

Post-Tensioned Connections

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The general question of connections in the field of precast prestressed concrete is at present ordinarily answered by two distinct solutions. The first, and by far the most predominant, is to interrupt the prestressing and introduce a conventional steel connection. This takes the form of lapped or welded mild steel bars or plates, and is familiar to all precasters. The theoretical disadvantage often mentioned about this type of connection is that a section of reduced stiffness is introduced. In practice, this disadvantage is neglected, or if not, is somewhat compensated for by reducing the working stresses in the steel. We recognize, however, that there exists other undesirable characteristics in these mild steel connections, among which might be mentioned unsightliness because of rust, close assembly tolerances, the necessity to fireproof, and possibilities for error resulting from misplacement of the connecting elements in the form. The precaster and the consultant continue to make a serious effort to overcome these deficiencies, and the present state of their accomplishments is being summarized through the efforts of the P. C. I. Committee on Connections.

The second solution for joining precast elements is post-tensioning, a practice, with certain exceptions, that is more common at present in Europe than in our own hemisphere.

It is this subject which I will describe in this paper.

Although the problem is one and the same, joinery by post-tensioning is commonly divided into two subjects:

1. Joinery to form rigid frame connections
2. Joinery to assemble individual units

In this page I intend to discuss some of the problems associated with these subjects, and provide a few examples.

It is axiomatic that rigidity in any construction is a prime requirement of the design. A one story warehouse does not present a large exposed face to winds, and sufficient rigidity has been obtained by the method of tack-welding simply supported girders to columns. This, in combination with the typical four anchor bolt connection at the footing, affords in effect a connection sufficiently rigid to withstand the usual wind forces and unbalanced vertical forces.

As the height of the structure increases, however, the horizontal forces become an increasingly important factor in the design. The engineer's choice then lies between incorporating definite moment-resistant connections, or shear walls, or both. The difficulty arising from the use of prestressing for these moment resistant connections comes, from the fact that additional strains are introduced, affecting the structure and in turn being affected by the struc-

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ture. Computations then take the form of repeated trial and error to determine the proper magnitude and location of prestress force.

As a simple demonstration of the influence that prestressing has upon a frame, we can take the case of a simple rigid frame, hinged at the footing, and supporting a concentrated load at mid-span. For the normal proportions of such frames, the horizontal thrust resulting at the footing is in the order of $1/10$ of the concentrated load. Because of static equilibrium, the same thrust is induced into the girder, but the subsequent shortening of the girder due to this thrust is normally neglected. If we were to prestress the girder of this frame with a force of sufficient magnitude to counteract the tensile stresses (at the centerline), we would find that the magnitude of prestress required would be in the order of fifteen times the concentrated load. (This will vary, depending on the girder-column properties and location of prestress). For these conditions, the axial force in the girder of the prestressed frame is then some 150 times the axial force in a non-prestressed frame. The strains resulting may have an important influence on the overall action of the frame, and can no longer be ignored.

As indicated, prestressing results in frame distortions which must be provided for—not to do so will result in a strain distribution different from that assumed in the design. It may be necessary, for example, to provide temporary hinges to overcome the effects of this distortion—not an inexpensive item. The distortion problem can also be reduced somewhat by stressing the frame while it is still relatively flexible—for example, before the floors are cast.

Other considerations can also be

cited. From the point of view of economy, short prestressing tendons are considered inordinately expensive. Long tendons, while less costly per pound of steel, (because the anchorage cost has less effect on the total cost), restrict the engineer, since the force cannot as readily be varied along the length. The beam shape, however can be varied. The weight of the tensioning jack may be considered by some to be a problem, perhaps more so by those who have not used them.

These are not unimportant drawbacks. However, we recognize that our role in the profession is to improve the quality of our product—our structures, and post-tensioning connections does permit these improvements. We can often eliminate casting large amounts of concrete at the joint in continuous structures, thus avoiding the unsightly appearance resulting from color differences. We can reduce the cross-section at the joint, as compared with a non-prestressed joint. Details can be so chosen that the members can be fully connected virtually upon erection, without the necessity of waiting for job-placed concrete to reach design strength.

The problem the engineer now faces will lessen as he becomes more experienced and learns to anticipate results without indulging in time consuming preliminary calculations. As to the problem the contractor faces—awkwardness of methods and equipment—this will also disappear to a large extent both as his own familiarity is developed and as the engineer—the man on whom primary responsibility should rest—learns more of the practical way to cope with the problem.

A typical rigid frame is shown in Fig. 1. In this example, the joint is chosen at the horizontal juncture of beam and column, in order to

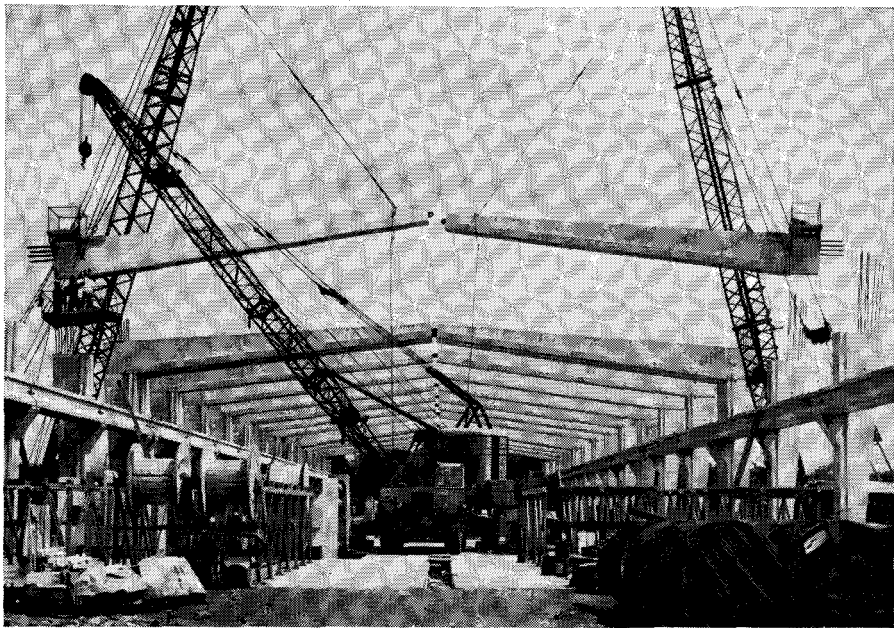


Fig. 1 Erecting a precast rigid frame.

facilitate casting and erection of individual components. The alternative arrangement, placing the beam-column juncture at the inflection point of the beam, may result in less prestressing material, but also a more complicated erection procedure. Placing the joint at the inflection point of the beam requires an inverted "L" shaped column, and the length of the top leg may be restricted by transportation requirements. From an erector's point of view the necessity of extending the post-tensioning tendons through the horizontal leg of the "L", and the possible requirement of temporary supports, may all be considered drawbacks of this latter solution. This example also illustrates a method of saving post-tensioning material, by ending the tendons when no longer required for structural strength.

Having dealt briefly with the question of post-tensioning to form connections in rigid frames, we turn our attention to the assembly of precast elements by post-tensioning.

This practice has the following advantages for the precaster:

1. Members which cannot be transported in their entirety may be shipped in sections, later to be assembled at the site.
2. Small sections are more readily adaptable to assembly line production techniques.
3. Stockpiling of sections becomes practical.
4. Higher quality elements than now common (both in strength and finish) may be anticipated.

At this point, before discussing specific projects, we might turn our attention to the question of joints between individual elements of a multi-element post-tensioned member. There are three methods in common use: dry-packed joints, poured joints, and flush joint (no additional concrete between precast elements.)

DRY-PACKED JOINTS

Dry-packed joints should be between $\frac{3}{4}$ in. and $1\frac{1}{4}$ in. thick, and

the depth of the packing (measured from the nearest accessible surface) should not be more than about 12 in. The advantage of dry-packing is that stressing of tendons can commence almost immediately—a few hours after curing is normal. A difficulty is the connection of the post-tensioning tendon at the joint, particularly if there are several cables, and if the cables are threaded through before packing the joint. One solution is the use of inflated rubber tubes, which are withdrawn after packing. It is apparent that any treatment of joints can be an expensive operation, and therefore should be limited to those situations where a flush joint is impractical.

POURED JOINTS

The procedures are similar to dry-packed joints, except that the joint thickness should be between 5 in. and 8 in., although a space as little as 2 in. has been used. There is no limit on the depth of the pour from the nearest accessible face, as there is with dry-packed joints. The question of threading the tendons and joining sections can be resolved in a similar manner as dry-packed joints; however, sleeves at the joint may also be used, since sufficient working room can be provided.

FLUSH JOINTS

This method is practical when individual elements are manufactured in extremely sturdy molds, or, for larger beams, when one section can be cast against a previously cast section. This joint has been used successfully, and is, in my opinion, the preferable method. Labor is reduced, and unsightly joints are virtually eliminated. For larger beams, individual sections are match-marked for assembly, and can be

drawn together by the post-tensioning and checked for alignment before anchoring. Where necessary, alignment keys may be incorporated in the ends of the precast elements.

One technique for the manufacture of precast elements is shown in Fig. 2, and the resulting "necklace" of precast elements, ready for joining together, is shown in Fig. 3.

It is natural to ask how such prestressed joints behave. In addition to the satisfactory performance record exhibited by numerous projects, test data on such joints is available. In particular, reference is made to the Magazine of Concrete Research, No. 31, of the Cement and Concrete Association, and the article therein on shear tests of various joint types. As one illustration of the results of this investigation, Fig. 4 shows the relationship between prestressing force and the shear force required to cause relative slippage, for the case of flush joints. All points are bounded within the range of friction factors of 0.45 and 0.62. Mortared joints showed similar results, with friction factors all falling within the range of 0.65 and 0.76.

For the remainder of this paper, we can review various projects incorporating the principles discussed. Fig. 5 shows the Naugatuck River Bridge in Connecticut, consisting of a series of spans about 100 feet in length. Since transportation difficulties precluded the shipment of full length girders, the manufacturer cast separate units, which were later assembled at the job site by post-tensioning. A typical interior girder, Fig. 6, is composed of a 44 foot long middle unit, pretensioned, and two 28 ft.-6 in. long end units. These shorter units were cast against the previously cast middle unit, and match marked for final

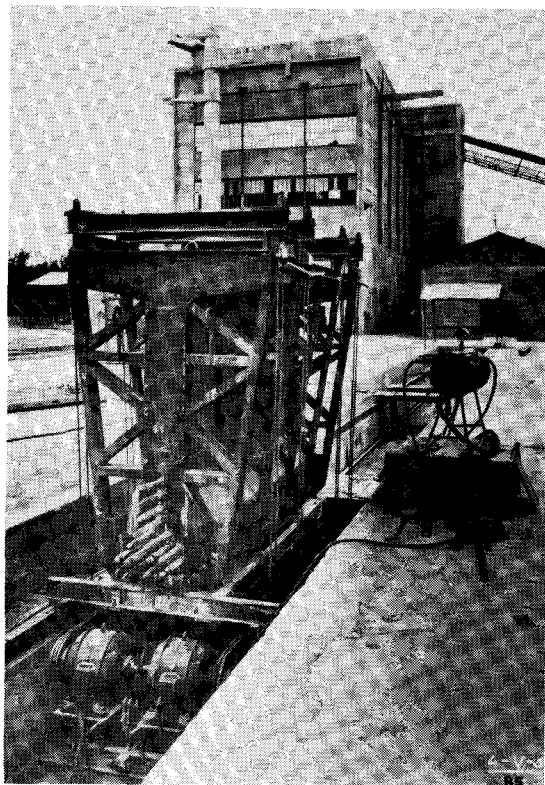


Fig. 2 Fabricating beam elements.

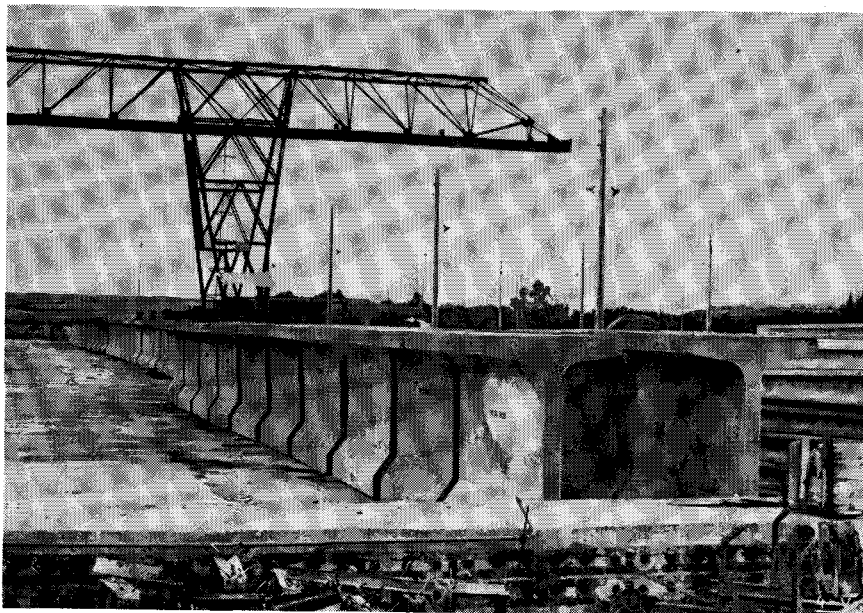


Fig. 3 Beam elements in alignment.

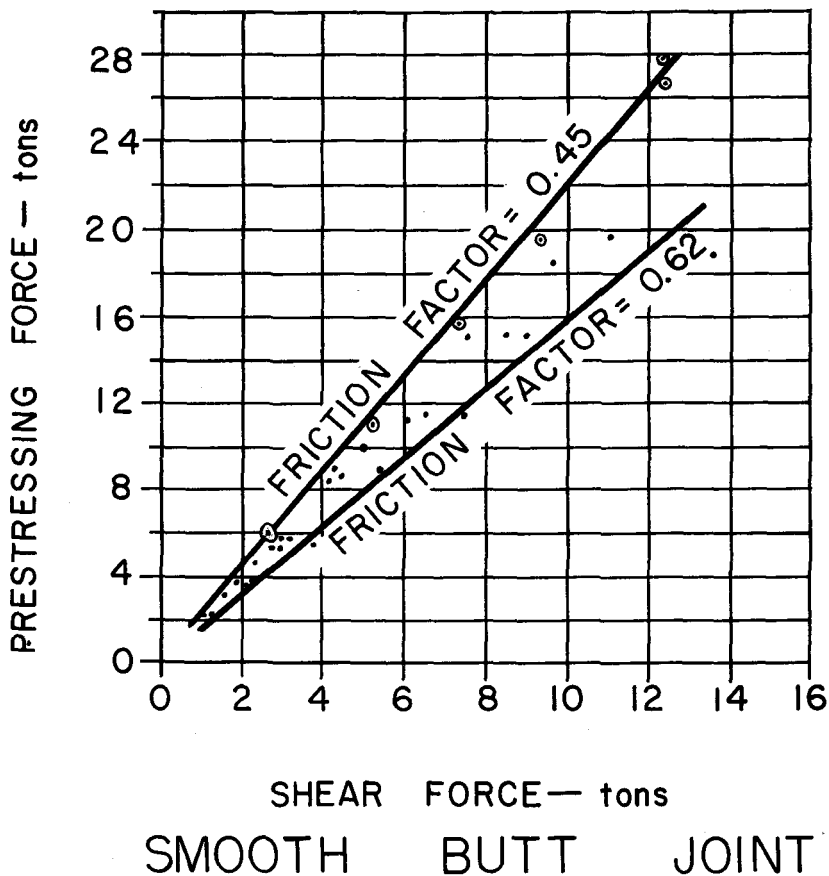


Fig. 4 Available shearing force in a prestressed flush joint.



Fig. 5 Naugatuck River Bridge.

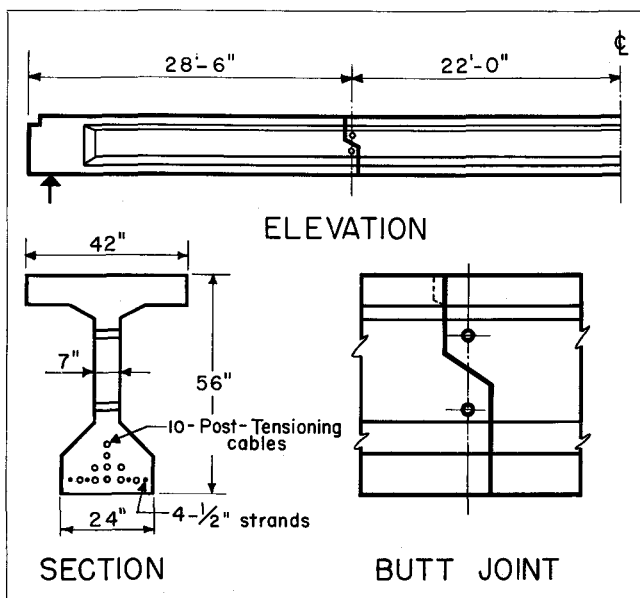


Fig. 6 Bridge beam details.

assembly. The butt joint is located at each diaphragm. To facilitate assembly, an alignment key (shown dotted), was incorporated.

A second example of casting in sections to avoid transportation difficulties is the Don Mills Sports Arena in Toronto, shown in Fig. 7. This structure is roofed with 120 foot long folded plate type beams, which are supported on bearing walls. The members were cast at the plant of Standard Prestressed Structures, and later assembled at the job site on the ground and lifted into place with two cranes. Flexible metal tubing is used to form the ducts to permit later insertion of the post-tensioning tendons. In this structure, the precaster chose to space the sections a few inches apart and filled in the space with a high strength mortar. Each 120 foot long beam was cast in three sections, with the tendons horizontal in the middle section, and raised to the anchorage in the end sections.

As discussed previously the one advantage of post-tensioning connections is that mass production of small units becomes practical. One application of this is illustrated in Fig. 8. The problem was to span a river with a sewage bridge, and the solution chosen was to post-tension standard concrete pipe sections made by New England Concrete Pipe Company. Fig. 9 shows the details that particularly concern us.

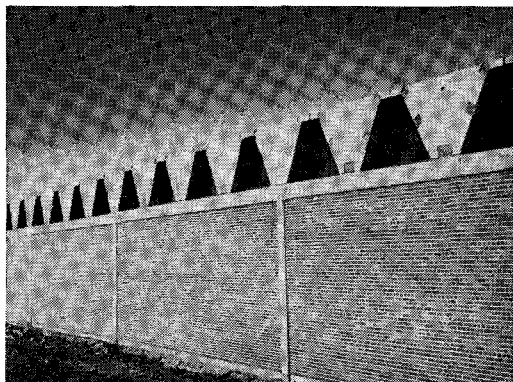


Fig. 7 Don Mills Sports Arena.

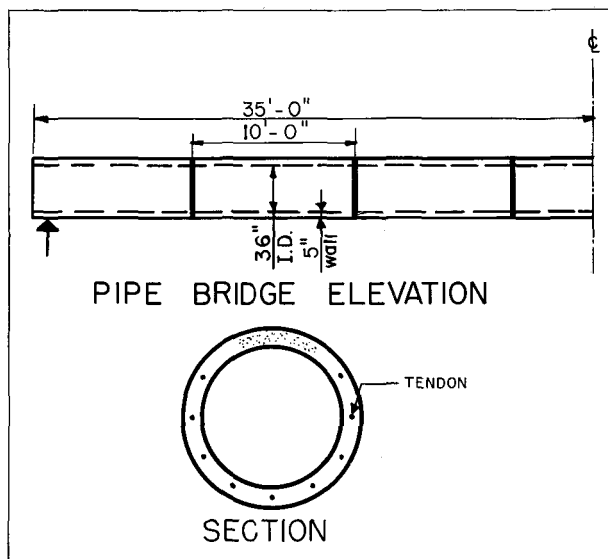


Fig. 8 Sewage pipe bridge details.

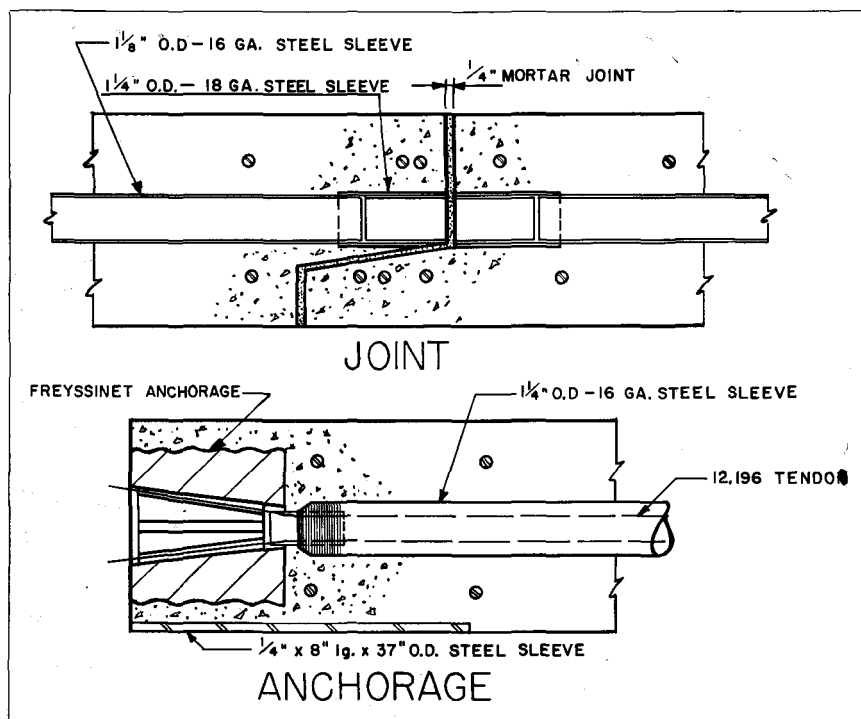


Fig. 9 Pipe connection details.

Smooth 16 ga. tubing is used to form the ducts for the later insertion of tendons, and at the joint, an 18 ga. sleeve is used to connect adjacent sections.

A second application of this principle is the well known and much illustrated B.E.A. hangar in London (Fig. 10). The 110 foot long beam is composed of a series of 7 foot long units, shown in Fig. 11, each with a stiffening diaphragm at one end only. The individual sections are unusually thin, which was made possible by the use of sturdy steel molds and vibration tables. The dimensions of the web in particular shows what can be accomplished in practice by this method of construction. An unusual difficulty came to light during one stressing operation. Failure of a girder was experienced, and it was one opinion that this was the result of the "washing out" of part of the mortar during grouting, resulting in eccentric load transfer between adjacent joints. Another expressed opinion attributed this failure to a deformation of one steel mold, caused by non-uniform heating action of the sun, and the resulting casting of a distorted section.

The use of prefabricated sections proved economical in a major structure built for Kodak in France. A view through the structure is shown in Fig. 12. As we can see, the beams were composed of individual elements, which again were post-tensioned together. These beams are supported on a hollow box girder, which is also used as a duct for air conditioning. Details of the manufacture of the individual elements will be of particular interest. A total of some 2450 individual sections were required. Except for the position of the post-tensioning duct within the web, all elements were

identical.

The manufacturing cycle consisted of 1½ hours for stripping, cleaning, and concrete placement, and 1½ hours initial steam curing. The concrete was cured at a temperature of 160 deg. F., sufficient in the stated period to develop a stripping strength of 800 p.s.i. Once the forms were removed, curing of the elements continued at the reduced temperature of 100 deg. F. It is of interest to note that only 2 forms were used, and that 8 men per shift, and two 12 hour shifts per day, produced 12 elements per day. Fig. 13 indicates the forming and handling of one element.

The use of post-tensioning to achieve rigid connections, or to assemble prefabricated elements, has been discussed, and the examples indicate that these applications are not uncommon in our industry. A combination of both methods, however, is perhaps less common. One outstanding early example is a department store in Paris, the Lafayette Galleries. This is an existing 6 story structure which contained three interior "light shafts", around which there were balconies. In order to obtain additional sales space, these "light shafts" were converted by building within them separate 6 story structures. This had to be accomplished so as to not interrupt store operations. A series of 6 story high frames, spaced about 20 feet on center, were constructed by assembling precast elements. The connections were achieved by post-tensioning. Individual elements were brought in, and the beam assembled on the ground and lifted into place. The column below was then post-tensioned, the column sections and beam above placed, and the procedure duplicated. Completing the

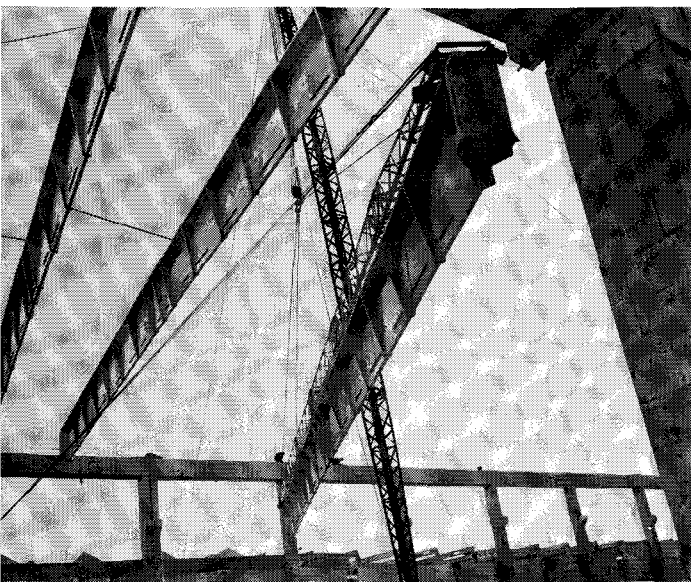
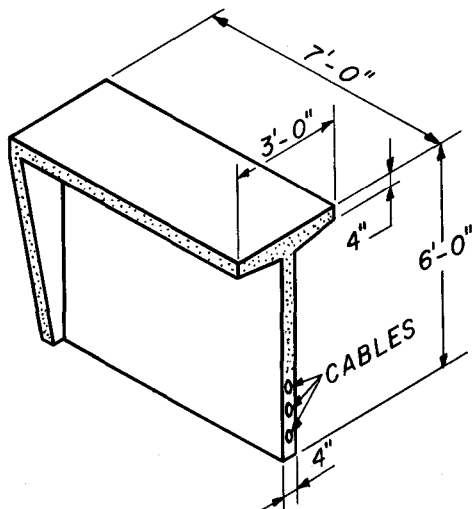


Fig. 10 B. E. A. hangar construction.

Fig. 11



TYPICAL PRECAST ELEMENT



Fig. 12 Elemental beam for the French Kodak plant.

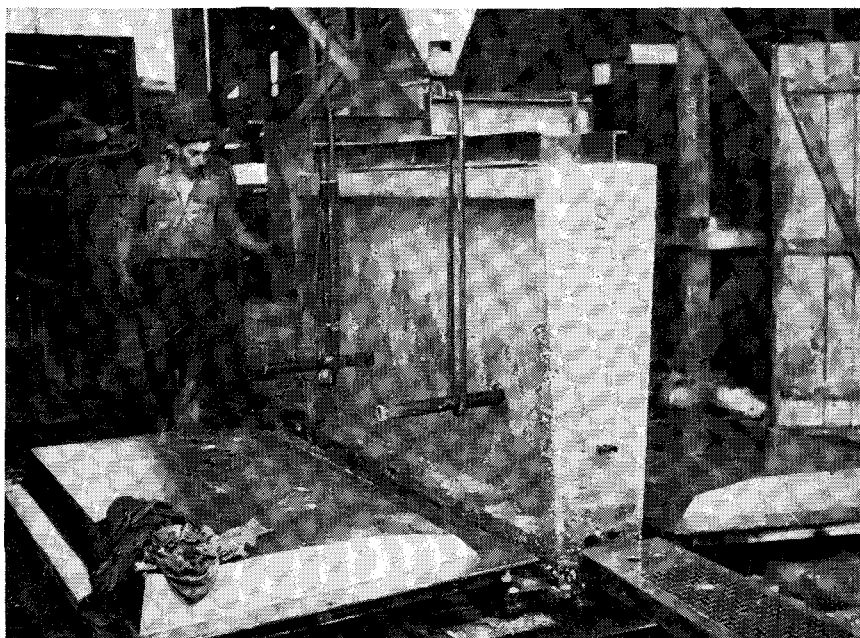


Fig. 13 Forming and handling a beam element.

structure were 36 in. wide by 12 in. deep double-tee floor members.

The primary purpose of this paper is to demonstrate the practicability of this method of construction, primarily from a structural

viewpoint. It is anticipated that the trend towards automation will require a more wide spread adoption of post-tensioning in the assembly of individual precast elements, coupled with a refinement of manufacturing techniques.