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PRECAST SEGMENTAL BRIDGES - STATUS AND FUTURE DIRECTIONS

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ABSTRACT

This paper provides an overview of current practices in precast segmental bridge construction. Various techniques for segmental construction are presented, and different aspects related to the erection are discussed. These include the erection methods, prestressing systems, geometric control and other problems which are discussed in the context of previously built bridges. Cross-section details, joints and the manufacturing of the segments are discussed next, and specific attention is given to problem areas and details that require close consideration in the planning, design and construction stages. Finally, present trends for future development in this construction technique are indicated.

INTRODUCTION

Concrete has been gaining popularity for medium to long span bridge construction in an industry that used to be the sole market for steel contractors (41, 44). This trend can largely be ascribed to the introduction of the relatively new method of segmental construction where the bridge is constructed in small segments. One increasingly used subset of this approach is the precast segmental method whereby segments of the structure are manufactured in a precast yard and then assembled on site. The increase in this type of concrete bridge construction can be ascribed (44) to the reduced amount of on-site labor, better quality control, increased speed of construction and an optimum use of material. Precasting the concrete segments now further gives concrete contractors the benefits of centralized and semi-mechanized production methods. Also, inclement winter weather has less effect on the construction of the bridge. A number of bridges have been constructed in this way, at costs comparable to steel alternatives.

The objective of this paper is to give an overview of precast segmental bridge construction. Different segmental techniques are first discussed and the differences between the precast and cast-in-place methods are pointed out. Then the erection or assembly of the precast elements are discussed, and reference is made to the methods of prestressing, geometric control, stability during the erection, and a number of problems that have occurred on previous projects. Next, details of the precast elements are discussed. These are related to the type of cross sections, joints between elements, and the fabrication of the elements. Finally, general problem areas with this type of construction are discussed and directions for future development are indicated.

SEGMENTAL CONSTRUCTION TECHNIQUES

Segmental bridges can broadly be defined as those that consist of a number of small segments fabricated either in their final position or in some other location and then assembled to form the bridge. Typically the size of each element is considerably less than a span length, and usually covers the full width of the bridge.

The traditional cast-in-place method consists of casting the segment in its final position in the bridge against the adjoining element. Formwork is erected in the final position, reinforcing steel and ducts for prestressing cables placed in position, and the concrete poured. After the concrete has reached sufficient strength, prestressing tendons are inserted and the new section stressed against the existing part of the bridge. As no further construction can commence before all work on a segment has been completed, the total construction time for the project depends largely on the curing time for the concrete and the segment lengths. The high quality concrete required usually necessitates an on-site batch plant, as well as sophisticated equipment for placing it. Formwork is usually nonstandard and must be self-supporting; the total capital investment of the contractor may therefore be high.

A more recent development, introduced initially in Europe, is to fabricate the segments in a precast yard. Standard precast techniques for placing and curing the concrete are used to obtain high levels of quality in strength and finish. The manufacturing plant may be situated at a convenient location with direct access to materials and labor. These elements are then assembled on site to construct the final structure.

Shear transfer across joints between the segments depends on mechanical interlock of shear keys on the contact faces, as well as the bonding agent (if present), the prestressing forces in the cables, and friction of the contact surfaces. Usually epoxy resin is used as an adhesive in most of the joints. Initially cement mortar was used to form the joints between segments, but this practice was abandoned and currently contact joints are used in the majority of bridges (31).

A combination of the precast and cast-in-place methods was used to construct a few bridges (31,36,37). One alternative is to use precast elements to form the central core of the deck, and then add the cantilever section of the deck after the structure is self-supporting. This reduces the dead load during the construction without significantly reducing the strength at the supports.

ERECTION

3.1 Erection Schemes

Four different methods of constructing the bridge can be followed. These are the balanced cantilever, span-by-span, incremental placing and incremental launching methods. The best erection method for a specific bridge depends largely on the total length of the bridge, the individual span lengths, the height of the bridge along its length, access to the area below, and the availability of specialized equipment.

Balanced Cantilever Method

Finsterwalder introduced the balanced cantilever method (Figure 1) in Europe during the early 1950's (36) and since then the method has been used for a large number of medium and long span bridges. Construction of the superstructure commences at one of the columns, for which the first (column) segment is either cast-in-place (e.g. Columbia River Crossing (20)), or precast (e.g. Kentucky River Bridge (43)). Once this element has reached the required strength, the next segment can be added to it in a cantilever manner. Either cast-in-place or precast segments can now be used. Subsequent elements are then added to either side to extend the cantilevers in both directions.

The unsymmetrical number of elements on either side of the column induces a large unbalanced moment at the column. Sufficient anchoring has to be supplied for the column segment to resist this moment (11), and usually the column has to be enlarged to take care of this. Most often, temporary restraints are used and are released or removed once continuity with adjacent spans has been established. Certain types of launching girders (33) can provide additional support which reduces the need for enlarged columns.

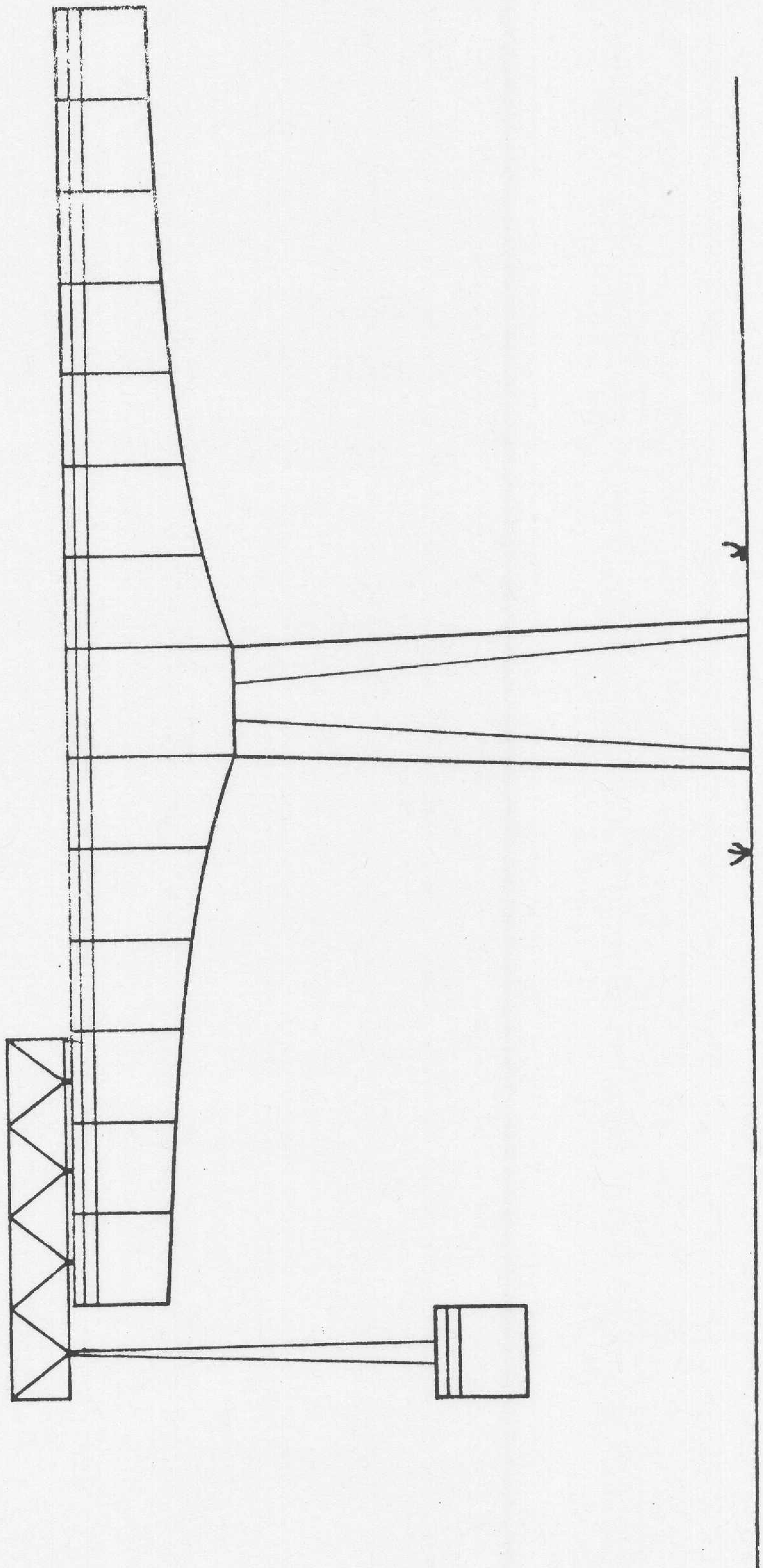

FIGURE I

SCHEMATIC REPRESENTATION OF CANTILEVER ERECTION METHOD WITH A LIFTING TRUSS

A coat of epoxy resin is usually applied to the joint surfaces prior to placing the segment in its final position. The precast element is then held in position by applying a constant pressure with temporary prestressing bars (Dywidag or similar bars), or by stressing some of the final prestressing tendons (29). The shear strength provided by the keys is sufficient to allow work to continue on the installation of the next segment.

A large variety of equipment can be used to transport the concrete or precast segments to the end of the cantilevers. The availability and cost of the equipment and access to the bridge usually determines the specific type of equipment.

A few examples of bridges where the balanced cantilever method was used in the U.S. are the Kentucky River Bridge (43) near Frankfort, Kentucky and the Kishwaukee River Bridges (26) near Rockford, Illinois, as precast bridges, and the West Seattle Bridge (23), which was cast in place.

Span-by-Span Method

The span-by-span method (Figure 2) requires a supporting system to support the entire length of the span during erection or construction. Consequently, the method is only applicable to shorter spans.

The method has been used extensively for cast-in-place bridges, and a number of variations have evolved. Segments can either span between supports, cantilever balance points or points of inflection. In the latter case, hinges are usually inserted at these points to enforce zero bending moments here. A relatively heavy supporting truss is necessary for the casting process. The truss can be fixed to the columns to support the formwork from below, or formwork can be hung from a truss above the deck. The major disadvantage of the latter procedure is that access is restricted by the truss. In some cases this method was used to construct the central load-bearing section of the superstructure, and additional cantilevers to the cross section were added at a later stage when the structure was self-supporting (36).

Only a few precast segmental bridges have been built in a span-by-span manner. A supporting truss attached to the piers or scaffolding supports the segments before they are prestressed. In the U.S. the only structures constructed in this manner are the Long Key and Seven Mile Island Bridges in Florida (13, 15) and the Wischasset Bridge in Maine. In Britain the Western Avenue Extension (19) and the Izarco River elevated motorway in Italy (16) are examples of the method.

Incremental Placing Method

The incremental placing technique (Figure 3) is very similar to the balanced cantilever method, except that construction starts at one abutment and advances in only one direction. No balancing construction is added to compensate for an out-of-balance moment,

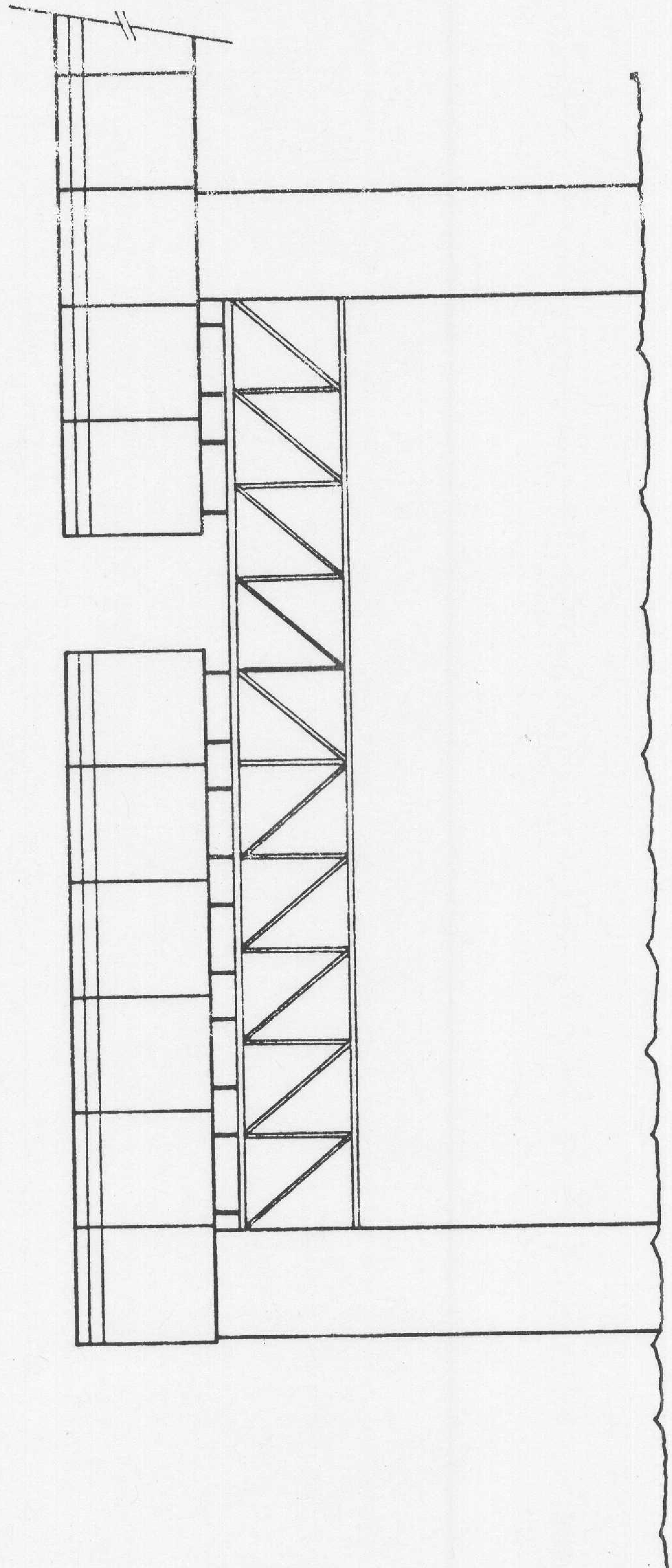

FIGURE 2

SPAN-BY-SPAN ASSEMBLY ON A STEEL TRUSS

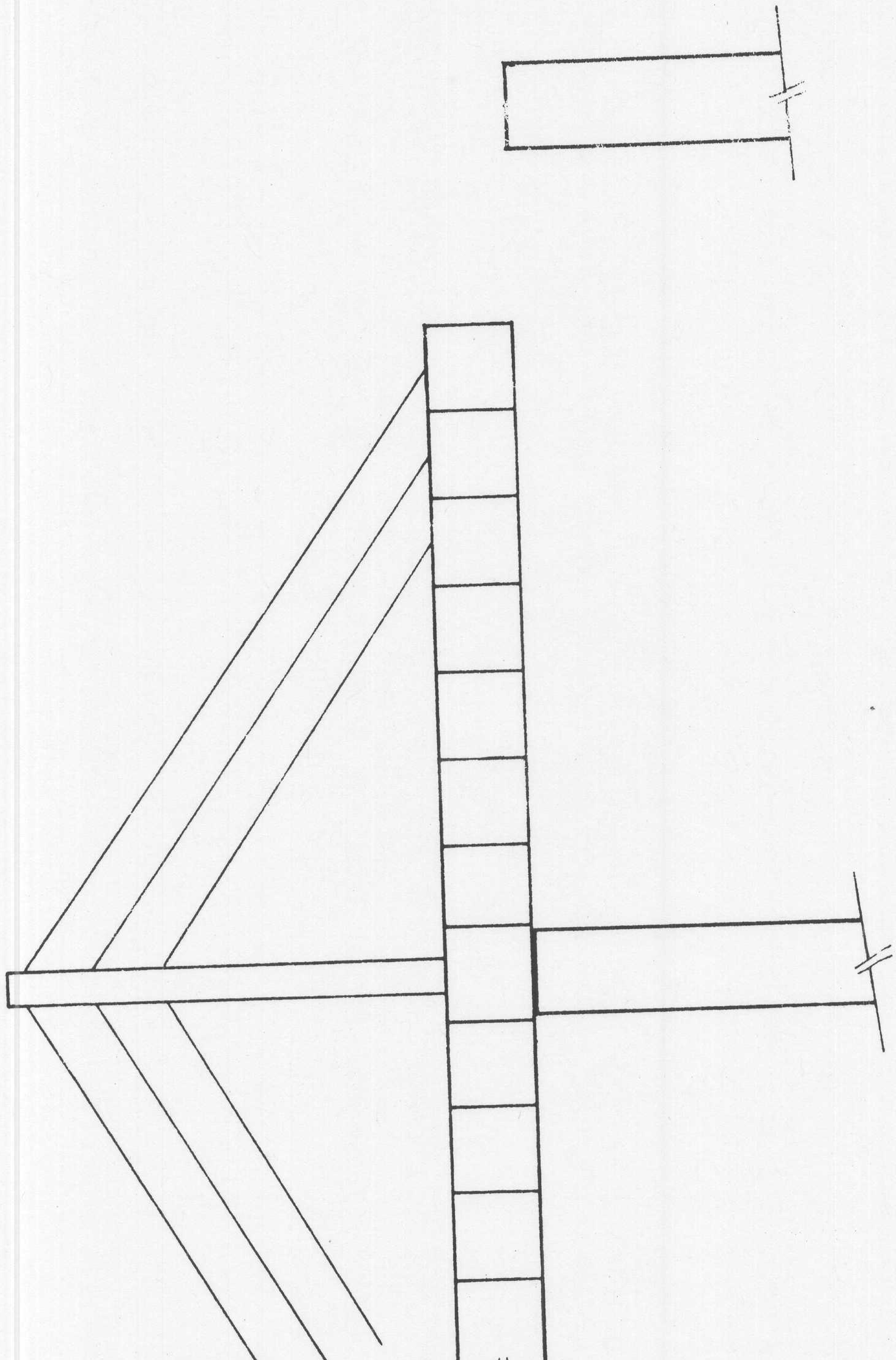

FIGURE 3

INCREMENTAL PLACING MATHOD WITH A TEMPORARY CABLE STAYS so that temporary supports have to be provided to keep the depth of the cantilevers within reasonable limits and ensure an economically viable proposition. These temporary supports are typically removable steel columns or cable stays, supported by temporary pylons at supports which eliminates the need to resist the large unbalanced moments in the columns.

Span lengths fall in the range of 30-50m (31). Examples of the method are the Linn Cove Bridge (North Carolina) (7) and a number of bridges in France (29).

Incremental Launching Method

With this method, after the supports have been completed, the first section of the deck, ten to thirty meters long, is cast on one of the abutments and a launching nose is attached to the leading tip of the deck. This precast assembly is then pushed forward to bridge the first span. A new segment is then cast on the abutment to form a continuous structure with the previously cast element. Prestressing is applied centrally and the deck moved forward again with hydraulic jacks. This process is repeated until the bridge has been completed. The launching nose on the leading tip of the deck reduces the free cantilever length of the leading span. The length of this steel truss is usually from 30 to 50% of a span length. Maximum span lengths are approximately 60m without any temporary stays between supports, while lengths of up to 100m can be attained by supplying temporary supports to reduce the free cantilever moments (18).

A limited number of incrementally launched bridges have been completed worldwide, and to date (1983), only in one case (Wabash River Bridge, Indiana (1, 8, 18) has the method been used in the United States.

Other

Conventional bridge forms are also constructed segmentally, and in most cases examples can be quoted where precast segments have been used. Cable-stayed long-span bridges have gained wide popularity, and in at least one case (Pasco-Kennewick Bridge (2)), precast elements were used. Both the deck and the arch of an arch bridge can be built with precast elements. One example where precast elements were used for the arch is the Gladesville Bridge in Australia (36).

3.2 Stressing Systems

The conventional method of prestressing a segmental precast bridge is to include ducts in the segments. The tendons are then threaded through these after the segment has been placed in position. With the balanced cantilever method there are two seperate sets of cables. The first set resists the cantilever moments during construction, while the other enforces continuity after the closing joint has been cast.

In some bridges that were built during the initial development of the construction type, the cable anchors were placed on the contact area in the web of the segments. This requires that all stressing be completed before the next segment can be installed. A number of variations of this method are now used. To overcome the problem of the anchors in the webs, anchors are now placed either in recesses in the slabs or in small protrusions (called "blisters") on the surface. This method has the advantage that more cables can be added at a later stage to reduce sagging at midspan due to creep.

Another alternative is to use external cables that run inside the box girder, but not in the concrete. The long Key and Seven Mile Bridges (13) are typical examples. The cables are anchored in the segments, and are protected from corrosion by polyethelene tubes.

On the Kishwaukee River Bridge (26) straight bars were used as longitudinal prestressing reinforcement. The main advantage is that the friction losses are considerably less. Straight Dywidag bars are used in many bridges as vertical shear reinforcement.

On large segments it is often necessary to apply transverse prestressing force to eliminate tensile stresses when stripping the framework. On one project (12) the prestressing induced high moments and excessive deformations in the deck slab. Two adjacent elements which were match-cast no longer matched after applying the prestress to the new elment. To avoid these problems, the amount of prestressing should be kept to the minimum during the initial stage before assembly.

3.3 Geometric Control

During construction of a segmental bridge, close control of the deflections of the structure is required to achieve a continuous structure with a smooth deck surface. Due to changes in loads, creep, shrinkage, and elastic deformation, the shape of the structure changes constantly with time. On span-by-span constructed bridges this effect is not so serious, but on balanced cantilever and progressively placed bridges, these changes will affect the relative positions of the deck at the points of closure. Consequently, elements have to be cast with an additional camber that counteracts these effects to obtain the required final shape. Matters are further complicated when the bridge is on a vertical curve, and even more when a horizontal curve with changing superelevation has to be accomodated (9).

A number of research projects have been conducted on the behavior of segmentally constructed bridges (24,38,40,42). Computational methods, which take the creep and other deformation properties of the concrete into account, have been developed to predict the deflections during the construction time and afterwards. These methods have been used successfully on a number of projects (21,28). The geometric control should be planned well in advance before construction commences, and close supervision during erection is needed to compare deflections with the predicted results. Should the actual deformations be excessive, adjustments can be made by using shims to change the joint thicknesses. These remedial measures should, though, be kept to the minimum.

3.4 Stability

Due to the immense complexity and range of loading conditions that can be expected during the construction of a segmental bridge, special precautions have to be taken for the stability of the partially completed substructures. All possible extreme loads and adverse weather conditions should be taken into account, and the absolute safety of temporary support measures should be ensured at all times.

A new approach to the requirement for safety of segmental bridges during construction was recently developed for the Ontario Highway Bridge Design Code (32). The main objective of this method is to limit the probability that any subassembled section of bridge will become unstable during construction.

Although this approach will be sufficient to guard against global instabilities, particular attention should also be given to the strength of local, small restraining devices. These include the holding-down prestressing tendons used to anchor the balanced cantilevers, temporary jacks and bearings, as well as spacer blocks used during the installation of expension joints. Especially the balanced cantilever construction method is prone to these problems. Their low degree of indeterminacy increases dramatically the effect of any of these failures.

3.5 Other Erection Problems

Designs very often differ substantially from each other, so that very little equipment used on a project can be reused in the future. This is particularly true for forms and erection equipment such as gantries, trusses and lifting devices. Usually all these have to be designed and built from scratch for each project, which then necessarily increases the costs and the time required to get everything operational (33), and prolongs the training process of the personnel.

The usual care should be taken to prevent any cement mortar from entering the cable ducts prior to threading or stressing the tendons. After the tendons have been stressed, grout tends to enter adjacent ducts when mortar is being injected. The leakage usually occurs at the joints between segments where there is no easy way of isolating the voids (29). It can be extremely difficult to open up these blocked ducts. Furthermore, grouting of the cables in the ducts can be a major operation requiring a special crew to perform the task. For those two reasons contractors seem to agree (21, 33) that the prestressing should be designed to allow the grouting to be done only after all the prestressing cables have been installed.

A problem may occur when additional prestressing is applied to the joints before the epoxy has reached the design strength. The higher stresses cause the epoxy to bleed into those ducts without tendons, and it can be a major expense to remove these obstructions (28). Any voids left in the webs by the block-outs of tendon anchors must be filled with grout to prevent ice from forming here.

Due to the complexity of a long-span bridge, a number of different parties are involved in the planning, design, bidding, construction, and maintenance of the structure. This should be kept in mind from the outset of the planning stages to allow for any conflicting interests that might develop into contractual claims. The modern trend to allow alternative designs by the contractor further complicates questions of responsibility for the safety of the designs and possible cost over-runs.

Examples are numerous. Disputes erupted between precasting and prestressing sub-contractors on a project when certain elements failed due to excessive stresses (22). On another project the contractor had major problems with the launching gantry that had been designed and built by him, and expected the client to reimburse him for these expenses (12). Similar problems also occurred on other projects (17). Proper forward planning on the technical side, as well as paying the necessary attention to contractual and organizational matters during negotiations between the different parties, can reduce these problems.

SEGMENTS

4.1 Cross Sections

The majority of segmental precast bridges have single or double cell box sections. Various typical shapes are given in the references (3, 39, 37). Three-cell box girders may be used for large sections, but the stability of the segments prior to assembly can pose serious problems and temporary stiffners often have to be added. Inverted T-sections with lateral webs were used on the Pasco-Kennewick Bridge (1).

On a number of projects (12), very complicated forms had to be used for the elements. At small surface irregularities, such as "blisters" that were required for prestressing cable anchors, it was virtually impossible to compact the concrete satisfactorily. Honeycombing also occurred at the bottom corners of the section, where compaction can be very difficult. To overcome some of the honeycombing, contractors are now using a new stressing device (12) which enables them to place a cable anchor in a recess in the concrete.

On certain sections of the Columbia River Crossing Bridge (17) severe concrete spalling occurred. This is usually caused by too many prestressing ducts in a thin concrete plate (27). It can also cause honeycombing when concrete cannot be compacted satisfactorily. During construction, prestressing ducts are often damaged or misplaced. Threading tendons through these ducts can be virtually impossible, and friction losses increase significantly. Heavier ducts would certainly reduce these complications at a fraction of the cost of the remedial work.

4.2 Joints

Due to the discontinuous unprestressed reinforcement across the joints, the joint regions can be the weak points in many segmental bridges. The construction method determines the type of joint that can be used, but should in all cases be designed with the following objectives in mind.

(a) in compression, shear and tension, the strength of the joint should be sufficient for any design load case;

(b) acceptable ease and speed of construction should be maintained; and

(c) prestressing tendons should be protected from corrosion.

Both cast-in-place and contact joints are used for precast construction. Cast-in-place joints are formed by placing cement mortar or grout between two adjacent segments. A gap to 1 to 24 in. (25 to 600 mm) is left between two elements, which is then filled with the joint material. With contact joints, on the other hand, segments are placed against each other with, in most cases, an adhesive or bonding agent between the two elements.

The first few precast segmental bridges in Europe were built with cast-in-place joints which varied in thickness from 2 to 4 in. (50 to 100 mm). These joints have become more and more unpopular, since extended curing periods are required, and additional equipment is needed to keep the new segment in place. Presently, cast-in-place joints are still used to correct any misalignment of the bridge and for the final closing pour between two adjacent cantilever sections.

The majority of precast segmental bridges completed recently or currently under construction have contact joints with epoxy bonding agents, while a few have dry contact joints. The type of joint largely depends on the method of construction.

The main purposes of the epoxy are to provide some shear resistance before the full prestressing force is applied, to lubricate the contact surface while the new segment is being placed, and to protect the cables from corrosion due to moist penetration at the joints. On the Long Key Bridge (15) neither of these effects was necessary, since segments were supported at three points during placing and could consequently be maneuvered properly. Furthermore, the prestressing tendons were placed inside the box girder and protected against corrosion in separate polyethylene ducts.

A number of typical joint details are shown in Figure 4. The different types are the heel joint, and the single and multiple shear key designs. The relative merits of the different types are not clear.

Extensive research has been done to formulate the epoxy adhesives for these joints. On at least three bridges, though, (21,26,41) contractors had to take special precautions to prevent failure of the joints when the epoxy did not reach the required strength in time. One example is the Columbia River Bridge, (38) where additional heat was applied to improve the curing of the epoxy at low temperatures. The large temperature gradient, in turn, caused the concrete to crack. Strict guidelines for the use of the materials and the workmenship, as well as a minimum temperatures at which the epoxy can be used should be specified.

Experiments indicate that at ultimate loads large cracks can form at the joints in a segmental bridge (24). This is particularly the case under load conditions where the bridge deck is subjected to predominantly large bending moments. Due to the absence of continuous unprestressed reinforcement across the joint, the usual distributed crack pattern is replaced by a few discrete cracks. Under normal static load conditions these cracks do not seem to impair the integrity of the bridge. If the loads change and the condition of pure bending moment changes to a case of severe shear forces at the joint, the shear strength of these joints could in fact be greatly reduced. No experimental results or other research has been done in this area, and designers should provide sufficient prestressing reinforcement to ensure the safety of these joints.

Another problem is to ensure proper alignment of the prestressing ducts at joints to prevent unnecessary bending of the stressing cables which would result in high frictional losses. At match-cast joints this does not seem to be a too serious problem, but more severe problems could occur at the joints between a cast-in-place support element and the precast units adjacent to it (21).

4.3 Production Methods

The precast elements are manufactured by either the long or the short line methods. In the long line system a supporting bed is constructed which forms the base on which the elements are cast. The shape of this temporary structure follows the shape of the bridge span, but allows for future creep and other deflection discrepancies. Each element is cast in its correct relative position and it is necessary to set up the formwork for each individual element. For the short line process, on the other hand, the formwork is retained in one position and the previously cast element positioned in such a way that the required match-cast joint can be formed.

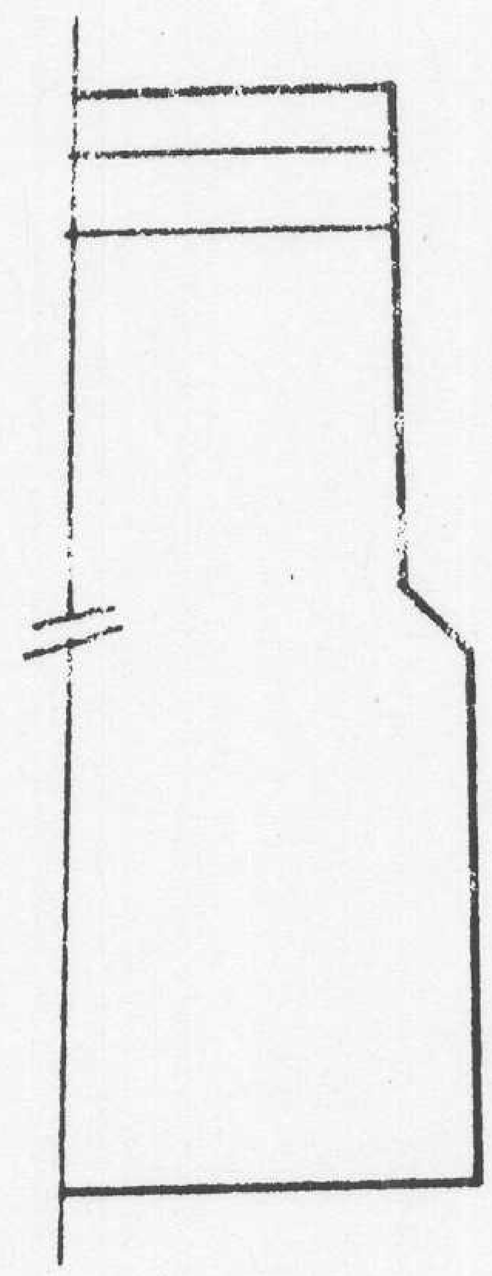

FIGURE 4A

HEEL TYPE SHEAR KEY

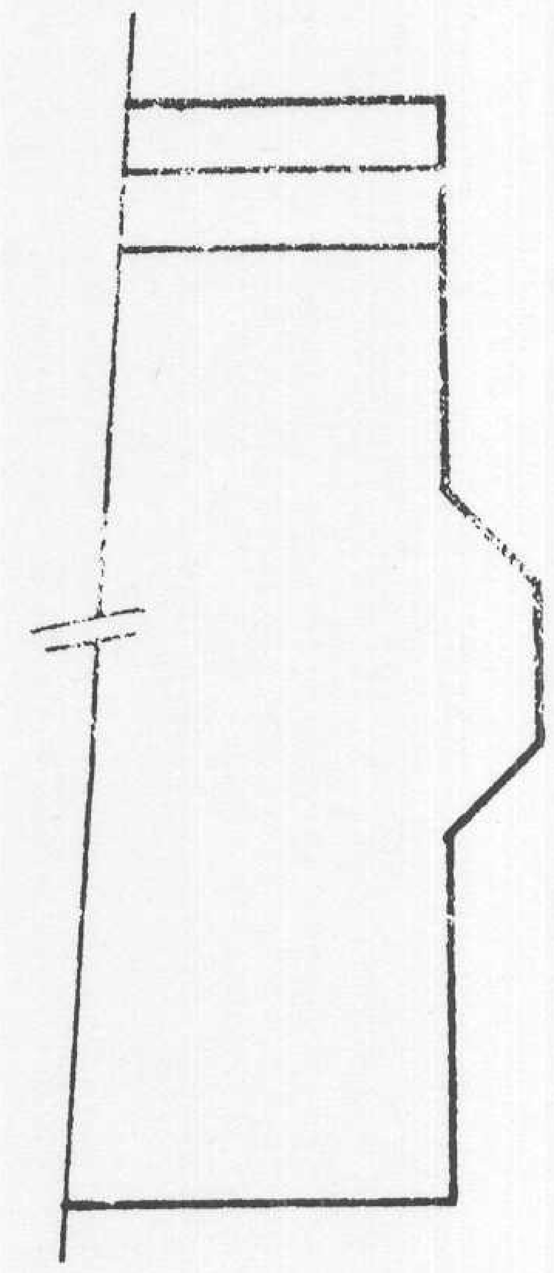

FIGURE 4B

SINGLE SHEAR KEY

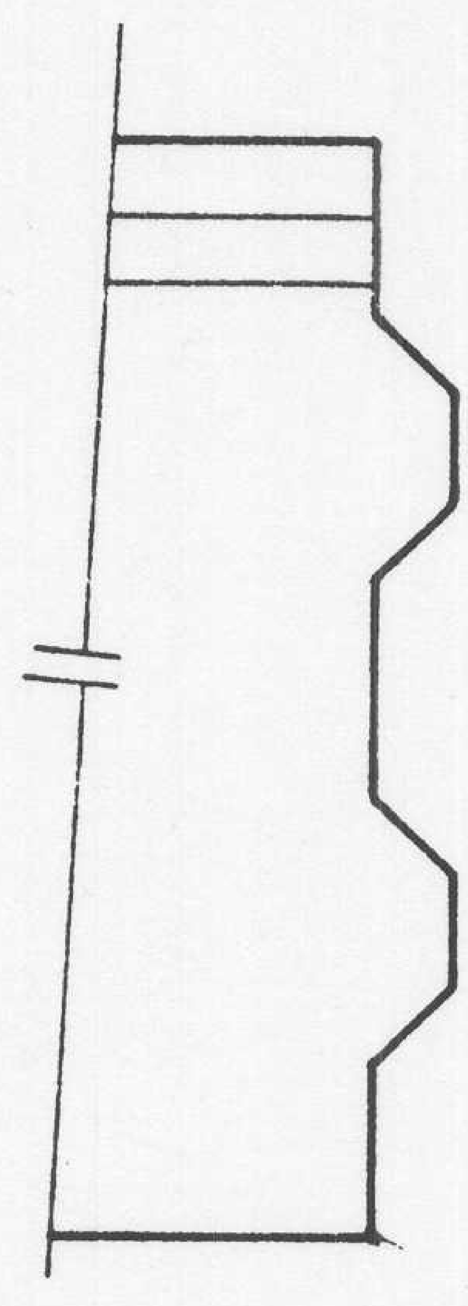

FIGURE 4C

MULTIPLE LARGE SHEAR KEYS

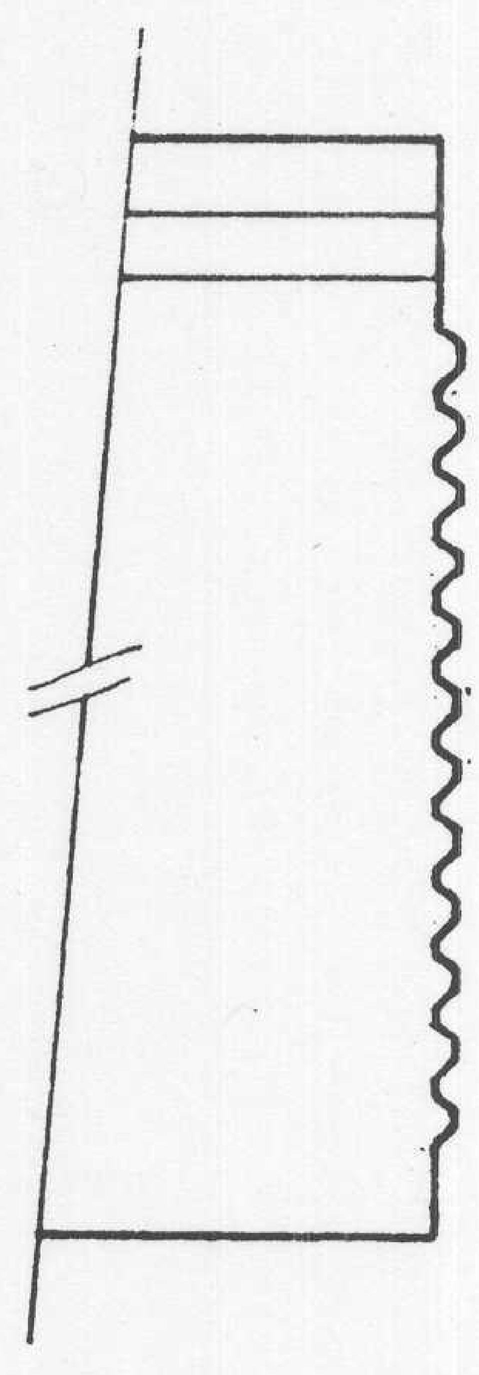

FIGURE 4D

MULTIPLE SMALL SHEAR KEYS

FIGURE 4

TYPICAL JOINT TYPES

Both methods are used widely. The main advantage of the long line method are that similar corrections are usually needed for each span, so that only one setup of the base structure is required for all the spans on a bridge (43). Consequently, costs for setting up the forms are considerably less. The short line approach needs much less space for the formwork, and the curing plant can be placed in a fixed location (7). A variation of the short line method was used on a number of bridges on the Rhone-Alpes motorway (31, 36) where the elements were cast in a vertical position.

The length of the elements varies between 6 and 24 ft. (2 to 8m) and depends largely on the available transport, lifting and prestressing equipment. In choosing the most suitable segment size, a compromise has to be made between using a constant length (which would then require less formwork adjustments) or a constant weight, in which case optimum use can be made of the transport and lifting equipment (28). The rate of erection for these bridges is controlled by the number of segments that have to be placed, and not be the strength of the concrete.

4.4 Concreting and Curing Techniques

The high design stresses and close tolerances on most parts require a high-quality concrete with small variation from the specified standards (34). The high initial strengths further complicate matters, since very high cement-water ratios are needed, which reduce the workability. These narrow tolerances are required to ensure satisfactory compaction and finish of the concrete and calls for strict quality control in the precasting process. Much, though, can be done to alleviate the problems of concreting by using the correct reinforcement details. The reinforcement has to be designed to allow the fresh concrete to flow easily in the moulds. Also, provision should be made so that vibrators can reach down as far as possible in the moulds.

Steam curing is used on virtually all projects so that the manufacturing cycle is approximately 24 hours long. While precasting the elements for the Zilwaukee Bridge, longitudinal cracks were discovered at the flanges of the segments (12). These were attributed to starting too early with the steam curing. These cracks later disappeared when the transverse prestressing was applied. Based on this experience, Casey (12) suggested that a waiting period of at least four hours should pass after placing the concrete and before applying the heat.

Special attention should be given to the shape of the cross section to eliminate rapid changes in the thickness of an element. Cracks often occur at connections between the vertical walls and the deck slab. Another problem occurred (21,22) where there was a temperature difference between the newly cast element and the adjacent unit which was used as a match-cast formwork for the joint. Ample heat should be applied to heat both elements to the sample temperature, or else the surfaces will not match at the joints once the segments cool off. To prevent warping and eventual deformations due to creep, units should not be subjected to external loads or placed on poor bearing surfaces.

FUTURE DEVELOPMENTS

Several segmental bridges have been built during the past few decades, and many of the major problems have been resolved. The future trends in this construction method will be to optimize the designs to reduce construction costs, improve the durability and to ensure safety under all possible load conditions. These developments will stem from the current competition in bridge construction and will force designers to exploit the available materials to their utmost. Until now, generally available methods have been used and extended for these types of structures. In some areas where these bridges differ substantially from normal reinforced or prestressed concrete structures, additional research and development is still needed to clarify certain design aspects.

Previous research (10,38,40,42) mainly focussed on the time dependent (creep and shrinkage) behavior of the bridge during construction. The major emphasis was to predict the deflections during the balanced cantilever erection process. With these predictions at hand, adjustments can be made to the slope of the segments to ensure a satisfactory closure at midspan. A number of experiments (14,19,24,30) have been conducted to investigate the ultimate behavior of segmentally constructed beams. A comprehensive summary of these results is available (19).

On some of the older bridges in Europe, the prestressing strands have corroded severely. In very few of these structures any provision had been made to renew the cables, or even to add new cables at a later stage, and comprehensive rehabilitation work is often required. It has now been suggested to use unbonded prestressing strands in these bridges. This would change the distribution of prestressing forces substantially, and in most cases an increased number of cables would be needed. It would also change the behavior of the joints, and larger cracks might be expected in the area of the joints. This method will certainly be more expensive to construct initially, but the total long-term costs could be reduced substantially. The full implication of this design change still has to be investigated.

Partial prestressing is often used for ordinary prestressed beams. This method allows some tensile stresses in the concrete, as opposed to the generally applied convention of not allowing any tensile stresses in prestressed concrete. Unprestressed reinforcement is frequently supplied to prevent large cracks from forming. However, it is not certain whether this method can be applied to precast segmental bridges, because no unprestressed reinforcement can be provided across the joints. Cracks can then form at these positions. If these joints can be designed to allow some cracking, the lower prestressing forces could possibly result in some cost savings.

The strength of segmental precast bridges greatly depends on the joints between segments. Although experimental work has been done on the ultimate strength of these joints in bending and shear (38), no design recommendations can be drawn from these results. Failure of these joints on actual structures indicates the need for further research. Although the presently used joint types seem to be satisfactory, a few aspects still remain uncertain. A great deal of research has been done on the epoxy materials, and generally problems do not occur when specifications are strictly adhered to.

The specific characteristics of different joint types should be investigated and compared. Presently, joints are designed laregly on an empirical basis, and very little experimental evidence is available on their exact behavior. Specific attention should be given to the effects of the shapes of the shear keys, the total number of keys in a joint and their behavior under ultimate loads. It can be expected that the irregular reinforcement and discontinuities in the concrete could cause stress concentration which could change the ultimate strength of these joints. Of particular importance is the effect that high intensity cyclic loads could have on the degradation of the joint region. New types of joints should be investigated and compared with those currently used to find the most cost effective and efficient joint configuration which would satisfy the criteria mentioned earlier.

Segmental precast construction has been used for many other types of structures. In the future, it will certainly be used for a range of new applications. These will include new types of bridges (eg. the precast concrete truss bridge in Saudi Arabia (6)) and also certain classes of off-shore structures (eg. the proposed floating spine hull for the generation of electricity (45)).

CONCLUSION

The large number of precast segmental bridges completed during the past few years certainly indicates that the method is an economically competitive and structurally viable desing concept in the United States. The major advantages of the method are that much less on-site labor is necessary as compared to other concrete structures, erection time can be reduced substantially, and no supporting temporary structures are required to make this the ideal construction method when working in areas with limited access.

The method basically consists of precasting the segments, and then assembling them on site to form the final structure. The segments can either be manufactured using a short line or a long line method, depending on the available working space. Three different techniques are commonly used to assembly the segments. The method used most often is the balanced cantilever method, but the span-by-span and progressive placement methods can also be used. The specific procedure largely depends on the configuration of the bridge and access to the site.

The major problems encountered on these bridges have been related to the joints between segments, cross section details, and adjustments to the alignment to account for creep effects. Although many of the problems have been resolved, there still is a number of topics that require further research. These are briefly discussed in this report. These aspects need to be studied and recommendation be made to include related design requirements in current design specifications.

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