PRESTRESSING PLANT EQUIPMENT AND PROCEDURES

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AND PROCEDURES

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PREFACE

The use of prestressed concrete in the United States has grown by leaps and bounds. Since its introduction in 1950, the many advantages of prestressed concrete have caused its use to spread more rapidly than that of any other building material. Knowledge of design and construction techniques has grown through numerous reports on actual structures and research projects.

Now knowing how to design and fabricate it, many architects and engineers are saying "I would use prestressed concrete where it is economical, but I have no cost data to tell me where this is and I have not the time to make a standard design plus a prestressed concrete alternate."

The same thing is true of the man who would like to set up a plant for fabricating but has not enough cost data to know what type of plant should be set up, and what kind of members would compete economically with other materials in his field.

This report discusses such practical considerations as prestressing plant operations, pre-tensioning equipment and techniques, and fabricating procedures in a manner that will enable the engineer to design members which can be fabricated economically and also help the fabricator to understand the factors which require his special attention.

I wish to express my indebtedness to Professor R. L. Flanders for his invaluable assistance and constructive criticism while acting as my major adviser. I also wish to thank Professor D. M. MacAlpine for his first reading of this report and timely advice. I would also like to thank the staff of the School of Civil Engineering for the valuable instruction they have given me.

I wish to express my sincere appreciation to Mr. Thomas Carrano of Fressinet Company, Inc. for his help. The Figures 3-1 to 3-10 are taken from reference No. 3, and Figures 5-1, 5-2, 5-3 from reference No. 4, 36 and 35 respectively.

I express my most sincere gratitude to my parents; without their faith and appreciation, I probably would never have returned to school for graduate study. I am also grateful to my father-in-law and mother-in-law for their timely help and encouragement.

I am indebted to the trustees of the Navalgund Sirasangi Trust, Belgaum, India for their scholarship.

Most of all, I am grateful to my wife, Sarojini, for her unselfishness and kind encouragement throughout this trying year.

In addition, appreciation is due to Mr. B. R. Patel for going through the manuscript, to Mr. Vijay Naik, Mr. Pyare Mohan, Mr. Arla Reddy, Mr. Guruswami and Mr. Brij Dhir for their cooperation and constant encouragement.

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CHAPTER I

INTRODUCTION

In only a few year's time, prestressed concrete has attained the status of an industry!

Any good structural engineer can master the mechanics of prestressed concrete design. Likewise contractors and manufacturers of concrete products can learn the simple procedures of framing, casting, and tensioning prestressed concrete members. However, mass production of prestressed concrete units that will meet or beat compeition of other building materials in the open market is not a simple procedure easily and quickly mastered by either the engineer or the manufacturer.

Now firmly intrenched in this country as a mass production industry, prestressed concrete, with its many ramifications, offers potentially the most efficient use of materials possessing architectural, engineering, and aesthetic appeal since it was conceived approximately a generation ago in Europe.

No longer considered a mere substitute, it is a keen competitor of many conventional structural materials. It is no cure-all or panacea, but in many situations it has very definite advantages.

On medium span bridges, for instance, prestressed concrete is fast becoming the standard design of many highway departments. And for good reasons. Prestressed girders or deck sections can be mass produced quickly and erected without falsework. They require less maintenance, take heavy loads, and, most important, cost less for many applications.

In general, it is believed that the pre-tensioning method is the most adaptable to mass production of prestressed concrete members for use in building construction with spans up to approximately forty feet and that in most cases longer members can best be fabricated by post-tensioning.

The following new market areas are being explored:

1. Prestressed pavements both for highways and airport runways.
2. Prestressed concrete railroad ties.
3. Decorative precast wall panels, etc.

All these make use of thinner sections of lower weight and cost. Easy assembly of prestressed concrete components made with lightweight aggregates, to be used in multi-unit construction of houses, is another field that has vast potential for the future.

Versatility and the speed of construction are of primary importance in the design of the new casting plant. Versatility is needed to allow manufacture of members of various cross-sections, width and length, and speed is required to effect economy of production. With these primary objectives in mind, the plan for the manufacturing bed can be prepared.

There are situations where prestressed concrete is not competitive such as in the case of very short spans. Also, these are still problems to solve. Connections of precast members, for instance, are not completely satisfactory. Continuous designs of prestressed, precast concrete also await the solution of the connection problem. It demands above average workmanship, special know-how, and careful handling.

In order that full utilization of the potentials of prestressed concrete be achieved, however, it is highly necessary that all producers, equipment and material suppliers, engineers, architects, contractors, and users of the end products of the industry join together aggressively to share the burden borne by the few adventuresome individuals who have pioneered in this field to date. In this cooperative effort, the Prestressed Concrete Institute and the American Society of Civil Engineers offer hope of a standardization in building members which will approximate the progress made in the standardization of bridge members.

The author wishes to emphasize the most valuable contribution of firms manufacturing equipment and materials peculiar to the prestressed concrete industry in solving problems arising in everyday application of theory and design. Without such practical cooperation in adapting and converting known practices to effective use of ideas generating from the new materials, many such ideas would remain dormant. It is with this conviction that the author dedicates this compilation of information on the prestressed concrete industry to the still relatively small coterie of men who are experienced in making ideas work efficiently.

CHAPTER II

PLANT LAYOUT

Introduction

The plant layouts and design which are currently used in American prestressing plants vary considerably. Prestressing plants which are to be used for only one project will be very different from plants which are designed to be permanent. Pretensioning plants generally require elongated parcels of land to accommodate the pretensioning benches, and the layout of the other facilities must be arranged around the benches.

Plant Planning

Over-all plant planning should be simple and logical. Materials handling schemes should not have any interference between stripping, set up, pouring, storage and loading out. End abutments should be simple, strong and easily expandable.

> The plant site should consist of an adequate area for casting operations and for storage. Great care must be exercised that the plant area is adequately drained so that the surface can be well stabilized or preferably paved. Casting yard areas must be kept clean and orderly to ensure maximum safety to plant employees. (22).

In the mass production of prestressed concrete there are two principal problems. One is materials handling and the other is the system of forming. The two are pretty much tied together. The system of forming that is used will dictate very largely the acceptable material handling system.

Necessary Plant Area

Pretensioning beds for prestressing take a lot of area. Attempts should not be made to economize on property and later be hemmed in by abutting land which could have been acquired at the start. It should be remembered that the volume of business will grow in the future. There should be sufficient room for future expansion. It will not always be possible to ship directly from bed to job site. Room for adequate storage of the finished product must be available. Transportation costs must be balanced against the cost of additional storage area. The best advice that can be had is that plenty of property should be available for expansion that is strategically located for water and rail shipment, as well as for highway transportation.

The plant should not be located near a source of chemical fumes, since such conditions may seriously harm high-tensile prestressing strands. Preferably, the storage of strands should be under cover or inside a building. This will avoid corrosion or rusting of strands from damp weather. Heavy rains, storms or snowfall may delay the work in the casting yard. So for this reason and other similar delay considerations, the whole operation of prestressing can be most profitably pursued within a building. Most of the more recently installed beds of large capacity have been so planned to enable operators to carry on work without interference from weather delays.

One of the outstanding installations in this regard is the plant of the Warner Company, Trenton, New Jersey, where the company invested close to $2,000,000 to acquire a car repair shop facility. The company has used the present overhead cranes to load the product directly into cars from the adjacent prestressing beds. All beds here will be inside the buildings in the future, when plans are completed.

Use of overhead crane equipment is advantageous in such establishments. It reduces the cost of handling products from bed to the trucks or cars for delivery to the job site.

Acquiring "Know-How"

Acquiring the knowledge to develop a plant and install the proper equipment at the start is a first necessity. In this type of business, there is little past experience. It is equally imperative that the person in this industry keep abreast of every development as changes occur quite rapidly. He should associate himself with such organizations as the Prestressed Concrete Institute, the American Concrete Institute, and regional groups which are forming in many areas.

The manufacturer of prestressed concrete products will be in a better position to succeed if he has an engineering background. He should appreciate the need of this type of training in the salemen he hires. As for the design of the casting beds and other equipment, he should employ competent engineering advice from one of the many good firms having experience in this field, and heed it in his choice of all equipment purchased later.

Mechanized Production

The ideal or the ultimate system of mechanized production of prestressed concrete would be one in which the raw materials, aggregates, cement, water, mild steel, and prestressing steel entered the process near one end; while from the other end a completed, cured, prestressed concrete member would be loaded on a truck.

The above brief statement of idealized mechanization points up one matter of special importance with prestressed concrete. The approach to mechanization and plant layout must include storing and loading as well as pouring, stressing, etc.

One other basic approach to mechanization is for the product to move through the process. In this approach, the completed product is pulled through, thus stressing the strands which are anchored in the completed product. The other end of the strands, a full cycle away (perhaps 1500 feet), are fed off reels, which are braked to provide the necessary tension. Concrete is fed in from the side and poured and vibrated at one point. The forms either travel with the freshly poured element until initial setting, or the sides are extruded and the soffit moves. This soffit continues on through a curing period. The soffit and side forms may be of continuous belting on rollers.

After emerging from the curing process, the units are cut to length, (if not divided in manufacture), lifted sidewise by a bridge or gantry crane to storage and loadout.

The application of constant high stress to the completed product is either by side friction or mechanical gripping devices, the pull being applied through continuous jacking or direct gear drive.

The braking of the reels may be directly connected to the driving gears or dynamic (electric) braking may be used with the power fed to the driving motors. Thus, the only new power needed, other than losses, is to overcome friction of the product in the line. By arranging the entire line on a slope, gravity can be employed to provide the basic force, augmented and controlled by a powered drive. (Patent applications have been filed for the above described process.)

A different basic approach to mechanization is for the process to move the product. This is essentially the method used in the typical pretensioning plants in the United States today. Fixed ends are utilized. The strand is stretched and stressed in the bed. The concrete is batched and mixed in a central plant and brought to the point of pour. Pouring starts at one end of the bed and moves along it, followed by screeding and finishing. Steam-curing covers are placed, the product is cured, then the product is lifted out to storage and from storage to loading.

Mechanized improvements already employed include the use of pouring machines that feed, vibrate and screed the concrete. Hydraulically actuated forms have been used. The stretching of the strand may be semi-automatic. Forms are designed that require little or no stripping. Automatic brush cleaning of the forms is frequently employed.

A Typical Factory Layout

The plant buildings cover an area of 86,000 square feet, and an additional 130,000 square feet area is available for storage of materials and products (Figure 2-1). (13). The latter area also includes a shipping yard. The factory has a capacity of 26,000 cubic yards (55,000 tons) of finished products per year and employs 110 workers. For climatic reasons, all processing is done indoors.

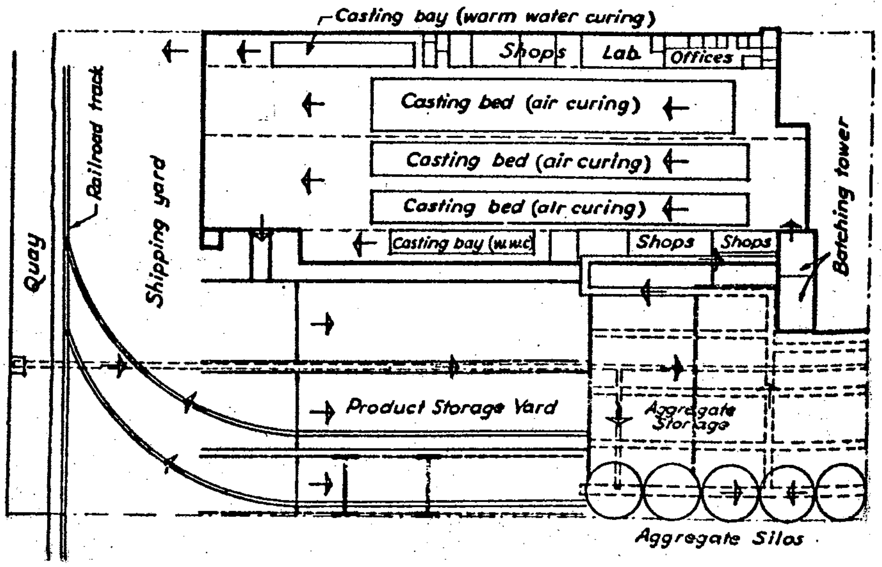


Figure 2-1. Factory Layout.

Recent Developments

Methods of continuous concrete prestressing and casting by vibro-punching, vibrorolling, vibropressing, etc., open up new horizons in this field. (32). More recently, electro-thermal stressing is being applied, with the strand being electrically heated while it is wound under moderate tension, with remaining prestress added by cooling of the wire.

Conclusion

In plant fabrication the following advantages are found:

1. Lower cost due principally to assembly line production.
2. Better working conditions and better supervision.

3. Chance is taken out of field construction.
4. Plant fabrication permits the prestressing techniques to be available to a number of contractors simultaneously.
5. Closer control of mix and cure, improved forms, higher frequency of vibration and greater knowledge of workmen specializing in that particular process.

There is also a great deal that has and can be done to make multiple and varied use of standardized prestressed concrete members. The examples of double-tee and single-tee in this country show how a single standard product can be sufficiently widely utilized to justify mechanized manufacture. Because of urgent need for better production processes, there has been a tendency to concentrate on improving existing schemes and to minimize detailed tasks, rather than to give consideration to entirely new approaches.

Our first and most important task is quickly to improve and master all new machines at prestressing plants, test them on automatic lines, and prepare them for use everywhere in large scale production.

CHAPTER III

PRETENSIONING EQUIPMENT AND PROCEDURES

Introduction

Pretensioning equipment and methods which are characteristic of American practice vary in many respects from the equipment and methods which are employed abroad. The basic principles employed in the design of prestressing facilities here and abroad are identical, but, because the normal type of product produced in domestic prestressing plants is larger than the average pretensioned products which are produced abroad, the prestressing facilities which are required domestically are also larger. The scope of this chapter is confined to the discussion of equipment and procedures which are peculiar to pretensioning as practiced in the United States. However, a reference is made to some of the most recent developments in some of the foreign countries.

Basic Operation

Pretensioning is defined by the ACI-ASCE Committee on Prestressed Concrete as "a method of prestressing reinforced concrete in which the reinforcement is tensioned before the concrete has hardened." Applied to standard practice in the United States, a more specific definition would be "a method of prestressing reinforced concrete in which the reinforcement is tensioned before the concrete is placed."

A casting bed for pretensioned bonded prestressed concrete members has two basic functions. It provides a flat base on which to cast the members and it provides anchorages to maintain the tension in the pretensioned strands until the concrete has been poured and cured. There are numerous variations in types of bed and equipment. The information contained herein does not attempt to cover all possibilities.

Basically, one complete cycle on a casting bed has five steps:

1. Tendons are placed on the bed in the specified pattern. They are tensioned to full load and attached to anchors at each end of the bed so that the load is maintained.
2. Forms, reinforcing bars, wire mesh, etc., are assembled around the tendons.
3. Concrete is placed and allowed to cure. In many cases, curing is accelerated by the use of steam or other similar methods.
4. When the concrete reaches the strength specified, the load in the tendons is released from the anchors. Since the tendons are now bonded to the concrete, they cannot move independently of the concrete. As they try to shorten, their load is transferred to the concrete by bond. This load is the prestressing force in the concrete member.
5. The tendons are cut at each end of each prestressed concrete member, and the members are moved to a storage area so the bed can be prepared for the next cycle.

Pre-Tensioning With Individual Molds

This technique is not considered practical in this country with the exception of a few firms which employ stress resisting molds in the manufacture of double-tee roof slabs, and pretensioned spun piles. In Europe, where pre-tensioned railroad ties and small joists for residential construction are economical in pre-tensioned concrete, this method has the advantage of allowing individual units to be man produced with the products (and molds) moving through the plant in a production cycle, rather than requiring the materials and plant being brought to the molds or forms, as is required with a pretensioning bench. In manufacturing spun pre-tensioned piles, this technique must be used, since there is no other practical means of spinning the mold and pretensioned tendons as a unit.

This technique has been adopted in the pretensioning of double-tee slabs by firms that normally manufacture their double-tee slabs in reinforced concrete and only pre-tension the slabs when an exceptionally long span, which cannot be done in reinforced concrete is encountered. In this manner, the cost of the pre-tensioning bench is avoided in normal production and it is claimed that the total plant investment is not as great as is required when the pre-tensioning benches are used to produce double-tee slabs. The higher unit cost of the individual stress-resisting molds over the cost of the molds which are used in conjunction with pretensioned benches should be apparent.

Rather than use individual molds which can resist the pre-tensioning force, other firms use post-tensioning on the long-span double-tee slabs which cannot be made in reinforced concrete.

Another advantage which can be stated for this method when employed on small, pre-tensioned products is that the prestressing plant need not be as large and as elongated, as is required in using a bench, since small, pre-tensioned products in their individual molds can be stacked and need not be arranged in long rows. This advantage applies, but to a lesser degree, with large products which can only be handled with very large cranes and which cannot be stacked very high, if at all.

Pretensioning Benches

Pretensioning benches are normally designed to withstand a specific maximum force which can be applied at a specific maximum eccentricity. Therefore, it is customary when stipulating the capacity of a pretensioning bench, to give the maximum permissible force (shear) and maximum permissible moment which the bench can safely withstand. The maximum moment is normally expressed in terms of the bench proper (slab portion of the bench which extends between the uprights at the abutments) and not necessarily in terms of the top surface of the abutments, which may be recessed to accommodate the stressing mechanism. Pre-tensioning benches are generally one of the following general types:

1. Column-type bench, which may serve as the mold or form, as well as the device which restrains the tendons.
2. Independent abutment-type bench in which the independent a abutments rely upon soil pressure, piling, or rock foundations for stability.
3. Strut-and-tie-type bench.
4. Abutment-and-strut-type bench.

5. Tendon-deflecting-type bench.

6. Portable benches.

Each of these types of benches has specific areas of application, and each will be discussed separately.

One additional definition which must be given before discussing the types of pre-tensioning benches pertains to the use to which the bench is to be subjected. Some benches are designed to produce a specific product and may be termed as a 'fixed bench.' Other benches are designed to produce any type of product that is normally encountered in practice and are termed 'Universal benches.'

Column Benches

Column benches rely upon the column action of the bench alone to resist the prestressing force. The eccentricity of the prestressing force, with respect to the bench, must be confined to relatively low values in order to achieve economy with this type of bench. For this reason, the use of column benches is generally restricted to fixed benches which are designed to produce a single tee, double tee or pile. An example of a column-type bench which is designed to produce double tee slabs, is shown in Figure 3-1.

The column type benches are generally designed using the Euler formula to compute the critical bulking stress. Adequate safety factors against both crushing of the concrete and buckling of the column must be allowed in the design. The dead weight of the bench alone is relied upon to prevent the column from buckling. The buckling of the column could occur at the center of the bench by buckling upward, at the ends of the bench which could buckle upward, or by a combination of both. These are illustrated in Figure 3-2.

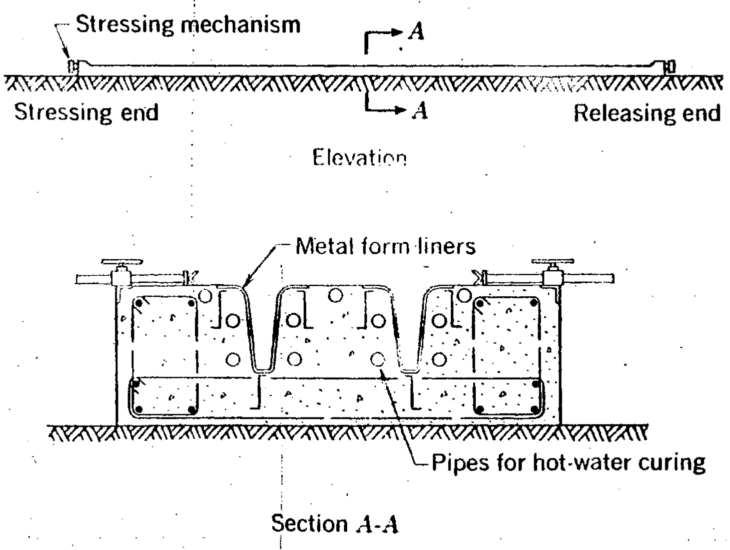


Figure 3-1. Column-Type Double-Tee Bench.

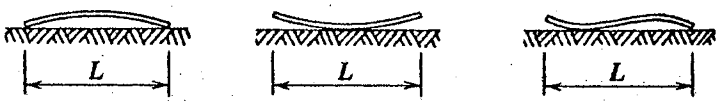


Figure 3-2. Possible Forms of Column Buckling.

Column type benches are not normally used for universal benches or in benches in which a relatively large eccentricity of the prestressing force must be accommodated.

Independent Abutment Benches

This type of pre-tensioning bench is composed of two large abutments which are structurally independent of each other as well as of the paving material which is used as a casting surface between the abutments. The abutments, when embedded in soil, may rely exclusively upon the weight of the abutment and passive soil pressure for stability, but it is more common to incorporate piling in the abutments, in order to increase the stability. Abutments of these two types are shown in Figure 3-3.

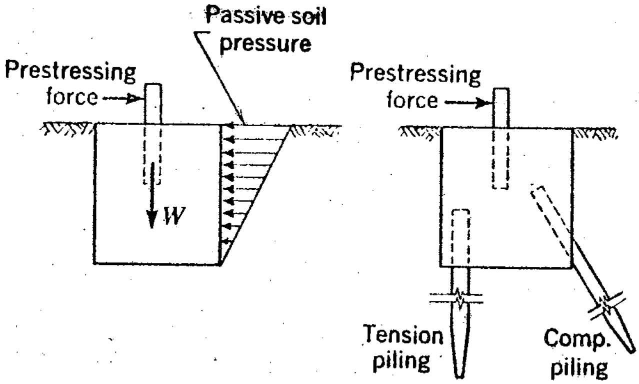


Figure 3-3. Independent Abutments in Soil.

When founded on sound rock, independent abutments can be formed by keying the abutments into the rock and if necessary, increasing the resistance of the abutments to overturning by providing anchors which are embedded in the rock. This is illustrated in Figure 3-4.

The design of independent abutments require accurate knowledge of the character of the soil or rock on which the abutments are to be located. The effects of long-term loading, variation of loading and variation of the moisture content on the mechanical properties of the foundation material are also important and must be known. Due to the difficulty in accurately determining the mechanical properties of the foundation material, this type of pre-tensioning facility is not

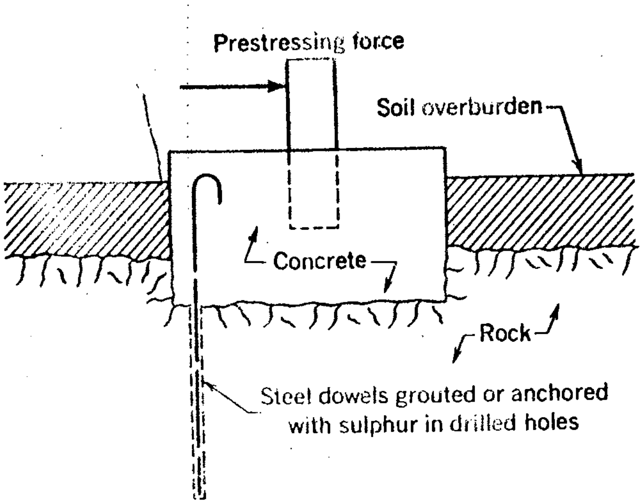


Figure 3-4. Independent Abutments on Rock.

frequently used. When the foundation material is adequate, this type of pre-tensioning bench is economical for long benches, since the casting surface is not a structural component and hence can be considerably lighter than is required for other types of benches.

Strut and Tie Bench

The principle of strut and tie pre-tensioning bench is illustrated in Figure 3-5. Examination of this illustration will reveal that the prestressing force (P) results in a tensile force in the tie (T) and a compressive force in the strut (C), and the uprights are relied upon to distribute the three forces.

This type of bench can be used for large eccentricities and is adaptable to universal pretensioning benches for this reason. One serious objection to this type of bench, when large prestressing forces are used, is that the compressive force in the strut is larger than the

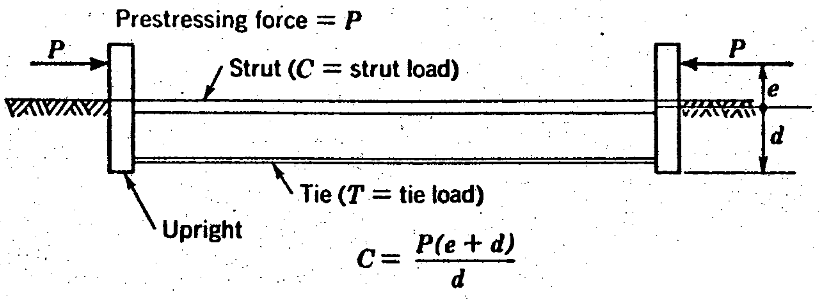


Figure 3-5. Elevation of Strut and Tie Bench.

prestressing force (C = P + T) and the dimensions of the strut may have to be large in order to prevent buckling of the strut. Another objection to the use of this principle on long benches is that the effect of the deformation of the bench during stressing can be large, because the tie becomes longer and the strut becomes shorter as the prestressing force is applied, and these deformations are amplified at the level of the prestressing tendons by the lever action of the uprights. For these reasons, strut and tie benches are generally used only on short benches, such as universal benches used in laboratories.

Abutment and Strut Bench

This is the most frequently used type of pre-tensioning bench. The structural principle of this type of bench is illustrated in Figure 3-6 in which it will be seen that the prestressing force, which is applied on uprights embedded in each abutment, has the tendency to overturn the abutments about the concrete hinges as well as to force the two abutments to slide toward each other. The overturning of the abutment is prevented by the slab or the strut which separates the two abutments. The provision of the hinge between the abutments and the slab insures that the slab action is subjected to a direct axial force (alone) which is equal to the prestressing force in magnitude.

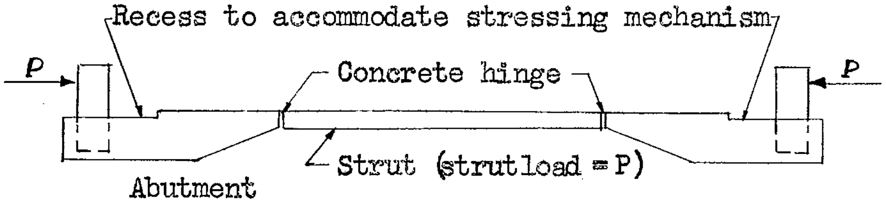


Figure 3-6. Elevation of Abutment and Strut Bench.

The design of this type of bench consists of determining the amount and shape of the concrete abutment. It should provide an adequate safety factor against overturning, the reinforcing of the abutment, and the proportioning of the slab. The abutment of this type of bench is usually made of heavily reinforced concrete or of post-tensioned concrete. The slab portion is generally reinforced with a welded wire fabric in order to help control cracking due to shrinkage. This type of bench can be used with deflected pre-tensioned tendons by employing the portable tendon-deflecting device.

Tendon-Deflecting Benches

Until recently, fabrication of large bridge members was considered a job-site operation. In fact, many of the larger structures being built in the United States today involve either a combination of pre-tensioning and post-tensioning or entirely post tensioning at the job site. But now, use of bonded, deflected strands in the production of large members is coming into the picture. It is rapidly changing the economic concepts of design and fabrication previously established for post-tensioning methods.

Pretensioning was originally developed for small members. Prestressing elements were small wires. But the American strand has made possible bonding of larger pretensioning elements and thus the production of larger members. However, the concentration of a large prestressing force in the bottom flange of a large beam for its entire length is highly undesirable. Use of deflected pretensioning strands overcomes this difficulty and accomplishes the effect of a draped post-tensioned element at less cost.

Deflected, pretensioned strands have other advantages, of which greater shear resistance, better distribution of anchorage forces, reduced strand requirements and less camber are among the more important. In continuous structures, curved strands are a necessity, because the strands must be raised above the center of gravity of the beams at the ends of each span to prevent overstressing the bottom flange under negative moment.

Pretensioned deflected strands were first used in the production of prestressed roof channels by the Nashville Breeko Block Company, Nashville, Tennessee in the early part of 1953. (14). Since that time, their use has been extended to the production of large beams and girders.

Fabrication of pretensioned members with deflected strands requires a special type of bed. It must be capable of resisting the vertical forces from the positioning devices that deflect the strands. The bed does not necessarily need to be of a great length. In the fabrication of both bridge and building members, it has been found that production of beams and girders on a short bed can easily keep pace with production of the elements that span between beams and girders.

The slab is subjected to a series of vertical loads as well as to the axial load which is associated with abutment and strut benches. This type of loading, and shape of bench which is usually employed under such conditions is illustrated in Figure 3-7.

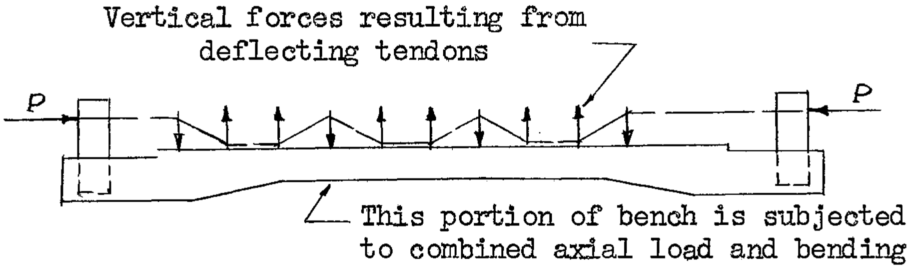


Figure 3-7. Elevation of Tendon-Deflecting Bench.

Due to the large vertical forces, which may have to be applied at virtually any point along the bench in order to achieve the desired results in prestressed products which are to be produced with deflected tendons, the use of the concrete hinge which is characteristic of the abutment and strut bench is not feasible. Furthermore, since the slab portion of the bench is subject to combined bending and direct stress, the slab must be made of heavily reinforced or prestressed concrete rather than the plain concrete (for all practical purposes) which is used in abutment and strut type of benches. The cost of this type of bench is substantially greater than abutment and strut benches of equal capacity.

Portable Benches

Pre-tensioning benches which can be moved from job site to job site have been used to a limited degree. The portable benches may be of any of the above types and may be entirely or only partially portable. An example of a partially portable bench is a bench of the abutment and strut type in which the principal components are portable and the strut and the counterweight portions of the abutments are not moved.

A universal, portable pre-tensioning bench of the abutment and strut type is a very practical piece of equipment for general contractors who are engaged in large highway and marine projects on which large quantities of pre-tensioned concrete may be required in areas where these are no permanent pre-tensioning plants. In a similar manner, portable benches of the column type are occasionally feasible for job site fabrication of double tee and single tee roof members for very large building projects.

In the design of the universal pre-tensioning benches it is often desired to provide means of adjusting the length of the bench so that the waste of the pre-tensioning tendons can be minimized for different production problems and maximum economy can be achieved in operating the bench. This has been accomplished by the use of pull-rod extensions in the stressing mechanisms, the mechanics of which will be apparent after considering the discussion of the stressing mechanisms.

Another method which has been used quite extensively is to provide a long dead-end abutment which has several alternate positions for the dead-end uprights, as is illustrated in Figure 3-8. The provision of an intermediate abutment which has removable uprights has also been used successfully. Intermediate abutments which are designed to withstand the prestressing from only one direction as well as abutments which are designed to withstand the prestressing load from either direction, as illustrated in Figure 3-9, have been used.

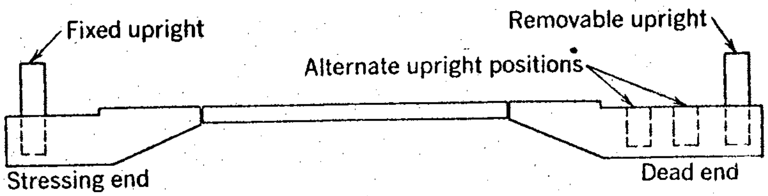


Figure 3-8. Bench With Adjustable Length.

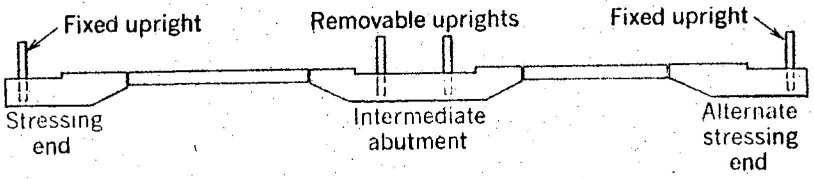


Figure 3-9. Bench With Intermediate Abutment.

The maximum force which is to be used in the design of the pretensioning bench should be about 15% greater than the total initial force applied to the maximum number of tendons which are to be used with the bench. Experience has shown that the shrinkage of the concrete and the effect of temperature variations, which take place during curing and stripping of the concrete, result in the prestressing force being larger at the time of release than it is immediately after stressing. The increase in the stress is a function of the ratio of the length of the tendon which is embedded in concrete to the total length of the tendon between the uprights of the bench, the type of cement, the type of curing which is used, the air temperature during stripping, and other factors. The gain in stress in the tendons increases with the ratio of length of the embedded tendon to total tendon length, the curing time, and is more severe when the air temperature during stripping is low.

A Survey of Existing Beds

A recent survey inquiring into the dimensions of pretensioning casting beds afforded data showing that the average plant had 4.1 casting beds, which averaged 272 feet in length and 8.3 feet in width. (35). Reported lengths ranged from 100 to 650 feet, the latter being probably the longest used to date. It is evident from inspections of many prestressing layouts that dimensions of casting beds are changing radically from those used previously, apparently to facilitate their functioning and to allow workmen to set up and dismantle forms and to provide the best platform for their work of placing and consolidating the concrete. Producers also reported that in 39 percent of cases the pretensioning facilities were housed, the remainder being in open. This factor would tend to influence the length of the bed. However, there is a decided tendency in the industry to house more facilities, to provide uninterrupted operation throughout the winter, especially in plants located in Northern areas.

One representative plant uses only beds 250 or 300 feet in length, rather than longer beds. Officials of this company feel that they profit by using more, and shorter, beds, and several smaller crews, rather than longer beds with one large crew. One crew stretches strand, and another crew, four hours later, pours the concrete, covers it, and steams it.

In another survey, the number of linear feet of casting bed per plant varied from 150 to 2,550 feet with an average of 750 feet of bed per plant. (15). Most plants had two or more beds with the length of most of the individual beds varying from 250 to 400 feet. In some plants one bed is designed for heavy prestressing forces, with the remaining beds designed for fabricating lighter members. The majority of beds were designed for an initial prestressing force of 300 tons. The average plant is equipped to handle a finished member weighing 20 tons.

Tendon-Deflecting Mechanisms

The devices which are used to deflect the tendons from the straight line are called tendon deflectors or tendon-deflecting mechanisms. Tendon-deflecting mechanisms frequently consist of devices which support the tendons in the high position and devices which hold the tendons in the lower position, and these components are generally referred to as hold-up devices and hold-down devices, respectively.

Stressing Tendons

Standard tensioning element is the seven-wire uncoated stress relieved strand; popular diameters are 3/8 inch and 7/16 inch. Strand may be purchased either in coils or on reels. Coil contains about 3,000 feet of strand, but reels have nearly five times that length. The choice between coils and reels depends on the job. If the bed is set up for a specific job, coils mounted on a swift car may eliminate some strand waste. If there is a large number of strands per pattern, and if the operation must be repeated often, coils on a shift car may have advantages. But for the commercial fabricator, the trend is toward reels. They are easy to handle, require less frequent replacing, and offer a more efficient set up.

The following are certain properties which every prestressed concrete tensioning element should possess:

1. High strength to minimize the percentage of stress loss due to such factors as shrinkage and plastic flow.
2. Low coefficient of creep.
3. Ease of handling. Not only do cranky wire and strand add considerably to the user's costs, and therefore, to his selling price, but the rough handling necessary to fight them into place often leaves them nicked, kinked or otherwise permanently damaged.
4. Good surface for bonding to concrete on uncoated strands.
5. Sufficient ductility, and uniform modulus of elasticity.
6. Resistance to stress corrosion.

Tendon Storage and Handling Equipment

A relatively small amount of pretensioning is being done currently in this country with smooth wires, although some large projects here have used tendons of this type.

The storage problems which are experienced with each of these types of tendons, as well as the precautions that must be taken during storage, are similar, but the equipment which is used to facilitate handling and placing the different types of tendons during normal production in a pre-tensioning plant is influenced by the design of the plant and the type and volume of the products which are being produced.

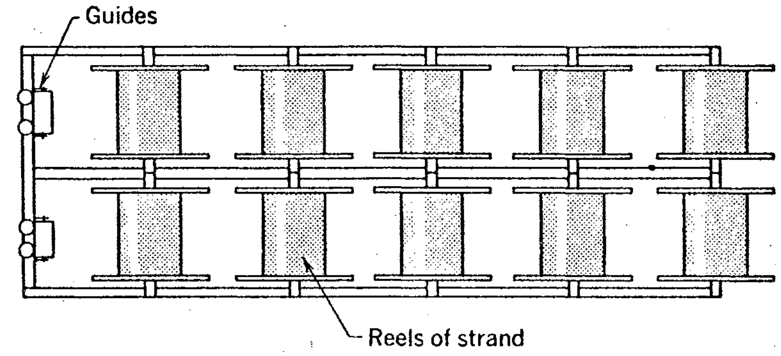
The high-tensile cold-drawn wire which is used as pretensioning tendons, whether in the form of strands or not, is susceptible to normal oxidation which, improves the bonding characteristics of the tendons; provided, of course, the oxidation has not progressed to such a degree that a flaky coasting is formed on the surface. In other words, a hard, non-scaling normal oxide (rust) is beneficial and desirable.

Since the substances which can cause stress corrosion may be present in the soil, high-tensile wires should be stored on clean, dry, wooden or concrete platforms and should not be allowed to come in contact with soil during the handling and placing of the steel. In a similar manner the wire should not come in direct contact with sea water if it can be avoided and prolonged exposure to air in the vicinity of salt water should also be avoided. In most areas where pre-tensioning plants are located, the protection of the tendons can be limited to ensuring that the tendons do not come in contact with soil and oil and, if tendons are to be stored for a period of several weeks before being used, the coils and reels should be covered with tarpaulins and kept dry.

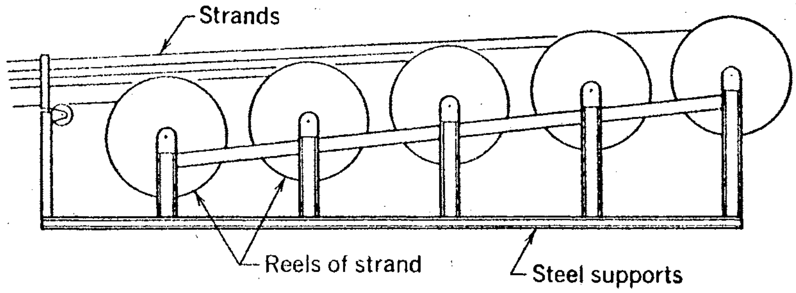
When large reels of seven-wire strands are used, the reels are usually supported on stands such as illustrated in Figure 3-10. In small operations the reel stands may only be large enough for one or two reels of strands, while in large operations the number of reels may equal the number of tendons required in the products which are being produced. When only one or two reels are used, the strands are normally threaded into the pretensioning bench, one at a time, and the strands are pulled down the bench by hand. If the number of reels is equal to the number of tendons which are required in the products being produced, all of the tendons may be pulled down to the bench at the same time, using a winch to pull the tendons. A convenient method which has been used in pulling a large number of tendons with a winch is to design the pretensioning mechanism so that the template at the dead end of the bench can be moved to the stressing end. In this manner the tendons can be threaded through the stressing and dead-end templates simultaneously, and the dead end template can be pulled back into position with the winch, with the result that all the tendons are placed correctly in one operation.

In most pretensioning plants, the production does not justify the large investment in strand that is required when all the strands are pulled into position simultaneously from reels. One means of overcoming this problem is to use coils of strands rather than reels, in which case the coils may be purchased cut to length or may be cut to length at the pretensioning plant prior to pulling operation. When smooth wires are used, since they are normally supplied in coils rather than on reels. The length of the smooth wire in an individual coil is very great and the wires are normally cut to length at the time they are installed in the bench.

Cutting the wires and strands may be accomplished with hand-operated



Plan



Elevation

Figure 3-10. Strand Reel Supports.

bolt or wire cutters, power wire cutters, or by use of an acetylene torch. When placing the tendons in the bench, the use of power-operated wire cutters is generally most efficient, since hand operated cutters are slow and acetylene torches often result in deformed ends being formed on the tendons, making them difficult to thread through the templates and the tendon anchorages.

Jacking Methods

Methods of tensioning vary considerably. Yet all systems must incorporate certain functions. Jacks should be powerful enough to handle the largest anticipated loads on the beds, yet portable enough to be shifted easily to adjacent beds. The jacking system must provide a method of transmitting the tension load to the end abutments so that jacks can be removed and repositioned.

Another important function of the jacking system is detensioning. Instead of cutting the strands one by one, thereby including unbalanced prestressing forces, it is better to release tension with the jacks so as to prestress the members uniformly.

One final requisite of a good jacking system is close control over the huge forces which come into play. Often, the stressing force is well over 1,000,000 pounds, and that kind of power must be harnessed. Safety is a top consideration.

The most common method of stressing the strands is by means of hydraulic jacking, because of the high-capacity of such equipment, and the relatively small force required to apply the pressure to the unit. Occasionally, screw jacking is used if the force to be exerted on the strands does not exceed 5 tons. A system of weights and pulleys are used to place stress in a single strand at a time.

When hydraulic jacks are used, one, two or more, such units are usually combined with a pump unit, with a control valve placing equal pressure in all jacks. Charts are available to determine the oil pressure in the jacking cylinder which will induce the tensioning force required for prestressing the strands. Since the amount of elongation in pretensioning in long beds is considerable, hydraulic jacks having long ram travel must be used. When purchasing jacking equipment, requirements should be analyzed in terms of the future as well as the present to accommodate longer casting beds or the use of larger diameter strands.

Commonly used types of jacking systems for pretensioning operations include: (1) single jack system, for tensioning single strand, or groups of strands in which the total force is within the capacity of the jack; (2) Two-point jacking system; (3) Four-point jacking system; (4) Carriage push plate.

Jacks

Jacking equipment demands special consideration. There can be no weak links in the system. Pumps, lines, valves, and jacks should be checked often.

High-pressure jacks operating at about 6,000 psi are most effective. Models range from 50-ton to 300-ton units, but the popular sizes are 150-ton and 200-ton. They are interchangeable in many types of beds and offer the most universal applications.

Hydraulic lines are no less important. They are a point of possible failure and should incorporate a safety factor of three or four. But the safety factor is good only so long as the lines are protected in the field.

The most accurate way to control strand tension is through elongation of the rams on the jacks. But with an unsymmetrical strand pattern, it is not always possible with conventional equipment to assure equal runout. A new system, developed by Elgood Hydraulics Company of Brooklyn, New York is specially valuable with directional and volume controls for holding the load at any time during the tensioning cycle even though line pressure are unequal. Volumetric control assures uniform elongation and has the advantage of minimizing the necessity of circling the jacks about the exact center of gravity of the strand pattern. So long as elongation is uniform, a slight eccentricity will not harm the jacks or twist the jacking frame.

Electrothermal Prestressing

Recently a new procedure of the electro-thermic method of prestressing the reinforcing bars has been worked out in the Mosgorispolkom Municipal Research Institute of Reinforced Concrete Products in the U.S.S.R. (34).

This method employs heating of the reinforcement outside the molds and subsequent cooling in the molds. The theory of this method consists of prefabricating reinforcing bars which are shorter than the distance between mold anchorages. After being heated by electric current, the bars extend and become longer than the distance between anchorages and are, therefore, quite easily laid into molds. In cooling, the bars try to shorten and thus are tensioned to the given degree.

The use of electrothermal continuous stressing excludes wire tearing and stoppage of stressing machines. Electro-thermo-stressing is a definite improvement in the method of continuous prestressing. The labor consumed by continuous prestressing now is 20-25 manhours of winded wire, considerably less than in other prestressing methods. Low labor expenditure and high productivity permit the development of automatic wire distribution, placing, fixing, and stressing processes. A light stressed framework at a very low price is obtained.

End Anchorages

As previously described, in pretensioning the strands are positioned in the casting bed and are quickly anchored by reusable fittings at one end of the bed and to the tensioning device at the opposite end. Tension is applied and then maintained at the proper amount by anchoring each group of strands to the end anchorages in such a manner that the tensioning device can be released for use elsewhere. Forms are placed as required, along with such reinforcing bars, mesh, stirrups, etc., as may be specified, and the concrete is placed, consolidated by vibration, and cured. When sufficient time has elapsed so that the concrete has gained enough strength to maintain the stress by friction bonding with the strands, the tensioning device is again applied, and the stress is gradually released and maintained at the designed load by newly placed concrete. Protruding strands at each end of the member, and at the intermediate points, are severed by means of a welder's torch, and the member is lifted out of the form and taken to the storage area, or direct to the job site.

Forms

One of the most important factors contributing to the speed and economy of production of prestressed members is form construction. Forms must be simple, rigidly constructed, and easily cleaned for reuse. To assist in achieving this objective, it is imperative that the engineer study plant operations so that he is thoroughly familiar with production problems to the end that he can incorporate this knowledge in design of prestressed members and evolve simple, practical details. In the final analyses, the concrete must be cast, cured and removed from the forms in the shortest time possible if compeition is to be met. Units cast the previous day are removed in the morning, forms cleaned, reinforcement installed and tensioned, and new members cast in the afternoon. Forms for a different design may then be installed on the casting bed and the performance repeated.

In general, the characteristics which are desirable can be summarized as follows:

1. High resistance to damage due to rough handling and to the high humidity associated with steam curing. This requirement normally eliminates the use of wood forms, which do not perform well under repeated use and, particularly, when exposed to steam curing. Although concrete forms have been used successfully, the lighter steel forms are generally preferred.
2. Precision of the form units and dimensions. Since the forms are generally in panels which can be connected together to form a large member, it is essential that the panels fit together precisely.
3. Ease of handling. When erecting or stripping the form, it is essential that the individual pieces of the form which must be handled are not awkward to handle and remain in a generally upright position. This characteristic facilitates laying the forms on their backs so that they may be cleaned easily and it facilitates setting and adjusting the form in the precise position required during erection.
4. The form should be designed in such a manner that one side may be erected in the final position independently of the opposite side. This facilitates the layout of the member which is being made as well as forming special blockouts and transverse holes through the member, securing the web reinforcing and post

tensioning units, if any, in proper location.

5. Adjustability of forms. The forms, or components of the forms, should be adjustable in such a manner that members of several shapes can be made from the form or form components.
6. Form vibration. The form should be sufficiently strong to withstand the effects of form vibration, and brackets or rails to facilitate placing form vibrators should be supplied with the forms.
7. Rigid, structural soffit form. The soffit form must be rigid and must not deform during use, since such deformation results in the soffits of the products being curved or uneven. In addition, the soffit form should be a structural element to which the side form can be securely attached (anchored against lateral and uplift loads) in order to prevent the side forms from moving during placing of the concrete. This latter requirement is particularly significant in the manufacture of I-shaped beams which have large, bottom flanges since the uplift may be very large under such conditions.
8. The forms should be made of a minimum of joints, and all joints should be as tight as possible in order to minimize leakage and bleeding.

Standard forms which satisfy all or some of the above requirements are produced by several firms. Custom-made forms which incorporate the above characteristics can be made by ordinary sheet metal fabricators.

Bulkheads

One phase of the forming operation that demands a lot of contractor ingenuity is the bulkhead, the part of the form that shapes the end of the member. It is difficult to standardize because so much depends on the shape of the piece to be cast. For instance, sometimes it is better to thread untensioned strands through a bulkhead, and at other times, it is preferable to erect a bulkhead around tensioned strands.

At any rate, bulkhead design is important. It can save much time in a repetitive operations.

A lot depends, once again, on whether the form has a uniform cross section. If it does, it may be better to thread the strands through a bundle of identical one piece bulkheads. After the strands are stretched along the bed, the bulkheads can be moved along them and left at any desired point.

Most fabricators, however, employ a segmented bulkhead which can be erected around tensioned strands any place along the bed. Made of both steel and wood they are braced in several ways. Steel "cat-heads," which are small open steel sleeves anchored to the strands with set screws, can support a bulkhead, but many firms rely on simple wood braces.

Need of Safety in Tensioning

In prestressing we are dealing with very large forces which must be handled safely if accidents are to be avoided. There are active, not passive forces, and they can do a great deal of injury to personnel and damage to equipment, unless they are known and respected.

Precautions which should be taken to prevent accidents during prestressing operations are:

1. Strong steel wire mesh to be placed between the operator and the stressing operation.
2. Covers should be placed over anchorages and the tops of the molds as a precaution against wire slip and breakage (sacks, tarpulins or metal shields have been used).
3. All personnel should be clear of the stressing beds during stressing operations.
4. The position of jacks in relation to the anchorage head should be checked before stressing.

Conclusion

In general, the pretensioning construction procedure may be concluded in the following operations:

1. Clean the forms of dirt and erect the soffit form on the pretensioning bench. In some type of products, the side forms may be set up at the same time the soffit form is errected. The soffit form should not normally be oiled when they are first set up.
2. The tendons are threaded into position and stressed. If plastic tubes are being used to prevent bond on some tendons, the tubes may be placed before, during, or after the tendons are being stressed.
3. Inserts and bearing plates which must be positioned under the tendons are put in place on the soffit form (some forms of

bearing plates must be positioned before stressing).

4. Tendons which are to be draped are deflected into position.
5. The soffit form is oiled. A shield must be used in this operation to prevent oil from accidently being applied to the tendons.
6. The reinforcing steel, post-tensioning tendons and end bulkheads are secured in position as required. One side form which has been oiled may be erected before these items are placed, in order to facilitate the securing of embedded items and bulkheads.
7. The side forms and end bulkheads are positioned and secured.
8. The concrete is placed, vibrated and cured. The vibrating of the concrete near the ends of the members must be given special attention, since good compaction is essential at the ends of the members in order to achieve good transfer bond.
9. When adequate concrete strength has been attained, the forms are stripped, the prestressing tendons are released with hydraulic jacks, and the tendons between the members are cut.
10. The pretensioned members are removed from the soffit forms and the cycle is reported.

Methods of placing and curing the concrete are discussed in the next chapter.

CHAPTER IV

PLANT FACILITIES AND PROCEDURES

Introduction

The plant facilities which are used in prestressing plants vary considerably. The capital which is available for the plant investment, as well as personal preference, has considerable influence on the methods and equipment which are used. The geographical location of the plant has significant influence on the curing equipment and structures which are required to maintain an efficient, year-round operation.

The purpose of this chapter is to discuss some of the types of equipment and procedures which are used in prestressing operations. The advantages and disadvantages of the various types of equipment are pointed out, and an attempt is made to list accessory equipment and facilities which are often required in efficient prestressing plants.

Batching and Mixing Plant

The size of the prestressing plant, as measured by the average daily production of prestressed concrete, is the factor which has the greatest influence on the type of batching and mixing facilities. In small prestressing plants, the average daily production may be 10 cubic yards of prestressed concrete, and the concrete can generally be placed in the forms at the rate of from 6 to 12 cubic yards per hour with a single placing crew. The average daily production in a large prestressing plant may be of the order of 200 cubic yards of prestressed concrete per day, and the rate of placing the concrete in large plants is approximately the same as in small plants, although there may be more than one placing crew. It is desirable, that the concrete be placed as quickly as possible in order to maintain the desired production cycle, and, as a result, the batching and mixing facilities which are employed must be of sufficient capacity to provide concrete at a rate which is not less than that at which the crews can place the concrete in the forms.

These considerations make it apparent that the minimum batching and mixing facilities should be capable of producing concrete at about 12 cubic yards per hour. Facilities of this size would only be used for about one hour a day in small prestressing plants and are capable of producing about 65 to 75 cubic yards of concrete in an 8-hour production day, under normal conditions. It is also apparent that the capital investment that would be required to install mixing equipment of this capacity could not be justified for many small plants and the better solution may be to purchase ready-mixed concrete which is delivered to the prestressing plant in mixer or agitator trucks.

Batching plants of a number of types are available. The most simple are small, elevated bins from which sand and gravel, or other aggregates, can be removed from the gates at the bottom of the bins and weighed in a movable hopper. The aggregates are then dumped into another hopper or skip loader or conveyed by other means to the mixer where the cement and water are added. The bins are charged from stockpiles of aggregates with belt or bucket conveyors or by small cranes with clam-shell buckets.

More elaborate batching plants in which the entire batching, conveying, and mixing operation is controlled electronically are also available. Equipment of this type is available with controls which allow the selection of several different concrete mixes by simply turning a selector switch. Although the labor required to handle the cement and aggregates is minimized with electronic batching equipment, the capital investment that is involved with this type of equipment is relatively large.

Concrete mixing equipment may be any approved make of the following types. (22).

(a) Truck mounted transit mixer.
(b) Central drum type stationary mixer.
(c) Pan type mixer.

Because of the stiff consistency which is necessary in the concrete for prestressing, the type of mixer which will best produce such concrete has been a matter of importance to consider. If concrete is brought to the beds in ready-mix trucks, there will be considerable difficulty encountered with discharging such low-slump concrete from mixer drum.

To handle this low-slump, high strength concrete, special mixer equipment has been developed. All of these are pan-type, designed to turn out the low-slump mixes used in prestressed concrete. All have great flexibility in charging or discharging the concrete, usually through 360 degrees; the blades are designed to braid the materials together for quick mixing.

Transportation and Placing

When concrete is batched and mixed at a stationary mixing plant, it is necessary to convey the concrete to the forms. This can be a major problem in prestressing plants, since the distance from the mixer to the forms can be appreciable. Various methods are used to convey the mixed concrete from mixer to the casting bed forms. These include the use of bin-type carriers on wheels, concrete buckets handled by cranes, types of special truck conveyors handling the low-slump concrete, special devices for handling ready-mix trucks for speedy discharge, and in some cases, the use of a monorail system which handles portable, self-propelled buckets which can be upset for discharging their loads into forms. In fact, practically every type of concrete handling equipment has been observed in plants. It is advisable to inspect equipment used by other producers, as each plant condition may warrant use of equipment not so well adapted for another's particular situation.

When a stationary mixer is used in a pre-tensioning plant, the concrete can be conveyed in buckets transported on small cars which travel on two rails. Since virtually all of the concrete that is required in the plant is used on the pre-tensioning bench, the area of the plant which must be occupied with the track for the cars would be confined to a strip along each bench and a switching area near the mixer. This type of equipment can be used without an operator and automatic switching devices and limit switches can be used to stop cars where desired for filling the buckets or delivering the filled buckets. The rails on which the cars run could also be used for moving the prestressed beams to the storage and loading areas if desired. Although the initial investment which is required is moderately high, due to the small amount of labor that is required with this type of system, it is believed that this is one of the most economical methods of handling the concrete.

In placing the concrete into the casting bed, some argue that it should be placed in level lifts of from 6 to 16 inches in depth. Other engineers think that such concrete should be placed starting at both ends of the member and working toward the middle of the member, to the full depth of the section. They claim that the placing of concrete in horizontal lifts might produce planes of weakness at the lift lines, and that by placing the concrete continually from each end to the center any planes of weakness would be more or less perpendicular to the diagonal tension cracks which might occur at high shearing stresses.

Placing the concrete in layers is the method which is recommended in normal structural concrete. This method is generally preferred, since it results in minimum sagregation of the aggregates and water gain.

Most techniques, in regard to mixing and placing, or other details of manufacturing good concrete, can be applied to prestressed concrete. A few factors peculiar to this material must be investigated, as to their possible effect in decreasing the high strength, not appreciably increasing the shrinkage and creep, and not producing adverse effects of any type in prestressed concrete.

Vibration

In order to obtain the maximum strength in the concrete, it is necessary that it be uniformly consolidated to the maximum degree consistent with economy. So much depends upon this compaction for strength that every type of vibration equipment is brought into use. Because of the extremely stiff consistency of the concrete which is to be prestressed, it is quite necessary to vibrate it into place. All types of vibrators have been used, including internal spud type, external high-frequency types, and screed types. These are operated by electricity, gasoline power, air, and in some cases by steam.

Much dryer mixes can be used when proper vibration follows. With the greater density resulting from this consolidation, impermeability and durability also increase. Shrinkage and creep are reduced by using lower water-cement ratios. Surfaces are better. Less sand can be used in vibrated concrete, and more of the larger aggregate, which improves strength considerably. Because of the narrow space between strands, this size is somewhat limited, as is the size of the spud vibrator head which can be used. Proper precautions should be taken to prevent concrete grout from leaking through the joint lines of the forms, under the greater pressure put into the concrete through vibration.

Considerable differences of opinions exist as to the best methods of vibration, particularly as to frequencies when using external vibration, position of application, amplitude, duration, force of vibrating blow, and the area of volume of the concrete through which vibration is effective. Both supervisors and workmen operating the equipment should be experienced in these variations, in order to accomplish the maximum consolidation.

Three general types of vibrators are employed: internal, form, and surface. The first two types are more generally applicable to the production of prestressed concrete members. Of these two, internal is to be preferred since the power is transmitted directly to the concrete and the portability of the equipment permits more flexible use during vibration. As stated above, opinions vary as to the influence of frequency and amplitude of vibration on strength. In some typical tests recently run, it was shown that frequencies ranging from 3,600 to 11,000 vibrations per minute, used in combination with different amplitude settings showed no consistent influence on the strength of zero slump concretes. However, both factors influenced considerably the duration of vibration necessary to achieve adequate compaction. At a particular frequency, a larger amplitude of vibration reduced the required time and at a given amplitude, a higher frequency reduced the time for compaction.

Equipment generally available, at least for internal vibration, is of the fixed-frequency type, with little opportunity for amplitude change. The choice of equipment for a particular application cannot readily be determined by theoretical analysis. The influence of factors such as frequency, amplitude, mix characteristics, and size and shape of member is difficult to evaluate. The type of equipment required is best determined by trial.

Any technique of compaction is suitable, provided full compaction can be attained. If this is obtained, then water-cement ratio will be as good a criterion of strength as void-cement ratio, since the amount of entrapped air voids should be small and exert little influence on the magnitude of the void-cement ratio.

Internal Vibrators

Most of the internal vibrators are operated by electric motors, air pressure or gasoline engines, and conduct the powerful, high speed vibration through flexible shafts to a spud head, which is inserted in the concrete, and moved about to reach as many spots as possible. Usually these run at about 3,600 r.p.m. with an amplitude of 3/16 inches. Such vibration permits the use of low-slump concrete, moves the mass into final placement easier and faster than by hand rodding or spading, and eliminates voids, air pockets, and cracking within the body of the concrete. It is being used in most of the prestressed plants today, sometimes in combination with external types. Light-weight, versatile, inexpensive types are coming into the market, powered by 110 volts current, enclosed in a sturdy steel case equipped with carrying handle for easy portability.

Form Vibrators

External vibration of the forms in the casting bed can accomplish considerable good in producing smooth outside surfaces on the member, practically eliminating the need for hand or tool finishing of these surfaces after the member is stripped from the forms. Such vibrators can be attached to the forms with pin-type clamps permitting easy removal to another spot, or they can be installed permanently by bolting at proper points. External vibration is not used today to the extent that internal types are used, but may in specific instances form a good combination for thorough consolidation of concrete. Occasionally certain types of external vibrators are attached to screeds used for forming or striking off the upper surface of the slab, where such equipment does not have vibration built into it.

Surface Vibrator

Combining both the strike-off and consolidation of the top surface of the structural member being prestressed, the screed vibrator is enjoying increased application lately.

The duel result cuts labor costs appreciably and produces a top surface of the slab which is eminently satisfactory. The usual unit consists of a beam with a vibrating unit attached to it, generally in the center, and a pair of end roller assemblies. The vibration is transmitted through the length of the beam directly to the concrete. There is no transverse movement of the beam. The screed is merely drawn directly forward with the end rollers riding on the forms.

Such screeds not only strike off the surface and shape it as they are pulled along, but they vibrate the concrete at the same time. This means that all the advantages of vibration are obtained, such as greater density and homogeneity in the concrete. They can handle a 1-in-slump concrete without trouble. Most of the vibrating screeds have rubber dampeners between the end roller assemblies and the beam, preventing too much vibration from being transmitted to the forms. A method is provided to stop and start the vibration when the screed is standing still.

Vibropunching

A new factor lowering the cost of prestressed concrete construction is the innovation of concrete vibropunching during casting. (32). This method has been recently developed in the U.S.S.R. The free vibration method used in casting of concrete members also gives good results, but here the concrete density is attained only from the concrete's own weight. Concrete mixed by vibration becomes plastic and spreads till its surface flattens -- the stiffer the mixture, the more time required for casting.

During vibration the stiff mixture acquires plasticity and fluidity. It is therefore possible to direct, move, replace and densify the mixture, in any, even very complicated profiles, by force. Vibropunchers or even boards in close contact with the concrete mixture can be used for vibropunching casting.

On completion of the above mechanized casting, and after vibration ceases, the mixture sets, and becomes strong and hard. The profile and the density of a member is obtained by the vibropuncher simultaneously with the application of a pressure of about 200 g/cm^2.

The exact profile print on the surface of a cast member is obtained from the same profile on the vibropuncher. The vibropunching method of member casting provides for quick vibropuncher and form board removal without injury to the concrete. Therefore, mold separation during vibropunching is an important link in the member casting process.

Curing Requirements

The term curing as applied to concrete units may be considered as the period between the casting operation and the time when the units are strong enough to be used. Hydration or hardening of cement takes place through chemical action between the cement and water. If water is not sufficient in quantity, the hardening reaction is impeded. Sufficient water must be present during the entire period after casting until the required strength is attained. With all methods of curing, three essential factors are involved; namely, time, temperature and moisture. In selecting the method of curing, the important consideration is to maintain the concrete in a moist condition until the cement has properly hydrated or hardened.

In the production of pretensioned pre-stressed concrete members of high quality, two of the most important considerations are the method and duration of curing the members in the casting bed. Several methods of curing are used, including steam, hot water, and hot oil for the basic type of heat production.

The duration of curing varies, depending upon the producer's time schedule and sometimes on the requirements of the customer. It is important to produce units of good quality and strength without placing undue restrictions as to type and duration of curing. Since too short a curing period may result in poor quality members, and too long curing adds to overhead costs, it is desirable to establish a conservative basis for the proper method and duration of curing which should be adopted in the production of such units. The purpose of any tests is to determine, experimentally, the effects of these variables.

The quality of a prestressed unit is mostly affected by the combination of strand stress, compressive and bond strength, and the modulus of elasticity of the concrete in the units. Since strand stress can be controlled accurately, it remains to determine how the compressive strength, bond, and modulus of elasticity would be influenced by the curing methods and curing duration. In all tests of this nature, the variation in the concrete strength is determined by cylinder and flexural tests of beams. Relative bonding properties are studied by measuring the amount of slip of the strands in the concrete as the stress is released. Modulus of elasticity is also determined by cylinder tests. The specimens for the test should be cured under a moist condition similar to wet burlap curing, and in a steam room at temperatures comparable to those presently used in casting beds equipped for such steam curing. Tests should be conducted for several days to study the daily variation caused by change in the curing duration.

Conclusions as to the proper methods of curing as determined by tests would include the following:

1. Sudden release of the strands should be avoided since this may cause large slips which damage the load-carrying capacity of beams or other structural members.
2. Beams of similar dimentions as those tested should be wet-burlap cured for five days or steam cured at 130 degrees Fahrenheit for three days before stress release.
3. Beams with 3,000 psi cylinder strength and 3 times 10^6 psi modulus of elasticity appear to have reached acceptable bond, compressive, and tensile strength, to proceed with stress relieving.

Curing arrangements, whatever these be, should always be designed to apply heat to the concrete in such manner that it will be subjected to the most favorable temperature throughout the member. This should be the criterion whether steam (wet) or heat (dry) curing methods are followed. The important part is that the concrete be kept covered, either by tarpaulins or by use of a sprayed on membrane coating, which will prevent evaporation of the water from the exposed surface. If heat is applied, the water must remain or craze-cracking of surface will result.

General requirements for curing reinforced concrete would apply to all types of prestressed concrete, but because of the necessity for speed in curing the latter, in installations which have a daily production cycle in which members must be taken from the forms in 16 to 18 hours, the curing must be accelerated. Forms of such curing include water curing with moist sand or burlap, integral of mixtures sprayed on surfaces, membrane curing, and steam curing.

Steam Curing

It is agreed that the best method of curing any prestressed members is by means of steam under tarpaulins, where the heat is applied to the concrete without loss of moisture from the surface. This method cannot be used in outside beds in cold weather. When such conditions are encountered, use of aluminum lined steam hoods provide the same basic results. These are sectional type hoods with recording thermometers showing the interior temperatures. The modulus of elasticity of steam cured test specimens has been better than those of wet burlap curing, which means that the steam curing saves time and allows earlier stripping. In other words, it provides higher production of a better product.

Hot Water Systems

If heat is conducted to the concrete by means of pipes, some method must be utilized to retain the moisture on the surface of the concrete while curing proceeds. It is necessary to avoid this evaporation to prevent cracks from occuring. Water is heated to around 150 degrees Fahrenheit and forced through piping for the length of the bed to supply heat. With this system, the bed should be covered, or sprayed with water, to retain top moisture. If sprayed, the water should be preheated so that the temperature rise from the hot water will not be dissipated by the spraying action. One operator installed a bed form across the top of the bed and had a water line within this cover to accomplish the spraying.

Hot Oil Systems

The use of hot oil, in place of hot water, carried to the casting bed through pipes, is fast becoming the medium for curing in prestressing operations. In such curing systems, the pipe travels along the length of the bed -- sometimes as far as 600 feet or more -- and a considerable loss in temperature is experienced with water. Oil holds the heat longer and is more efficient in supplying the dry heat to the concrete. Moisture must be retained on the surface, if the system is to function properly.

According to one manufacturer of hot oil heaters, the use of oil for curing features the following: low maintenance, low operating costs; no rust, freezing, scaling, or corrosion is experienced; the system guarantees an even temperature throughout the entire length of the casting bed; it is a completely automatic operation; no stationary fireman is required, as is the case with a hot water boiler; and steam for curing members is available at lower costs than when generated with other apparatus.

Handling Equipment

A wide variety of hoisting equipment is now employed on casting bed around the country. In fact, virtually every type of crane can be found somewhere. There are crawler cranes, truck-mounted cranes, overhead, locomotive, and gantry cranes. And there are several schools of thought on which type is best.

Decisions regarding types of handling systems to be used in any prestressing plant must be based on several factors which apply to each individual operation. These would include, for example, the amount of capital available for such equipment; the size of the plant and area available for storage, etc.; what type of prestressed concrete members are to be produced; how rigid is quality control to be; and the location of the plant, as regards to railroad facilities, waterfront facilities, etc.

The operation must be planned first, and the type of equipment best suited to handle the production then decided upon, regardless of types used by other producers. If the operations are to be conducted indoors, forklifts or other mobile handling equipment are almost immediately eliminated, in favor of the use of bridge cranes or like equipment spanning the beds.

Specially equipped lift trucks are very useful in most plants, regardless of the type of operation. The minimum number is two, as these must be generally used in pairs, unless they are of large capacity and equipped with special cross beams. In fact, any plant transportation equipment must be so equipped to pick up members from the casting bed, with slings attached to the lifting hooks in each. In such cases, usually a total lifting capacity of at least 20 tons is required. Lift trucks can afford almost unrestricted movement and have the ability to get things out of cramped spaces. If production is not 2,500 square feet per day of double T slabs, for example, fork lift trucks can probably handle this.

Cranes of all types are used extensively in prestressing plants, for handling both concrete and the completed cast members. It pays to buy sufficient capacity in cranes. A decided trend is seen today in the increasing use of various types of straddle carriers for handling the completed prestressed members from the casting beds to storage points, and in some cases, to move concrete from batching plants to beds. In all cases the handling units are equipped with special type slings or cross booms so that the member is supported from the pickup points near the ends. It must be remembered that any prestressed concrete member must always be supported at the same points as it will be supported from the structure.

Whatever the method of handling materials or completed products is resorted to, it must be remembered that it is important to reduce the amount of storage of product as much as possible, since the storage area must be serviced, and requires two handling operations -- once in, once out -- in each instance.

Hauling

Transporting members to the job is handled in several ways. Flat bed trucks, railroad cars, and trailers are all suitable, depending on conditions. The important thing to remember is that the beam in transport must be supported at the same points it will be supported in the structure. Units up to 80 feet long can be transported over highways without much difficulty. Rail and water vehicles can carry bigger members — another reason for strategic locating of the casting yard.

Most versatile pieces of erecting equipment are mobile cranes. They can handle just about anything. The important factor is the proper education of the operator. He must be taught to understand the type of product with which he is working, and he must realize its weaknesses. It is not like steel. You cannot treat it ruggedly, or it will fail.

Supervision and Quality Control

The need for quality supervision of concrete placing is great. On large jobs it is considered good practice to utilize a man at the batching plant and another at the job site for control purposes. To date, standard slump tests and cylinders have been largely used to control and determine the strength of the concrete. In general, there are two types of inspection: that which the producer does himself to ensure a high quality product; and the other done by the engineer to assure that his client is getting a job which is built according to the specifications. All inspectors should be well trained in all phases of concrete mixing and quality control. Also, he should know all the factors involved where he may go astray. Because of the relative newness of the industry, supervision of prestressing operations are doubly important, and no opportunity should ever be lost to instruct men who are entering this industry, as to this importance.

Detensioning of the strands in a member, for example, must be done in a balanced pattern, to avoid throwing excessive stresses into the remaining strands. There are many other typical operations which must be done properly to avoid trouble. Care should be taken in the preparation of both test and control cylinders to see that they represent the actual condition of the concrete from which they are taken. Correct position of stirrups must be watched.

As specified by the P.C.I. standards for prestressed concrete plants, "Each plant should have a competent installation supervisor whose suggested duties are as follows":

(a) To check the progress of jobs in process to assure that the structure is ready to receive the prestressed members before shipment, and that no condition exists which would cause an unsatisfactory installation.

(b) To inspect at the casting yard all manufactured members for conformance with plans prior to shipment.

(c) To supervise handling and installation of members in structure to insure that installation is in conformity with plans.

(d) To check after every erection phase with the prime contractor or owner to assure satisfaction with the work done.

(e) To make a written report of any irregularities observed (such as dropping a beam during handling).

Additional Plant Facilities

Plant Office

The minimum office at the plant should have separate facilities for the manufacturers' personnel and for the inspectors who represent the owner of the prestressed products which are being made.

Laboratory

Minimum laboratory equipment should include a testing machine which is capable of testing concrete cylinders, a number of precision, steel cylinder molds, a slump cone, hand and recording thermometers, apparatus for determining the moisture content of sand, miscellaneous small tools and laboratory equipment. Complete laboratories may include constant-temperature curing rooms in which a uniform humidity is maintained, equipment for determining the gradation of the aggregates, and other equipment that is required for basic research and product development.

Drafting Room

Shop drawings are required for nearly all prestressed concrete products. The preparation of shop drawings should include the computation of the quantities of materials which are required in the manufacture of products, and determination of the effects and plastic deformation of concrete as well as inclination of the structure (grades on bridge members) on the length of the members which must be used in the fabrication of the members. Anticipation of camber and deflection should also be computed and indicated on shop drawings. The correct preparation of shop drawings is essential in order to obtain products which will give good service, and, in addition, well-prepared shop drawings will facilitate the fabrication of the products and cost accounting of the manufacturing operation. Competent engineering personnel are required to prepare computations and review the drawings.

Small Tools

Small tools including hammers, wrenches, pliers, vibrators, shovels, etc., must be kept in sufficient quantity and in repair. A workman who serves as a tool-room keeper and mechanic is frequently required for this purpose.

Supplementary Fabrication Shops

Separate shops for carpentry and steel fabrication are frequently needed for fabricating special forms, cutting and bending reinforcing steel, fabricating steel bearing plates, constructing jigs, and other devices to facilitate the manufacturing operation.

Other facilities and services may be required under special conditions. The determination of which of the above facilities as well as others which would be required for a particular plant is obviously influenced by the location of the plant and the types of products which are to be manufactured.

CHAPTER V

STANDARD PRODUCTS AND COSTS

Introduction

One of the most perplexing phenomena on the American economic scene is the prestressed concrete industry — perplexing, that is, to economists. Never before had they experienced such rapid acceptance of a major innovation in design and construction techniques. Upon a closer look, however, prestressing can be seen to have had a sound foundation of research, development and field trials before the first flush of popularity in the United States.

In prestressed concrete we have a competitive product. But the cost differential between it and competing materials is so narrow that the consumer just will not tolerate shoddy workmanship. It is usually poor workmanship that is a cause for complaint, not poor engineering. Mostly the difference between good and bad workmanship is simply one of management attitude — not dollars and cents. Many plants which have not succeeded were those whose management ignored the fact that to exist today a business must offer an exceptionally good product or an exceptionally cheap one. The purpose of this chapter is to discuss the standardization of the products and financial considerations.

Standardization

Throughout the country enough beams have been designed on a multitude of jobs of every description so that certain depths and shapes can be accepted, and the designer required only to calculate the stressing units to fit the shape, span, and loading. Even the shape can be standardized, if necessary, but may be left open to competitive systems, if desired. Standardization is particularly important in fabricated sections manufactured in established yards. It is only through an assembly-line-standardized-product that economy can be realized.

The development of the A.A.S.H.O.-P.C.I. standard bridge beams, box beams, and slabs for highway bridges has done much to introduce simplicity and uniformity in the design of short-span highway bridges, and to shorten design time. This frees the engineer for the more complex aspects of design, and with evergrowing store of both technical and construction experience, he can provide better designs.

In addition to the standardization in beam sizes and shapes, other members are even more standardized today. There are now more than 200 members of the industry making standard double T slabs from the same size forms. The T joist beam and channel have also received a high degree of standardization. The companies making strands have largely standardized the sizes and formation of the elements of the strand member, with loading tables agreeing in most instances where the same strand and area of concrete member is used in the design.

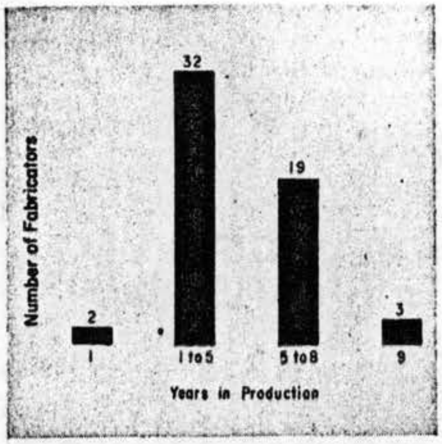
The possibility is rapidly becoming a reality when standard prestressed concrete beams may be secured from a supplier much as timber or steel beams are now ordered. After experimenting with various sections, bridge members are now being standardized so that manufacturers will find it economical to provide semi-permanent forms for repeated use.

Except in special cases, there is no reason why designing engineers should have to design prestressed concrete members. As a manufactured product it is up to the prestressed concrete industry to provide such engineers with standard designs and data for their consideration and use. Such standardization will lead to greater economy in their design, and, from the manufacturing point of view, production costs.

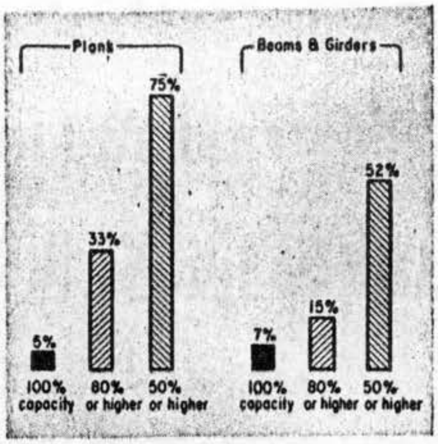
Products to be Made

In a survey made by Modern Concrete in the Fall of 1959, prestressed concrete producers advised that in types of structural members made in the plants of firms reporting, 33 percent of the output was in beams, 26 percent in doublt T's, 9 percent in channel slabs, 8 percent in columns, 5 percent in piling , and the remaining 19 percent in miscellaneous shapes in the other categories. (35). Of these producers, 11 percent made only one type of the above members, 52 percent made two types, and only 2.5 percent made four or more types. (4). The results of another survey conducted are given in Figure 5-1.

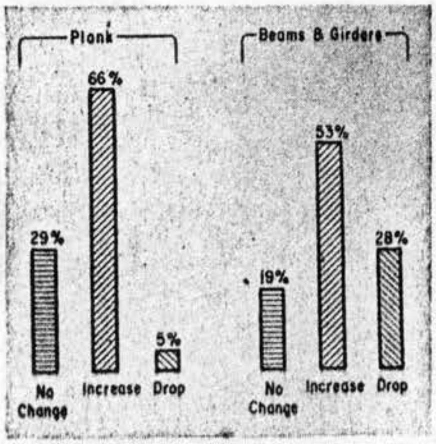
The double T roof and floor slab is probably the most popular form of prestressed structure members made today. Next comes the channel form of these same slabs. Both types can be made up to 60 feet span, by an increase in depth of leg and an increase in strand area. The ability of the doublt T to cantilever leads to many interesting designs utilizing this section. Both types offer large area per unit,



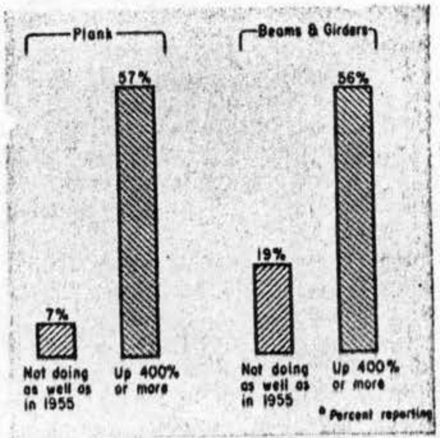
YEARS 56 fabricators surveyed have been in production.



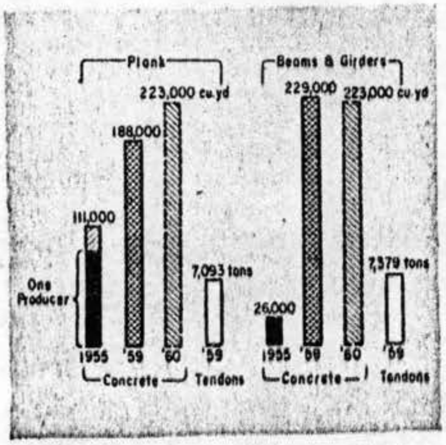
PERCENT CAPACITY of plant operation —few are at 100%.



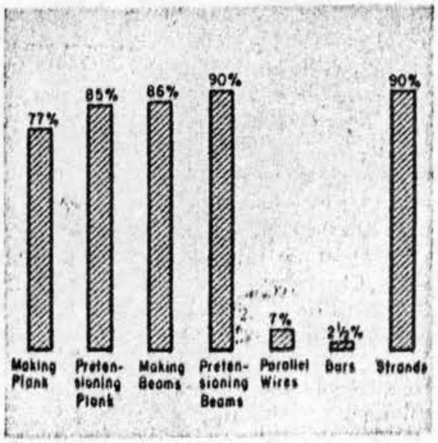
OUTLOOK—More plant producers are optimistic for 1960 than beam men.



PLANK vs BEAMS—More beam producers are hurting this year than plant men.



OUTPUT of these fabricators rose from 1955 to 1959, now leveling off.



TYPE OF OUTPUT—Trend is to pretensioning plank and beams with strands.

Figure 5-1. Some Facts of Importance About Concrete Producers.

and roofing or flooring materials can be applied directly to the level surface which is afforded. Channel slabs have been greatly used in bridge and building floors where heavier live loadings have been specified.

The T-shaped joist offers interesting possibilities where the exposed ceiling is preferred. The standard I beam section may be advantageously employed as floor or roof girders where medium to long spans are desired, and depths are unrestricted. It may be used as a separate unit, or in composite construction with a cast in place slab, when stirrups are extended into the slab for shear connections. The wide flange I beam is the ideal floor or roof girder section where long spans with very heavy loadings are required. It may be used as a separate unit or in composite construction. It is recommended where depths are restricted for architectural or structural reasons. It is regularly furnished for spans of from 30 to 60 feet.

The hollow slab unit may be employed to good advantage in bridge construction where rapid completion and minimum deck depth are of primary importance, such as in a roadway or sidewalk unit. Ordinarily fabricated in 36 inch widths with continuous shear keys to provide proper distribution of live load, this section is adaptable to right bridges and with slight modification of the ends to skew bridges. The unit ordinarily is used in spans of from 24 to 58 feet.

Remaining units commonly produced in prestressed concrete would include piles and flat slab planks. The former of these units may be square or octagonal in cross section and in diameters of wide range. Predominant advantages possessed by prestressed concrete piles are that they can take a great deal of handling abuse, and that because of the compression in concrete they will not show cracks from either shrinkage or flexing. Flat slab units, similar to tongue and grooved planks, are being used increasingly in short span roofs, where depth limits are restricted, or headroom is required. The unit is also ideal for use in bridge decks, spanning space between longitudinal beams or girders, for the support of poured-in-place concrete wearing decks. An index of the prestressed products is given in Figure 5-2.

Lin T Joist

A very efficient T joist has been developed by T. Y. Lin, of T. Y. Lin and Associates, Van Nuys, California, known as the Lin T joist. (35). With only one set of steel forms, it is possible to produce with this joist building panels up to 120 feet span and bridge sections up to 50 feet span, in accordance with the latest recommendations of the Joint A.C.I.-A.S.C.E. Committee 323 on prestressed concrete. In the section shown in Figure 5-3, a very flexible design can be obtained, since it is possible to vary the width of the panel, the width of the stem, the thickness of the flange, and the depth of the section. With the thicker stem the section affords much better fire resistance than the normally designed T joist. Professor Lin has published an excellent engineering brochure giving all design data on his joist.

Double-Tee Slab Economy and Resiliency

Bread and butter item of any plant is the double-tee. It is the closest thing the industry has to a standard product. It has a greater degree of flexibility of use than other forms. This apparent trend cannot be otherwise because this type of construction gives beauty,

I-BEAM — Popular shape for floor, roof, or bridge girders where medium to long span is required and depth is not important. Used as separate unit, or in composite construction.

WIDE-FLANGE BEAM — Same application as I-Beam, except it is superior on long spans with very heavy loadings. It is also desirable where depths are restricted.

MODIFIED-I — Best application is on bridge girders where deck acts as composite unit. In this case, stirrups are extended into slab to provide shear connection.

HOLLOW SLAB — Ideal unit for bridge construction where fast erection and minimum deck depth are most important. Placed side by side, they simplify surfacing.

DOUBLE-TEE — Most popular unit for roofs. Contains beam and slab in one unit. Spans up to 60 ft. Insulation and roofing are applied directly to smooth top surface.

CHANNEL — Cast like double-tee, but has no cantilever. Takes heavier loads. Excellent for bridge and building floors. Large area is covered per unit.

PILES — Square or octagonal, solid or hollow, prestressed piles are superior to reinforced piles because they can take more handling abuse, and eliminate shrinkage cracks.

JOISTS — T-shaped unit is popular in structures with exposed ceilings. It has striking appearance. However, competition is keen from similar precast units that are not prestressed.

FLAT SLAB — Resembling tongue and groove planks, these members are relatively new to the industry. They are ideal for small span roofs where headroom is a prime factor.

Figure 5-2. An Index of Prestressed Products.

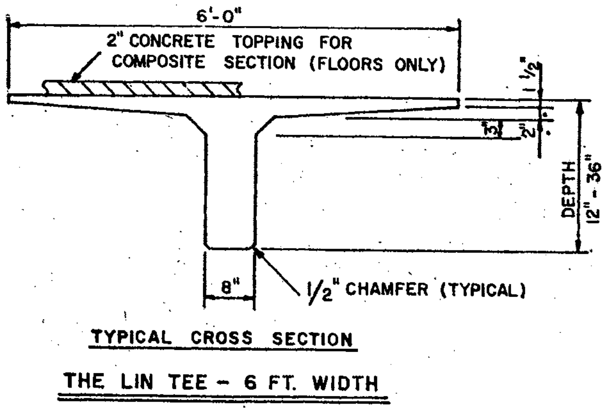


Figure 5-3. Cross-Section View of 6-Foot Wide Lin Tee Joist.

insulation, acoustical control, fire resistance, low maintenance, and long spans in an exposed ceiling requiring no additional expense of hung ceiling.

Forms for pouring the double-tee are a fabricator's dream. They never have to be stripped; the double-tee is simply lifted from the form.

Permanent steel forms for the double-tee cut costs to the bone, because they have maximum interchangeability. (36). One double-tee form can produce 37 different castings. Besides a number of double-tees, it can be modified to form channels, single tees, joinsts, and even bleacher seats.

Because it does not have to be stripped, the double-tee form can easily incorporate permanent curing fixtures. When costs are compared, this new system of roof and floor construction can approach the $1.25 per square foot installed cost of doublt T slabs. Cost and speed of erection will make the contractor a repeat customer and booster for prestressing. Flange bearing and cantilevering ability will appeal to him. The architect will also like the sound-absorbing qualities and the pleasing texture. The freedom to cantilever concrete T joists offers him an outlet for imaginative design in beauty of parallel lines in exposed concrete. Maintenance, low first cost, lower air conditioning and heating bills, will all appear to the owner. In many cases, he will value highly the availability of long, clear spans of 30 to 50 feet or more, without excessive depth of joist.

The high efficiency in the use of materials makes it possible to design a double T concrete roof slab capable of spanning 70 feet, having an over-all depth of but 14 inches, and requiring only 0.11 cubic yards of concrete per square foot.

Resiliency can be achieved in concrete through prestressing. A load deflection and recovery test must be witnessed for one to realize these properties which concrete takes on when prestressed. Brittleness and the possibilities of sudden failure can be very remote in certain prestressed designs. The prestressed T section is characteristically a low stress design. Overloads merely increase deflection, which serves as a warning of overload. Even at ultimate load, the double T does not collapse. It will even recover a large percentage of the deflection when the overload (ultimate) is removed.

Recovery after overload is a characteristic of a prestressed joist. For example, an overload of three times the design load on a 40 foot joist will show a deflection of 4 to 6 inches, and yet the recovery will be better than 92 percent. There is no tendency to buckle on these overloads. The joist –– at either dead loads, or dead and live design loads –– is free of tensile cracks. The first tensile crack usually shows up at dead load plus 1¼ (or greater) design live load. If tensile cracks should develop from an overload, they will close when the load is removed.

The standard width of the double T sections has been 4 feet, but many manufacturers are producing such slabs of 5- and 6-feet sections, effecting a handling economy that further reduces the cost-in-place of this versatile type of slab.

Financial Considerations

The prestressed concrete industry is young, is growing, and its eventual potentials are unlimited. Being thus comparatively new, and as yet not fully exploited, the method appeals as an added source of income to many who conduct related businesses. Prestressing is a complex subject and many influencing factors enter into the ultimate profit attained from it. In a recent review of the operations of many of the newer firms which have gone into this business, it appears that insufficient capitalization has been a major cause of difficulty. Lack of understanding of the basic requirements of the production facilities necessary to underprice structural steel shapes by 30 percent was the underlying cause which upset the rosy prospects. Those who suffered in this manner have but themselves to blame for having underestimated the capital required. While long-line steel forms are productively high, their initial costs are equally greater than the usual form expense. Obsolescence is the specter confronting any user of equipment in a newly developed industry, and prestressing is especially vulnerable in this regard. The prestressing bed and its constituent equipment is the heart of the whole production, and unless ingenuity is used in its choice and operation, fast-changing conditions could render it obsolescent in a surprisingly short period.

The higher cost of the new high-tensile steel strands, of around $500 per ton, compared with conventional reinforcing bars at $100 per ton, is typical of material cost increases which will be experienced with prestressing. Concrete strengths of 4,000 to 6,000 psi cost much more to produce than the 2,000 psi variety.

The cost of average precasting plant exclusive of land varies from $50 to $75 per linear foot of casting bed. (15). This includes concrete base, power jacking equipment, vibrators, re-usable anchor fittings, stands for reels or coils of strand, intermediate anchorage stations, a set of standard forms and the services of a consultant to design the bed and the standard members to be fabricated. Beds for casting light members only, such as roof channels and purlins, can be installed and equipped for less.

To sum up the general conclusions of producers who have made successes in the field of prestressing, we might say that if $100,000 is the limit of available capital, the venture is almost certain to fail. If $300,000 is at hand, plus intelligent accumulation of information before expenditures occur, it is likely that the venture may succeed.

Prestressing by Contractors

To successfully introduce prestressed concrete on a large scale in to a new area, the manufacturer must overcome the reluctance of local contractors to accept this new building material. This is particularly true in the erection of prestressed members. Comparatively few contractors have handled and erected prestressed members, and consequently are inclined toward higher cost estimates when submitting competitive bids on a project where use of prestressed concrete is contemplated as either a base bid or an alternate. Consequently, the manufacturer may find himself priced out of the market before his production is well under way.

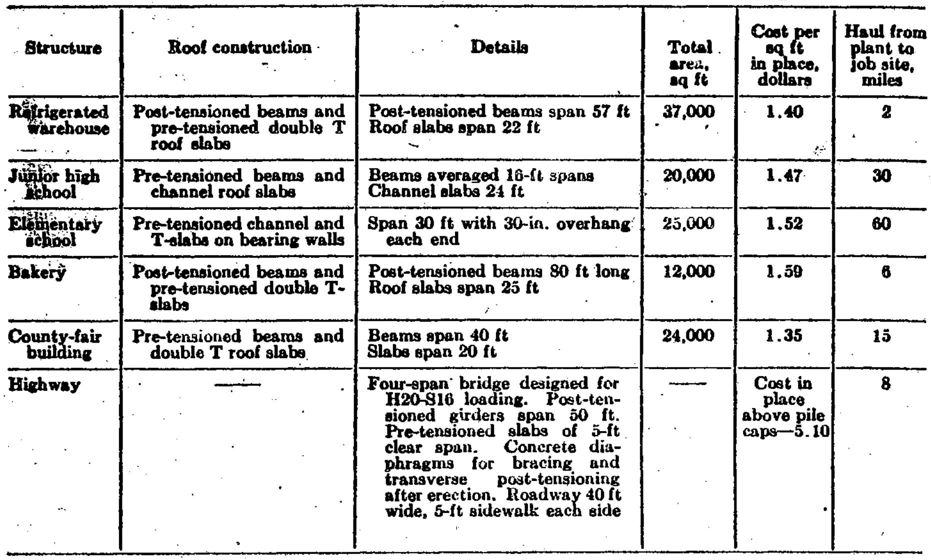
To avoid such a serious pitfall, the manufacturer should, for the first several jobs, quote the price of his product erected complete in place. Erection can be by the manufacturer, if he has the proper equipment and trained personnel, or he can associate himself with a competent contractor who will take an interest in carefully planning for the erection at the least possible cost. After it has been demonstrated by several successful and economical jobs that prestressed concrete can be placed in competition with other building materials, the local construction industry should realize that handling and erection of prestressed members do not present a difficult and costly problem.

Although the final cost of the prestressed concrete project will vary in different parts of the country in direct relation to the cost of labor and materials, cost of installations completed in the Denver area are indicative of what may be expected -- Figure 5-4. (17).

Summary

If prestressed concrete is to take place as a standard building material along with reinforced concrete and structural steel, the following factors must be kept in mind.

1. Full use should be made of the properties of the prestressing elements.



Structure	Roof construction	Details	Total area, sq ft	Cost per sq ft in place, dollars	Haul from plant to job site, miles
Refrigerated warehouse	Post-tensioned beams and pre-tensioned double T roof slabs	Post-tensioned beams span 57 ft Roof slabs span 22 ft	37,000	1.40	2
Junior high school	Pre-tensioned beams and channel roof slabs	Beams averaged 16-ft spans Channel slabs 24 ft	20,000	1.47	30
Elementary school	Pre-tensioned channel and T-slabs on bearing walls	Span 30 ft with 30-in. overhang each end	25,000	1.52	60
Bakery	Post-tensioned beams and pre-tensioned double T-slabs	Post-tensioned beams 80 ft long Roof slabs span 25 ft	12,000	1.59	6
County-fair building	Pre-tensioned beams and double T roof slabs	Beams span 40 ft Slabs span 20 ft	24,000	1.35	15
Highway	——	Four-span bridge designed for H20-S16 loading. Post-tensioned girders span 50 ft. Pre-tensioned slabs of 5-ft clear span. Concrete diaphragms for bracing and transverse post-tensioning after erection. Roadway 40 ft wide, 5-ft sidewalk each side	——	Cost in place above pile caps—5.10	8

Figure 5-4. Job Costs and Details

2. The proper type or combination of prestressing elements should be used.

3. Designers should become familiar with prestressed concrete costs and specify prestressed concrete without alternatives where it is the most economical material. There is, however, one advantage to offering alternatives. A study of numerous recent bids where prestressed concrete was offered as an alternative shows that quotations on other materials were considerably lower than on jobs without alternatives.

4. Several consulting engineering firms have considerable experience in the design and operation of casting beds. The fabricator who is planning to build a casting bed will probably save money and time by retaining such a consultant to design a casting bed for him.

Conclusion

Prefabricated or precast structural members such as panels, slabs, beams, frames, columns and piles are rapidly coming into wider use. It is predicted that the precast concrete business is destined for a phenominal increase and that in the near future it will be possible to go to a precasting yard and purchase structural concrete units about as readily as we now buy lumber or metal materials. Prefabrication has also stimulated startling new developments in architectural concrete applications.

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