# Some Design Issues Facing American Bridge Constructors

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This paper attempts to pinpoint some design issues which directly affect bridge constructors. While the discussion is aimed primarily at constructors in North America, many of the ideas can be applied effectively in other locations throughout the world. In particular, five major items will be discussed:

1. Non-prestressed reinforcement — Discusses the necessity and desirability of using non-prestressed reinforcement to control structural behavior and increase member strength during various construction stages of a segmental concrete bridge.

2. Deflection control — Describes the roles that hinge location and addition of supplementary tendons play in controlling deflection in segmental bridges.

3. Choice of deck sections — Discusses the various sections available for segmental construction, including single-cell and multiple-cell boxes, T's, I's, waffle, and wing sections.

4. Fabrication and erection techniques — Compares match casting of segments using epoxy joints with conventional casting methods including the use of open joints and wet joints.

5. Span-by-span casting versus precasting — Compares casting segments on launching trusses and movable forms using span-by-span construction as distinct from the use of individual match cast precast segments. Whole-span or half-span precast elements will be described. However, the issue of double cantilever construction, i.e., comparing cast-in-place concreting to precasting techniques, will not be discussed.

NOTE: This paper is based on a presentation given at the Segmental Concrete Bridge Conference in Kansas City, Missouri, March 9-10, 1982. The Conference was sponsored by the Associated Reinforcing Bar Producers — CRSI, Federal Highway Administration, Portland Cement Association, Post-Tensioning Institute, and Prestressed Concrete Institute.

The authors discuss five design areas facing prestressed concrete bridge constructors, namely, selection of non-prestressed reinforcement, deflection control, choice of deck sections, fabrication and erection techniques, and span-by-span casting versus precasting.

## Non-prestressed Reinforcement

Almost all segmental bridges are post-tensioned no matter whether the concrete segments are cast in place or precast. Moreover, the segments invariably incorporate non-prestressed reinforcement in one form or another. Therefore, practically speaking, almost all segmental bridges are in effect partially prestressed even though no tensile stress is theoretically permitted.

The computation of stresses for purposes of comparison to allowable code values has generally been limited to global longitudinal stresses. Although bridge deck stresses are computed in the transverse direction, some basic sources of stresses, such as local shrinkage and temperature, are not usually considered. In other words, most codes deal with global stresses but not with localized stresses.

Some localized stresses for which there are no accepted methods of calculation and no definite allowable stress values are:

(a) Stresses at tendon anchorages.
(b) Stresses along curved tendons.
(c) Stresses resulting in slab delamination.
(d) Stresses at blisters and diaphragms.

Similarly, the causes of certain local stresses are often not specified; neither are the magnitude of such stresses, as for example:

(a) Local temperature differential between the outside and inside of slabs, top and bottom of slabs, and around corners.
(b) Local shrinkage due to nonhomogeneous concreting procedures.
(c) Local creep due to high localized stresses.
(d) Stresses resulting from construction procedures, construction joints, stage stressing, etc.
(e) Effects of local reinforcing bars and tendons in reducing concrete areas and increasing local stresses.

On the one hand, it is very difficult to predict the factors causing these stresses. On the other hand, even if the stresses could be predicted, the method of computation or the mathematical model would be too difficult to specify or formulate. Furthermore, the use of the so-called no-tension criterion cannot be applied since most local stresses will be heavily tensile, resulting in local cracking.

Therefore, in the final analysis, the introduction of non-prestressed reinforcement is often the only effectively simple solution. However, determining when such reinforcement is required

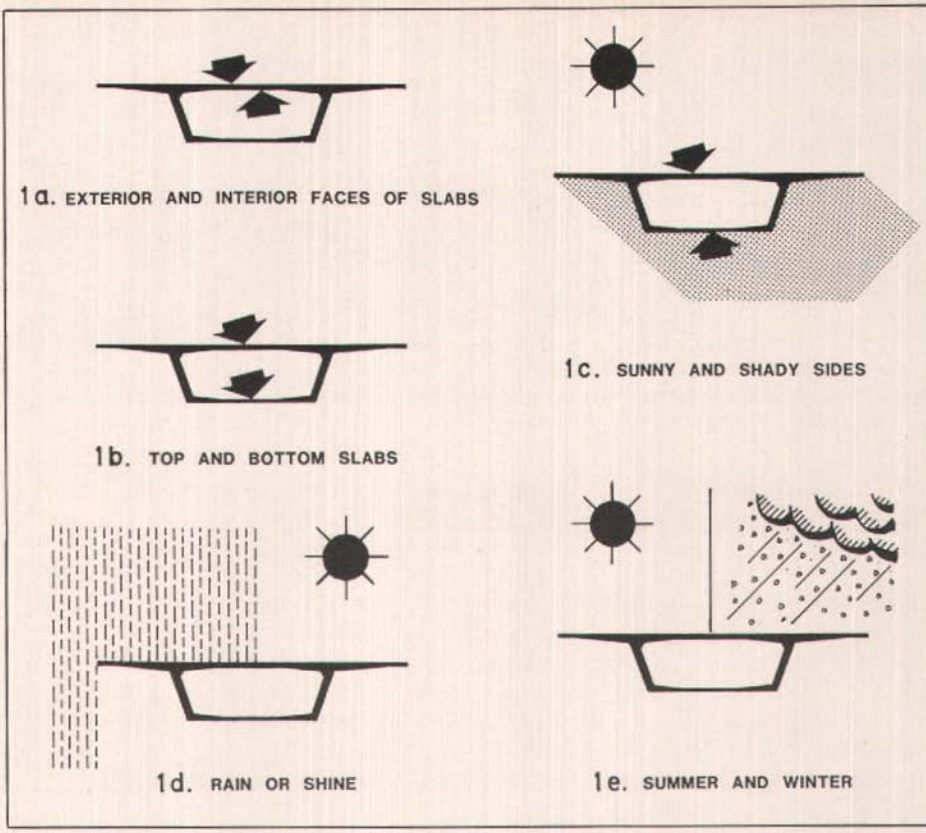


Fig. 1. Various causes of temperature stresses in a segmental box.

and finding how much is needed to control the structural behavior and to increase the member strength locally are difficult questions to answer.

One important local problem that frequently arises is temperature stress. Such stresses produced in segmental boxes can be attributed to several factors:

(a) The exterior and interior faces of a slab may possess different temperatures (Fig. 1a).

(b) The top and bottom slabs are subjected to different temperatures (Fig. 1b).

(c) The sunny and shady sides of a box obviously would have differing temperatures (Fig. 1c).

(d) Rain or sunshine will cause differing effects on the slabs of a box (Fig. 1d).

(e) Summer and winter will produce variable temperature differentials (Fig. 1e).

A difficult question to answer is which of the above conditions should be considered in the analysis of a given bridge. For example, if all of the above factors were computed, it is almost certain that high tensile stresses would occur somewhere in the box under some combinations.

Can we afford to make that much analysis? If so, what would be the allowable stress values under various combinations?

Obviously, the only reasonable solution would be to provide temperature

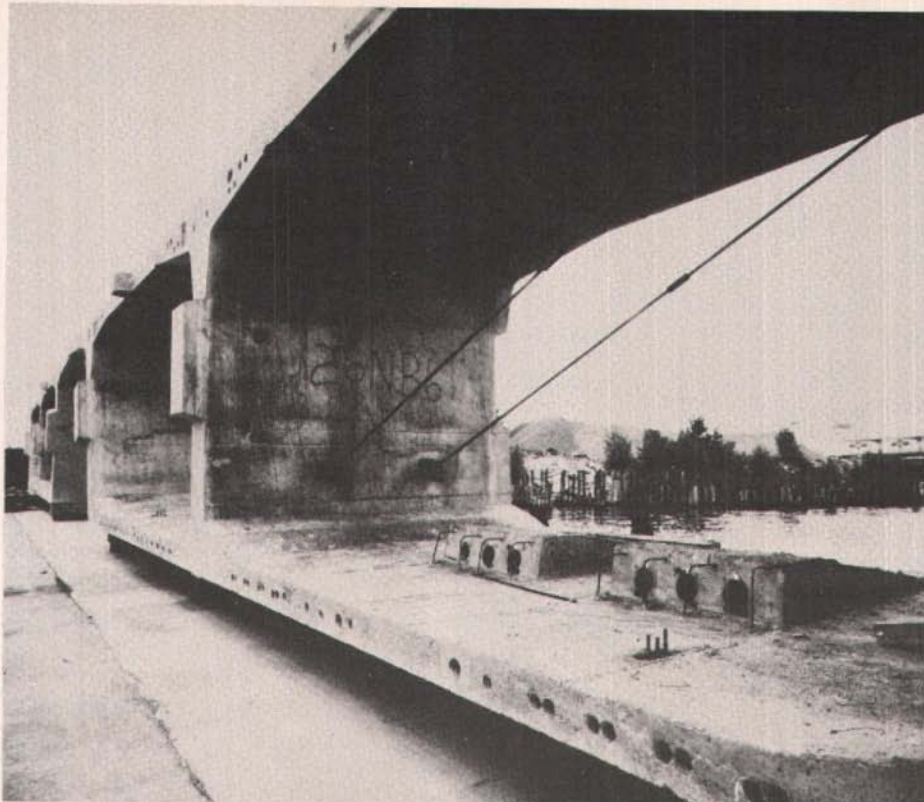

Fig. 2. An anchorage for tendons terminated along a segment is commonly known as a blister (I-205 Columbia River Bridge).

steel in an empirical manner. A small amount of temperature reinforcement can go a long way in controlling stresses in segmental bridges. But exactly how much steel is needed, no one knows as yet.

Some other examples of causes of local stresses are:

(a) Blisters and anchorages (Fig 2).

(b) Slabs heavily separated by tendons running in two directions and closely spaced together (Fig. 3).

(c) Stresses during handling, e. g., a two-cell box during transportation (Fig. 4).

(d) Stress along sharp curves, producing high localized stresses, resulting in failure (Fig. 5).

## Deflection Control

Of particular interest to constructors is the long-term deflection of segmental concrete bridge spans. Some double cantilever bridges in Europe have shown an excessive deflection at the midspan hinges and as a result this method of construction has been discouraged in some countries. On the other hand, there are many existing bridges whose midspan hinges have deflected within acceptable limits and today exhibit a smooth riding surface.

Recently, some bridges in both North America and Europe have been designed with permanent hinges near the quarter-span point instead of at midspan. In double cantilever construction, this requires a constructional continuity

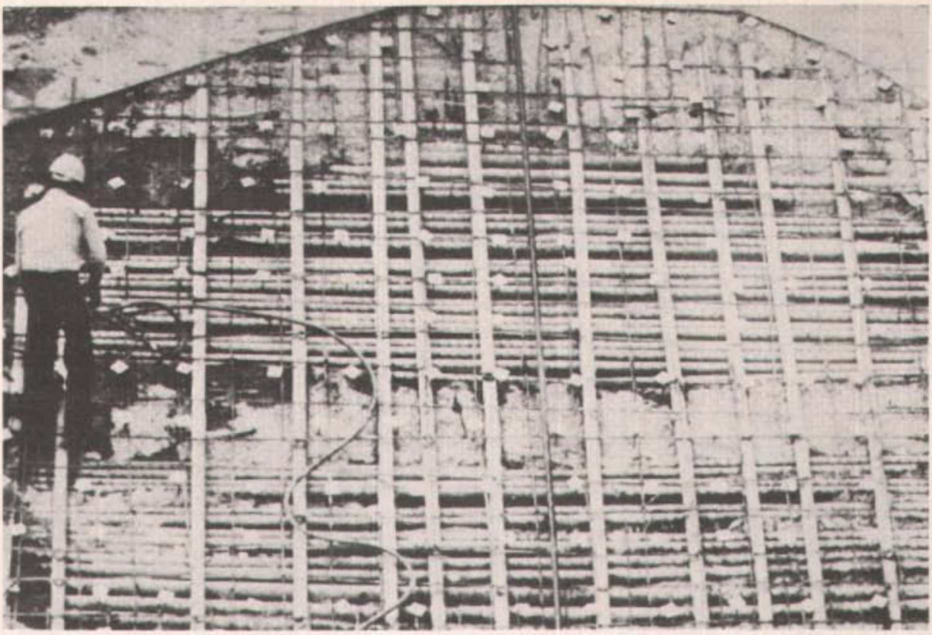

Fig. 3. Deck slab with closely spaced tendons in two directions. Note that congested reinforcement will cause difficult concreting.

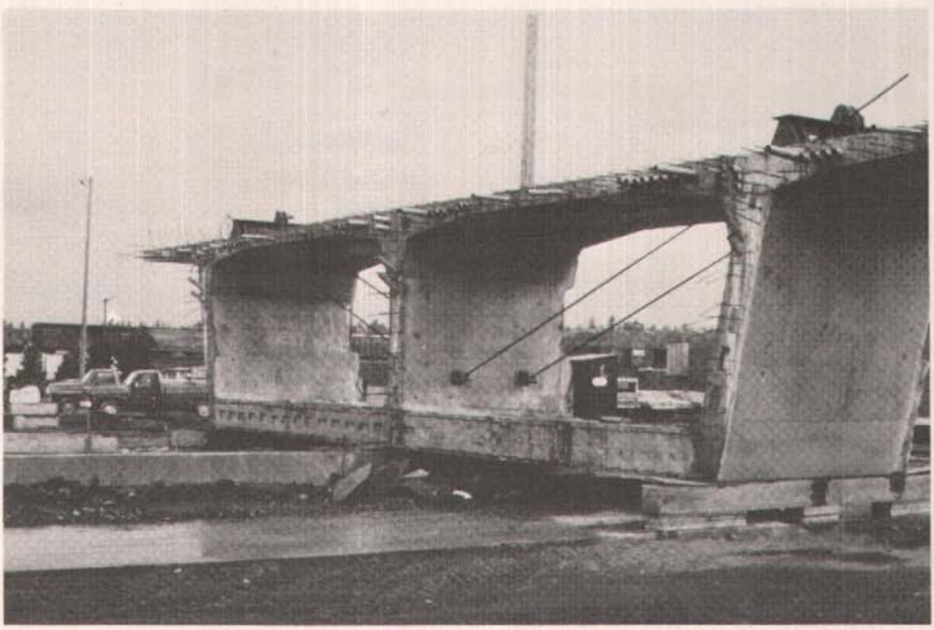

Fig. 4. A two-cell box segment during handling, requiring diagonal tendons to transfer weight of inner web to the outside webs (I-205 Columbia River Bridge).

Fig. 5. Curved tendons forcing themselves out of the webs of a segmental box (Las Lomas Bridge, California).

through the quarter-span point in order for the two cantilevers to reach midspan. After closure, the midspan point is made continuous and the quarter-span hinge is transformed into a permanent hinge. While such a method has been and can be successfully carried out, it is a costly and fairly complex operation requiring additional construction time.

It is believed that the midspan permanent hinge can be constructed without undue deflection under certain conditions:

(a) Long-term deflection at a midspan hinge can be more reliably predicted (including the effect of creep, shrinkage, and temperature differential) for short spans and for spans with high depth-span ratios and uniform sections than is the case for slender, long, and haunched spans. It follows that if the elastic deflection is small, then the time-dependent deflection will also be small.

(b) Midspan deflection can be better controlled if longitudinal prestress is used over and above that required by the code. This will result in more uniform stress blocks at critical points (for example, near the piers) so that any variation in the modulus of elasticity, creep factor, friction expectation, weight, and other vari-

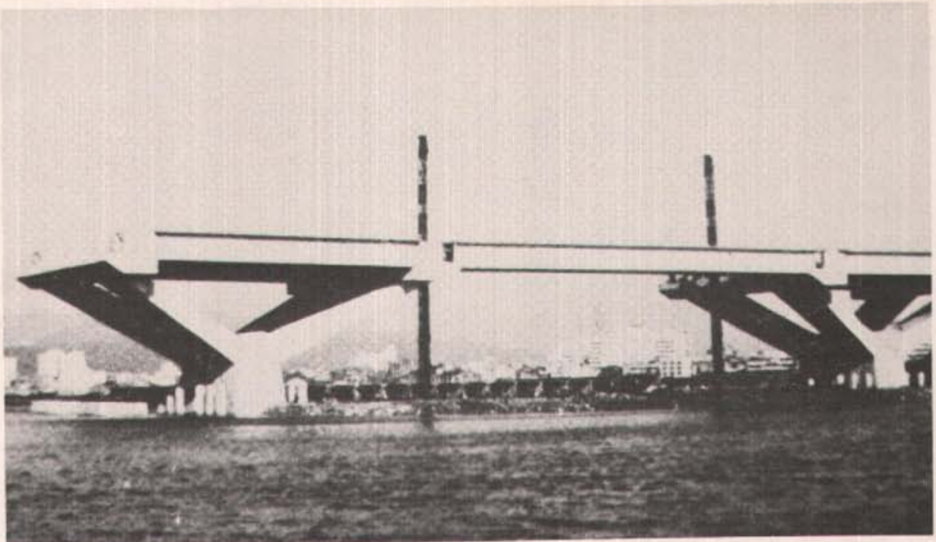

Fig. 6. Chung Hsiao Bridge, Taiwan. Built of I-girders, with lengths of 165 and 99 ft (50.3 and 30.2 m) span and 264-ft (70.5 m) centers between piers.

ations will not cause serious deflections at midspan. The addition of these tendons can be less expensive than the construction process needed to provide quarter-span hinges, especially in shorter spans.

If deflection control is needed, ducts can be provided to insert additional tendons:

(c) The addition of unbonded tendons across the midspan hinge to raise the midspan point can be used to control the amount of deflection at midspan and yet permit horizontal movement at the hinge. This technique is very effective and has been used in the Rio Colorado Bridge in Costa Rica.

The above techniques are alternatives offered in controlling deflection at midspan hinges, thus eliminating quarter-span hinges, which generally are objectionable from a constructor's viewpoint. Whether these alternatives are a more economical solution will, of course, depend upon the circumstances.

## Choice of Deck Sections

In segmental construction there are many types of deck sections that can be considered. So far, the most popular type has been the box shape, particularly the single box, which is convenient for both precast segments and in-place construction with travelers. The box section can be used up to about 70-ft (21.4 m) wide roadway decks, using transverse post-tensioning. For wider roadways, double-cell or triple-cell boxes can be utilized, although they do require more complicated formwork and casting methods. Also, special handling methods are often needed to transport and erect a double-cell or triple-cell precast box.

It is important to note that the box section is not the only structural solution, and certainly not for short spans. For spans under 140 to 160 ft (42.7 to 48.8 m), a box is often uneconomical and not structurally efficient because the bottom soffit serves little structural purpose for such spans. Therefore, the soffit can be eliminated resulting in simpler formwork in addition to re-

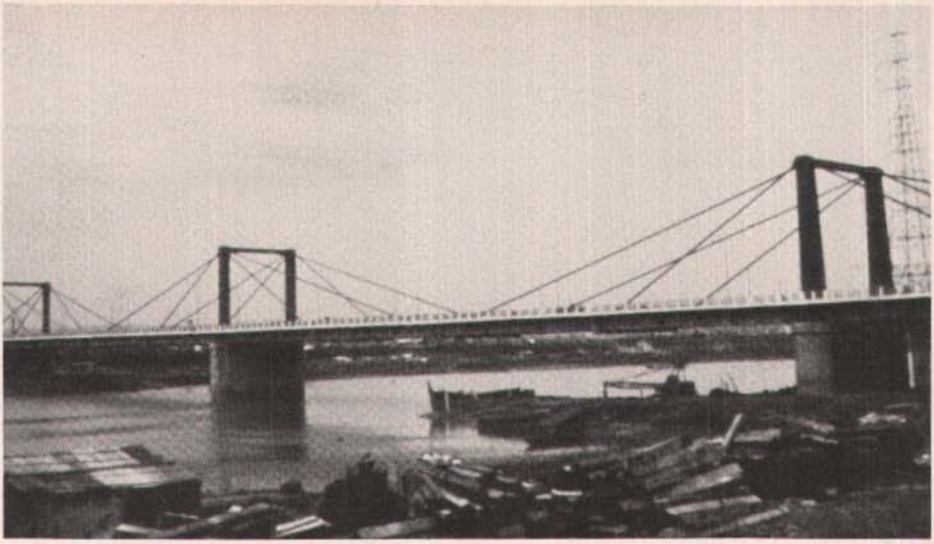

Fig. 7. Kwang Fu Bridge, Taiwan. Constructed with I-girders placed along four panels at 125 ft (38.1 m) forming a 500-ft (153 m) cable-stayed segmental bridge.

ducing the amount of concrete, reinforcing bars and tendons.

For positive moment resistance, the T-shape is much more efficient than the box shape. It is only when the span gets long, and the negative moment requires a heavier bottom soffit near the piers, that a box section becomes more suitable. Indeed, when the depth at the piers can be increased, the T-section will be more economical for even longer spans.

The I-section, although seldom used for transverse segmental construction in the manner that a box segment is, has nevertheless been used in longer segmented spans with several of them placed in parallel to form the width of the bridge deck. In addition, standardized I-beams have been used very effectively as approach spans in combination with the main segmental spans, as was done recently for the Houston Ship Channel Bridge.

I-girders, similar to the AASHTO I-sections, have been economically used for spans up to 264 ft (80.5 m) by incorporating Y-shaped piers, which shorten the center span to 165 ft (50.3 m), as in the Chung Hsiao Bridge (Fig. 6). I-segments have also been used for cable-stayed segmental construction, with four 125-ft (38.1 m) panels forming a span of 500 ft (153 m), as is the case with the Kwang Fu Bridge (Fig. 7).

The waffle section is another interesting type. It uses precast bathtubs placed upside down, which are joined to form a bridge deck without epoxy. Concrete is cast between the waffles on all four sides, thus integrating the waffles into one deck. Tendons are placed between the waffles and post-tensioned in two directions to transfer the load as desired.

This type of segment will accommodate wide bridges, which essentially span in two directions, as for example the Hegenberger Bridge (Fig. 8). The width of this bridge is over 100 ft (30.5 m), with a span of 300 ft (91.5 m) supported at the four tips of Y-piers. This design reduced the actual suspended span to only 160 ft (48.8 m). Note that waffle construction is being applied at the San Juan Airport in Puerto Rico (see

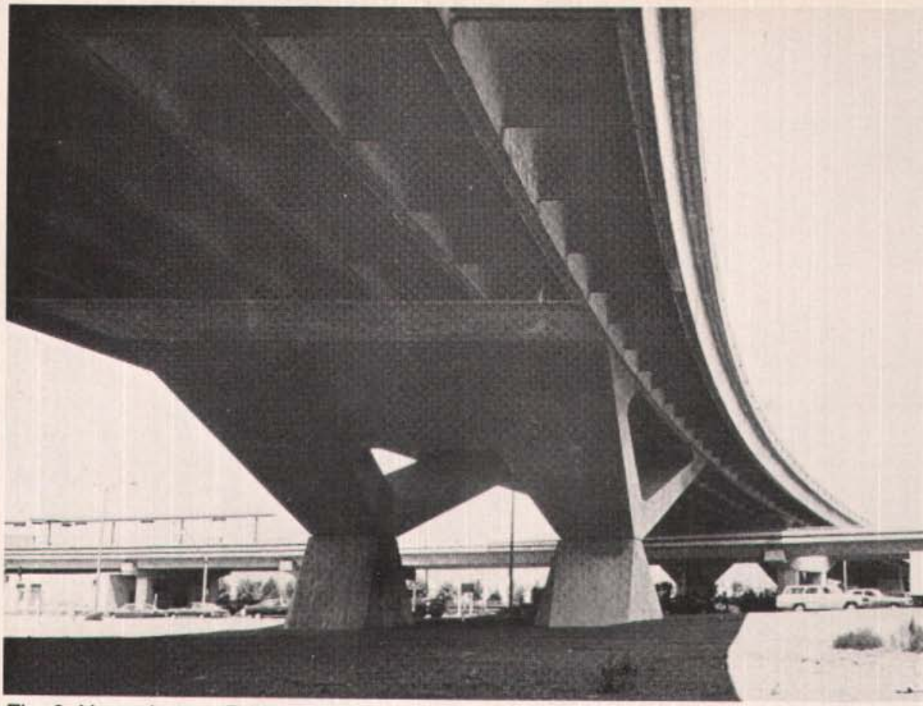

Fig. 8. Hegenberger Bridge, Oakland, California. Built of precast waffle segments post-tensioned together in two directions.

Fig. 9. Airport Bridge, San Juan, Puerto Rico. Constructed with waffle segments.

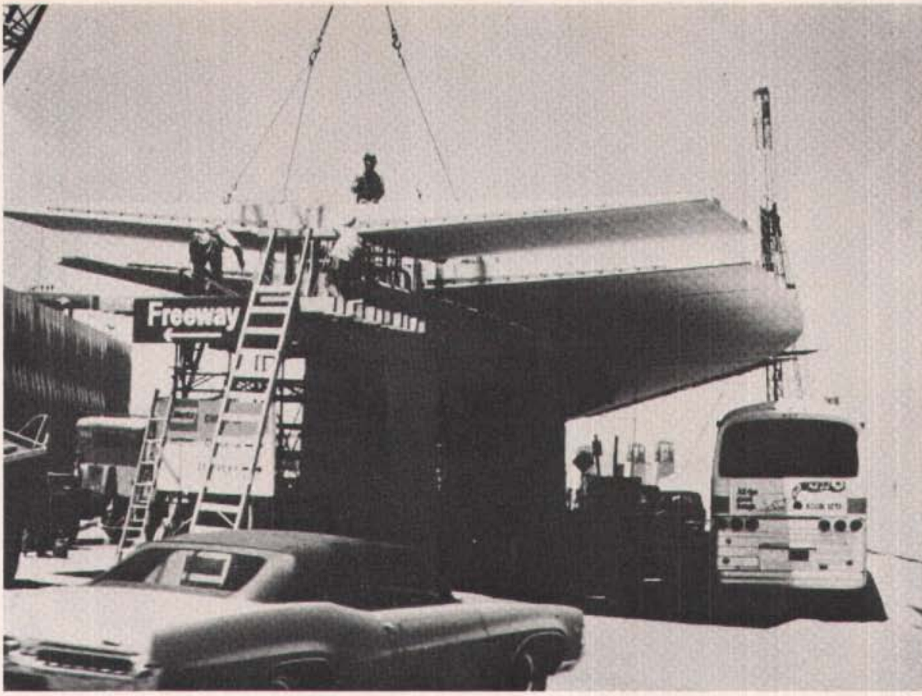


Fig. 10a. San Francisco Airport Elevated Roadway Bridge. Built of precast wing segments without match casting or epoxy joinery.

Fig. 9) and has been found to be extremely economical in the accommodation of curved sections. The system fits particularly well when columns form a more or less square pattern.

A further interesting section is the wing type element which was initially developed for the San Francisco Airport (Figs. 10a and 10b). Here the wings were precast at a conventional long-line pretensioning plant. These precast segments require only straight pretensioned tendons, which run along the top of the wing ribs and resist the transverse cantilever moments. The wing segments are placed side by side leaving a small gap between. They form the shell, on top of which the deck concrete is cast. The spinal beams carry the longitudinal moment and are post-tensioned to transmit the load to the pier supports. This design allows for an extremely economical production and erection procedure, without the use of match casting or epoxy. The wing elements are spaced ½ in. (12.7 mm) apart and the joints are taped prior to in-situ casting. The pieces are not in direct contact and therefore the question of tolerances is not a problem.

These wing sections were also employed in Bogota, Colombia (Fig. 11), where an international bidding contest showed this design to be the most economical; to-date, six intersections have been built by this method. The wings are supported on steel forms for the deck and spinal beam concreting. These forms span only 16.5 ft (5.0 m), thus requiring supports at 16.5-ft (5.0 m) centers and permitting cross traffic to go under. However, the forms are adaptable and can be lengthened to 30 ft (9.2 m) or more if required.

Currently under design is another bridge in Vancouver, Canada, where

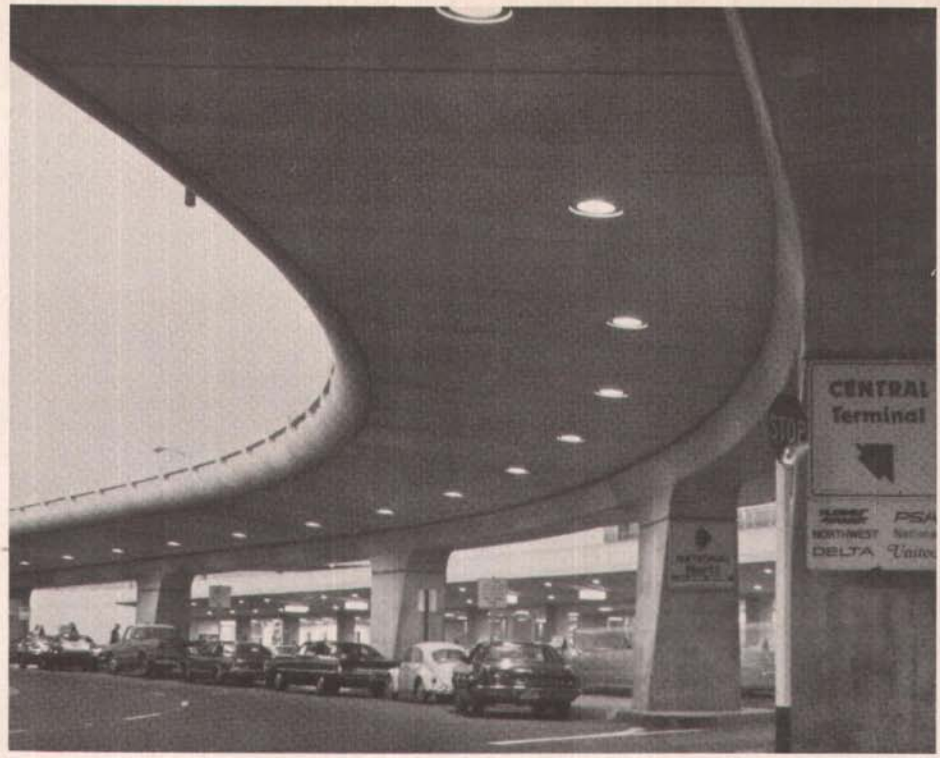


Fig. 10b. Finished view of San Francisco Airport Elevated Roadway Bridge.

these wing sections will span up to 138 ft (42 m). This type of construction is definitely more economical for shorter spans; however, it does consume more in-place concrete and is heavier than normally precast sections. Nevertheless, the elements can be produced by conventional pretensioning plants in North America and can be erected by constructors without much experience.

## Fabrication and Erection Techniques

Although epoxy joints have been used extensively in North America, they frequently create problems for the inexperienced constructor. Also, match casting allows little room for adjustment if dimensional inaccuracies occur during placement or storage.

It is suggested that other means of joinery should be explored. For short spans, some box segments have been match cast but joined without epoxy. For larger spans, wet joints should be explored, e. g., using formed joints several inches thick which can be grouted in place. Such joints require special forming at the connection, but the formwork can be highly mechanized. Furthermore, the formwork may extend over several segments so that forces can be transmitted across the wet joints through the steel forms, until the grout has hardened. Then the steel form can be moved ahead to the next joints.

This method, if explored properly, can be an economical approach, avoiding the use of match casting and epoxy jointing altogether. Such a system could be developed in North America but will need close cooperation between design engineer and contractor.

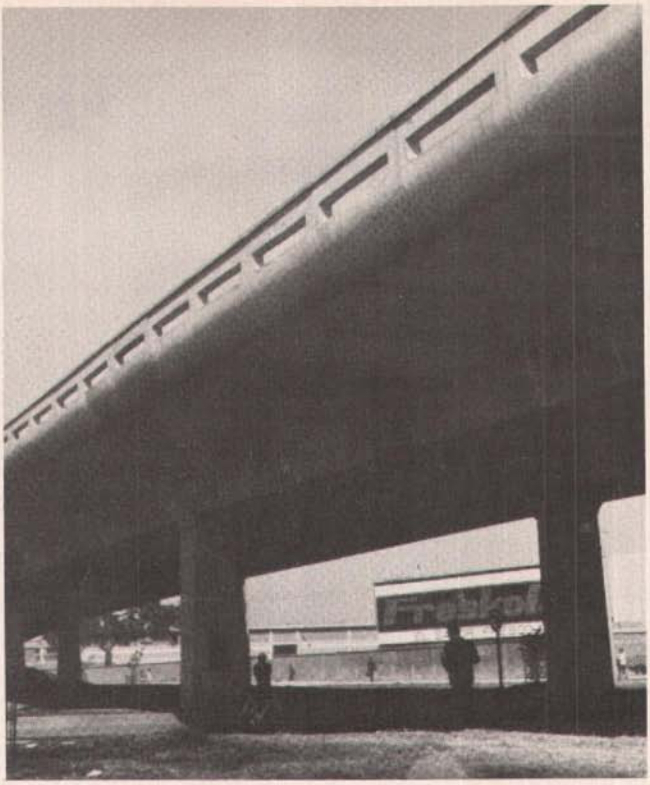

Fig. 11. An overcrossing in Bogota, Colombia. Constructed with precast wing segments.

## Span-by-Span Casting Versus Precasting

While double cantilever construction has developed essentially along two methods of construction, namely, (1) match precasting, and (2) traveling forms with in-place concreting, span-by-span construction has barely begun in North America and much work remains to be done in this area.

The use of travelers has indicated that there is an important place for in-place concreting, due to the availability of ready-mixed concrete trucks, movable concreting plants, and pumped concrete. For double cantilever bridges, in-place concreting has proven to be economical under certain conditions, specifically for very long spans, curved soffits, and a relatively small number of span repetitions.

In span-by-span construction, the use of launching trusses for in-place concreting may have a promising future in the United States. The problems concerning launching truss forms traveling from pier to pier can be solved by American constructors and engineers. Such trusses can move in a variety of ways. They can be underslung, traveling upon brackets established at pier tops. Or they can be overslung, traveling above the bridge deck to cast the segments. The forms can then move along, leaving the cast elements to be lowered into position. Such methods can be justified when there is enough repetition of spans.

It might be mentioned here that in

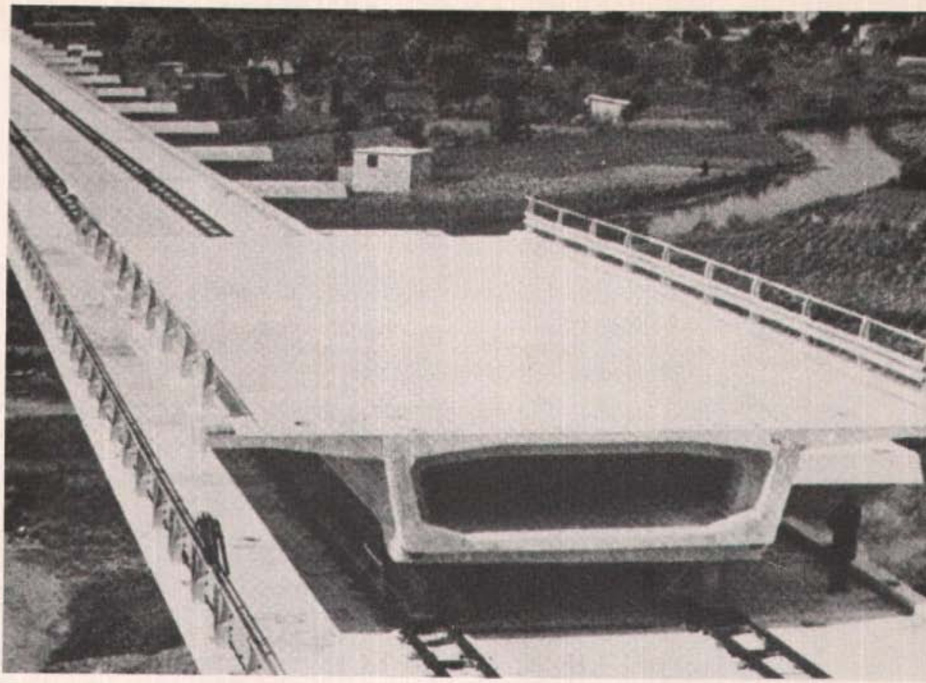

Fig. 12. Precast whole spans (in Italy) pushed along completed portion of bridge toward its destination.

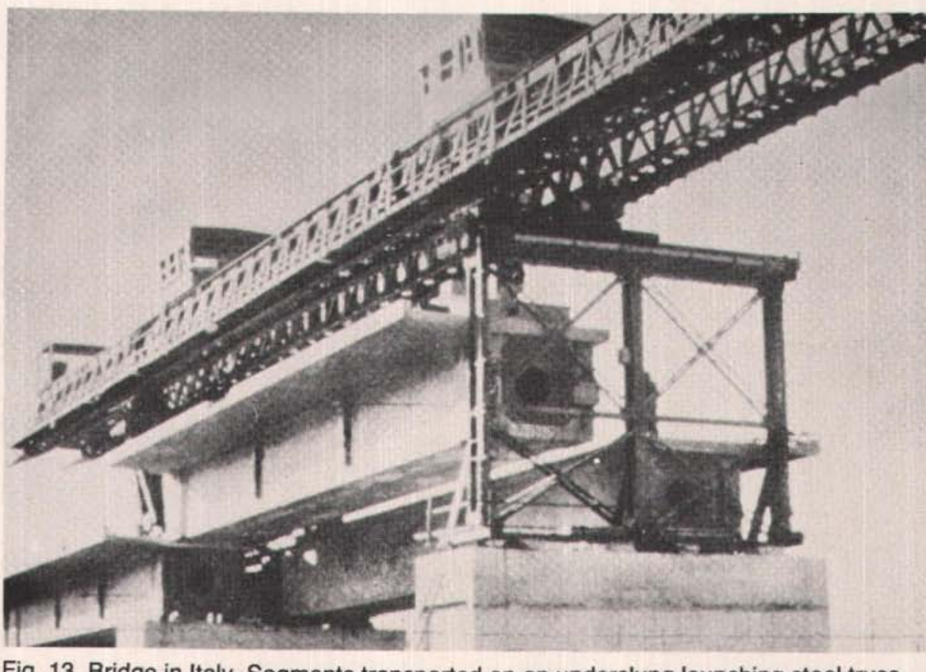

Fig. 13. Bridge in Italy. Segments transported on an underslung launching steel truss.

some European countries whole precast spans are hauled overland with trusses that are either overslung or underslung, as indicated by the photographs from Italy (see Figs. 12 and 13). Note that for heavy or wide bridges, they can be launched in half-spans.

From the experience gained so far, it appears likely that segmental concrete bridges will continue to be constructed using a variety of methods. There will, therefore, be an important role for both precast and cast-in-place construction, either done separately or in combination.

## CONCLUDING REMARKS

It appears obvious that in a large continent, such as North America, the development of bridge construction does not necessarily have to follow European or any other practice. Of course, we can always learn from others, but to adapt other methods to conditions here may require an open mind and different approach. Some of the peculiarities of American conditions are enumerated as follows:

1. Since the conditions in North America are so diverse, it is not easy to develop a highly specialized and specific method of construction which will be established and practiced among all contractors throughout the continent.

2. Again, because of its large size, conditions are quite different across the country. Geographically, labor supply and a contractor's experience can vary greatly, requiring different construction approaches.

3. There are many innovative contractors in North America in addition to a large number of contractors who are very conservative and only accustomed to traditional methods. In order to utilize the advantages of both factions, the design must be made in such a manner that most, if not all, contractors can combine their inventiveness.

4. There are both large and small contractors in North America. For certain bridges we should utilize small, local contractors while for others, bigger contractors must be brought in from elsewhere. This is unlike Europe, where countries are small and the larger contractors can cover the entire country, perhaps without much competition.

5. American contractors are extremely innovative even though they often do not work with engineers in design. North America has an established industrial base in machinery design and supply. If given the opportunity, mechanized production for multiple spans can become extremely economical.

6. In America there are well over 500 precasting plants. Although their equipment, experience, and capabilities are somewhat different, most plants have product versatility and innovative personnel.

7. There are several experienced post-tensioners who innovate and compete. They can supply tendon hardware or post-tensioning technology as needed. It should be possible to combine their expertise with the constructors in an optimum manner.

Finally, while we are interested in introducing segmental construction methods from other countries, we should also broaden our own viewpoint. We should visualize segmental construction as consisting of different types and forms of segments, different methods of precasting or concreting, and different ways of transportation, erection and joinery.

From that viewpoint, segmental concrete bridge construction is only beginning in North America. Unquestionably, the practice will expand and vary as experience is gained and as the engineers work together with the constructors to come up with economical ways of designing and building bridges which in turn will also attract the attention of the international engineering profession.

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