SYSTEMS CONSTRUCTION TECHNIQUES FOR SHORT-SPAN CONCRETE BRIDGES

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Systems construction techniques have recently been used in the widening and replacement of numerous substandard or deteriorated short-span bridges in Virginia. The techniques involve the mass production of precast concrete components to one or more standard dimensions. Standard designs have been used for precast slab superstructures in the 3.1 - 9.1 m (10-30 ft.) span range, and for precast, prestressed single T-beams in the 9.1 - 20.1 m (30-66 ft.) span range. A modular precast parapet has been developed to accommodate all span lengths. Other modular concrete components that have been used include the channel beam, box beam, I-beam, and permanent bridge deck form. Evaluations have shown that the use of these mass produced components can minimize bridge costs; the same forms can be used many times and costly on-site forming and form removal are eliminated. Also investigations have shown that the use of precast components enables a reduction in on-site construction time that provides motor vehicle fuel savings for construction personnel and the traveling public. The experience in Virginia suggests that systems construction is an economical and operationally efficient method for widening or replacing short-span bridges.

Systems bridge construction may be defined as the on-site assembly of bridge components mass produced at an off-site plant to one or more standard dimensions. Because systems techniques have been used successfully in other industries to reduce costs by improving production efficiency, it is reasonable to expect that the same techniques could be applied successfully to bridge construction. When compared with conventional bridge construction techniques, systems techniques should improve construction efficiency because the same forms can be used for numerous bridges; fabrication can proceed in a systematic manner; fabrication can often proceed in bad weather, because protection from the elements is usually readily available; fewer man-hours are required for travel to and from the bridge site; and the cost of concrete is usually less, since the concreting operations are more centralized and haul distances are generally shorter. Also, since the systems techniques allow most of the bridge construction to take place at an off-site plant, the appearance and condition of the bridge site is restored in a short time; inconvenience to the motorist is lessened; motor vehicle fuel is conserved because there are fewer work trips to the bridge site, and fewer delays due to traffic detours and closed roadways; and working conditions are improved, as a majority of the work time is spent in the convenience and safety of the fabrication plant. Finally, it is anticipated that systems construction techniques will provide for a reduction in maintenance costs since high quality concrete is generally more readily attained in a fabricating plant than at a bridge site. Recent developments in concrete technology which may enhance the quality of bridge decks, such as vacuum dewatering, superplasticizers, wax beads, and polymer impregnation, may be more easily applied to modular components at the fabrication plant than to a large bridge deck at the bridge site.

Systems bridge construction techniques have been implemented in Virginia after some six years of joint efforts by many individuals, organizations, and committees. The Research Advisory Committee for Industrialized Construction, a committee made up of individuals from the Virginia Department of Highways and Transportation, the Virginia Highway and Transportation Research Council, and private industry, supported the basic concepts and recommended action by the Virginia Department of Highways and Transportation. Through the coordination of the Portland Cement Association, the Virginia Prestress Concrete Association cooperated with bridge contractors in Virginia to provide the Department with designs of bridge systems which could be competitively fabricated and erected in Virginia. The Bridge Division of the Department provided input to the systems design concept and supplied the final design details for the structures. The Research Council is monitoring the implementation of each bridge system.

The modular components that have been used successfully in Virginia, and which are discussed in detail in this paper, are a precast slab, which is used for 3.1 - 9.1 m (10-30 ft.) bridge spans; a precast, prestressed concrete single T-beam used for 9.1 - 20.1 m (30-66 ft.) bridge spans and a precast concrete parapet that is an option on almost all bridge spans. Other modular components include a channel beam, box beam, I-beam, and stay-in-place bridge deck form.

Precast Slab Bridges

For more than two years maintenance forces in the Virginia Department of Highways and Transportation have been using a systems construction technique to upgrade deteriorated and inadequate short-span bridges. The systems technique involves the fabrication of numerous precast concrete slabs in standard 1.2 m (4 ft.) widths and various lengths and skews using one set of forms. The slabs are cast at a district casting yard and stored until the substructure of the bridge on which they are to be used is properly prepared. They are then hauled to the bridge site and installed in a very short time. The modular precast slab members have been successfully used to widen concrete slab superstructures (Figure 1) and to replace substandard steel stringer-timber deck (SS-TD) superstructures (Figure 2).

A solid concrete slab is probably the easiest precast modular component to fabricate. A satisfactory casting bed is very simple to prepare and a systems casting operation is easily implemented. Three men worked about two weeks in preparing one of the first casting beds to be used by maintenance forces in Virginia. The bed was made from railroad ties, 5 cm (2 in.) thick timbers, exterior plywood, and miscellaneous hardware. It is 1.2 m (4 ft.) wide and 24.4 m (80 ft.) long (Figure 3).(1) The sides may be raised or lowered to produce slabs of various depths.

Slabs can be fabricated during the winter when there usually is a surplus of construction manpower. The precast slabs can be more economically heated and protected during curing than can site-cast slab superstructures.

Procedures for providing a rail with precast slab superstructures include casting a few large reinforcing bars into the exterior slabs to provide anchorage for the parapet, with the remainder of the parapet steel and all the concrete being placed at the bridge site; casting all the parapet steel and threaded metal inserts for anchoring the parapet forms into the exterior slabs; or precasting a concrete curb on the exterior slabs and bolting guardrail to the outside of the curb. A parapet is not precast on the exterior slabs because the combined weight of the parapet and slab would cause handling problems, but separately precast parapets can be satisfactorily connected to the exterior slabs at the bridge site.

In a typical widening and replacement project on a secondary road in Virginia, seven modular slabs can be placed and connected in one work day, and usually the road is closed for only a few minutes. A traffic detour usually is eliminated.

Shear transfer between adjacent slabs is provided by using a field weld to connect transverse reinforcing bars in the keyways, or by tensioning threaded metal rods placed through the slabs in the transverse direction. Cement mortar is used to grout the keyways between adjacent slabs.

Whereas precast slabs can be placed to widen a bridge in a few hours, a considerable amount of construction time at the bridge site is necessary to widen a bridge with site cast (SC) concrete. The falsework and forming and the placing of the concrete must be done at the site and in the presence of traffic. A lot of time is lost each day mobilizing the men, equipment, and materials.

As reflected by Table 1, a study of the operations in which maintenance forces widened and replaced 10 bridges in Virginia revealed that the precast slab superstructures were about 25% cheaper than the conventional alternative SS-TD and SC concrete superstructures. (2) Also the precast slabs reduced

Figure 1. Precast slabs used to widen bridge.

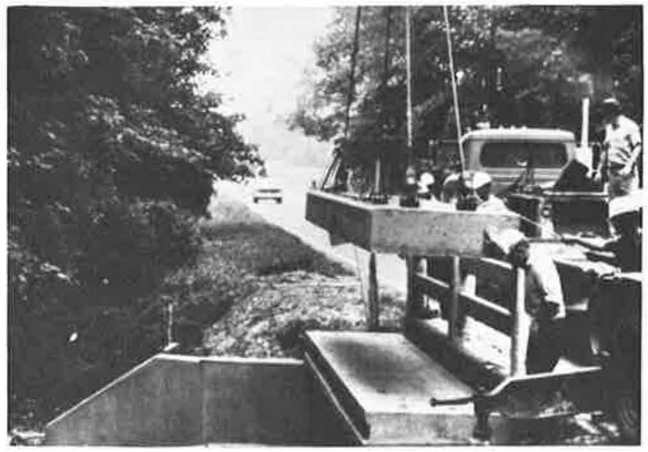


Figure 2. Precast slabs replace substandard steel stringer-timber deck superstructure.

Figure 3. Wood casting bed.

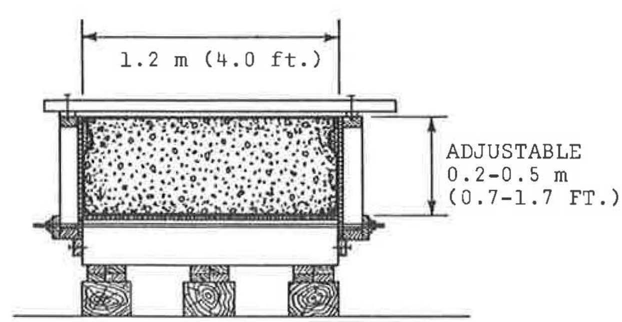


Table 1. Costs, man-hours, and travel required for precast slab construction as compared to SC concrete and SS-TD construction.

	Item	Percentage of Item Required for Precast Slabs	
		Site-Cast Concrete = 100%	Steel Stringer-Timber Deck = 100%
Costs	Labor	63	114
	Equipment	78	115
	Materials	107	40
	Total	77	69
Man-hours	In travel	22	42
	At-site	13	24
	Total	61	113
Travel	Fuel consumed	26	51
	Labor cost	21	38
	Equipment cost	57	117

on-site construction time by about 80%, which significantly benefits the motorist. Since precast slab construction requires fewer trips to the bridge site, less fuel, about 65% less according to the study, is required for moving the men and equipment.

The precast slabs fabricated by state forces are more economical than the conventional alternatives, primarily because of the turnkey concept. State forces design, fabricate, and construct the precast slab superstructures. Slabs designed by the state, fabricated by a subcontractor, and erected by a prime contractor may not be as economical as reported here. With adequate communication between the three parties the precast slabs should prove to be economical when advertised on a competitive basis. From a cost to society viewpoint, the precast slabs will be economical because they reduce delays and inconvenience to the motorist, conserve fuel in travel to and from the bridge site, and provide efficient use of manpower, equipment, and materials.

Precast, Prestressed Single Tee-Beam

The precast, prestressed concrete single T-beam provides for efficient bridge construction for numerous reasons. The shape of the member is particularly suitable for use in systems construction in that by maintaining a constant stem width of 0.3 m (1 ft.) and a flange width of about 1.2 m (4 ft.), only the bottom pallet and end bulkheads of a form have to be adjusted to provide economical beams for spans between 9.1 m (30 ft.) and 20.1 m (66 ft.) long as shown by Figure 4.(3) Since the flanges of the T-beams serve as the lower half of the bridge deck, in one step, which takes only a few hours, the contractor can advance from the bridge seat stage of construction to the forms-in-place stage (see Figure 5). Major deck forming is eliminated. Because of the reduced volume of SC concrete required, more extensive use of high quality concrete mixes that enhance durability may be reasonably justified for the 10.2 cm (4 in.) composite overlay. Usually a local prestressor will fabricate the single T-beams for a bridge and store them until the contractor completes the substructure. A lowboy is used to transport the beams, one or two per trip, to the job site. During 1976 and 1977, nine T-beam bridges

Figure 4. Systems T-beam shape. (1 ft. = 30 cm)

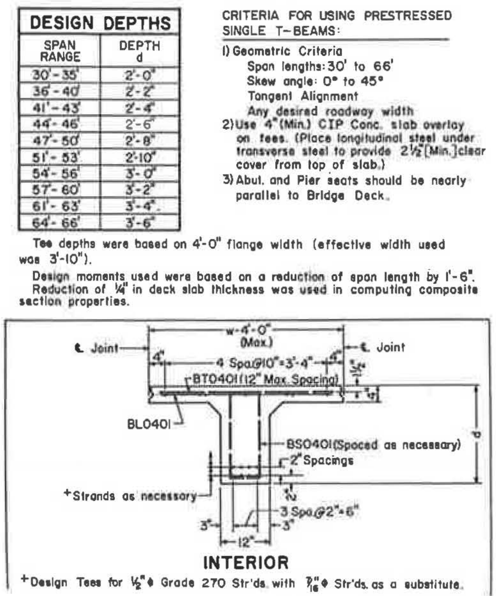
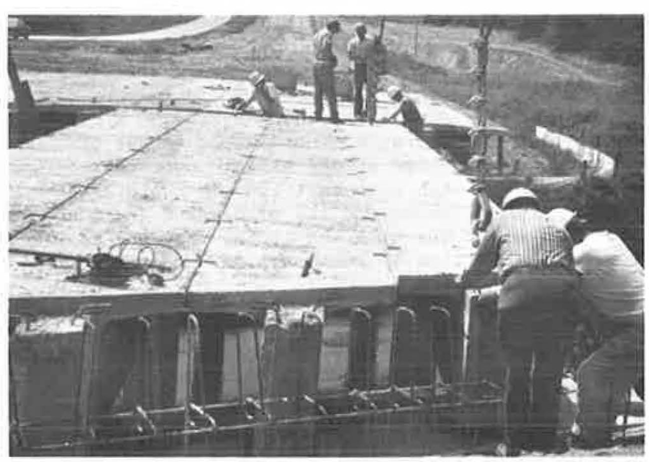


Figure 5. T-beam is placed in position.



were competitively advertised and constructed. In general the T-beam superstructures were about 10% cheaper than the conventional alternative steel-stringer SC concrete deck superstructures.

Figure 6 shows the construction sequence data for a typical 4-span precast, prestressed single T-beam bridge.(4) Working with a bridge crew of two to four men, the contractor erected, connected, and overlaid the T-beams in the 4-span bridge in roughly four weeks. A 4×10^4 kg (45-ton) truck crane and four men erected the eight 10.7 m (35 ft.) T-beams for each span in several hours. Another three days per span were required to form and cast the concrete diaphragms and to grout the keyways between the beams (see Figure 7). The side forms were prepared, the reinforcing steel positioned, and the concrete placed to provide a 10.2 cm (4 in.) overlay in another day and a half.

The amount of site time required to construct a concrete bridge superstructure is the sum of the times required to prepare the formwork, place the steel and concrete, strip the form work, and obtain cylinders with the design strengths. None of these four activities can be completely eliminated unless all SC concrete is completely eliminated. The precast, prestressed single T-beam design reduces site time by eliminating most of the forming and form removal usually required for conventional SC bridge decks and beams. But when the diaphragms are formed and cast at the site, an overlay cannot be placed until the diaphragm concrete has attained 75% of its design strength, which usually takes from three to seven days. Additional spans cannot be overlaid until the concrete in the adjacent overlays has reached 50% of its design strength, which takes from two to three days. If the backwall is used to support the screed, it also must have attained 50% of its design strength. A bridge cannot be opened to traffic until all the concrete in the superstructure has attained its 28-day design strength. The T-beam design reduces site labor considerably, but reduces site time only marginally when compared with more conventional types of construction.

Figure 6. Construction sequence data for Dickenson County bridge. (1 psi = 6.894 Pa)

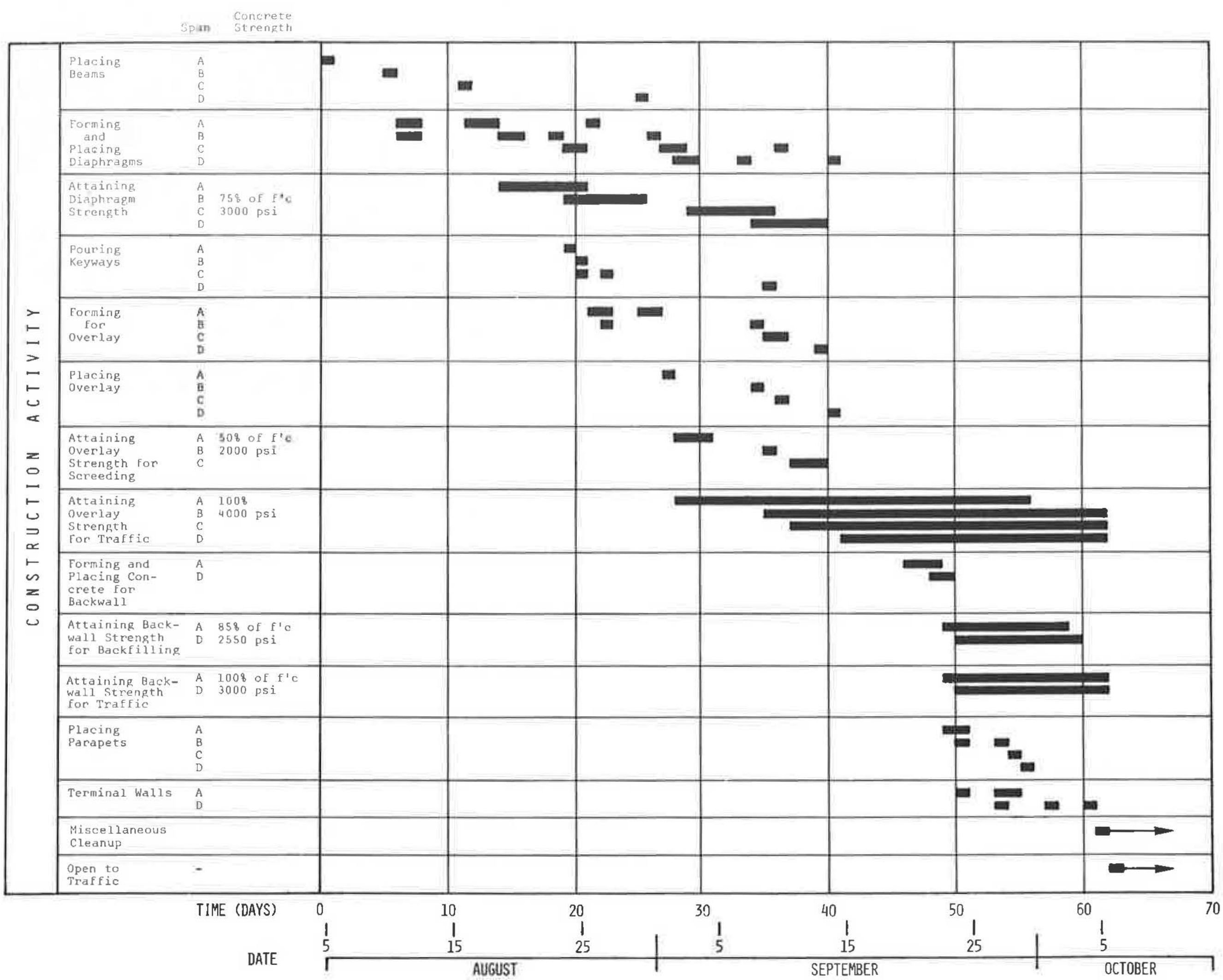


Figure 7. Nonshrinking cement paste is placed between adjacent T-beams.

Figure 8. Modular precast parapets.

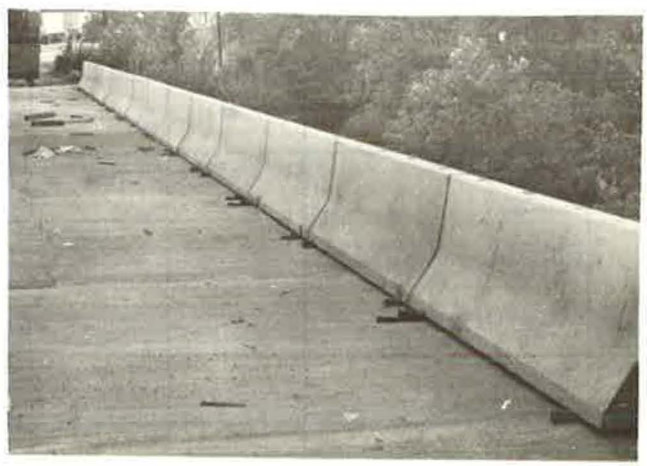
Site time for a single T-bridge could be reduced if less SC concrete or high early strength SC concrete were used in the structure. For example, the use of precast concrete or steel diaphragms would reduce site labor time by three days, strength development time from three to seven days, and total site time from six to ten days per span. Forming for the overlay could begin the same day that the T-beams are placed and the diaphragms connected. The use of precast backwalls would allow the contractor to screed off the backwall and begin grading operations immediately after the backwall is positioned. Conceivably all the precast pieces could be placed and connected in one day, the overlay could be placed in another day, and grading operations could be completed on a third day. However, until the overlay develops 85% of its design strength, the parapets cannot be placed; and until the overlay develops 100% of its design strength, the bridge cannot be opened to traffic. Only when the single T-flange is designed to provide the full-deck thickness can one hope to open a single T-superstructure to traffic after one work day. A single T-bridge requiring no SC concrete will likely require transverse posttensioning for load distribution, longitudinal posttensioning to accommodate differential camber, and a waterproof membrane and bituminous wearing surface to protect the concrete.

Precast Parapets

Since placing the forms for conventional SC concrete parapets can be a costly and time-consuming job, precast parapets have been used with all of the T-bridges built in Virginia, and on many other bridges. The parapet lends itself ideally to a systems concept as it has a constant shape suitable for mass duplication (Figure 8) and is used in sufficient volume statewide to make precasting economical. The standard 2.4 m (8 ft.) long precast parapets are fabricated upside down to help eliminate honeycombing.

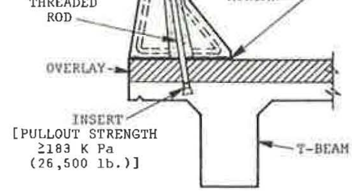
With the aid of a light truck crane, three men can place and connect the 1.8×10^3 kg (2 ton) parapet sections on a three-span structure in two or three days. The parapets may be set in cement mortar spread on top of the deck or they may be set on temporary wooden shims (Figure 9). The parapets may be anchored to the bridge deck in several ways,

Figure 9. Modular precast parapets positioned on shims prior to being anchored in place with grout.



but thus far all the contractors have chosen to make the connection with threaded metal rods which screw into inserts precast into the deck and extend upward through voids cast into the parapet (Figure 10).(4,5) Cement mortar is used to grout the voids and anchor the parapet. From the results of a pullout test conducted in the laboratory, it was concluded that the spacing of approved inserts on 0.6 m (2.0 ft.) centers anchors the precast parapet sufficiently to satisfy AASHTO rail specifications.

Figure 10. Connection detail for precast parapet.



Further Considerations

Quality control and efficiency at the fabrication plant are probably the most essential ingredients for the successful construction of a modular or prefab structure. Precast components will fit together satisfactorily in the field only if they are cast to close tolerances. Since the major portion of a modular construction project takes place in the factory, the major portion of the supervision and inspection also must take place there. Fabrication errors that are not detected at the plant can be very costly and time-consuming to remedy in the field. Precast components cast in a good set of forms and under close supervision will fit together quickly and securely in the field and will provide a structure that is far more economical and of superior quality to one built with more conventional construction techniques.

Systems bridge construction has been initiated in Virginia with an emphasis on bridge superstructures. Since 50% to 80% of total bridge construction time is involved with the substructure, it is believed that considerable savings in time and related costs can be achieved by specifying precast substructure components where their application can contribute to speed off construction. A contractor who has a large crane on hand to install superstructure elements should be able to efficiently and economically erect substructure components. Substructure systems are being considered at this time, but a prototype has not yet been designed in Virginia.

Conclusions

Evaluations of the systems construction techniques have shown that concrete bridge components mass produced in off-site fabrication plants can be used to minimize bridge costs; the same forms can be used many times and costly on-site forming and form removal are eliminated. Also investigations have shown that the erection of precast components enables a reduction in on-site construction time that provides motor vehicle fuel savings for construction personnel. Fuel savings for the traveling public are implied, since detours and traffic congestion are minimized and at times eliminated. The greatest benefits are found in remote areas where haul distances for ready-mix concrete are excessive and in highly congested urban areas where many motorists are inconvenienced by detours, delays, and traffic congestion accompanying the widening or replacement of a bridge. Recent experience and ongoing research indicate that systems bridge construction will have a significant role in Virginia's bridge replacement program. Since transportation officials have estimated that there are over 100,000 short-span bridges in the U. S. that need to be upgraded, it is envisioned that systems bridge construction will have national application in the years ahead.

Acknowledgements

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