Design and Construction of Spliced I-Girder Bridges

Ahmad M. Abdel-Karim, Ph.D.
Design Engineer
LoBuono, Armstrong &
Associates Inc.
Sacramento, California

Maher K. Tadros, Ph.D., P.E.
Cheryl Prewett Professor
of Civil Engineering
and Director
Center for Infrastructure Research
University of Nebraska-Lincoln
Omaha, Nebraska

Precast, prestressed concrete I-girders are more economical than other bridge systems, if the span length allows them to be used in full span segments, i.e., for spans up to about 150 ft (46 m). Many designers are unfamiliar with the possibility of splicing I-girder segments to reach longer spans in the range of 150 to 280 ft (46 to 85 m) and therefore rule out this potentially economical alternative. The following paper provides a summary of a state-of-the-art report on the design and construction of spliced I-girder bridges, which are quickly gaining popularity in the United States and Canada. The report was prepared by the University of Nebraska on behalf of the Bridges and Bridge Producers Committees of the PCI. The full report is available as a separate PCI document. The report contains information on over 40 bridge projects and gives design, production and erection considerations, and other details for many of these bridges. It also includes a fully worked example of preliminary design of a 350 ft (106 m) long overpass, made of two equal spans. The example calculations are done by a handheld calculator without need for any specialized computer facility. Also included is reference to a PC-based computer software for detailed time-dependent analysis of this bridge type.

Spliced precast, prestressed concrete girder bridges are becoming increasingly popular in the United States and Canada. Splicing is used for one or more of the following reasons:

- To increase the span capabilities of standard I-girders
- To achieve continuity over the piers
- To overcome transportation limitations for girder segments

Spans in the range of 150 to 280 ft (46 to 85 m) are made possible by splicing, thus making pretensioned concrete I-girder systems competitive with steel in the medium span range that traditionally has been reserved for steel.

A survey aimed at gathering information on the state-of-the-art of spliced girder bridges[1] was conducted. Responses were received which provide information on more than 40 bridges designed using several splicing techniques. These bridges were either designed or built between the years of 1960 and 1991. The full report discusses the techniques that have been developed to splice precast, prestressed concrete girders and gives the name and address of a contact person for each of the bridges listed.

The survey helped identify some current trends that are taking place in the precast concrete bridge industry. Among the most notable of these trends is the increasing use of high strength concrete in the range of 6 to 10 ksi (42 to 69 MPa). There also appears to be a tendency to use more slender and lighter sections.

Modifications of the AASHTO standard I and bulb tee shapes appear to be emerging to allow for efficient utilization in both positive and negative moments. Additional changes are also taking place in the casting and forming of deck slabs. Precast, prestressed concrete deck panels are becoming increasingly popular, as they allow the elimination of deck slab formwork.

Reference is given in the full report to available PC-based computer software for time-dependent analysis of spliced girder bridges. The computer analysis accounts for differential creep and shrinkage between the girders and the deck slab. It also considers such factors as multi-stage prestressing and temporary supports. However, the numerical example given in the report does not rely on a computer for preliminary design calculations.

DESCRIPTION OF STRUCTURAL SYSTEMS

Girder Shape

Standard AASHTO-I, AASHTO/PCI bulb tee and locally developed shapes have been used for spliced girder bridges. Since more bridges are being built with continuity over the piers, the need for an optimum I-girder section is becoming more important. The I-shape must be adequate for both the negative and positive moment regions. This is a departure from the design basis for the current girder shapes which were developed for simple

Fig. 1. Annacis Channel East Bridge, British Columbia, Canada.

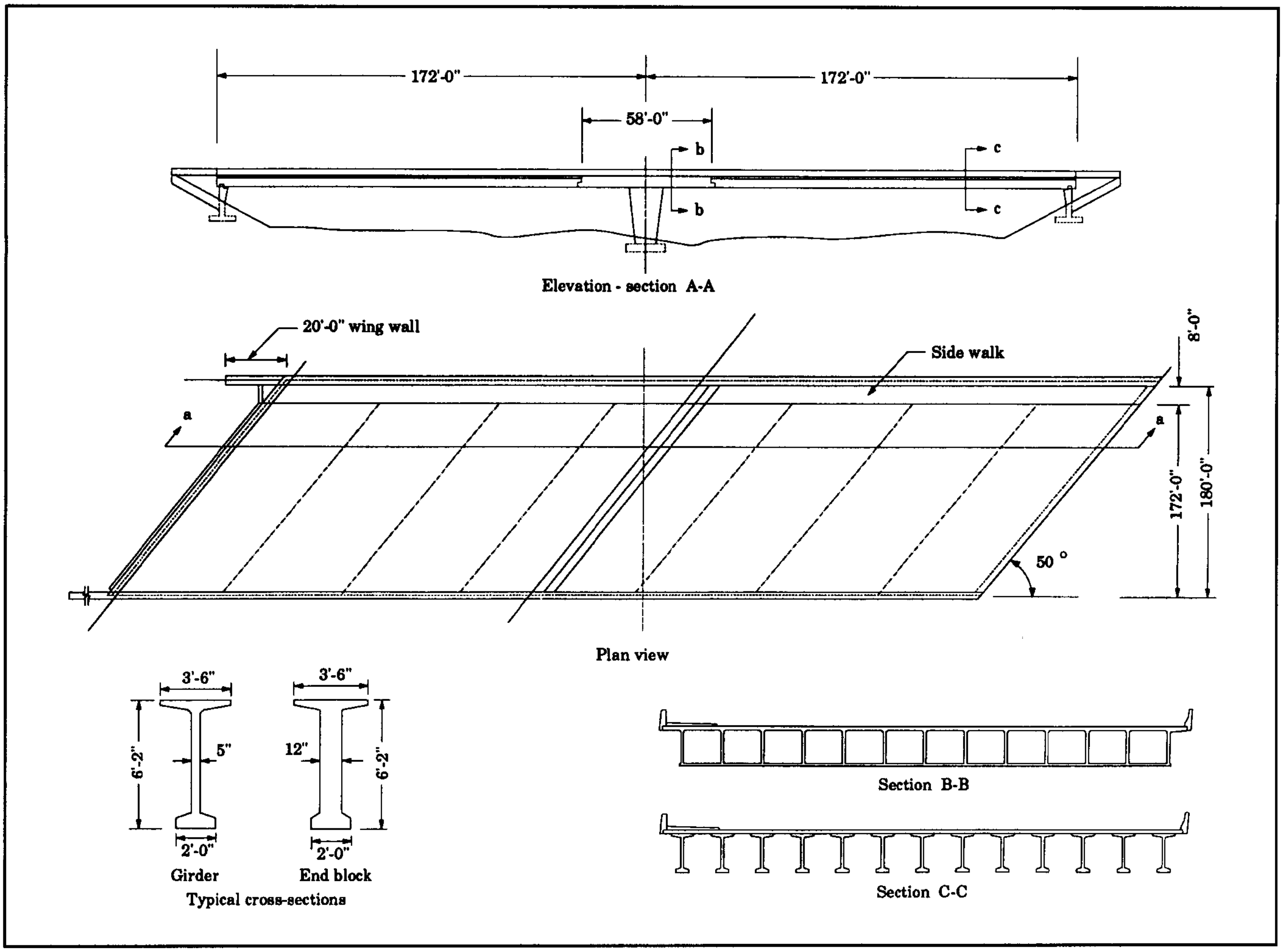

Fig. 2. 128th Street Bridge, Snohomish, Washington.

spans without giving attention to negative moment resistance and continuity prestressing.

According to AASHTO, end blocks are required at post-tensioning (P/T) anchorages. Experience with recent bridges in Canada has shown that end blocks can be eliminated successfully. If eliminated, end blocks are usually replaced with special end diaphragms at the P/T ends to accommodate the P/T hardware, and to help distribute the concentrated anchorage forces in the end zones. More detailed information on this aspect is given in the full report.

Span Arrangements and Splice Location

In the design of concrete bridges using spliced girders, the span layout is frequently determined by site conditions. The maximum segment size is usually governed by transportation constraints and facilities at the fabrication plant. Segment sizes are selected to accommodate these constraints and to provide splices at locations that are accessible at the construction site, or at locations dictated by the flexural stresses in the girder.

One of the features of girder splicing, which is very advantageous in many situations, is the ability to adapt to the requirements for a curved alignment of a superstructure. By precasting the I-girders in appropriate segment lengths and by providing the necessary transverse diaphragms, girder segments may be chorded along a curved alignment. The result is an efficient framing system and acceptable appearance as shown in Fig. 1.

The use of precast concrete elements in the spans, combined with cast-in-place box girders over the piers, achieve lightness and shallowness where they are most beneficial, while allowing increased depth and greater mass where negative moments and shears are high. Continuity of spans provides greater structural capacity, better dynamic response, a more efficient use of materials than simple span construction, and the elimination of deck joints and their potential for long-term maintenance problems.

These types of structures, often referred to as hybrid structures, are characterized by their aesthetically pleasing appearance. An example of this type of bridge is shown in Fig. 2. Another notable bridge is the Esker Overhead, shown in Fig. 3. This single-span and sharply skewed bridge is an example of the versatility of spliced I-girder bridges.

TYPES OF GIRDER SPLICES

The most common precast concrete girder splice used in the construction of bridges is the cast-in-place splice. This splice is made with or without post-tensioning. There are other types

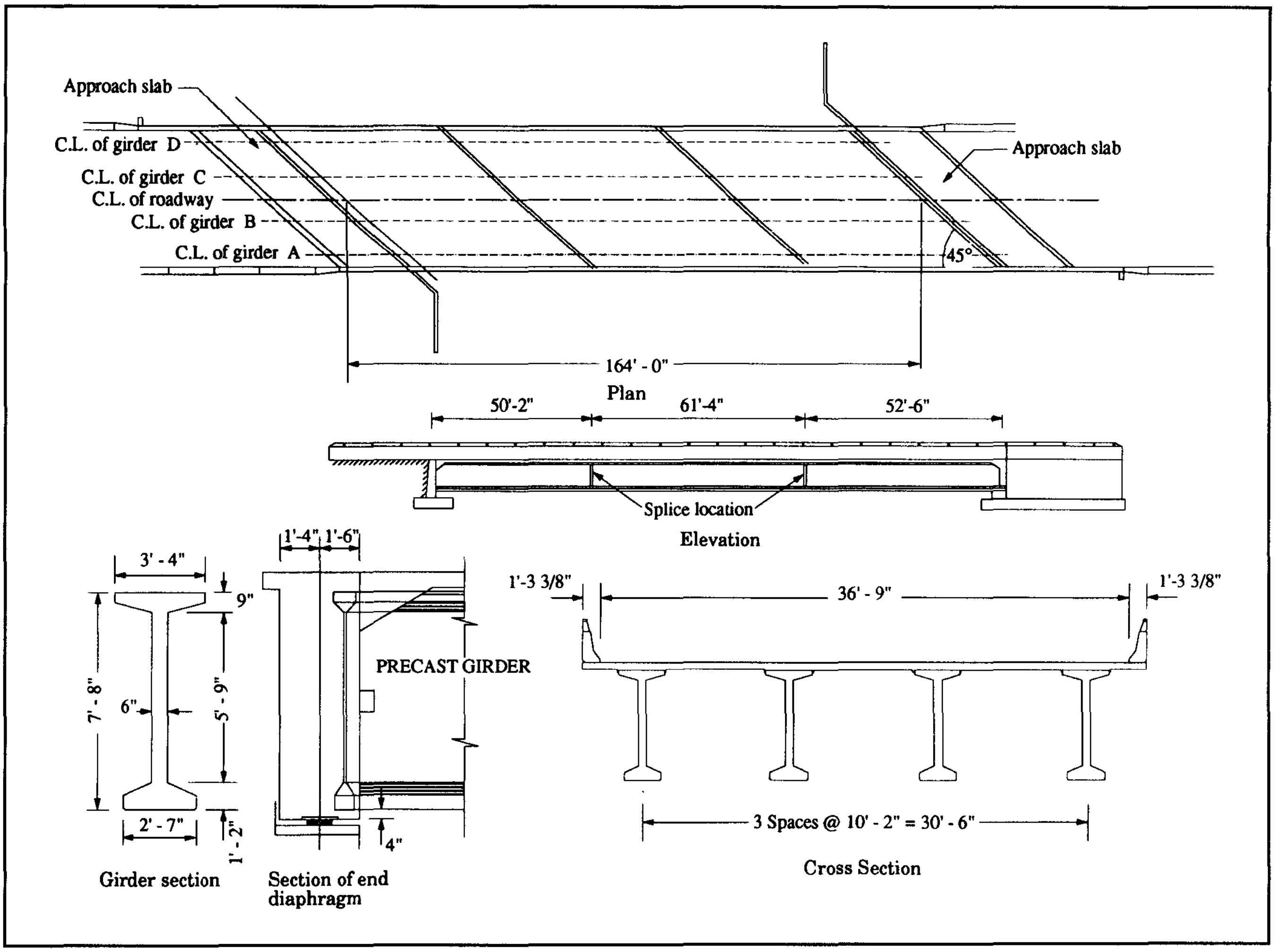

Fig. 3. Esker Overhead, Northwestern British Columbia, Canada.

of splices such as epoxy filled post-tensioned and structural steel splices. All these types of splices are discussed in the full report.

CONSTRUCTION METHODS AND TECHNIQUES

The design of a spliced girder bridge must consider all aspects of the fabrication and construction sequence. Proper attention to details is important to ensure a practical and economical design. Site conditions, availability of lifting equipment, shipping restrictions and capability of local precasters and constructors must be considered in the selection of the size of segment and type of splice to use.

Fig. 4 gives the details of the girder support conditions and the necessary steel nose sometimes used for alignment of the segment ends. A more detailed discussion of the construction techniques of spliced I-girder bridges is included in the full report.

SPLICED GIRDER BRIDGE SURVEY

The full report gives information on more than 40 bridge projects. Some of the bridge projects are discussed in detail, giving information on design, production and construction considerations. It also includes a table giving the name and address of a contact person for each bridge described. These people are willing to share their knowledge and experience with engineers interested in considering this system.

ANALYSIS AND DESIGN OF SPLICED GIRDER BRIDGES

In most cases involving multi-stage construction, it is important to accurately calculate the stresses, deflections and end rotations of the components of the structure during the various stages. The method of analysis used should take into account the effects of creep and shrinkage of concrete, relaxation of steel, and should be applicable to statically indeterminate structures.

One such method was developed by Tadros et al.[2] The method was implemented into a mainframe computer program in the mid 1970s. The program has been used for time-dependent analysis of several bridges.

Recently, Abdel-Karim[3] introduced significant program enhancements and converted it into the PC environment. The program can be employed to evaluate stresses in concrete and steel at any cross section in a statically indeterminate composite beam or plane frame. It also gives deflections at various stages of construction.

Additional features of the program include up to three different concrete

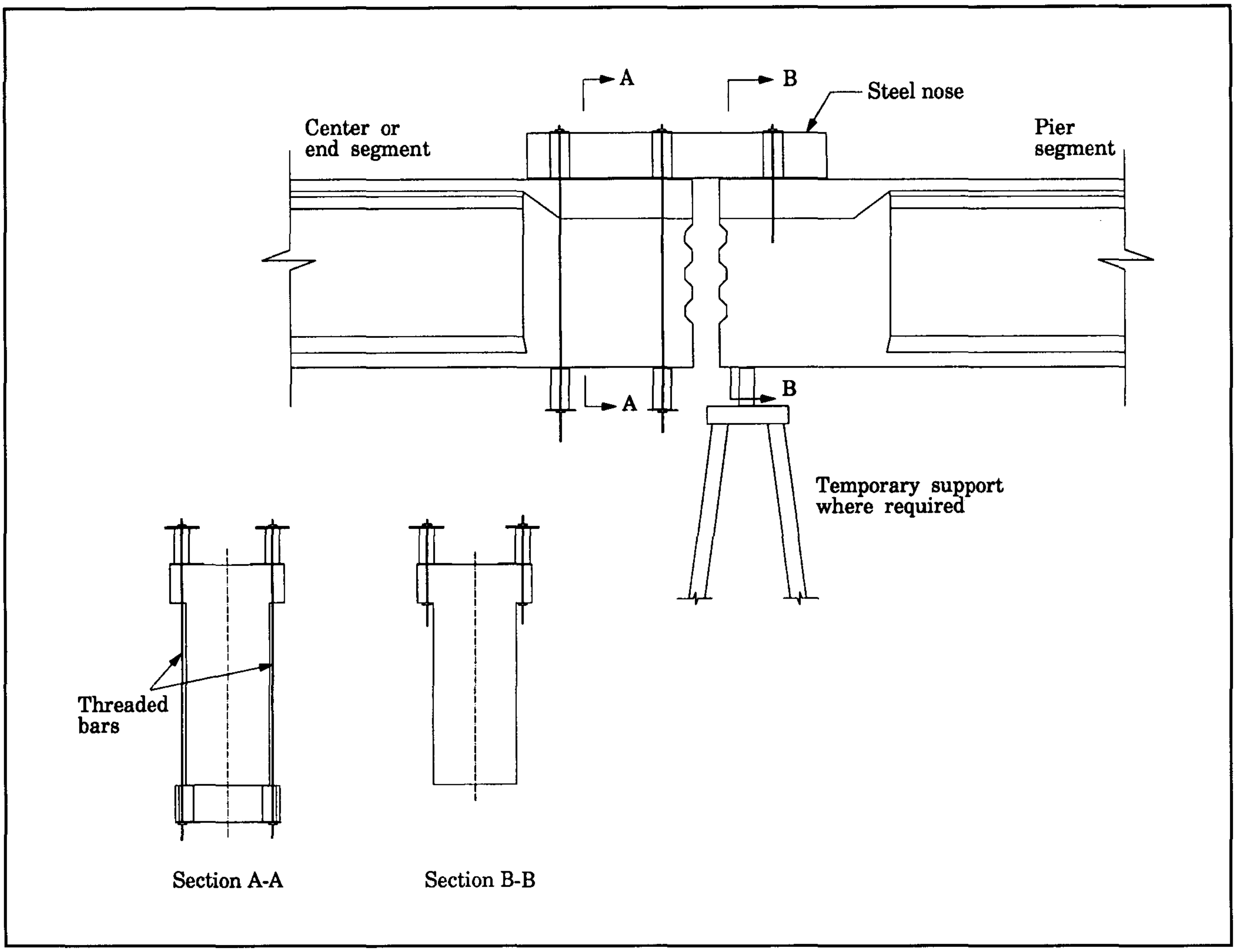

Fig. 4. Schematic detail of steel nose for erection alignment.

types in a cross section, support settlement, internal generation of prestressing profiles, calculation of friction and anchorage set losses, multi-stage post-tensioning, shear deformation and temperature gradient effects.

DESIGN EXAMPLE

This example was selected based on discussions at PCI Committee Days, April 1990. No innovations or deviations from current practices are attempted here. The preliminary design is limited to the design of an interior girder. A two-span bridge example is used here to illustrate the design steps in detail. The necessary data is summarized below. Fig. 5 shows the bridge layout and cross section.

In the preliminary design of this example a lump-sum procedure was used to account for the time-dependent effects. However, the final design of the bridge should be based on a more detailed method of analysis. The following design criteria are given:

Design specifications:
AASHTO Bridge Specifications.

Material properties:
Concrete: f_c' (precast girder) = 7000 psi (48 MPa)
f_c' (CIP joint and deck) = 4000 psi (28 MPa)
Prestressing steel: Grade 270 low-relaxation steel
Mild reinforcing steel: Grade 60 steel

Loading:
Superimposed Dead Load (SIDL) from wearing surface, parapet, and miscellaneous items = 320 lb per linear ft (4.67 kN/m) per girder
Live Load (LL): AASHTO HS25-44

Construction schedule:
The bridge is constructed according to the schedule in Table 1.

Preliminary Design and Results of Stress Analysis

The preliminary selection of the amounts of pretensioning and post-tensioning steel and the tendon profiles are shown in Fig. 6. The prestressing requirements were determined based on the AASHTO allowable stresses. The composite section was then checked for ultimate conditions and was found to be adequate.

The stresses in the composite girder at the end of each construction stage are shown, in Fig. 7, for the maximum positive and maximum negative moment locations. It can be seen from this figure that satisfactory stress levels prevail throughout the entire construction period and under the effect of the SIDL (Stages 1 through 5). However, upon introducing the effect of live load in Stage 6, the compressive stress in the top fibers of the precast girder at Section B is calculated to be 2.834 ksi (19.5 MPa), i.e., 0.034 ksi (0.23 MPa) more than the stress limit at that stage.

At the same stage, the compressive stresses in the bottom fibers of the girder at Section D′ are calculated to be 2.976 ksi (20.5 MPa). At Stage 7, after all time-dependent losses have occurred, the compressive stress calculated in the top fiber of the girder section at B is 2.908 ksi (20.1 MPa). The compressive stress calculated in the bottom fibers of the girder at Section D′ at Stage 7 is 3.190 ksi (22 MPa).

The Ontario Bridge Code allows a maximum compressive stress of 0.45 f'_c, which is the same value allowed by the ACI 318 Code. It is interesting to note that some authors have questioned the need for limiting the compressive stress at service load.[4,5] The use of $0.40 f'_c$ in the AASHTO Specifications is currently under review. It is possible that the limit will be changed to $0.45 f'_c$ due to effective prestress plus dead load, and $0.6 f'_c$ due to effective prestress plus full load. A similar proposal is currently under consideration by ACI Committee 318-G for adoption in the 1995 ACI 318 Code.

Table 1. Construction schedule.

Construction steps	Days since precasting
1. Pretension and pour concrete	0
2. Release pretensioning force	1
3. Erect precast concrete beams	28
4. Cast CIP deck and joints	35
5. Perform post-tensioning and remove support	42
6. Apply superimposed dead load (SIDL)	60
7. Apply live load (bridge open to traffic)	70

Cost Analysis

The preliminary design of a 350 ft (106 m) long, two-span bridge was performed, and is included in the full report. Table 2 provides an estimate of the cost per girder line of the superstructure. The cost estimate of a steel alternative with comparable span lengths is also given in the same table. These estimates do not include earthwork or substructure costs.

The prices shown are quoted from local precasters and contractors who operate on a national level and are used for comparison purposes only. The spliced girder precast concrete option becomes even more attractive if aesthetics and long-term maintenance costs are considered.

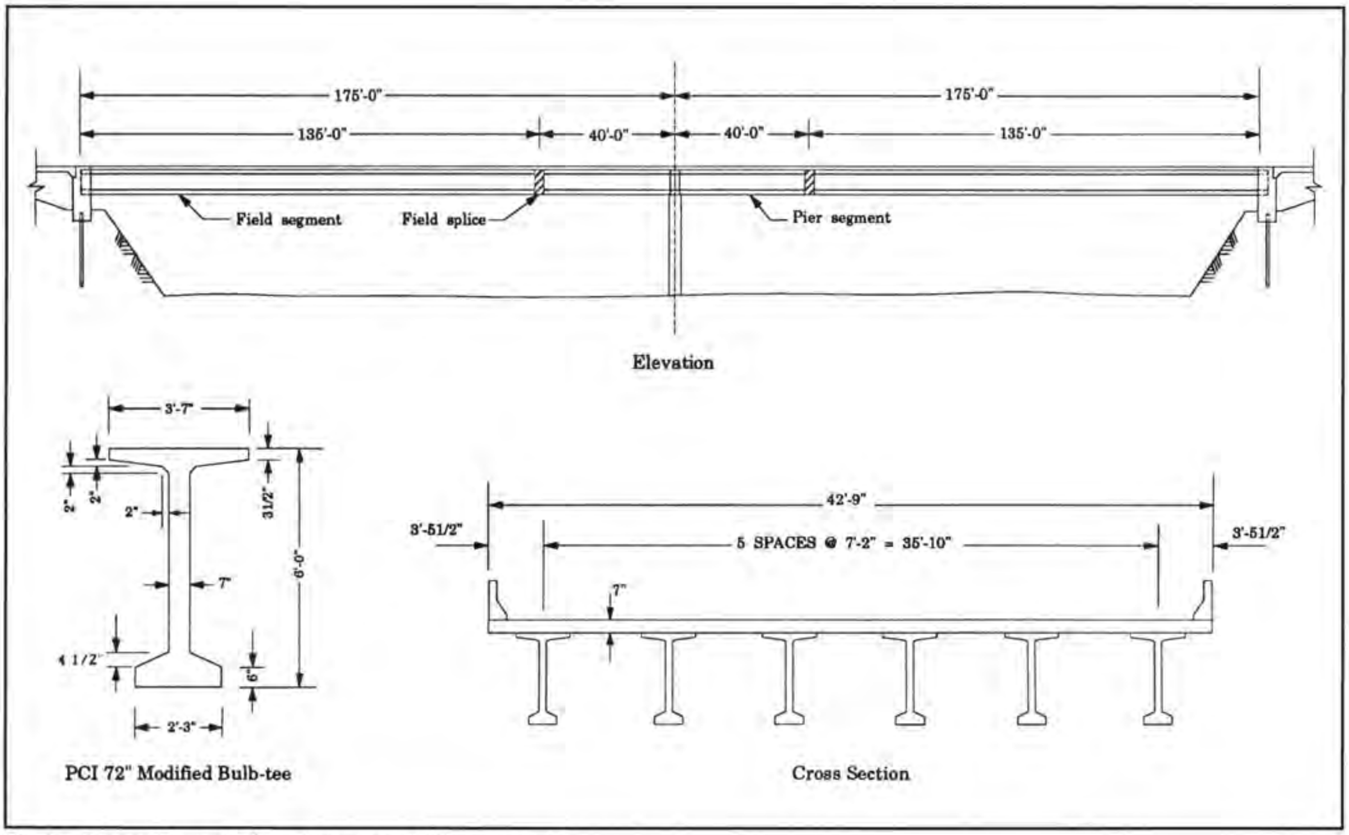

Fig. 5. General layout of the two-span bridge example.

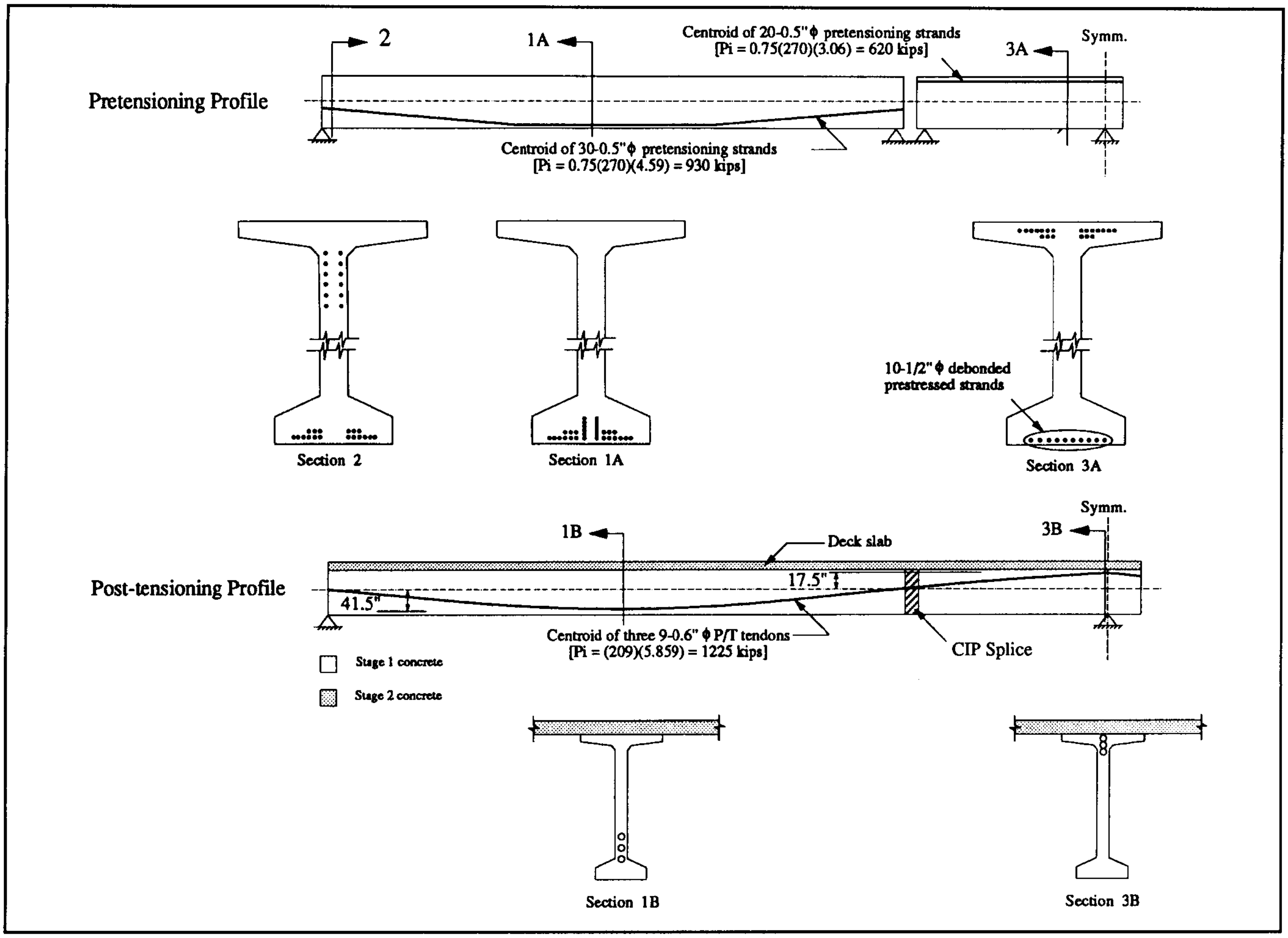

Fig. 6. Prestressing profiles and eccentricities of two-span bridge example.

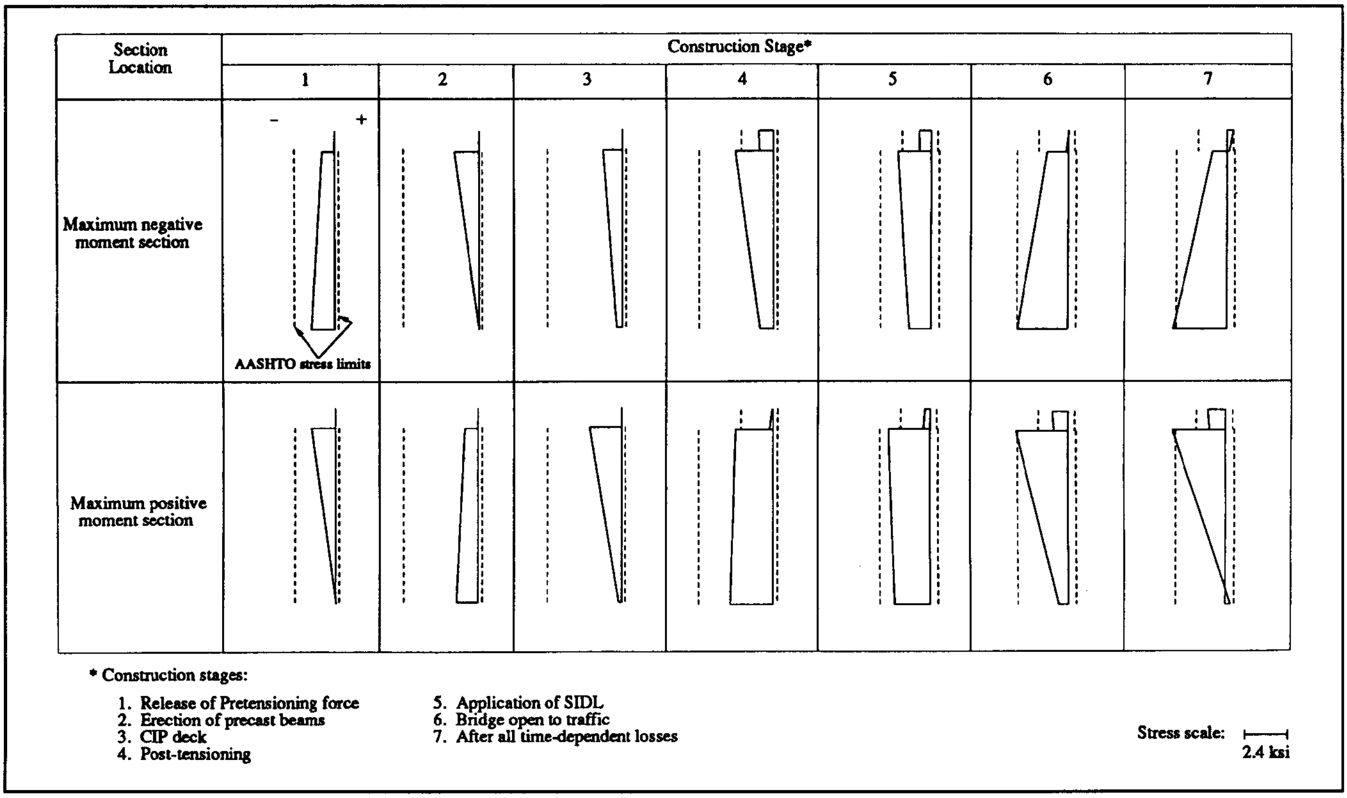

Fig. 7. Total stress diagrams during the various construction stages, ksi (tension = +).

Table 2. Approximate quantities and cost per girder line.

Description	Quantity	Unit cost	Total cost
I. Spliced I-Girder Precast Concrete Option			
(1) Precast girders	75 cu yd	$ 570	$ 42,750
Post-tensioning (includes post-tensioning hardware, labor)	6891 lb	1.5	10,336
Diaphragms (includes framing, labor)	9 cu yd	450	4,050
(2) 7 in. deck (includes concrete, forming, reinforcing bars)	54 cu yd	300	16,200
(3) Traffic barriers	133 ft	25	3,325
Total Cost per sq ft of deck = $76,660 x 6 girders ÷ (42.75 ft x 350 ft) ~ $31 per sq ft of deck			$ 76,660
II. Structural Steel Composite Girder Option			
(1) Structural steel girders (at 421.1 lb per ft)	147,385 lb	$ 0.84	$ 123,803
Stiffeners, field splice, miscellaneous items (5 percent)	7369 lb	0.84	6,190
(2) 9.5 in. deck (includes concrete, forming, reinforcing bars)	125 cu yd	300	37,500
(3) Traffic barriers	266 ft	25	6,650
Total Cost per sq ft of deck = $174,143 x 3 girders ÷ (36.5 ft x 350 ft) ~ $41 per sq ft of deck			$ 174, 143

* Note: 1 ft = 0.3048 m; 1 in. = 25.4 mm; 1 lb = 4.448 N; 1 sq ft = 0.0929 m², 1 cu yd = 0.764 m³.

CONCLUSION

The survey conducted for the purpose of this research revealed several important trends in the design philosophy of bridges. Among the most important of these trends is the desire to eliminate all deck joints, including those at the abutments (i.e., by providing integral abutments).

Other trends include the increasing use of high strength, lightweight concretes, precast deck panels, and more slender section shapes capable of resisting both negative and positive bending. A swift response by the precast concrete industry to these and other market needs will ensure sustaining the competitive edge of concrete over alternative materials.

Splicing of I-girders provides a convenient means of extending the span capabilities of existing standard AASHTO and PCI shapes beyond their conventional span ranges. It can be viewed as a step forward in the evolution of precast concrete technology in the area of bridges.

The new spans are not only longer, but they are structurally more efficient and provide a better riding surface due to the added continuity. In some cases, longer spans make it possible to reduce the number of piers required, thus substantially reducing the substructure cost.

ACKNOWLEDGMENTS

An earlier version of the full report had been drafted by a subcommittee of the Bridges Committee chaired by Robert M. Barnoff. Other members of the subcommittee were Gordon Nagle, James K. Iverson and Robert Loehr. The final report was developed at the University of Nebraska-Lincoln (UN-L) by Maher K. Tadros, Cheryl Prewett Professor of Civil Engineering, and Ahmad M. Abdel-Karim, Ph.D. candidate, as a service to the Bridges Committee of the Precast/Prestressed Concrete Institute (PCI). Financial help from the PCI and from the Center for Infrastructure Research (CIR) of UN-L is acknowledged.

The University of Nebraska team sought information on spliced girder bridge projects and received an outstanding response on more than 50 bridges. Table 2 of the full report contains the names of the individuals responding to this request.

Numerous individuals contributed to the review of the document. The following persons deserve special mention. Without their leadership, dedication and willingness to spend much of their valuable time, the full report would not have been accomplished.

- Alex Aswad
  Pennsylvania State University
- Robert M. Barnoff
  R. M. Barnoff & Associates
- Kris G. Bassi
  Ontario Ministry of Transportation
- Jeffrey Curren
  The Schemmer Associates, Inc.
- Walter Dilger
  University of Calgary
- William Dowd
  HDR Engineering, Inc.
- Larry Fischer
  Concrete Industries, Inc.
- William L. Gamble
  University of Illinois
- Antonio Garcia
  Florida DOT
- Scott Gilliland
  HDR Engineering, Inc.
- David Harvey
  Associated Engineering (BC) Ltd.
- Richard R. Imper
  Morse Bros. Inc.
- James Kohout
  Batheja Associates
- George Laszlo
  Morse Bros. Inc.
- Joseph LoBuono
  LoBuono Armstrong & Associates, Inc.
- Scott Marshall
  Con-Force Structures Ltd., Vancouver
- W. T. McCalla
  Consulting Engineer
- Sharad Mote
  Kiewit Engineering Co.

- Gordon Nagle
  Schuylkill Products, Inc.
- Jagdish Nijhawan
  Wilson Concrete Co.
- Scott Olson
  Elk River Concrete Products
- William Slaughter
  Concrete Industries, Inc.
- C. Douglas Sutton
  Purdue University
- H. M. Walker
  American Engineering Co.
- Garry Winch
  Con-Force Structures Ltd., Winnipeg
- Stephen Zendegui
  LEAP Associates International, Inc.

REFERENCES

1. Abdel-Karim, A. M., and Tadros, M. K., "State-of-the-Art of Precast/Prestressed Concrete Spliced Girder Bridges," Report prepared by the University of Nebraska-Lincoln for the PCI Bridges and Bridge Producers Committees, Precast/Prestressed Concrete Institute, Chicago, IL, 1992.

2. Tadros, M. K., Ghali, A., and Dilger, W. H., "Time-Dependent Analysis of Composite Frames," *Journal of Structural Division,* American Society of Civil Engineers, V. 103, No. ST4, April 1977, pp. 871-884.

3. Abdel-Karim, A. M., and Tadros, M. K., "Computer Analysis of Spliced-Girder Bridges," accepted for publication in *ACI Structural Journal,* September 1991.

4. Peterson, D. N., and Tadros, M. K., "Simplified Flexural Design of Partially Prestressed Concrete Members," PCI JOURNAL, V. 30, No. 3, May-June 1985, pp. 50-69.

5. Tadros, M. K., "Expedient Service Load Analysis of Cracked Prestressed Concrete Beams," PCI JOURNAL, V. 27, No. 6, November-December 1982, pp. 86-111. See also discussion of the same paper by J. Bachmann, E. W. Bennett, D. E. Branson, T. Brøndum-Nielsen,. A. S. G. Bruggeling, S. E. Moustafa, A. H. Nilson, A. S. Prasada Rao and S. Natarajan, G. S. Ramaswamy, A. Fattah Shaikh, and Author, PCI JOURNAL, V. 28, No. 6, November-December 1983, pp. 137-158.