THE COMPOSITE U-BEAM BRIDGE SUPERSTRUCTURE

John R. Salmons
University of Missouri—Columbia
Columbia, Missouri

William J. Kagay
University of Missouri—Columbia
Columbia, Missouri

As a result of an expanding bridge construction program and rapidly increasing construction costs, there is a great demand for more efficient, more economical bridge structures. Precast, prestressed composite concrete construction in general offers these features. The composite U-beam construction was developed and evaluated to show even greater efficiency and economy and the results of these studies are presented in two successive papers ("The Structural Performance of the Composite U-Beam Bridge Superstructure" will appear in the next issue of the PCI JOURNAL).

GENERAL DESCRIPTION

The system consists of a series of precast, prestressed U-beams furnished with an interior top slab form and used in conjunction with the cast-in-place concrete deck. The U-beams are set side by side on supporting bent beams or abutments, similar to setting conventional precast, prestressed box beams. The legs of the U-beams extend upward with corrugated metal arches fitted between them to serve as stay-in-place forms for the cast-in-place top slab. The resulting bridge deck is very similar to a multi-cell box superstructure. A typical cross-section of the composite U-beam bridge deck is shown in Fig. 1.

Beam dimensions. The beam dimensions were standardized (Fig. 2) in order to realize increased economy through repetition in precasting. The width of the member was fixed at 5 ft. (1.5 m) with a variation in depth limited to 4-in. (10 cm) increments for beam heights of 20, 24, 28, 32 and 36 in. (51, 61, 71, 81 and 91 cm). This variation in depth will accommodate AASHO HS20-44 loading over a span range of approximately 30 to 80 ft. (9 to 24 m) depending upon the thickness of the cast-in-place top slab. The usual range in roadway widths can be provided with the standard-width beams and by varying the width of the overhangs.

A composite U-beam bridge superstructure was developed in order to realize increased economy with precast, prestressed bridge construction. The concept of the proposed system is presented, and direct cost comparisons with existing bridges are made.

Interior voids. The voids in the bridge deck do not necessarily extend continuously through the entire span length, but may be interrupted prior to reaching a pier or at intermediate points between piers. This provides for diaphragms as well as solid bearing ends at the supports. This also furnishes a medium through which mild-steel reinforcement or post-tensioning rods can be placed transversely to provide lateral ties. The stay-in-place slab forms can be fabricated from a variety of materials. The corrugated metal forms proved to be quite satisfactory; the springing line edges of the forms are securely attached to the U-

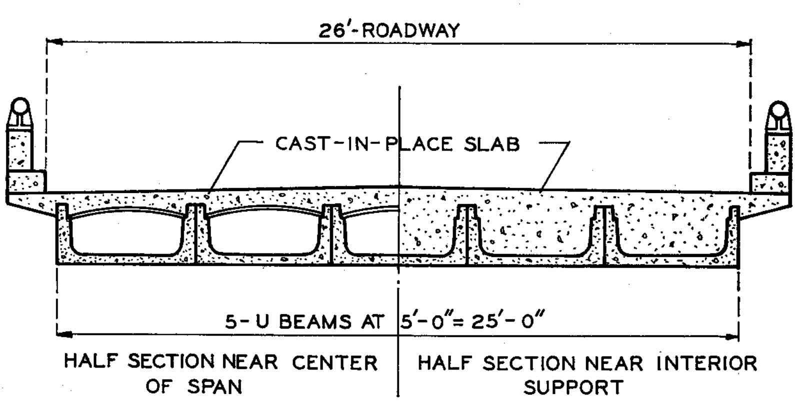
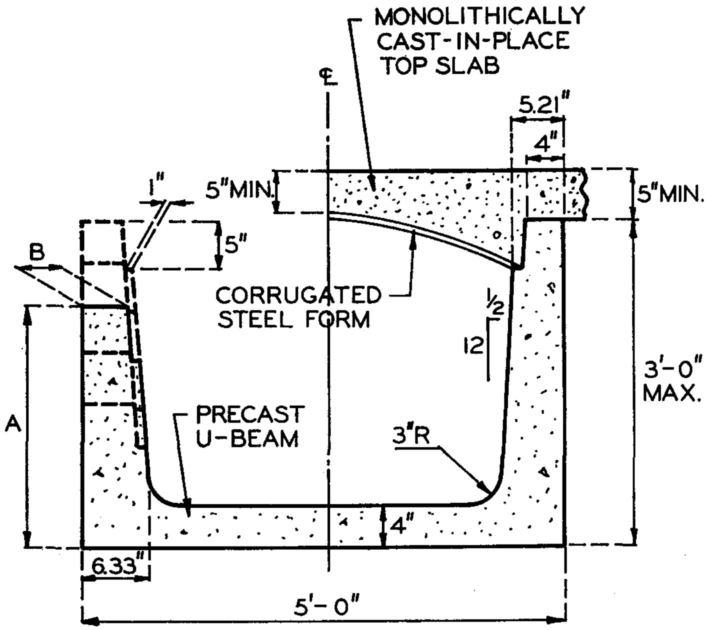


Fig. 1. Typical cross-section of the composite U-beam bridge deck



A	20"	24"	28"	32"	36"
B	4.67"	4.50"	4.33"	4.16"	4.00"

Fig. 2. U-beam dimensions and details

beam uprights when shipped from the plant.

STRUCTURAL PERFORMANCE

Since a full scale bridge using the composite U-beam superstructure has not yet been constructed, structural evaluation was based on laboratory investigations. Three types of tests were conducted—two test series were with single units while the third test was with a multi-unit system.

Single-unit tests. The single-unit test series was a model-and-prototype study using a 5-ft. (1.5 m) wide, 18-in. (45 cm) deep, 36-ft. (11 m) long prototype member and one-half scale models. Three members of each size were tested and the results were used for model-to-prototype correlation and general verification of the design procedure. The behavior of the prototype could be reliably predicted from the model and the design procedure was substantiated.

Multi-unit test. The third test was of a five unit, one-half scale bridge deck. The interaction of the units, the transverse load distribution and the composite behavior of the units making up the system were studied. Again, the test results were consistent and predictable. In general the structural performance was as anticipated and the bridge can be designed according to conventional procedures and standard practices of precast, prestressed composite design. The detailed results of the structural evaluation phase of the study are available in research reports[1,2,3,5].

ECONOMIC EVALUATION

Before any new or different structural system can be adopted it must

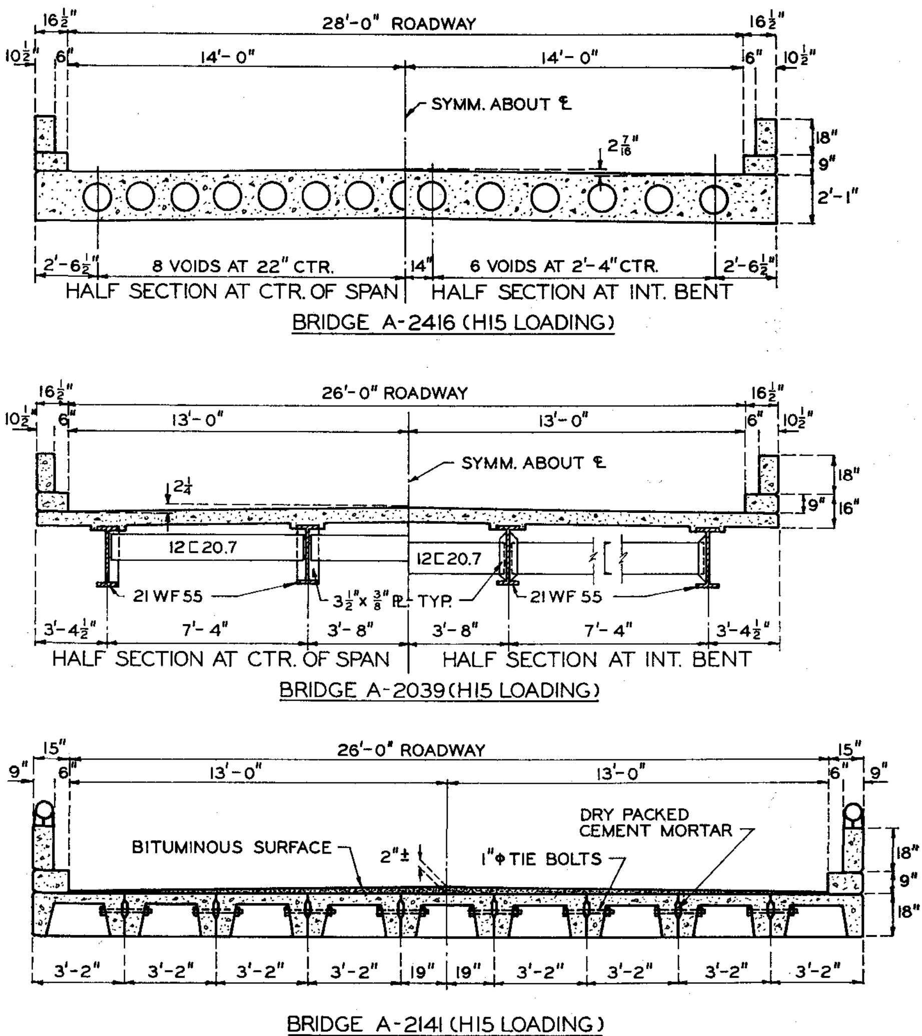
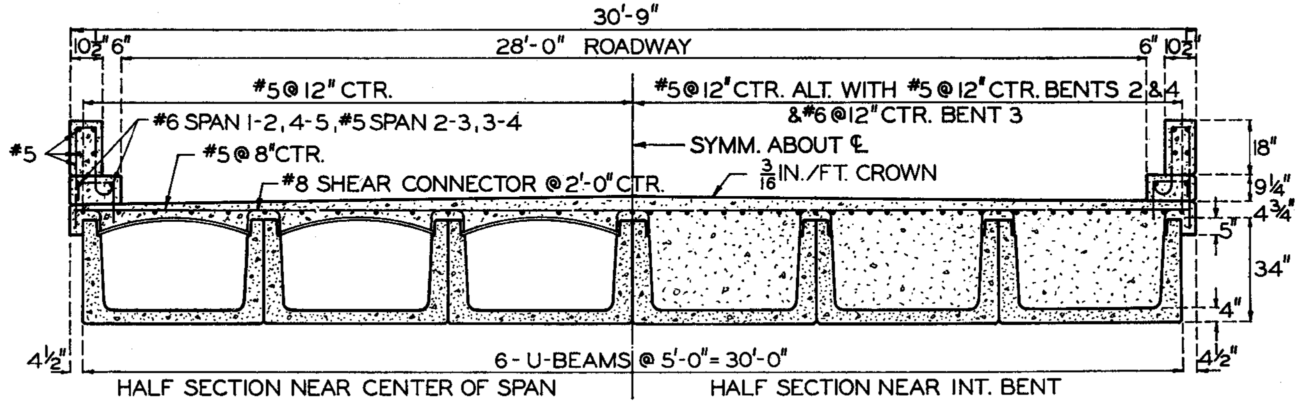


Fig. 3. Superstructures of completed Missouri highway system bridges



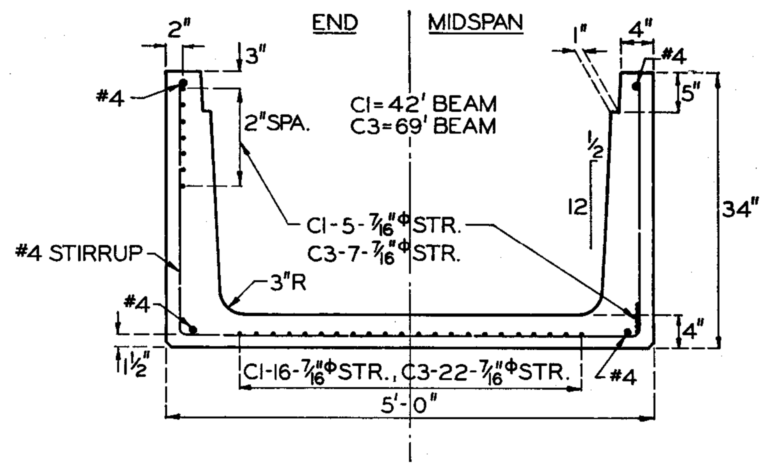


Fig. 4. Re-designed Bridge A-2416 (H15 loading)

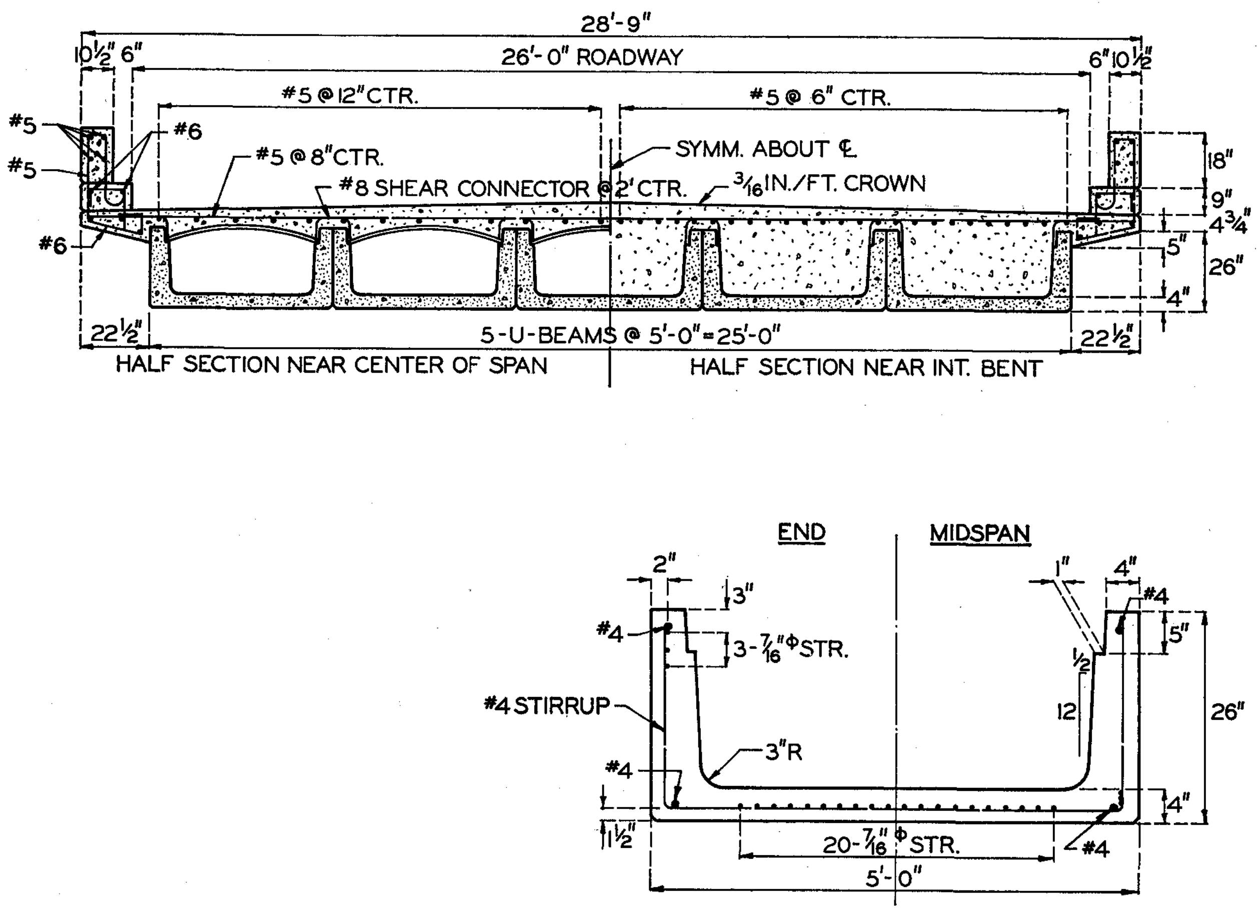
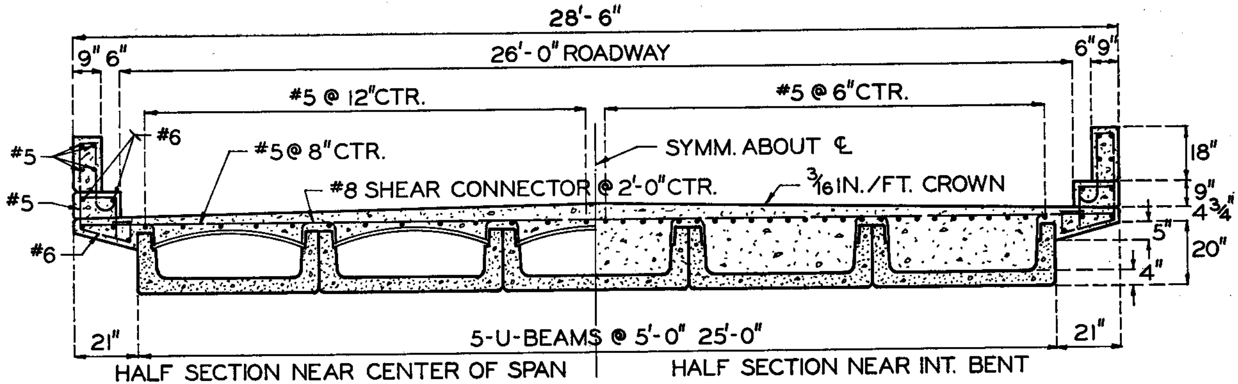


Fig. 5. Re-designed Bridge A-2039 (H15 loading)



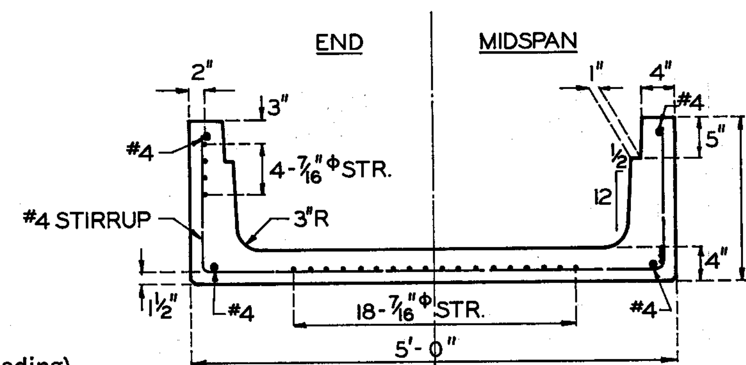


Fig. 6. Re-designed Bridge A-2141 (H15 loading)

exhibit superior structural performance, increased economy, or both, over existing methods of construction. Without the benefit of field construction, an economic study must of necessity be theoretical, but since one of the prime considerations is cost, an intensive effort was made to realistically evaluate the cost of the system.

Method of evaluation. One method of obtaining a realistic cost evaluation of the U-beam system was to compare actual costs on completed bridges with estimated costs on the same bridges re-designed with the proposed system.

Three typical bridge structures, designed with conventional superstructures and recently constructed in Missouri, were used as the basis for comparison. They were selected to give a representative range of span length and to consider the most common types of bridge superstructures used for shorter spans in the Missouri highway system.

Existing bridge dimensions. The first structure considered is a three-span precast slab structure designated A-2141. It has equal spans of 34 ft. (10 m) and a 26 ft. (7.9 m) roadway. The second is a continuous composite steel I-beam structure with a 26 ft. (7.9 m) roadway and three spans of 35-43-35 ft. (11-13-11 m), designated A-2039. The third bridge, designated A-2416, has four spans of 43-70-70-43 ft. (13-21-21-13 m) and a 28 ft. (8.5 m) roadway. It consists of a voided cast-in-place slab deck. Each of these structures was designed for AASHO H15 loading. The cross-sections of the superstructures are shown in Fig. 3.

The bridges considered in this study were built in late 1966 and 1967. The Missouri State Highway Commission made available actual unit costs on these three structures, along with superstructure quantities, to be used in the cost analysis.

U-beam re-design. The superstructure of each of the three bridges was re-designed using the proposed composite U-beam bridge deck system. The design procedures were similar to that used for the design of normal prestressed composite bridge beams, where the dead load is simply supported and the live loads resisted by the continuous structure.

The dead load of the U-beams and of the cast-in-place top slab are supported by the beams as simple members. However, after the top slab has cured, and if this top slab is continuous and reinforced over the supports, any additional loads applied to the deck will be resisted by the resulting continuous, composite system. For the AASHO truck loadings considered in the re-designs, the design moments were determined for this continuous condition. The resulting cross-sections of the re-designed bridge decks are presented in Figs. 4, 5 and 6.

U-beam production costs. Where lengths and weights do not exceed permissible limits, the most economical prestressed concrete members are usually precast and pretensioned. Since the U-beams are not drastically different from some commonly used precast, pretensioned building members, prestressed concrete producers could be expected to estimate the production and delivery cost of the U-beams with a reasonable degree of accuracy.

The initial re-designs of the three bridge decks was made sufficiently detailed to allow a realistic production cost estimate. Several prestressed concrete producers in Mis-

TABLE 1. Cost per square foot of precast, prestressed U-beams

Producer	Casting method	Size of units—depth/length				
		20"/33'	26"/34'	26"/42'	34"/42'	34"/69'
No. 1	Inverted	$3.15	$3.50	$3.75	$4.26	$4.51
No. 1	Upright	3.25	3.60	3.50	4.05	4.10
No. 2	Upright	3.15	3.54	3.46	3.71	4.03
No. 3	Upright	3.21	3.52	3.81	4.45	4.51

souri, Kansas, Iowa and Nebraska were asked to make cost estimates for the prestressed concrete members. At the same time these producers were asked to make recommendations for any changes to the U-beam configuration or to the method of production.

Three prestressed concrete producers responded to the request with both estimates and recommendations. The prices obtained are listed in Table 1.

The cost estimates furnished by the producers were made for the members delivered within a 100-mile (161 km) radius of the plant. They were also asked to consider a reasonable volume of production, rather than estimating on the basis of custom members. Variations in the price estimates for each of the members considered was quite small.

Manufacture of U-beams. From the initial conception of the proposed system, it was anticipated that the most economical method of production was casting the beams in an inverted position. However, two of the three producers immediately recommended that it would be more economical to cast the U-beams in the upright position because of high handling and inverting costs for the inverted position. The third producer was requested to provide estimates for both methods of production. His figures show that the inverted casting method is more economical in the shorter spans and the upright casting method more economical in the longer spans.

It was concluded that the upright method of casting should be used for beam production. This allows the horizontal shear connector to be a conventional connector of U-shaped reinforcing bars extending from the top of the legs. This type of connector is used in standard precast, prestressed I-beam bridge construction. Additional minor recommendations from the producers were received and incorporated into the designs.

Construction costs. In order to complete a cost analysis of the proposed bridge deck, an evaluation of the on-site construction costs was required. To accomplish this in a realistic manner, two general contracting companies, with considerable experience in bridge construction, were consulted. Since detailed plans for a complete bridge were not available, they were asked to furnish unit costs and methods of estimation for the proposed system. As would be expected, each company used methods

Table 2. Summary of superstructure costs

Bridge		Cost of superstructure			Savings	U-beam cost	Materials	Labor	Equipment and overhead
		Proposed system		Actual bridge					
		Total	$/sq.ft.	$/sq.ft.	$/sq.ft.	%	%	%	%
A-2141	High	$19,882.40	6.83	7.38	.55	41.8	70.6	14.3	15.1
	Average	19,284.23	6.63	7.38	.75	42.1	71.5	14.7	13.8
	Low	18,760.58	6.45	7.38	.93	42.5	72.5	15.0	12.5
A-2039	High	24,820.91	7.44	8.22	.78	41.5	71.6	13.3	15.1
	Average	23,956.68	7.18	8.22	1.04	41.8	72.8	13.7	13.5
	Low	23,156.60	6.94	8.22	1.28	42.2	74.0	14.1	11.9
A-2416	High	58,756.60	8.74*	10.33	1.59	51.2	74.0	10.7	15.3
	Average	54,376.58	8.12*	10.33	2.21	52.1	76.6	11.0	12.4
	Low	50,088.78	7.51*	10.33	2.82	52.8	79.2	11.3	9.5

*For Bridge A-2416, the cost of the superstructure was increased by $0.38/sq.ft. to account for the bent beams which were an integral part of the voided slab superstructure.

of estimating that were slightly different and resulted in cost estimates with some variation. On the other hand, many of the unit prices and labor estimates were very consistent.

Both companies considered the following items in estimating cost:

1. Erection cost which included both labor and equipment.
2. Forming costs for slab overhangs, curbs and parapets. This item contained forming material as well as labor rates, and included a working space outside the slab overhangs.
3. Concrete, including labor and material cost.
4. Overhead, equipment, insurance and supervision.

In addition, reinforcing steel was considered in the estimates. However, the Bridge Division of the Missouri State Highway Commission furnished unit prices for this item which included material and placement labor.

The contractors were also consulted regarding the completeness of the estimate. Each indicated that this procedure would provide as complete an estimate as possible without detailed design drawings and knowledge of the locations of the structures.

In general, material and labor costs were the same for both contractors. The three principal differences in the final estimate were in the erection of the precast, prestressed U-beams, forming of the slab overhang, and in overhead. These differences partly account for the variation in superstructure prices presented.

SUMMARY OF SUPERSTRUCTURE COSTS

To complete the economic evaluation of the proposed composite U-beam bridge system, beam costs and construction costs were combined for the three re-designed bridge superstructures. These combined costs were subsequently broken down into total cost and percentages of total cost according to the following divisions:

1. Total costs of the U-beam systems and comparative sq. ft. costs of the original and re-designed structures
2. Percent for U-beams
3. Percent for on-site construction materials, including U-beams
4. Percent for construction labor
5. Percent for equipment, overhead and insurance

Since four estimates for each beam and two estimation methods were available, several total cost figures are possible. For comparison purposes, high, low and average values were considered. Costs and percentages are presented in Table 2.

Cost evaluation. From the prices listed in Table 2, it can be seen that for the shorter span bridges, A-2141 and A-2039, the cost of the original superstructures exceeds the average estimated cost of the proposed system by 10 and 13 percent, respectively. These values would indicate that, even with the conservative nature of the estimate, the proposed system does not appear to be significantly more economical than present types of construction. However, the estimated average cost of the proposed system for bridge A-2416 is about 21 percent less than the actual cost of the original voided slab superstructure. It appears that for medium span ranges the proposed system has an economic advantage.

Table 2 indicates that beam cost accounts for about 45 percent of total superstructure cost. The estimates for these members were made

Table 3. Cost per square foot of U-beam superstructure under two types of loading

	Bridge A-2141		Bridge A-2039		Bridge A-2416*	
	H15-44	HS20-44	H15-44	HS20-44	H15-44	HS20-44
High	$6.83	7.00	$7.44	7.54	$8.36	8.49
Average	6.63	6.76	7.18	7.30	7.74	7.87
Low	6.45	6.56	6.94	7.05	7.13	7.23

*Bent beam costs not included

without the benefit of production experience and costs would be expected to lower as this experience is gained. Because of the nature of the system, any reduction in the square foot cost of the beams results in almost the same (about 87 percent) decrease in the square foot cost of the superstructure.

The distribution of costs, as expressed by the percentages of the total superstructure costs, should also be considered. For most bridge construction, a minimum of 30 to 40 percent of the total cost of the structure is on-site labor cost, as compared to 10 to 15 percent for the proposed system. As a result, fluctuations in the labor market and variations between local labor wage scales should have a relatively light effect upon the overall cost of the structure.

Effect of bridge loads. In addition to the AASHO H15 loading, all three superstructures were designed for HS20 loading. This resulted in an increase of cost averaging 2 percent. The superstructure costs for the two types of loading are given in Table 3.

Construction time. An item which cannot be considered from the information presented in this paper is the reduced construction time which is possible with the proposed bridge system. An evaluation of the effect of construction time involves many factors which are known only after the bridge site has been selected and construction is considered along with the total highway project. However, there are many instances when the construction of a bridge, or bridges, is critical to the completion of a project, whereby the construction time becomes an important economic consideration.

CONCLUSIONS

The proposed U-beam bridge system has been shown to be structurally sound and economical for 30 to 80 ft. (9 to 24 m) spans. Plans are presently being made in Missouri to construct some trial structures using the proposed system. This construction should not only help to verify the cost estimates, but should also provide useful information by which some of the unknown factors previously mentioned can be evaluated.

ACKNOWLEDGMENTS

This investigation was part of a study sponsored by the Missouri State Highway Commission in cooperation with the U.S. Department of Transportation, Federal Highway Administration. Sincere appreciation is expressed to Wilson Concrete Company, Nebraska Prestressed Concrete Company, Prestressed Concrete of Iowa, Inc., Tobin Construction Company and Wilkerson Construction Company for their assistance with costing the proposed bridge system.

REFERENCES

1. Salmons, J. R. and Poepsel, J. R., "Investigation of a Prestressed-Precast Composite Bridge System," *Missouri Cooperative Highway Research Program Report 68-8,* University of Missouri, Department of Civil Engineering, May 1968.
2. Salmons, J. R. and Mokhtari, S., "Model Study of Prestressed-Precast Composite Bridge System," *Missouri Cooperative Highway Research Program Report 68-9,* University of Missouri, Department of Civil Engineering, June 1968.
3. Salmons, J. R. and Mokhtari, S., "Study of Precast-Prestressed Model Bridge Slab," *Missouri Cooperative Highway Research Program Report 68-14,* University of Missouri, Department of Civil Engineering, November 1968.
4. Salmons, J. R. and Kagay, W. J., "Economic Evaluation of the Proposed Precast-Prestressed Bridge System," *Missouri Cooperative Highway Research Program Report 69-1,* University of Missouri, Department of Civil Engineering, January 1969.
5. Salmons, J. R., "Study of a Proposed Precast-Prestressed Composite Bridge System," Final Report, *Missouri Cooperative Highway Research Program Report No. 69-2,* University of Missouri, Department of Civil Engineering, April 1970.

Discussion of this paper is invited. Please forward your discussion to PCI Headquarters by Sept. 1 to permit publication in the Sept.-Oct. 1971 issue of the PCI JOURNAL.