial or total elimination of falsework requirements; greater spans; and aesthetically pleasing, slender structures. One recent example of this type of construction is the Kishwaukee Bridge in Rockford, Illinois.

Progressive placing (1) consists of placing precast concrete sections cantilevered out progressively from a pier or abutment in a continuous manner from one abutment to the other. This method appears to be practical in span ranges from 100 to 160 ft (30-35 m), where the balanced-cantilever method is generally not economical. This system has the obvious limitation of cantilever stresses becoming excessive in relation to construction depth, and a temporary stay may be required.

The cable-stayed system uses temporary cables anchored to a prestressed concrete beam at the top of the tower bent to place the traveler and deck segment during erection. Additional temporary fore and back stays, which stretch long distances, support the bent during deck construction. Before the traveler is advanced for the next section, two prefabricated permanent stays are attached. Sliding hangers haul the stays up a guide cable to steel anchorages atop the tower columns. Once stays are positioned at the tower head, the lower ends of the cables are jacked into anchorages in the deck segments. Placed on opposite sides of a section, both stays are stressed simultaneously as the erection cables are eased. Spans of more than 1000 ft (305 m) have been constructed by using this method. This method is particularly suitable where the height of the structure precludes the use of lifting cranes from barges. The cable-stayed design has proved to be structurally more efficient and economical than a cantilever steel truss for spans between 600 and 1800 ft (183 and 549 m). The 981-ft (229-m) main-span Pasco-Kennewick Bridge in the State of Washington (a recent example of this technique) was estimated to cost $110/ft^2 ($1184/m^2) against $150/ft^2 ($1614/m^2) for steel.

The BEBO precast concrete arch uses counterarch deformation action of passive earth pressures to balance arch deformations. Precast concrete BEBO arch spans up to 60 ft (18 m) have been successfully constructed. A recent project in Edina, Minnesota, is an example of this technique.

These and other standardized techniques and procedures (4) for precast concrete superstructure construction offer many advantages. They include the following:

1. Considerable savings in construction costs and time,
2. Drastic reduction or total elimination of the need for falsework,
3. Reduction or elimination of problems related to concrete shrinkage,
4. Factory casting conditions allow better quality control and higher-strength concrete, and
5. Longer and more slender-looking spans (at lower costs) have become possible.

There are also limitations of these techniques and procedures. They include the following:

1. Need for heavy site-lifting equipment, such as cranes and gantries;
2. Need for close proximity of precasting plant to be cost effective;
3. Difficulties in maintaining control of horizontal and vertical alignment;
4. Trucks used to transport precast concrete sections are subject to load restrictions along their routes; and
5. Depending on the technique used, fabrication of special launching girders, trusses, or gantries is expensive (e.g., $900 000 launching truss fabricated for the $11.4 million Denny Creek Bridge in the State of Washington) (5).

Applications for Superstructure Rehabilitation

Use of precast concrete technology in partial or total rehabilitation of concrete bridge superstructures has become increasingly common in recent years. Plain or voided precast concrete deck modules, railing sections, and even precast concrete superstructures (complete with curb, sidewalk, and railings) are currently being used (6).

The precast deck modules being used have been basically nonstandard items than have dimensions that suit individual rehabilitation projects. These range from 5 to 8 in (12-20 cm) in thickness, 4 to 8 ft (1.25-2.5 m) in width, and up to 30 ft (9 m) in length. Mobile truck cranes that have lifting capacities of 10-15 tons (9.1-13.6 Mg) can generally handle the erection and placement of these modules. Precast modules are then fastened together by means of welded, epoxy, and/or cement-grouted connections. Where placement is to be over steel beams, modules are epoxy-glued to the top flanges and further attached by stud connectors and grout.

Types of precast railings commonly used are AASHTO Type J, which weigh about 400 lb/ft (600 kg/m) and typically cost from $25 to $35/ft ($82-$115/m). The precast concrete superstructures (complete with curb, sidewalk, and railings) are nonstandard and much heavier sections, which pose erection and placement difficulties.

The economic and operational efficiencies of using precast technology in superstructure rehabilitation have been quite significant. In addition to better quality construction, it can result in substantial reduction in time required for on-site rehabilitation work, often with portions of the structure under heavy urban traffic. With traffic-detour-related costs soaring high and with the energy crunch, current trends indicate increasing future use of precast concrete in superstructure rehabilitation.

CAST-IN-PLACE CONCRETE SUPERSTRUCTURES

Current practices in the construction of concrete superstructures indicate that, for the short to medium single-span range [20-130 ft (6-40 m)], cast-in-place concrete, for the most part, is being replaced by precast concrete systems. However, cast-in-place concrete systems are being used for multiple spans with continuous design and bridges with curves and flares (7). Innovative techniques in design and construction of cast-in-place structures are being developed to overcome the obvious disadvantages of greater on-site labor and construction time for falsework, forms, rebar placement, as well as placement and finishing of concrete. These innovations have been in terms of standardized construction techniques and procedures; standardization in design, specifications, and details; and scheduling of construction operations.

Standardized Techniques and Procedures

Standardized techniques and procedures that are currently used in the construction of cast-in-place concrete superstructures include the following: balance cantilever, span by span, and incremental launching.

The balanced-cantilever technique (1), although basically similar to the one used in the precast system, uses movable formwork supported from a previously erected segment or form-traveler, while the segment is formed, cast, and stressed. The Pasco-Kennewick Bridge in the State of Washington was constructed with this technique. Span lengths up to 300 ft (92 m) have been successfully and economically built by using this technique.

Span by span (1) is construction of the superstructure in one direction, one span at a time, by using a movable form carrier. The form carrier provides a type of factory operation at the job site; its advantage is that it permits versatile adjustments in the field. It is supported on piers or on the ground when possible. As each segment is cast, the reusable forms are released and the segment rolls forward by means of structural steel out-riggers on the outside of the form carrier. The carrier may be located above or below the deck, depending on space and span requirements. This type of construction is especially suitable for long viaduct-type structures, where repeated construction can afford economies. It was used in the construction of the Denny Creek Bridge in the State of Washington, where typical construction time for a 100-ft (30.5-m) span was five to eight calendar days.

Incremental launching (1) is a segmental construction technique. It involves superstructure segments, from 33 to 100 ft (10-30.5 m) in length, which are match-cast in place in stationary forms behind the abutment. After the concrete reaches sufficient strength, the new segment is posttensioned to the previously cast segment. The assembly of units is then jacked forward, horizontally and vertically, over teflon and stainless-steel bearings on top of the piers. Straight or simple curved superstructure alignments are possible with spans up to 200 ft (61 m). Construction of spans up to 300 ft (92 m) are possible with this technique if temporary falsework is used. The incremental-launching technique is particularly suitable where the terrain and use of heavy crane equipment are difficult. Construction of the Wabash River Bridge in Covington, Indiana, was planned by using this technique.

Standardization in Design, Specifications, and Details

Although there is great potential for their application, systems concepts are not being applied commonly to design, specifications, and details. Current applications and their benefits are as follows:

1. Standardization of design components in order to simplify formwork and reduce labor, materials, and equipment costs, as well as overall construction time;
2. Standardization and optimization of rebar details (i.e., sizes and spacings) to simplify placing and effect savings in placement time and costs;
3. Design that reduces the number of joints or eliminate time-consuming and costly expansion joints;
4. Design that uses commonly available equipment and locally available materials;
5. Use of objective and realistic tolerances in the specifications;
6. Use of standardized details to simplify placement of materials and save on-site labor, equipment time, and cost;

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.

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System Construction of Medium-Span Bridges in Prestressed Concrete

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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-