PRESTRESSED CONCRETE AND LOCAL APPLICATION

HUSAYNI, Abdur-Rahman

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LOCAL APPLICATION

Abdur-Rahman Rabah Husayni.

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INTRODUCTION

Prestressed reinforced concrete is a new method of construction which did not yet enter to the Arab Countries of the Near East. Even in the United States it is newly adopted as a method of construction compared to its use in Europe. In Europe it is fully developed due to the appreciable saving on materials of construction, steel and concete.

This thesis is intended to give a good knowledge of what is prestressed reinforced concrete in general. It is intended to be a sort of a general reference about the subject discussing it from all points of views as much as possible.

The most important part of the thesis is the economical aspect of the subject. It will prove that the application of prestressed concrete in this country will be more economical than the application of ordinary reinforced concrete or any other type of construction under certain conditions mentioned later in the thesis.

The scope of this thesis will be limited to the theory, design and construction of beams and bridges in prestressed concrete.

The candidate is delighted to take this opportunity to express his deepest gratitude to Prof. I. Rubinsky, for his most valuable guidance and advices which proved to be indisponsable in the realization of this project.

THEORETICAL PHASE

1.- What Is Prestressed Reinforced Concrete in General ? :

The function of a structure, from a structural point of view, is to be able to carry safely the load which it is supposed to carry. These loads will produce stresses in the members of the structure and these members have to possess the property to compensate for these stresses.

Ordinary reinforced concrete is one kind of structure that serves this function. Concrete is good in compression and poor in tension, thus it can serve as the compression part of the structure. Steel is good in tension, thus it can serve as the tension part, or sometimes compression, of the member of the structure. Thus a combination of concrete and steel is a good combination to serve the purpose.

But there is a loss in concrete in a reinforced concrete section which is the concrete below the neutral axis. This portion of concrete is wasted and has no utility for the structure as such and its only function is to bond the steel to the concrete so that both will act as a unity.

Now take a certain ordinary structural member made of concrete to carry a certain load, and before this member is loaded an eccentric force is applied to the member which will produce compression at the bottom and no stress, or tensile stress, at the top. After the member is loaded, these stressed produced by theaction of the force will be compensated, because the load will produce tension at the bottom and compression at the top.

This idea of producing initial stresses in the member, before the member is loaded, opposite to those that will be produced afterwards by the load is the idea of prestressed concrete.

In this, the entire section of the beam was utilised and made to function without waste of materials.

2.- A Comparison Between Prestressed Concrete and Ordinary Reinforced Concrete Showing Advantages and Disadvantages of Each :

1) In ordinary reinforced concrete "under the working load the concrete on the tension side of a reinforced concrete beam is generally cracked since it is unable to conform to the normal stress in the steel"[I] While in prestressed concrete, cracks are completely eliminated because all the section of the concrete is always in compression.

2) "The second weakness of ordinary reinforced concrete is that the dimensions of a beam are determined by diagonal tension; if the shearing force is high a very large beam is required and for long beams the dead load becomes too great for practical purpose"[I]. While in prestressed concrete the diagonal tension on the beam is opposed by the compression on the concrete section due to prestressing and is easy to deal with.

3) In ordinary concrete, the shrinkage of concrete during hardening may result in cracks even in the absence of load. In prestressed concrete this does not happen. In pre-tensioned prestressed concrete the only action of shrinkage of concrete is to reduce the amount of prestressing by a certain percentage taken from experiments and judgement. In post-tensioned prestressed concrete, shrinkage takes place mainly before prestressing is applied to the section.

4) "In ordinary reinforced concrete, full use cannot be made of high strength concrete; that is, if the size of a beam were reduced beyond a certain limit, the amount of reinforcement required would make the beam uneconomical. It might be said thatit would be sufficient to replace mild steel having a higher yield stress so that the area of steel be reduced to, say, one-sixth of its previous value; but this solution is not acceptable since the strain of the high-strength steel

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I Reference 1, Page 1.

would be about six times the strain of the mild steel, and this would cause wide cracks, for example a beam under working load" [x]

5) "One of the disabilities which reinforced concrete members in bending suffer is the loss of the concrete area on the tensile side in computation at section near the maximum bending moment. This loss is due to the assumption that the concrete has cracked to the neutral axis" [xx]. In prestressed concrete all the concrete section is utilized and no cracks occur.

6) "Members that must be watertight have the additional handicap that such cracks reduce the thickness of impermeable concrete" [xx].

7) In case that the prestressed concrete member is subjected to abnormal excessive load that produce cracks, then these "cracks become invisible on reduction of load, and an entirely closing of the cracks being ensured when the tensile stresses are reversed into compressive stresses. Thus it is permissible to assume a straight line stress distribution in a homogeneous material independantly of whether temporary cracks have developed or not." [xxx]

8) In prestressed concrete "smaller depth-to-span (d/L) ratios are possible, giving more headroom.

9) The architect can design concrete structures with cleaner, slimmer lines.

10) Design calculations can be quicker and more accurate.

11) Long spans can be constructed from smaller precast units, made in a factory and trucked to the sight for assembly" [@]

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x Reference 1, Page 1

xx " 3, Page 205

xxx Ref. 2, Page 11

@ Ref. 7.

12) One of the disadvantages of prestressed concrete, when applied locally, is that it requires testing of the materials used, nd mainly concrete, which is not common and not always available.

3- Facts about Prestressed Coñcrete that Have to be Considered in the Treatment of Design:-

In designing prestressed concrete shrinkage of concrete and creep of concrete and creep of steel are very important elements. In prestressed concrete when the concrete has hardened sufficiently and the wires released to act on the concrete, the concrete becomes in compression. During hardening, concrete will shrink and will become shorter. After some time, because of the continuous action of the force on the concrete, the concrete will yield to this force causing creep of concrete. This creep appears to be considerable at the start and negligible after a certain time. The phenomena of creep of steel is similar in behaviour to that of the creep of concrete.

These elements, shrinkage and creep, are important because they reduce the prestressing force thus reducing the allowable loading as reached under the assumption that they do not act.

To reach the amount of reduction, or the percentage of reduction, a study of each phenomena is desirable. A study of this sort will require, more than anything else, tests on the materials to be used to determine their behaviour.

As it is not possible in the time being to run experiments locally a study of what others did will solve the problem partially.

Concrete:-

"When a concrete prism is loaded axially to a certain stress it has an instantaneous strain δ_i, if the load is kept constant for a certain period the strain increases to δ_t. The coefficient of creep is therefore $C_c = \delta_t/\delta_i$. Creep is very difficult to measure since shrinkage occurs at the same time and it is not easy to seperate the two phenomena. This is probably one of the

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reasons why the movement of the concrete due to creep is generally given as greater than the values found by the writer"* (Prof. G. Magnel).

To seperate the effect of both, shrinkage and creep of concrete, Prof. G. Magnel held on experiments on two kinds of beams of identical cross-section. The first on prestressed beams where the strain of concrete due to shrinkage of concrete and creep were measured. This was done by measuring the change in length between two fixed points on the prestressed beam. Many measurements were taken during the first

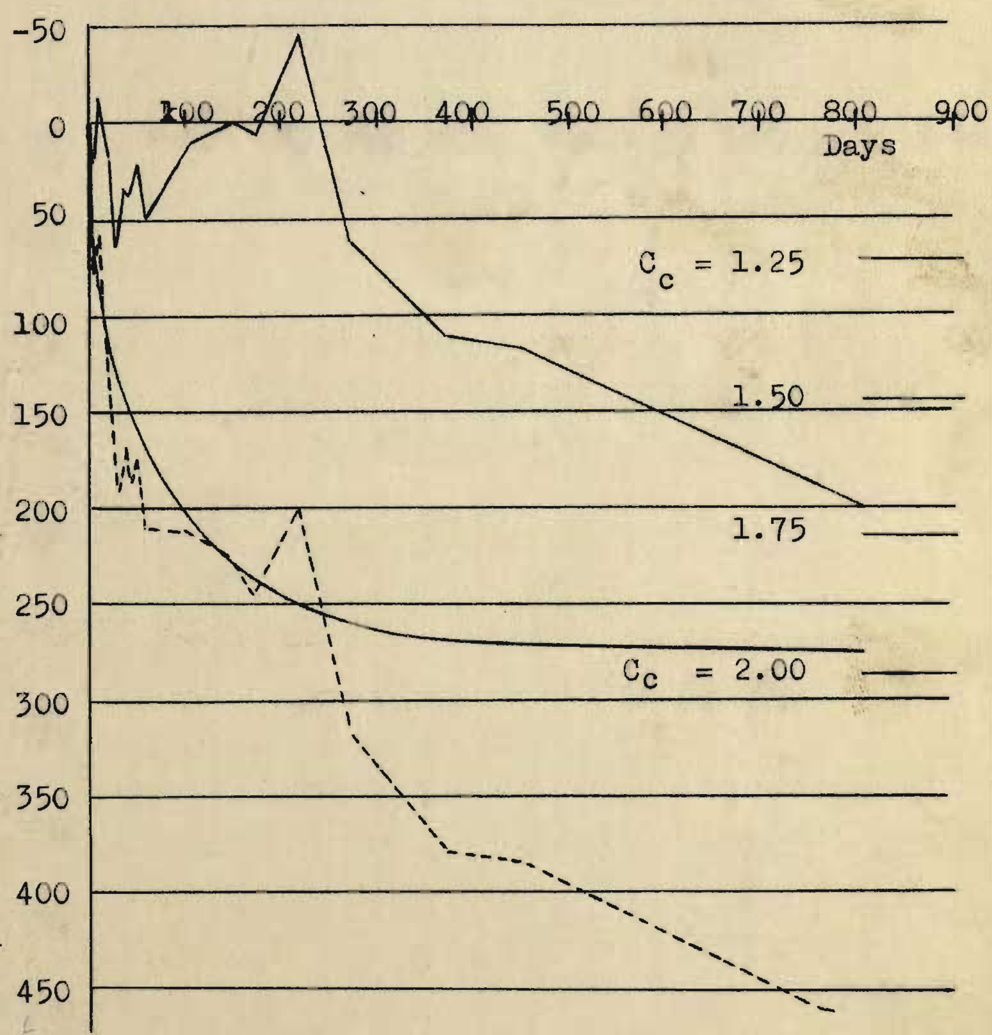

Figure (9 - 1)

Creep test of Prestressed Beam. (Fig. 122 from Ref. 1, P. 182)

* Ref. 1, P. 174

28 days and less measurements afterwards. The second was on beams of identical section which are not prestressed. The same set of measurements were taken. Figure (9 - 1) shows graphically the results of one experiment. (The figure is figure 122 on page 182 from Reference 1). The horizontal axis represents the time in days. The vertical axis repreaents the strain to be devided by 10^6 .

In the first case the measurements included the strain in the concrete due to shrinkage, creep of concrete and creep of steel. In the second case the measurements included only the strain in concrete due to shrinkage.

So the difference between both gives the stain effect due to the creep of the concrete and the creep of the steel. But as the strain effect of the steel is known, from other set of experiment described later, the strain effect due to the creep of concrete alone was determined.

In figure (9 - 1) the full line represents the strain in concrete due to shrinkage and creep of concrete. The dotted line represents the strain of concrete due to the shrinkage of the concrete. The heavy parabolic like line is the result of the subtraction of both which is the strain of concrete due to creep alone.

The following table which givesthe properties of one sample used in the tests for creep of concrete is from table XXIII from Reference 1, Prestressed concrete by Prof. G. Magnel.

Age in Days	Elastic Modulus in psi At 720 psi	At 1,440 psi	Breaking stress in psi Comp. on 8 in.	Bending
7	------	------	5,150	756
28	6,050,000	5,400,000	8,770	---
57	------	------	8,880	910
92	6,130,000	5,560,000	9,150	905
210	------	------	9,800	940
435	6,520,000	5,930,000	10,400	1,270

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" All the test pieces were curad in the open air with a roof over them. When the specimens were made the temperature varied between 32 degrees F. and 40 degrees F. " I Prof. G. Magnel believes that " For air cured concrete the generally accepted value of shrinking is 400 x 10^{-6}, half of which has taken place at 28 days this means that the shrinking after 28 days is 200 x 10^{-6} " II

P. W. Abeles suggests ~~that~~ the following: " The shrinkage coefficient of concrete generally varies between 0.00025 and 0.0005 for different qualities and the approppriate value for high strength concrete as used with prestressing approaches the lower limit. The magnitude of creep depends not only on the quality of the concrete and it's age, but also on the magnitude and duration of the stress. It may be assumed that the greatest shortening and creep of the concrete does not exceed 0.001. This results in a loss of 0,001 E_s i.e 25,000 to 30,000 lb. per square inch for a modulus of elasticity of 25 to 30 x 10^6 lb. per square inch provided that the concrete stress at transfer is not two high, say a third of the cube strength and does not exceed 2,500 lb. per square inch, otherwise a greater loss will occur and a higher value than 0.001 E_s should be taken into account." III

Steel:

The creep of steel was determined also by experiments performed by Prof. G. Magnel under two conditions. The first was at a constant load on the wires. Measurements were taken more at start and less afterwards. See figure (9 - 2). His conclusions were " (1) The creep of steel is very high during the first hour and remains important during the first twenty hours; its intensity then decreases gradually without, however, reaching its greatest value even after two months. (2) It seems reasonable to assume that the

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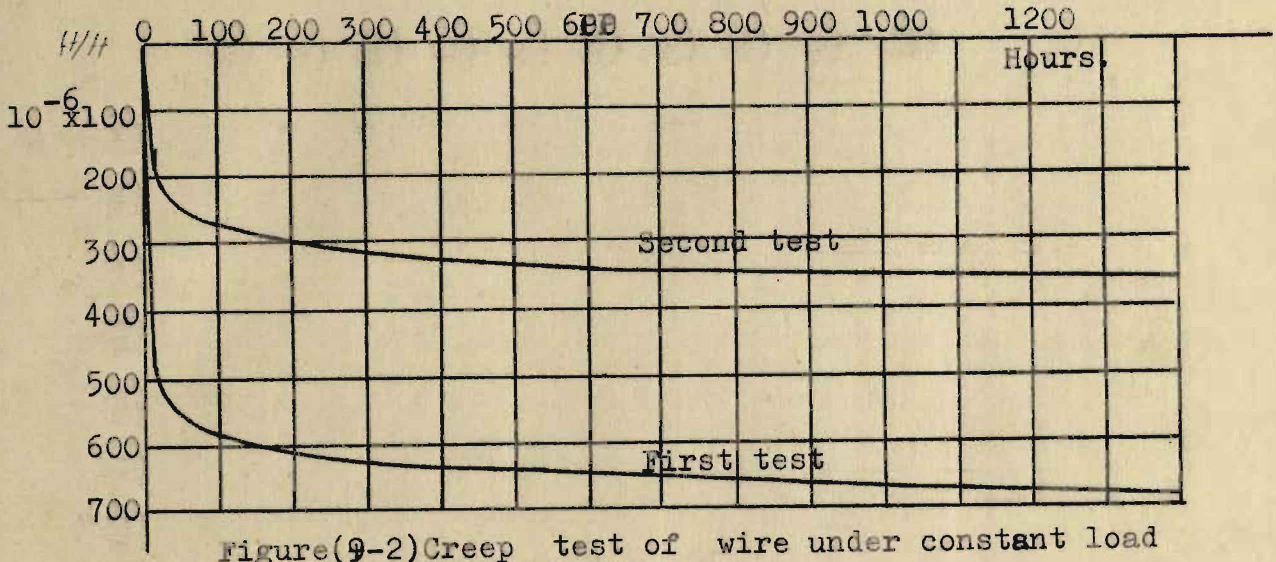
I Ref. 1, P. 174

II Ref. 2, P. 9

III Ref. 1, P. 184

the greatest creep is 10 per cent. more than that after two months, giving a total increase of 16.2 per cent. of the initial elongation".[I]



Figure(9-2) Creep test of wire under constant load
(Copied from reference 1, P. 170)

The second test under the same condition was to raise the stress in the wire up to 137,000 psi in 2 1/2 minutes and kept for two more minutes. Measurements were taken the same manner as previously. The conclusions were as follows: " (1) The creep is considerably reduced in comparison with the first test; the greatest value seems to be 7.3 per cent. of the initial elongation. (2) The decrease is due to the fact that, during the period of 2 minutes in which the stress is kept at 137,000psi, the wire has about the same amount of creep as in the first four or five hours at a stress of 123,000 psi."[II] These characteristics are shown in figure (9 - 2). The horizontal axis represents the time in hours. The vertical axis represents the strain in steel.

The second condition was at constant length of the wire. Measurements of the remaining stress in the wires were taken more at the start and less afterwards. The conclusions were " The loss in stress occurs mainly in the first few hours and completely ceases

I Ref. 1, P. 169

II Ref. 1, P. 169

after 12 days, and the total loss is 12 per cent. for an initial stress of 123,000 pounds per square inch established in 2 1/2 minutes."[I] The second test was also done by raising the stress in the wire up to 137,000 pounds per square inch under the same

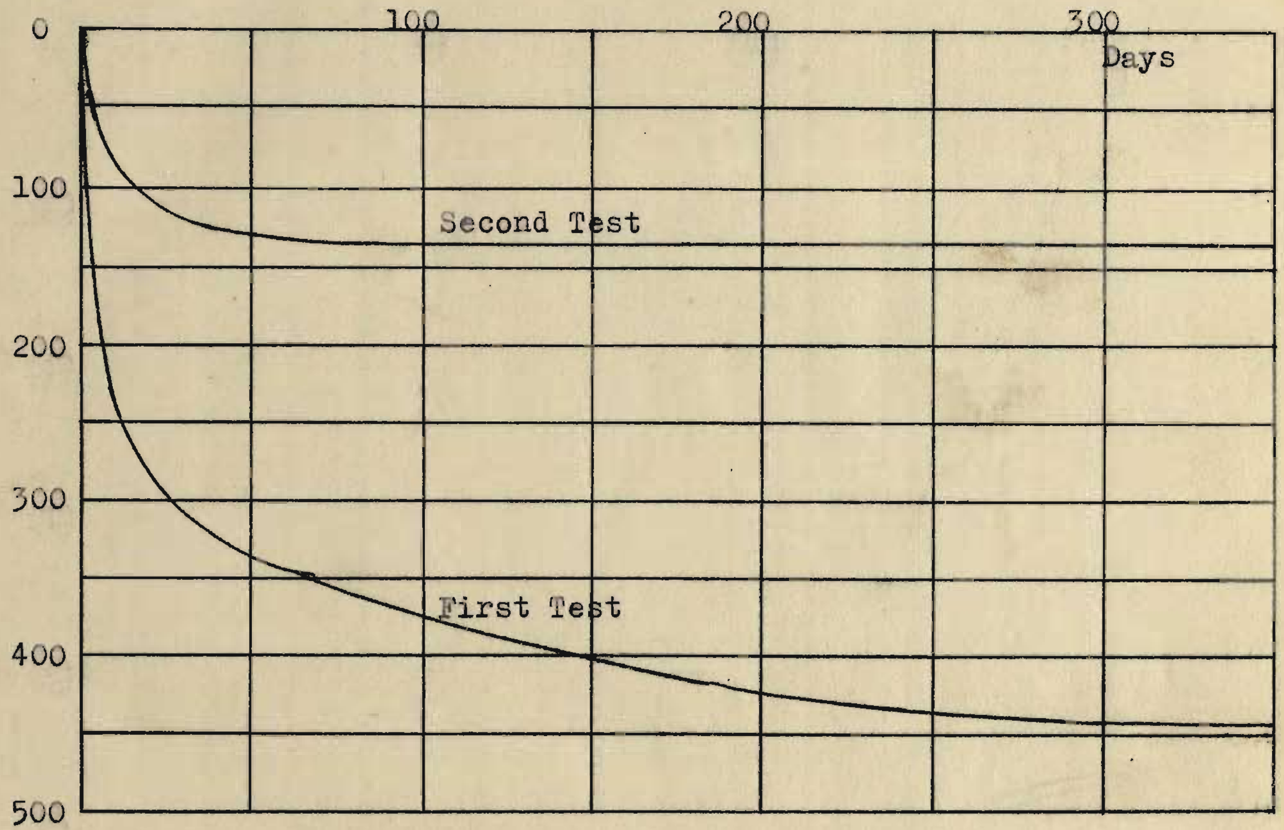


Figure (9 - 3) Creep test of wire under constant length (Copied from Reference 1, P. 173)

condition of the one previous. Readings were taken the same way and the conclusions were " (1) The creep occurs very rapidly, and completed in a little more than two days, and (2) the total creep is not more than 3.6 per cent. "[II] These characteristics are shown in figure (9 - 3).

" The loss of initial prestress in steel is: n(E_s/E_c) times

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I Ref. 1, P. 172

II Ref. 1, P. 172

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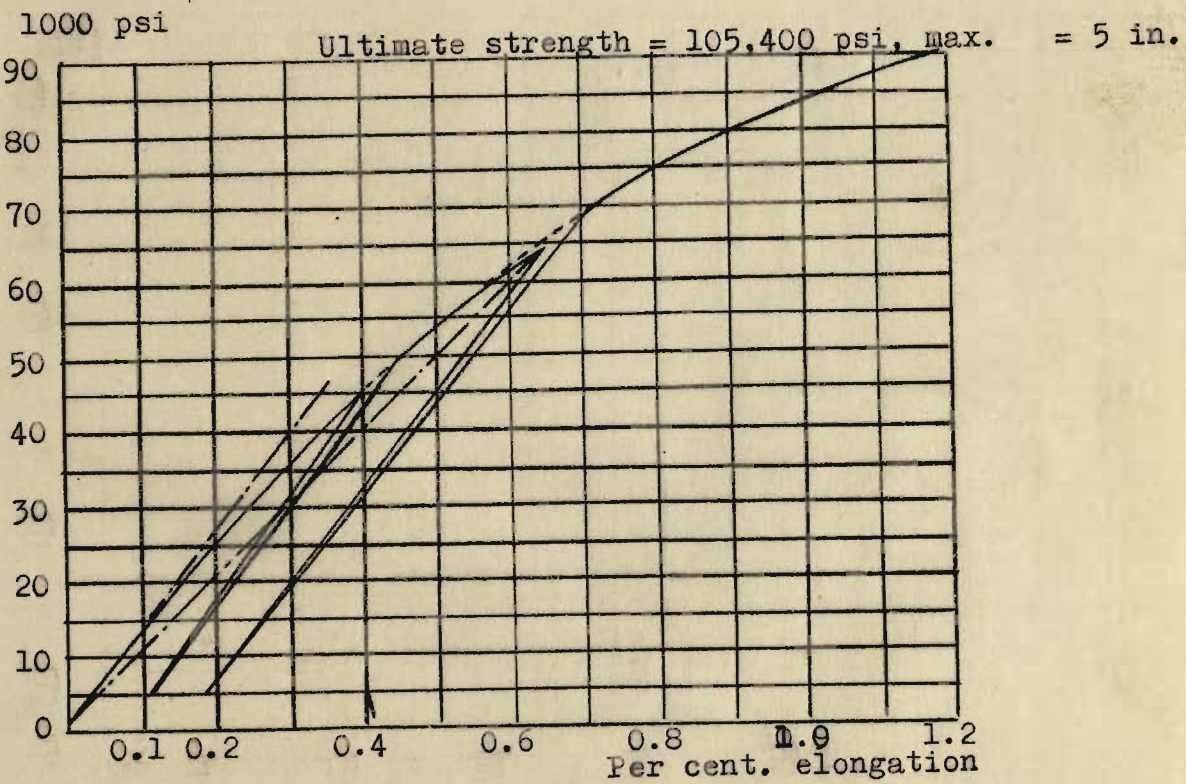
the concrete stress due to the pre-compression at transfer in the fibre of the tensioned reinforcement, n vareying between 5 and 8 "[x].

Figure (9 - 4) is a stress-strain diagram of a hihg tensile wire usually used in the practice of prestressed concrete. There is no distinct yield point. A plastic flow of the steel may occur at low stressed such as 4 tons per sq. in. The modulus of elasticity, which is the slope of the line, varies between 28×10^6 to



Figure(9 - 4)Stress-Strain diagram of high strength wire
(Copied from Reference 2, Fig. 4)

30.9×10^6 depending upon the stress at which the modulus of elasticity of steel is found.

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x Ref. 2, P. 9

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In the following an example is given to illustrate the practical considerations of the above mentioned discussion:-

" Example of loss of prestress due to shrinking of concrete, creep of concrete and creep of steel:

Consider a beam prestressed to 1,440 psi with a stress in the cable of 123,000 psi. Assume that the concrete has a crushing strength on 8 in. cubes at 28 days of about 8,700 psi . The shrinking produces a strain of 200×10^{-6}, corresponding to a loss of stress in the steel of about

$$E_s \times 200 \times 10^{-6} = 26{,}800{,}000 \times 200 \times 10^{-6}$$
$$= 5{,}360 \text{ psi}$$

The creep of the concrete with a coefficient of creep of 2.2 produces, if it exists alone, a strain variation of

$(2.2 - 1) \times 287 \times 10^{-6} = 346 \times 10^{-6}$, corresponding to a decrease of stress in the steel of

$26{,}800{,}000 \times 346 \times 10^{-6} = 9{,}300$ psi. Consequently the remaining stress in the steel is

$$123{,}000 - 5{,}360 - 9{,}300 = 108{,}340 \text{ psi}$$

The creep in the steel results in a loss of prestress of 12 per cent,, say 13,000 psi; the remaining stress is 108,340 - 13,000 = 95,340 psi, or 78 per cent. of the initial stress.

If for a period of 2 minutes the steel was overstressed to 137,000 psi as explained previously the loss of stress inthe steel due tothe creep of the steel would be reduced to 4 per cent., say 4,400 psi, so that the remaining stress would be

108,340 - 4,400 = 10,940 psi, which is 84 per cent. of the initial stress. The losses are then as follows:-

Due to shrinkage of concrete	5,360 psi
Due to creep of concrete	9,300 psi
due to creep of steel	4,400 psi
	19,060 psi (16 per cent.)

Since the values are rather high, it can be agreed that it will be safe if the loss of prestress due to all causes is assumed

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to be 15 per cent., axcept when the concrete is not of the very best quality or if it is stretched more than 1,440 psi."[A]

" If the concrete has a crushing strength of only 5,700 psi, it is recommended that a loss of 18 per cent. be assumed.

If wires without creep are used, these values may be reduced from 15 and 18 per cent. to 12 and 15 per cent. respectively."[AA]

Prof. Magnel suggests that the engineer should not take arbitrary vales and follow them but should think before assuming any value.

A Ref. 1, P. 183

AA Ref. 1, P. 184

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4. What Are the Materials that Have to Be Used in Prestressed Concrete:

The materials that are used in prestressed concrete, concrete and steel, have to possess certain characteristics that are not, or not necessarily found in ordinary reinforced concrete. Shrinkage and creep of concrete and creep of steel have a considerable effect in the design of prestressed concrete. If ordinary mild steel is used it will lose its prestress in a short time making ordinary mild reinforcing steel useless for this purpose. In order to know something about the materials to be used a study of the characteristics of each is necessary.

Concrete:

A good concrete have to be used in order to attain high compressive strength, low coefficient of shrinkage and low creep. To attain this, the quality of the cement has to be good and the ratio of cement has to be higher than usual, in comparison to what is used in ordinary reinforced steel. The aggregates have to be properly designed.

Water-cement ratio is a very important factor to be studied and has to be taken care of. The wqter-cemtn ratio has to be as little as much as workability of the concrete permits. Figure (4-1)⊕ shows a relation between the quantity of water used and the strength of the concrete. The portion XY is the part that follows Abrams' water-cement Ratio Theory. "Abram's Water-Cement Theory states that the strength of a mixture depends on the quality of mixing water in the batch, expressed as a ratio to the volume of cement, so long as the concrete is workable and the aggregates are clean and structurally sound. The strength of the concrete decreases as the water ratio increases."I "Abrams' considered, as a result of thousands of tests, that the relation between the water ratio and the strength of concrete could be

⊕ Ref. 10, P.166, Fig.3

I Ref. 10, P.167

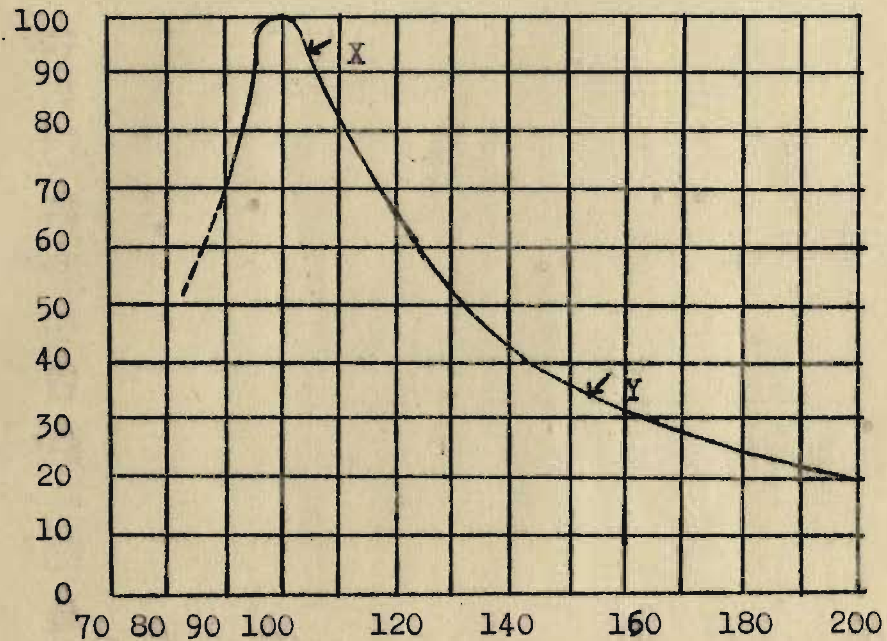

Fig.4-1.- Water and Strength.
(Copied from Ref.10, Fig.3, P.166)
Vertical Axis: Percent of Maximum Strength

Horizontal Axis: Water used - Figures are per cent of quantity giving Max. strength.

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expressed by

$S = A/B^x$, where

S = Compressive strength of concrete at 28 days in lb. per square inch for standard curing conditions.

A = Constant.

B = Constant.

x = Water ratio by volume (an exponential)"[1]

Reference 10 suggested the following equation for avarage conditions based on certain laboratory tests:

$S = 14,000/7^x$

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[1] Ref.10, P.169

In expressing an equation of this type it should be borne in mind that every equation corresponds to one set of conditions such as the ratio of cement used, as it is obvious from the fact that cement ratio is not expressed in the formula. Thus the strength of the concrete may be increased by increasing the cement ratio and by decreasing the water-cement ratio.

As stated before this theory applies only for portion XY in figure (4-1). The part of the curve to the left of the maximum point represents dry concrete such as that used in the manufacture of concrete blocks. Relatively porous concrete will result as the particles of the mix will not be allowed enough to consolidate. In the part of the curve to the right of the maximum value, two much water was used resulting in a porous concrete when the water in excess was evaporated besides reducing the strength of the concrete itself and increasing shrinkage. The minimum water ratio to be used is governed by workability of the concrete. Thus the ratio of water used should be the the minimum and still be workable.

Equations of the same type, as that suggested above, will also be affected by factors other than water-cement ratio such as type of cement, type of aggregates and temperature.

To establish values for the equation locally experiments should be performed enough to give values for the current use of cement ratios and for the kind of concrete to be used in prestressed concrete.

A way of producing good concrete is by the addition of admixtures, or accelerators, or by using other kinds of cements such as rapid hardening cement or high alumina cement.

Admixtures, or accelerators, are added for other reasons. The most common admixture, or accelerator, used is calcium chloride. "It is fairly well established that addition of this salt, up to 2 per cent.

by weight of cement are beneficial in cold weather for accelerating the rate of strength development, and thus reducing the time period over which the concrete is succeptible to frost damage."I

"Calcium chloride causes reduction in the setting time as the amount added is increased. Addition of 1 to 3% calcium chloride also cause an increase in the drying shrinkage of about 40 per cent. over that of 1:2:4 concrete with water ratio of 0.60, and made with normal Portland cement without addition. Larger quantities of calcium choride cause greater shrinkage."II

High alumina cement can be used also to produce good concrete. It is also subject to the same idea of Abrams' Water-Cement Theory. "High alumina cement is produced by heating together a mixture of lime and bauxite or aluminum ore. This cement has an exceptionally high proportion aluminates (35-44), resulting in a very rapid development in strength; in fact high alumina cement concrete is as strong in 24 hours as normal Portland cement is in 28 days. Setting and hardening result chiefly from the formation of mono-calcium aluminate, and are accomplished by a very rapid evolution of heat, a factor of considerable value when concreting at abnormally low temperatures but a distinct disadvantage at normal temperatures in all but thin section from which the heat can escape quickly."III

"Great care should be taken to keep high alumina cement apart from Portland cement, as small quantities of either may cause a flash set in case of mixture. High alumina cement concrete cannot be satisfactorily patched with normal Portland cement concrete even after it has thoroughly hardened, owing to the formation of unstable dicalcium aluminate at the junction. The converse is equally true."II According to the previous discussion high alumina cement may have some application in prestressed concrete if used in winter time and in comparatively

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I Ref. 9, P. 74

II & III Ref.9, P.63

cold climate. In thin sections, (such as that used in the design of standard floor system discussed later) high alumina cement may be used where areation is possible.

As to the required crushing strength of the concrete used "if we assume a working compressive stress of 1,700 lb. per square inch the concrete should have a crushing strength of 5,100 lb. per square inch. This is good concrete requiring good cement, good grading, little water, good workmanship, and proper consolidation and curing. In special cases stresses up to 2,100 lb per square inch have been adopted for prestressed concrete construction. Even if the working stress in the concrete is not so high, it is recommended that concrete of high quality be used in order to avoid excessive shrinking and creep."I

Steel :

Steel to be used in prestressed concrete has to possess the ability to be prestressed to a certain value that the loss in prestress due to shrinkage of concrete, creep of concrete and the steel or at least greater. This cannot be obtained from the ordinary reinforcing steel used in the ordinary reinforced concrete. This is because the allowable stress is low that it will be compensated. The area of the required steel will be very big which will make it almost impossible to place the steel in the section. The compensation will be due to the shrinkage and creep of the concrete, and the considerable creep of the ordinary reinforcing steel. Thus ordinary reinforcement is not used in prestressed concrete.

To solve this problem another kind of reinforcing steel have to be used. This kind of reinforcemtn must have an allowable stress higher than that used in ordinary reinforcement. Thus high grade steel, which possesses these factors, is used. This steel can be used in the form of wires bonded to the concrete, or cables not bonded to the concrete.

I Ref.1, P.8.

According to Mr. Freyssinet "a cable must be made of high-tensile steel if the prestress is to be a permanent one. The wires have an ultimate strength of about 210,000 lb. per square inch. This permits prestressing up to the smaller of the two values:

0.6 x 210,000 = 126,000 lb. per square inch

0.8 x 170,000 = 136,000 lb. per square inch."I

Prof. G. Magnel considers the fulfilment of the following requirements as essential in a cable for prestressed work:-

"1) The wire must be placed in the cable in a predominant order and kept in that position during the prestressing operation;

2) The cables must be areated; that is, any wire in it must be kept at a distance of from the adjacent wires at least equal to 3/16 inch in all directions; otherwise the grouting in of the cable after prestressing cannot be done proparly and its effect in protecting the wires against rust formation and in establishing a bond giving a cheap supplementary security is lost;

3) The prestressing must be done in a statically determinate manner by stretching only two wires at a time; otherwise there can be no certainty that all the wires have exactly the same stress

4) It must be possible to make cables of any size from eight wires of 5 millimetres diameter up to, say, sixty four wires of 7 millimetres diameter;

5) The prestressing apparatus and the anchorage must be standardized in such a way that they will be the same for large or for small cables;

6) Cables must be made in such a way that the frictional resistance during prestressing will be negligible; this means special spacers and limited curvetures in the cable; for example, bending up cables at 45°, as is done for ordinary reinforcing bars, must be prohibited."I

I Ref. 5, P.161

5.- Factor of Safety in Prestressed Concrete and the Justification of the Values Given and Specifications:-

In Britain it is common to consider that the working compressive stress in concrete due to bending is one third of the strength of 6-in cubes at 28 days.

Prof. G. Magnel " considers that the working stress in concrete in compression should not exceed one-quarter of the crushing strength of 6-in. cubes (or one-third of that of 6-inch cylinder) made when the concrete is placed and tested at the age of which the structure is likely to be subjected to the load for which it is designed."* He gives a greater value (1/3 the crushing strength) for the working compressive stress in concrete when the member is still supported when prestressed.

As an example: "if the concrete has a crushing strength of 8,800 lb. per square inch when the structure is placed in normal service, but for example, only 5,700 lb. per square inch when the member is prestressed, the adoption of a working stress of 2,200 lb. per square inch is permissible under the superimposed load, but only

5,700/3 = 1900 lb. per square inch at the time the prestress is established."**

As to the allowable tensile strength in the concrete, P.W. Abeles considers that "the tensile strength may be taken as follows: $f_{tw} = 0.4\ f_{cw}$ and $f_{tt} = 0.3 f_{ct}$."*** (f_{tw} = permissible tensile stress at working load, f_{cw} = permissible compressive stress at working load,

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* Ref.1, P. 201
** Ref.1, P.201
*** Ref.2, P.95

f_{cw} = permissible compressive stress at working load, f_{tt} = permissible tensile stress at transfer, f_{ct} = permissible compressive stress at transfer) He allows 1,200 psi as permissible tensile stress at working load and 750 psi as permissible tensile stress at transfer load.

Prof.Magnel suggests that a 6-in. cube having a tensile strength of 700 psi may have as a working load of one-third of the tensile strength of 230 psi.

As to steel, according to Freyssinet, having an ultimate strength of, say, 210,000 psi and a conventional elastic limit of 170,000 psi, the allowable stress in the steel should the smaller of the following values:

$(0.6) \times 210{,}000 =$ 126,000 psi

$(0.8) \times 170{,}000 =$ 136,000 psi

As it is seen from the previous discussion, the factor of safety in concrete exceeds that in steel.

In ordinary reinforced concrete the factor of safety is important and high because it takes care of: defects in steel in manufacturing, wide range in change of stresses in concrete and steel, cracks in concrete and abnormal loading and other minor factors.

In prestressed concrete the danger from defects in steel because of manufacturing does not exist and produces no problem. This is so because in the process of prestressing the wires a sort of a test is run on the wire. The increase of the allowable stress by 10% applied for 2 or 3 minutes, (to reduce the creep of steel as ~~will be seen later~~) makes it sure that the wire has no defect. Otherwise it will break.

Wide change of stress in the concrete has to be taken care of because there is a wide change of stress. But in steel the stress is almost constant and no wide variation of stress occurs. The variation in stress due to the live load only will produce a small increase which is between 3 and 4% of the stess of steel. This fact makes it obvious that fatigue effect presents no worry.

As to cracks in concrete in prestressed concrete the section is always in compression thus cracks are eliminated completely.

Thus it is justifiable to use a factor of safety of steel less than that used in concrete. Also the fact that we are more sure of the steel wires than the concrete, makes it is justifiable to do so.

6.- Systems and Methods of Prestressing:-

There are two main systems of prestressing which are (a) Post-tensioning, and (b) Pre-tensioning. In the system of post-tensioning the steel is not bonded to the concrete and the stress is transferred to the section by means of anchorage dvices at the ends. In the system of pre-tensioning, the steel is bonded to concrete and the stress is transferred to the section by means of this bond.

There are many methods of prestressing but the most common are the following:

1) "Beams with External Cables:-

It is not necessary to place the cables before placing the concrete in the beam. For example, a plain concrete I-beam can be cast and the cables placed on both sides of the web. The slope of the cables can be changed where needed, rods or pins projecting from the concrete web as seen in figure (6-1) resisting the vertical component of the ~~stretching component of the~~ stretching force. At each end of the I-beam, the web is thickened to allow for the passage of the cables and to provide a bearing surface for the device that secure the ends of the wires.

2) Beams of Precast Elements:-

It is not necessary that the concrete should be placed in situ, for beams can be made of precast elements. In this case the cables are placed on both sides of the web as mentioned in the previous method in the case of I-beams. In the case of box-girders, the cables may be placed in the cavity. In both cases, however the special end-blocks are required. See figure (6-2)

3) Straight Cables:-

Whenever possible, a slight upward camber should be given to the

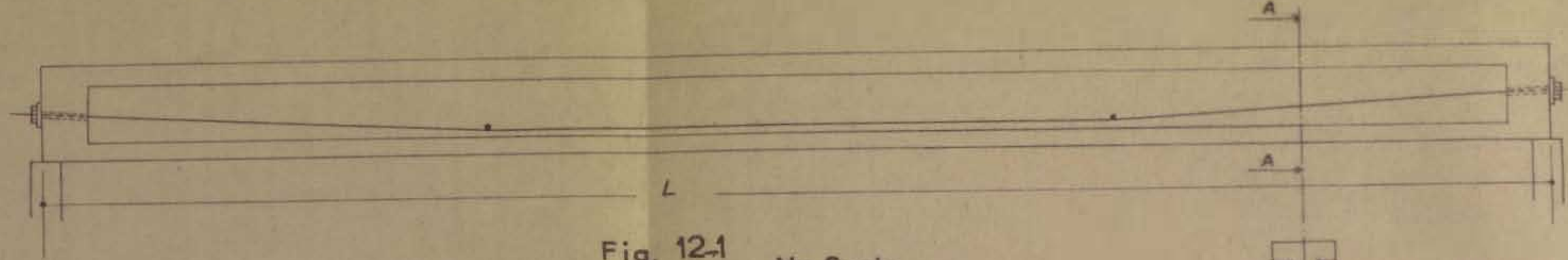
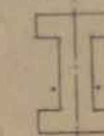


Fig. 12-1 No Scale



Section A-A

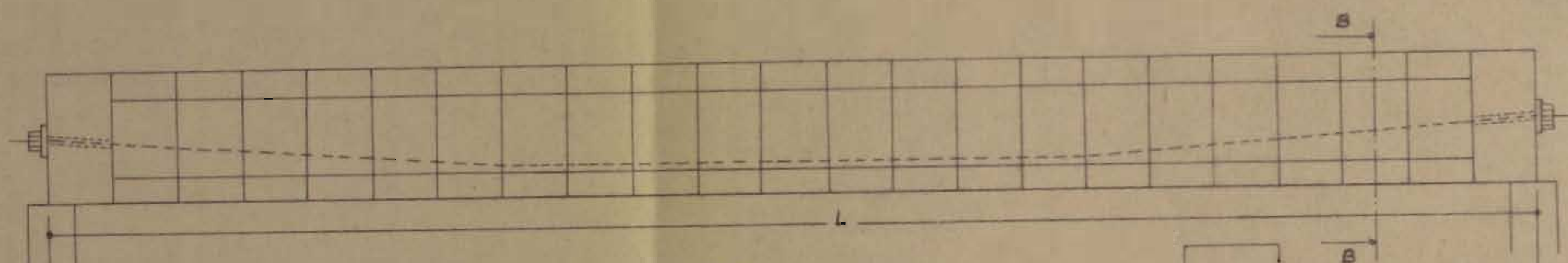
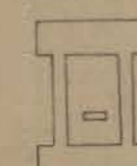


Fig. 12-2 No Scale



Sec. B-B

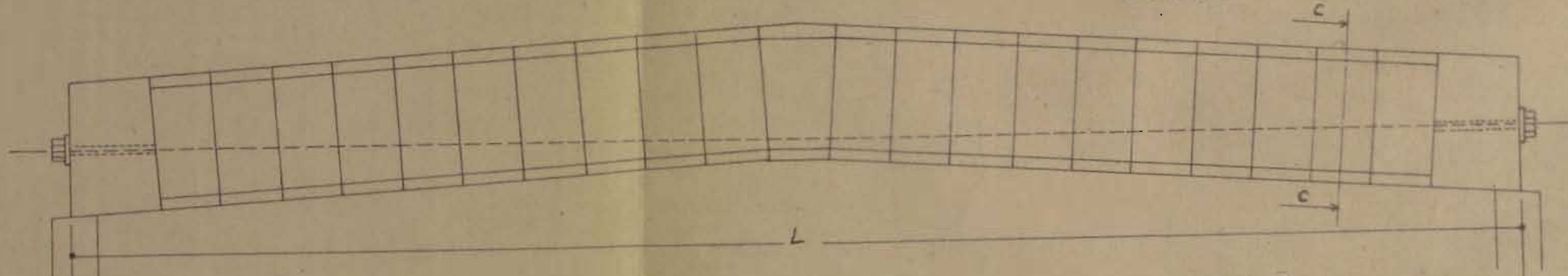
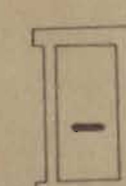


Fig. 12-3 No Scale

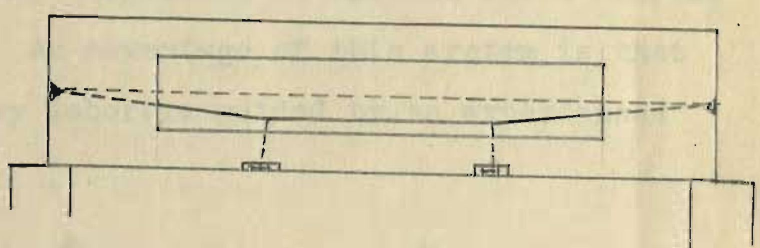


See, C-C

beam as in figure (6-3) that the cables can be kept straight. There will then be no eccentricity at the ends, while maximum eccentricity at mid-span is still obtained, and frictional resistance when the cables are stretched is avoided."*

4) Method Suggested by Prof. I. Rubinsky:-

The method is to have external cables, similar to that as described in the first method, anchored at both ends as straight cables. At this stage the cables are not stretched but placed. Actually there is no need for the cables to be stretched by a jack or any other device. The second stage is to catch the cables by means of hooks or rings at the place where the bending up of the cables start. These hooks or rings are attached to a thread and nut placed ~~placed~~ outside the beam at the bottom in their proper place. These nuts are placed inside the concrete and do not project outside. The nuts and the hooks, or rings, are connected together through the concrete with a hole provided for this purpose. The third stage is to turn the nuts and by doing so, the cables are stretched producing tension in the steel. The ~~cables~~ nuts are turned until the desired proper position of the cables is obtained. This position will be decided upon by the design of the beam and the desired amount of stress in the cables. The fourth stage is to grout the nuts with the concrete of the beam that the nuts will not loosen in the future. In this method a jack is not used,



* Ref. 1, P.8.

and end anchorage of the cables need not be expensive as used in the other methods. The force applied in turning the nuts will be comparatively small because the slope of the cables will be small.

5) "The Roebling Method:-

"The Roebling method consist of galvanized (coated) bridge wires in the form of prestressed strands. Cables covered by paper tubes may be cast right in the beam, or, unprotected they may be threded through holes in precast blocks. Attached to the ends of the cable are small terminals, threded for nuts which are tightened up against steel bearing plates at the ends of the beams. An advantage of this system is that beams can be fabricated by ordinary laborers guided by an experienced superviser."*

In post-tensioning, if the prestressed is established by one cable, or more, and this cable, or cables , will be bent up at one point and end at one point, the following procedure suggested by the writer is given to determine theoretically the place where to start bending up the cables:-

The idea of bending up the cable is to reduce the eccentricity of the acting forces at the ends of the beams because actually there is no need for any eccentric force at the ends because there is no moment to counter-balance. To have the force at both ends concentric will distribute the compressive stress more evenly and will help in reducing the diagonal tension on the beam. It will secure enough space for the anchorage plates at both ends.

Set the following general equation of stress for the bottom fibres of the beam :

$$P/A + Pec/I - Mc/I = 0$$

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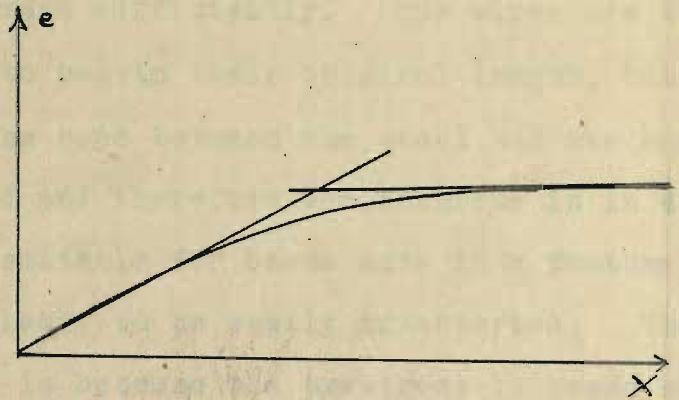
* Ref.7, P.148

Find M in terms of X, where X is the distance from the end of the beam to any point in the beam.



Find e in terms of X, i.e. $e = f(X)$. (If we plot a curve of this relation it will give us the required eccentricity to counterbalance the acting moment).

The actual applied eccentricity should be more or at least equal to the required eccentricity. Differentiate e with respect to X and substitute Zero for X, i.e. $de/dX = f'(X)$, and find $f'(0)$ = how much. This will give us the slope of the tangent line of the curve at $X = 0$. From this find the equation of the tangent line, and solve with the equation of the horizontal line at maximum eccentircity and find the point of intersection. This point will be the place where it is permissible to start bending the cable ending, with a straight line, to the centroid of the section at both ends.

6) "Prestress Transferred to the Concrete by Bond:-

The results obtained in the methods described can also be obtained in a different way. Assume that a straight I-beam is to be made. A steel mould capable of resisting a longitudenal compression equal to the required prestress is used, and the steel plates forming the end of the mould are provided with holes corresponding to the number and position of the wires to be used. The wires which may be 0.08 in. in diameter of very high yield stress (280,000 lb. per square inch) are fixed before the concrete is placed, and are secured to one ~~endp~~ end-plate of the mould. At the other end ~~of~~, the wires are stretched with a force of 200,000 lb. per square inch and they are secured to the end of the mould; the wires are then in tension and the mould in compression. The concrete is then placed and allowed to harden sufficiently. The wires are then released from the mould and try to regain their original length, but are prevented from doing so by the bond between the steel and the concrete; the wires remain stretched and therefore the concrete is in compression"*"This method is mainly suitable for beams made in a factory and for beams which are not too heavy to be easily transported. The reason for using such thin wires is because the prestress is based on bond, so that there must be a large circumferential area compared with the cross-sectional area of the wire."**

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* & ** Ref.1, P.8

7.- Comparison Between Two Systems of Prestressing:-

The two systems of prestressing are (a) post-tensioning and (b) pre-tensioning. In the first system, as is said before, the steel is not bonded to the concrete. After the concrete hardened sufficiently the steel is stressed against the ends by means of plates. In the second pretensioning system the steel is stressed before the concrete is placed. The concrete is poured and allowed to harden sufficiently, then the stress on the steel is released and the prestress is established by means of the bond between the concrete andthe steel.

In the post-tensioning system, the steel used is in the form of cables. These cables are a collection of wires of high grade steel and act as a unity. In the pre-tensioning system, the steel used is in the form of wires of the following diameters: 0.08 in.(2mm), 0.2 in. (5mm) and 0.285 in. (7mm) diameter. The most commonly used is the one of the 0.2 in. (5mm) diameter. This is because if the one of the 0.08 in. (2mm) diameter is used a numerous number of these wires would be required for a certain section and the anchorage would be more expensive; if the one of 0.285 (7mm) diameter wire is used, the area of the surface with respect to the cross-sectional area will be smaller and the bond between the steel and the concrete will be less effective.

In the pre-tensioning system, the prestress is subject to losses due to shrinkage of concrete, creep of concrete, creep of steel and loss due to strain of concrete under the prestressing load and equal to n x P/A. In the post-tensioning system, shrinkage of concrete due to hardening have no effect and introduces no loss of prestressing because prestressing is applied after the shrinkage of concrete took place. Also loss of prestress due strain of concrete under the prestressing load do not have any effect because prestressing occurs at the same time. Ifthe Roebling or any similar method is used, loss due to creep of concrete and steel could be eliminated by coming back after a month or so and stressing the steel back to its original stress.

8.- Theorètical Treatment of the Principles of Design of Prestressed Concrete:-

In the following is the theory on which prestressed concrete is based upon:

A general formaula of stress for a homogeneous section with a force and a moment adting on it with the force eccentrically applied is:

$$f_c = P/A \pm (Pe - M_T) \times y/I$$

Here, in prestressed concrete, positive values of f_c indicate compression and negative values of f_c indicate tension.

It is required to have no tension at the top fibres and in order to accomplish this condition

$$P/A - Pe\, y_t/I = 0$$

$$e = r^2/y_t$$

Stress due to the total design moment, considering the section to be homogeneous,

At top, $f_c = M_T \times y_t/I$

At bottom, $f_b = M_T \times y_b/I$

To determine the area of the wires, the bottom girder, or member stress is set equal to zero, which is the limiting value in the design specification. This, again, is done not to have any tension in the concrete after the member is fully loaded. Then,

$$P/A + (Pe - M_T \times y_b/I = 0$$

$$P = \frac{M_T}{r^2/y_b + e}$$

But dùe to the flow and creep of concrete and to the crsep of steel a certain loss in prestress is considered and taking <u>k</u> as the portion of the prestressing force which is left after the loss is deducted for, then,

$$P = \frac{M_T}{k(r^2/y_b + e)}$$

To find the area of the wires, then,

$$a = P/f_s$$

As to the shear, the maximum shearing stress occurs at the centroid of the section. Shear is calculated by the following formula :

$$v = (VQ)/(IB)$$

but this should be combined with the compressive stress produced by the prestressing forces. This compressive stress at the centroid will be equal to

$$S_x = P/A$$

The produced principal stress will be

$$S_t = \sqrt{v^2 + (S_x/2)^2} - S_x/2$$

which has to be withing the allowable.

The following corrections have to be considered:

1) Strain of concrete under the prestress load P (considering it to be concentric) is $- P/(AE_c)$, this would produce equal strain in the bonded steel with corresponding change in the stress equal to :

$$(PE_{st})/(AE_c) = n \times P/A$$

2) It was assumed that the prestress is the same in all wires f_{si} and f_{st}

This is correct only if the upward deflection due to the force P is equal to the downward deflection due to the total moment. Actually the downward deflection is greater, so the combined deflection is downward. The top wires finally have become shorter and consequently their stress smaller while the bottom wires have become longer and their stress larger.

At top

$$= - n(Pe - M_T)\, y_{st}/I = \Delta f_{st}$$

At bottom

$$= + n(Pe - M_T)\, y_{sb}/I = \Delta f_{sb}$$

3) The effect of the stress found in (2) i.e. Δf_{st} and Δf_{sb} in the steel stress are due to the following forces:

At top

$$= \Delta f_{st} \times a_t = \Delta P_t$$

At bottom

$$= \Delta f_{sb} \times a_b = \Delta P_b$$

$$\text{Top} = (\Delta P_b - \Delta P_t)/A - (\Delta P_b \times y_{sb} + \Delta P_t \times y_{sb}) \times y_t/I$$

$$\text{Bottom} = (\Delta P_b - \Delta P_t)/A + (\Delta P_b \times y_{sb} + \Delta P_t \times y_{sb}) \times y_b/I$$

4) The moment at which the first crack will appear will be

$$M_{cr} = M_T + f_{cr} \times I/y_b.$$

5) Deflection of the beam at the middle should be within the allowable and is equal to

$$\Delta(\text{max.}) = (5/384)(wL^4/E_cI) = (5/48)(M_LL^2/E_cI).$$

9.- Design of a Girder Bridge in Prestressed Concrete by Pretentioning System :-

Design of a girder for the following conditions :[A]

L = 60 ft.

Allowable initial steel stress	= 150,000 psi
Concrete stress	= 2,000 psi

Concrete strength at time girder is subjected to prestress

= 5,000 psi

Tensile strength of steel wire = 250,000 psi

No tensile stress is allowable in the concrete anywhere on the section under any combination of design loads and prestress.

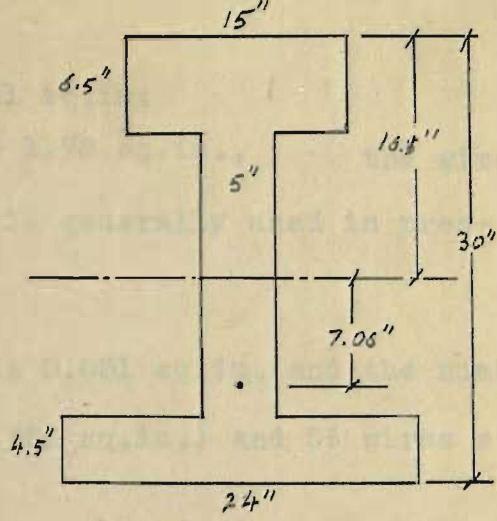
Live load moment M_L	= 1,870,000 in. lb./girder
Dead load moment M_G	= 1,700,000 in. lb./girder
Total moment M_T	= 4,000,000 in. lb./girder
Maximum live load shear	= 21,180 lb./girder
Allowable maximum deflection	= (1/1200) x L
Loss of initial prestress	= 20%

Assume the section in the figure:-

Area A	Static Moment Q
A_1 = 6.5 x 10 = 65	Q_1 = 65 x 3.25 = 211.25
A_2 = 30 x 5 = 150	Q_2 = 150 x 15 = 2250.00
A_3 = 4.5 x 19 = 85.5	Q_3 = 85.5x27.75 = 2372.62
300.5 sq.in	4833.87 in.^{3}

y_t = 4,830/300.5 = 16.1 in., y_b = 13.9 in.

A Data given by Prof. Rubinsky from example in the pamphlet of Portland Cement Association and computed by the writer.



Moment of inertia I

$65(6.5^2/12 + 12.85^2) = 10,960$

$150(30^2/12 + 1.10^2) = 11,430$

$85.5(4.5^2/12 + 11.65^2) = \underline{11,750}$

$34,200 \text{ in.}^4$

$r^2 = 34,140/300.5 = 113.6 \text{ in.}^2$

Total design moment = 4,000,000 in. lb.

$e = 113.6/16.1 = 7.06$ in.

Check for stress due to total design moment (considering the section to be homogeneous),

At top, $f_t = M_T y_t / I = 4,000,000 \times 16.1/34,2000 = 1890$ psi

At bottom, $f_b = - 4,000,000 \times 13.9/34,200 = - 1,630$ psi

As the allowable stress is 2,000 psi, the section is close to being developed in compression at the top fibres. If this was overstressed, adjustment in the section could have been made before proceeding any further.

Determination of the wire area,

Setting the bottom stress fibre equal to zero and considering 20% loss of initial prestress, i.e. k = 0.8, then

$$P = \frac{4,000,000}{0.8(\frac{113.6}{13.9} + 7.06)} = 328,000 \text{ lb.}$$

The allowable stress in the specification is = 150,000 psi, then

$$a = 328,000/150,000 = 2.19 \text{ sq.in.}$$

This area is divided between top and bottom steel in an inverse proportion to their distances from the center of gravity of the wires which is e = 7.06 in. below the centroid of the concrete section.

Top wires = a_t = 2.19 x 4.84/26 = 0.41 sq.in.

Bottom wires = a_b = 2.19 x 21.16/26 = 1.78 sq.in., the wire diameter is chosen as 0.2 in. (5mm) which is generally used in prestressed type of construction.

The nominal area of an 0.2 in. wire is 0.031 sq.in. and the number of wires chosen is 12 wires at top (a = 0.372 sq.in.) and 56 wires at bottom (a= 1.73 sq.in.).

Computation of Stresses:

1.- Stresses in concrete due to Prestressing forces:

Top: f_t = 328,000/300 - 328,000 x 7.06 x 16.1/34,200

= 1,090 - 1,090

= 0 psi

Bottom: f_b = 1,090 + 328,000 x 7.06 x 13.9/34,200

= 1,090 + 940 = 2,030 psi

2.- 20% reduced

f_t = 0 psi

f_b = 1624 psi

3.- Stressed in concrete due to prestress and ~~total moment~~ weight of girder:

Moment M_G = 1,700,000 in.lb.

At top = 1,700,000 x 16.1/34,200 = 800 psi

At bottom =-1,700,000 x 13.9/34,200 = - 690 psi

4.- Stresses in concret due to prestress and total moment:

At top = 4,000,000 x 16.1/34,200 = 1,890 psi

At bottom =- 4,000,000 x 13.9/34,200 = - 1,630 psi

Combining this with step 1, we have,

$f_t = 1,890$ psi

$f_b = -400$ psi

5.- Combining step 4 with step 2, we have,

$f_t = 1,890$ psi

$f_b = 0$ psi

<u>Computation of Shear Forces :</u>

The maximum live load shear is 21,180 lb.

Then $v = (21,180 \times 1,483)/(34,200 \times 5) = 185$psi

The prestress force = 0.8 x 328,000 lb. creates a horizontal compression stress at the centroid of

$S_x = 0.8 \times 328,000/300.5 = 873$ psi

Those two stresses v and S_x combined will produce a principal combined stress at the centroid and at the support which is,

$S_t = \sqrt{(148)^2 + (873/2)^2} - 873/2$

$= 37$ psi

Moment of first crack,

$f_{cr} = 700$psi

$M_{cr} = M_T + f_{cr} \times I/y_b = 4,000,000 + 700 \times \frac{34,200}{13.9}$

$= 5,720,000$ in. lb.

Check for deflection, $M_L = 1,870,000$ in.lb.

$\Delta (max.) = \frac{5}{48} \times \frac{1,870,000\ (60 \times 12)^2}{5,000,000 \times 34,200}$

$= 0.59$ in

which is approximately 1/1,200 x L .

Corrections for Appoximations in Design Procedure:-

Consider thegross concrete area subjected to ohly a prestress force of P = 328,000 lb. applied at a distance of e = 7.06 in. below the centroid of the concrete area. The section is then subject to a concentric force P and a bending moment Pe. The concentric force will create a concrete stress P/A and a strain of P/AE_c along the centroid of girder, Since the wires are bonded to the concrete the loss in stress along the same axis equal to nP/A. The stress loss in the wire amounts to 6 x 328,000/300.5 = 6500 psi. which is 4.3 per cent of the initial prestress of 150,000 psi. Compensation for the loss may be made by increasing the prestress applied to the wires by the jacks to, say, 157,000 psi. This correction elimiates one source of inaccuracy.

The immediate prestress force of 328,000 lb. gradually diminishes to p = 262,000 lb. and at the ultimate stage creates a moment of Pe which is considered acting simulteneously with M_T = 4,000,000 in. lb. For this load combination, the concrete stress of 1890 psi. at top and zero at bottom have been determined on the assumption that the prestress in all the wires remains equal to 120,000 psi. This is correct only if the upward deflection due to the force P equals the downward deflection due to moment M_t. Actually the upward deflection is smaller than the downward deflection so the combined deflection is downward. The top wires have become shorter and their stress smaller, while the bottom wires have become longer and their stress may be computed as follows:

Top $\frac{n(Pe - M_t)}{I} \times y_t$ (steel)

Bottom " " $\times y_b$ (steel)

$= \frac{6(262,007 \times 7.06 - 4,000,000)x}{34,140}$

(14.1 = 5300 psi

(11.9 = 4500 psi

It is significant that these stress changes are small, approximately 4 per cent of the permanent presttess. For all practical purposes, discripacies of this order are negligible in ordinary design problems.

If necessary, the investigation may be continued one step further in order to determine what effect the computed changes in steel stress have on concrete stresses. The change in theoretical prestress force is 0.41 x 5300 = 2200 lb. at top and 1.78 x 4500 = 8000 lb at bottom. These corrective forces act on the concrete section ~~in the direction indicated in Fig. 5~~ because the original prestress forces were assumed too large at top and too small at bottom.

The changes in concrete stress are:

Top $$\frac{8000 - 2200}{300.5} - \frac{8000 \times 11.9 - 2200 \times 14.1}{34,140} \times 16.1$$

$= 19 - 60$

$= -41$ psi.

Bottom $$\frac{8000 - 2200}{300.5} - \frac{8000 \times 11.9 - 2200 \times 14.1}{34,140} \times 13.9$$

$= -19 - 51 = -70$ psi.

The top fiber stress goes down from -1890 psi. to -1850 psi. and the bottom fiber stress goes up from zero to -70 psi. Both changes are insignificant and on the safe side.

PRACTICAL PHASE

Practical Phase:

The practice of prestressed concrete has different aspects from the practice of ordinary reinforced concrete. In constructing prestressed concrete, one should forget, as much as possible, what is practised in ordinary reinforced concrete and start as a totally new form of construction.

The local way of designing and constructing ordinary reinforced concrete will give a wrong and dangerous approach to the way how prestressed concrete should be practised. There are many points ignored and passed without notice by the local designers and builders in the practice of reinforced concrete that if followed in the practice of prestressed concrete will lead to undesirable serious results. Water-cement ratio, for example, is a very important item in the practice of prestressed reinforced concrete. This item is almost ignored by the local builders and the meaning of water - cement ratio seemed not to be appreciated.

It should be borne in mind, that the practice of prestressed concrete is delicate and care should be taken in dealing with it.

1.- Problem of adapting to the new idea:-

Prestressed concrete will be a totally new idea and way of construction. People are not accustomed to it. They never saw a prestressed concrete structure. So it will be difficult , in the beginning, to convince people to build prestressed concrete. The only way to convince people that the application of prestressed concret is sound is to prove to them that it is more economical than other ways of construction, such as ordinary reinforcedd concrete or steel. Besides ecomomy, it should be shown that other aspects should be, if not better, equal to that in other ways of construction, such as safety, architecture and function. More than that it should be proved that it is possible to start and apply the practice locally.

2.- Practical Problems to Be Considered on the Job arising from a Totally New System of Construction :-

People are accustomed to see and work ordimary reinforced concrete structures. But in the application of prestressed concrete different attitude should be taken by the workers and supervisors. The use of vibrators, hydraulic jacks or other devices, cranes and other instruments make the work more mechanized and scientific.

Precaution in owrk is stressed upon because in prestressed concrete any defect, misunderstanding or mistake done will appear and show and will weaken the structure considerably.

3.- Materials to be Used Have to Be Examined Well:-

The materials to be used in prestressed concrete, cement, aggregates, water and steel, have to be examined well. The materials to be used have to be in a perfect condition as practical as possible. Testing of the materials has to be done as frequent as possible. In order to determine the time on which the prestress has to be applied, tests have to be peroformed on specimens of concrete taken on the job and the time by which the concrete acquires the required strength is determined.

The cement used and its proportion should be determined by testing different proportions and ages on the concrete as to have a good information on the concrete submitted and its strength.

The aggregates should conform to the required specifications concerning their size. Their size should be in a way as to submit a consolidated material free of voids and to enter with ease through the wires.

The water-cement ratio should be the minimum amount in order to produce a wet mix and still be workable with the aid of vibrators. This is so, because according to Abram's Water-Cement Theory, the strength of the concrete is inversely proportional to the amount of water put in mixing the wet concrete. In brief, a good concrete with a rich mix is required.

As to steel, there is no need for testing it in the laboratory, because in stretching the steel in the process of prestressing, a sort of a good test is run on the steel.

4.- Cranes, Vibrators, Jacks and Others:

In prestressing, equipment is needed such as hydraulic jacks and anchorage devices. The capacity of the hydraulic jack will depend upon the steel, it is supposed to pull whether one wire, two wires or a cable. The jack has to possess the device by which the wires or cables are caught by it. There are different types of anchorages where every type requires different equipment and conditions.

To produce good concrete, free of voids with little water as possible, vibrators are a necessity.The use of vibrators is not common in local practice but it is easy to learn how to handle and use them.

They do not require intelligence and are not difficult to deal with.

As it is more desirable to cast the prestressed members not in place where they are to be located finally, but in a factory, or near the place, cranes have to be used to lift those members in place.

5.- Supply of Labor and Supervisors:-

As said before, people are accustomed to ordinary reinforced concrete. The local practice in ordinary reinforced concrete is accompanied by bad habits which are undesirable and even injurious if applied in prestressed concrete. So it is suggested that people who are to work in the application of prestressed concrete should not have practical experience in ordinary reinforced concrete. Labor is expected to be intelligent and obedient.

The supervisor of the work should think in terms of prestressed concrete and should know what he is doing. The supervision should be strict and present all the time.

ECONOMICAL PHASE

ECONOMICAL PHASE:

In the Arab countries of the Near East materials of construction are mostly imported from outside markets. Steel, which is the most important item in the materials of construction, is wholy imported from outside. Cement is not manufactured sufficiently to fulfil the demand, and most of it is imported from outside. This will consume from the foreign exchange assets these countries have. So any saving on these items will serve to balance the economy of these countries.

Construction materials, steel and cement, are an important item in the trade movement of these countries. Any saving through this item will render an appreciable service to them.

Prestressed concrete in replacing other types of construction will prove to be economical. The economy will be considerably and specially in steel.

It is true that prestressed concrete work will require more skilled labour and better equipment. But still this will not counterbalance the saving on materials, and the final cost will still be considerably less. Even so, the money spent on better labour and equipment will not be lost but will be preserved in the country itself. So even if prestressed concrete will cost the same as other types of construction, which is not the case, still it will serve the economy of the country.

A.- Prestressed Concrete in Comparison with Ordinary Reiforced Concrete:

The commonly used allowable stress in mild steel in tension is

18,000 psi, while the allowable stress in high tensile steel used in prestressed concrete is 150,000 psi to 125,000 psi. In Europe, for both kinds of structures to serve the same purpose, the cross-sectional area, or weight, of prestressing high tensile steel is considered in avarage as about 17.5% of the cross-sectional area, or weight, of the mild steel used for tension. In the U.S.A. a higher value is considered.

In ordinary reinforced concrete web reinforcement is always used to provide for diagonal tension. In prestressed concrete it is almost unnecessary to provide reinfordement for diagonal tension due to the fact that the compression of the prestressing forces will reduce the diagonal tension and in almost all cases will reduce it within the allowable without web reinforcement. Saving from this item is also obtained.

As for concrete used in prestressed concrete due to the fact that shear is not important, as it is in ordinary reinforced concrete, and does not govern in the design of members, it became possible to design high beams, higher than usual, with a thin web. Making the beam higher will increase the moment of inertia of the section thus increasing the capacity of the section to carry more moment proportional to the square of the height. Making the web thinner will reduce the weight of the beam and allow more superimposed load on it.

As to the price of steel, let us take the Belgium steel as an example.

The price of high tensile steel in Belgium is three times as much as the price of mild steel. Transportation cost on articles of this kind is paid on the weight of the materials transported. So when high tensile steel will rach Beirut its price will not be three times as much as mild steel, also transported from Belgium to Beirut, but less. Assume the price be 2.7 times. The price of mild steel in Beirut in April 19, 1952 was L.L. 510 per ton (metric) of steel taking the 16 mm round bar as a base. So the price of high tensile steel will be 2.7 x 510, or L.L. 1377 per metric ton.

Other countries have a similar condition to that of Belgium.

The concrete used in prestressed concrete will be different from the concrete used ordinarily. This is so because it is required to have a richer concrete mix than usual which needs more cement. The price of one bag of cement (50 kgs per bag) is taken as L.L. 4 per bag. The addition of one bag of cement on a cubic meter of concrete will increase the price about 7%. It also requires the use of vibrators because little water is used. The cost of vibrators and power to drive it will increase the price of the concrete L.L. 1 per cubic meter of concrete which is almost 2%. But as the quality of concrete is improved the allowable stress on the concrete will be higher. So actually the increase in cost in improving the quality of concrete will be paid by using higher allowable stresses in the concrete. This will allow less cross-sectional area of concrete required which will reduce the weight of the member also.

Other extra equipment used such as hydraulic jacks, anchorage devices and others will not contribute much to the cost, because they could be used many times, however their initial cost is not too high.

As to labour problems, for the first few applications, the work will not progress as is supposed to be. This is because the first applications will be a sort of introduction of the new method of construction to the workers. The people who first work on the application of prestressed concrete should be tought the subject each in his concerned field. After mastering this, the work will be as efficient as expected.

The most favorable condition for application of prestressed concrete locally will depend upon the volume of constructionand the scale of construction.

In the volume of construction is meant how big the construction is going to be. The application of prestressed concrete in a two story building composed of two apartments, for example, will not be economical and even will show to be disadvantageous. Prestressed concrete could be applied in building where heavy loading and comparatively large spans are required, such as warehouses, airoplane hangers, cinema halls and public buildings. Prestressed concrete could be applied in the construction of bridges also. This is so because equipment used for prestressing and other equipment required for prestressed concrete work will not be used economically where they are used only for a small portion of the time. They have to be used almost continuously and if used once they have to do something worth. For example the cost of the process of prestressing a small beam of , say, 4 meters span will be almost the same for that of a bigger beam, say, 10 meters span or more. So it will be more advantageous and economical to deal with big spans than with small spans. Also, as it is almost the case in prestressed concrete, beams are not constructed in their final position but near and are lifted by a crane to that position, it will not make a big difference whether the beam is light or heavy, within a certain range.

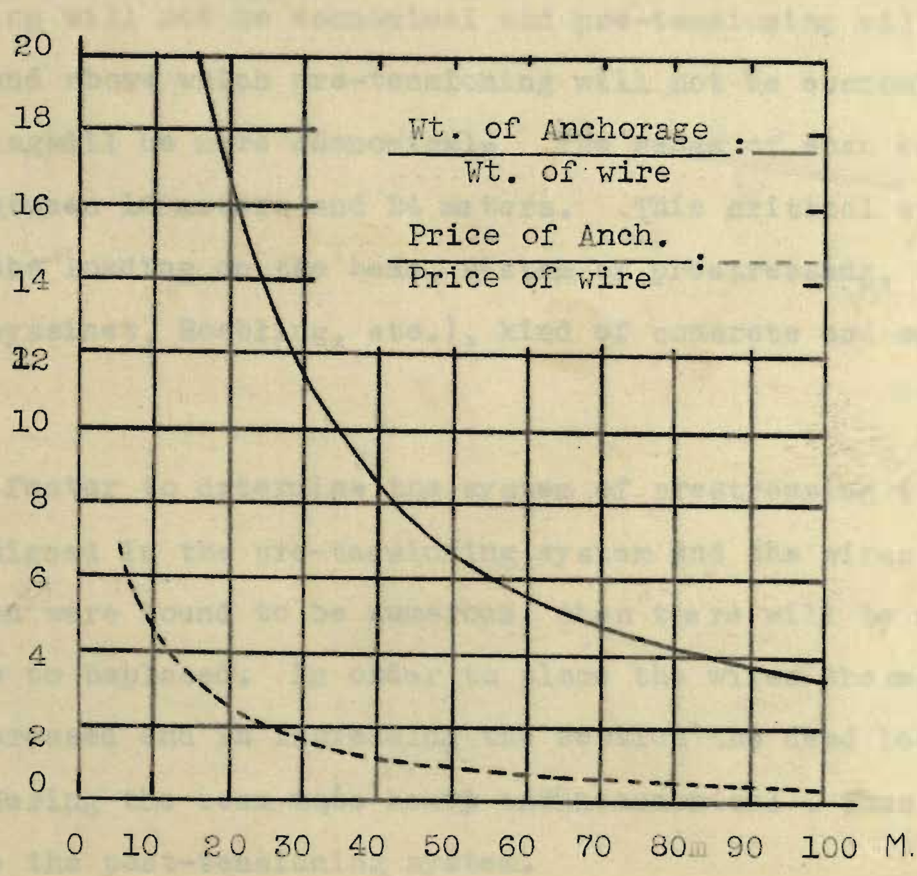
In the scale of construction is meant the number of times by which a certain act is repeated or the number of things done at the same time and in one act. For example it is more desirable and more economical to deal with members of simialr section and length and repeat the act several times, than dealing each time with a different section and length. As an example, take the design of the prestressed concrete bridge, mentioned later, in this thesis. The exterior beams were found to carry less moment than the interior beams. But the difference between both moments was not found to justify the use of another concrete section. Using a different concrete section for the exterior beams, aside from the trouble of designing another section, will require a new study from the designer of the shatering the beams to be poured in, which will consume extra time and energy, and will also consume more wood in constructing two different kinds of shatering Having the section for all the beams the same will make it possible to use the forms more than once and the same form may be used for all the beams with little replacement. Having a number of beams constructed at the same time and in one act will economise much on the labour and will take more advantage on the equipment used. For example, in the design of Prestressed Precast Beams, mentioned later, about 25 beams are constructed at one time, The steel of all the beams is stretched onee, because steel couldbe obtained in any required length. The cost of anchorage and stretching the wires will be the same whether one beam is constructed or any other number of beams. The economy here is obvious from the point of view of time and use of the materials present. The number of hydraulic jacks, sandwich plates and anchorage poles will be less and will be used to the full advantage.

So prestressed concrete could be used locally to produce the best favourable economical conditions is to be applied to big structures or in smaller units such as standard precast beams, door and window lintels, or any other similar thing on a large scale.

B.- A Comparison Between the Two Systems of Prestressing (1) Pre-Tensioning and (2) Post-Tensioning:

In the system of pre-tensioning the steel is in bond with the concrete and adequate bond shouldbe provided. The prestress to the beam is transferred by means of this bond. In the system of Post-tensioning the steel is not in bond with the concrete and the prestress to the beam is transferred by means of end plates that hold the steel and press at the ends of the beams. In the pre-tensioning system, because the steel is in bond with the concrete, whatever happens to the concrete of the section has to effect the steel also. When the concrete hardens it will shrink and due to the continuous loading of the section the concrete will creep. This shortening of the concrete will shorten the stell with it. The steel itself will elongate due to creep of steel. This shortening and elongation of the steel will cause some loss of prestress in the steel. This loss is taken as a percentage of the initial stress on the steel. This loss will reduce the capacity of the beam producing aloss also in the materials used. The loss in prestress in design, in the pre-tensioning system, is taken as 20% to 16%. If we take the variation of stress as 5% then we will have 15% to 11% of the initial prestress lost. In the case of the post-tensioning system some of these lossed do not exist, such as most of the shrinkage loss due to hardening and due to force of stressing. This may amount to about 4% to 5% of the initial prestress. This loss may be gained if post-tension is used.

But on the other hand anchorage at the ends of the beam will add to the cost in the case of post-tensioning. A graph suggested by Prof. G. Magrel is presented to show the relation between the span of beams and the avarage weight and cost of anchorage.



The horizontal axis represents the span of the beams, the vertical axis represents the percentage of weight and price of anchorage with respect to the weight and price of steel used in prestressing. The full line represents the percentage of weight, the dotted line represents the percentage of price. This graph is based on the assumption that the Belgium practice is used with Magnel's Sandwich Plates anchorage. This graph indicates to us that the anchorage at the ends is nearly independent of the length of the beam. The shorter the beam the more the anchorage will cost with respect to the beam. To this is added the cost of preparing the cable covering it with material and other expenses.

From this discussion we conclude that there is a certain limit, in length of beam accompanied with the loading on it, below which post-tensioning will not be economical and pre-tensioning will be more economical, and above which pre-tensioning will not be economical and post-tensioning will be more economical. The range of span suggested by some is between 18 meters and 24 meters. This critical span will depend upon the loading on the beam, system of prestressing, (whether Magnel's, Freyssinet, Roebling, etc.), kind of concrete and such factors.

Another factor to determine the system of prestressing is when a beam is designed in the pre-tensioning system and the wires required for the section were found to be numerous, then there will be no room for the wires to be placed. In order to place the wires the section have to be increased and in increasing the section the dead load will increase rendering the beam to be heavy and uneconomical . Thus it is better to use the post-tensioning system.

DESIGN PHASE

a: In the following a bridge is designed in ordinary reinforced concrete and in prestressed reinforced concrete. For the sake of comparison between both methods of design the same span, loading and nearly equal widths are taken. The design in ordinary reinforced concrete is a deck girder T-beams bridge. The design in prestressed concrete is done as beams with a slab cover over them.

1.- Design of a T-Beam or Deck Girder Bridge in Ordinary Reinforced Concrete:-

Data and specifications: It is required to design a T-beam or deck girder bridge for the following specifications in ordinary reinforced concrete:

Clear span	68 ft. 0 in.
Clear width	21 ft. 0 in.
Live load	H-20

$f'_c = 2{,}500$ psi; $f_s = 18{,}000$ psi; $f_v = 20{,}000$ psi; $n = 12$.

The bridge is to consist of 4 intermediate beams and 2 outside beams supporting a floor slab. The outside beams are to project at least 9 in. above the floor slab to act as a curb.

H-20 loading for spans above 60 ft. is:

Concentrated load: 18,000 lb. for moment; 26,000 lb. for shear

Uniform load 640 lb./linear foot of lane

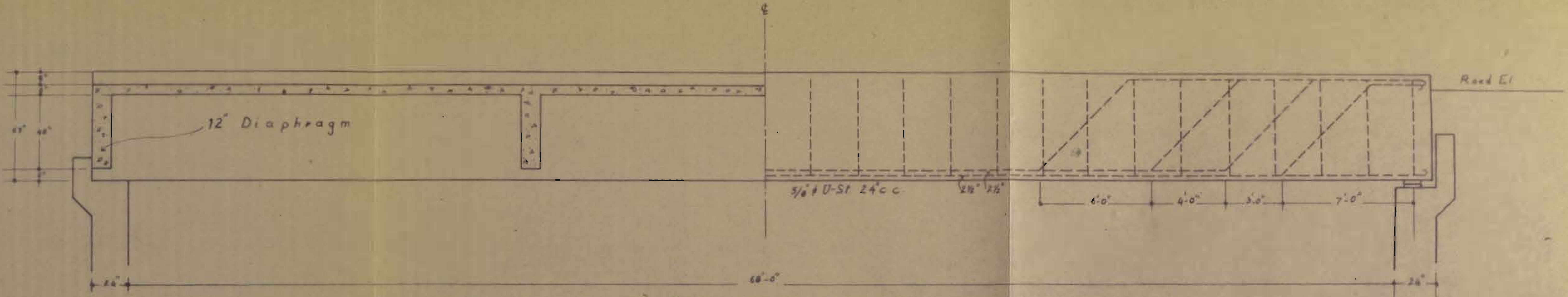
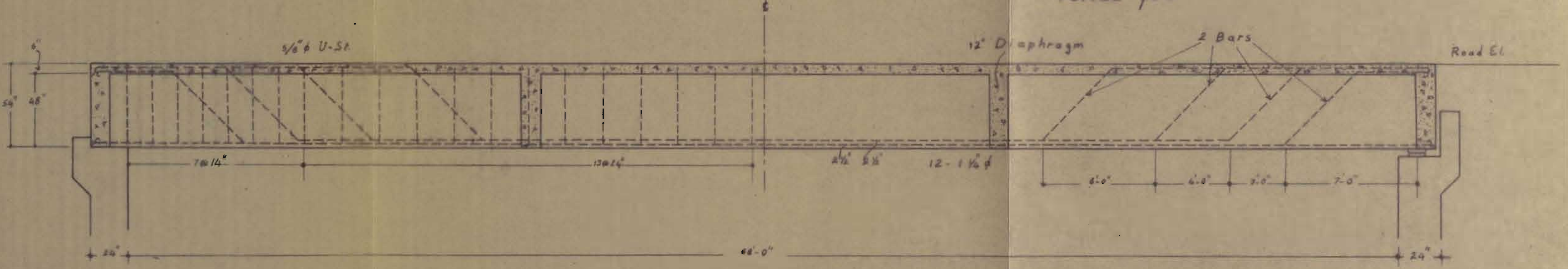


Figure 36-a Details of Exterior Beam

SCALE 1/60



SCAEE 1/60

Fig. 36-b Details of Interior Beam

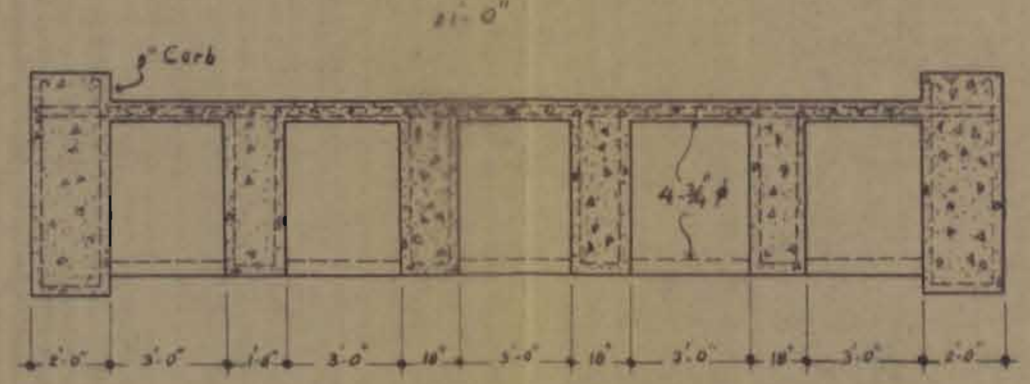


Fig 36-d Cross-Section

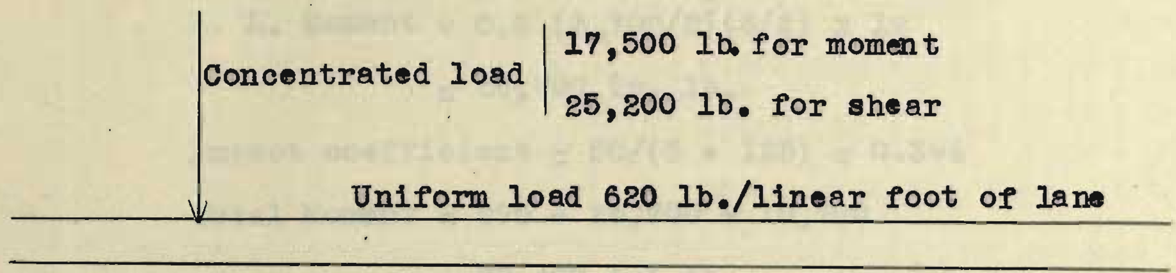
SCALE 1/60

Fig 36-c Half-Cross Section

Showing Slab Reinforcement

SCALE 1/20

Because 21 ft. is more than 18 ft., which are two lanes, by 3 ft. then the load is reduced by 3% and becomes:



<u>Slab</u>: The slab distance will be taken as the clear distance between supports as the outside beams will be heavy in comparison with the floor slab and slab and beams are going to be poured monolithically and reinforced with a diaphragm. Assume the section shown in figure (36-c) and (36-d). The clear span of the slab is equal to 3 ft. Interior beams have a width of 1 ft. 0 in. Outside beams have a width of 2 ft. 0 in. According to the American Association of State Highway Officials, concrete floor slabs built continuously over supporting beams are desinged for 80% of maximum bending moment of a simply supported slab of the same span.

Assume a total thickness of slab 6 in. (including 3/4 in. wearing surface) and allowing 15 lb./sq.ft. for possible future protection dovering, the total dead load is :

$$(6/12) \times 150 + 15 = 90 \text{ lb./sq.ft.}$$

To find effective width of one wheel E,

$$E = 0.7(2D + T)$$

$$D = 4.5/2 = 2.25 \text{ ft.}, \qquad T = 1.67 \text{ ft., then}$$

$$E = 0.7(2 \times 2.25 + 1.67) = 4.32 \text{ ft}$$

Therefore the concentrated load at the center of one foot strip of slab is:

$(32,000)/(2 \times 4.32) = 3,600$lb.

D. L. Moment = $0.8(1/8 \times 90 \times 3 \times 3 \times 12)$

= 973 in. lb.

L. L. Moment = $0.8\ (3,700/2)(3/2) \times 12$

= 26,700 in. lb.

Impact coefficient = $50/(3 + 125) = 0.394$

Total Momant = 970 + 26,700 + 10,700

= 38,400 inl lb.

$M = Kbd^2$, K = 173, then

$d = \sqrt{38,400/(173 \times 12)} = 4.28$ in.

Take d 4 1/4 in. with 1 in. insolation bellow the center of the bars, total thickness 3/4 + 4 1/4 + 1 = 6 in. as assumed.

$A_s = 38,400/(18,000 \times 0.867 \times 4.25) = 0.58$ sq. in.

This is furnished by 5/8 in. round bars at 6 in. c.d. Each alternate bar is bent up over the support, and additional straight bars 12 in. c.c. are placed in the top of, the slab continuous from outside beam to outside beam to complete the negative-moment reinforcement. Temperature and distribution stressed in the direction of the span are provided for by placing 3-1/2 in. round bars in the top and bottom of each slab panel, parallel to the beam. Details are shown in figure (36-c)

<u>Interior beams</u>: are T-beams with flange width of 54 in. The required dimensions are governed by either maximum moment or maximum shear. The bridge seats will be assumed 2 ft. 0 in. in width and the effective span length center to center of bearings taken as 70 ft. 0 in.

L.L. Moment = 1/8 x 620 x 70 x 70 x 12 +

(17,500/2) x (70/2) x 12

= 8,220,000 in. lb.

Impact coefficient = 50/(70 + 125) = 0.257

L. L. Moment per girder = 8,220,000 x (4.5/9) x 1.257

= 5,160,000 in.lb.

D. L. Moment: The weight from slab = 4.5 x 90 = 405 lb./ft.

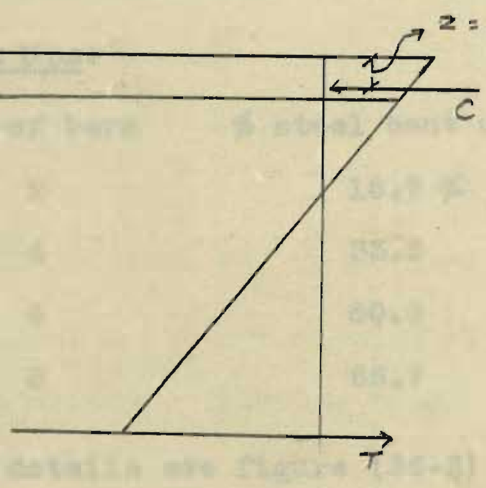
The cross-section of the beam bellow the slab is assumed to be 18 in. x 48 in. Weight per foot is = 48 x 18 x 150/144 = 900 lb./ft. Total D. L. = 900 + 405 = 1,305 lb./ft.

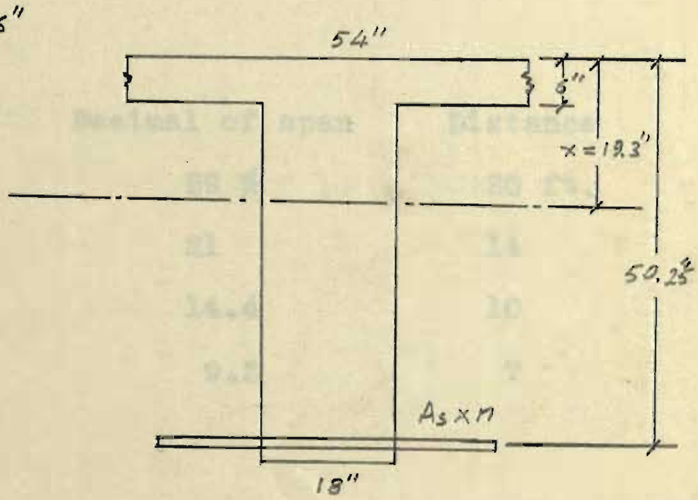
D. L. Moment = 1/8 x 1,305 x 70 x 70 x 12 = 9,600,000 in. lb

Total Moment = 9,600,000 + 5,160,000

= 14,760,000 in. lb.

To find the moment that the concrete can carry, assume the bottom area of steel 18.75 sq. in., with two raws of steel at the bottom, with 2½ in. insolation till the center of grafity of the bottom raw of steel and 2½ in. distance between centers of gravity of both steel raws. The moment is found by the method of transformed section. Assume area of steel as 12-1 1/4 in. sq. bars A_s = 18.75 sq. in.





To find X,

$X \times 18 \times X/2 + (54 - 18)(X - 3) \times 6 = 18.75 \times 12 \times (50.25 - X)$

$X = 19.3$

To find Z,

$C = \frac{1}{2} f_c \times 45 \times 19.3 - 12 \times f_c \times (13/19.3) \times 36 \times 13.3$

$= 521 f_c \qquad - 165 f_c$

$= 356 fc,$ then,

$521 \times 19.3/3 - (165(6 + 13.3/3) = 356 Z$

$Z = 4.6$ in.

Moment arm $= 50.20 - 4.60 = 45.6$

$M_c = 356 \times 1{,}000 \times 45.6 = 16{,}200{,}000$ in. lb.

$M_s = 18.75 \times 18{,}000 \times 45.6 = 15{,}350{,}000$ in. lb.

The governing moment is 15,350,000 in. lb.

The existing moment is 14,760,000 in. lb., thus the design is safe.

Check for bond:

$\Sigma\, 0 = 92{,}600/(125 \times 7/8 \times 50.25) = 16.88$ in.

This may be furnished by 4-1 1/4 sq. bars.

Bent Ups:

No. of bars	% steel bent up	Decimal of span	Distance
2	16.7 %	29 %	20 ft.
4	33.3	21	14
6	50.0	14.4	10
8	66.7	9.2	7

For details see figure (36-2)

Shear and Web Reinforcement:

To find shear at points take distributed L.L. as 620 x 1.257 = 780 lb./ft./lane. Or 780 x 4.5/9 = 390 lb.ft./beam. And concentrated load as 25,200 x 1.257 = 31,600 lb in a lane. Or:

31,600 x 4.5/9 = 15,800 lb. in a beam.

Concrete carries 18 x 50.25 x 50 x 7/8 = 39,600 lb.

Maximum spacing of stirrups 50/2 = 25 in., make it 24 in. of 5/8 in. round bars U shaped stirrups.

Shear at 35 ft. from support:

15,800/2 = 7,900

-39,600 = ------ Use 5/8 in. round bar stirrup at 24 in. c.c.

Shear at 30 ft. from support:

(390 + 1,305) x 35 - 1,695 x 30 + 15,800 x 40/60

= 8,470 + 10,500 = 18,970 lb

- 39,600 = ------- Use same as before.

Shear at 20 ft. from support:

1,695 (35-20) + 15,800 x 50/70

= 25,400 + 11,300 = 36,700 lb.

- 39,600 = ------ Use same as before.

Shear at 10 ft. from support:

1,695 x (35-10) + 15,800 x 60/70

= 42,400 + 13,500 = 55,900 lb.

- 39,600 = 16,300 lb

s = (0.61 x 50.25 x 20,000 x 7/8)/16,300 = 32.9

Use same as previous

Shear at 0 ft. from support:

1,695 x 35 + 15,800 = 59,300 + 15,800*

= 75,100 lb.

\- 39,600 = 35,500#

s = (0.61 x 50.25 x 20.000 x 7/8)/35,500 = 15.0 in.

Use 5/8 in. round bar U stirrups at 15 in. c.c. For details see figure (36-b)

Exterior Beams:

are designed as rectangular beams since they are to project 9 ins. above the slab.

Moment: Weight from the slab per linear foot is equal to 90 x 1.5 = 135 lb./ft.

Assume dimensions as 24 in. x 68 in.

Wt. = 68 x 24 x 150 x 1/144 = 1,700 lb./ft. Assume the weight of railing to be 300 lb./ft. then,

Total weight = 1,700 + 300 + 135 = 2,135 lb./ft.

D. L. Moment = 1/8 x 2,125 x 70 x 70 x 12 = 15,680,000 ~~lb./ft.~~ in. lb.

L. L. Moment = 1.256 x 8,220,000 x 1.5/9 = 1,720,000 in. lb.

Total Moment = 17,400,000 in. lb.

$M = Kbd^2$ = 173.3 x 24 x 64.25 x 64.25 = 17,200,000 in. lb.

Thus we assume height = 69 in. then,

Wt. = 1,720 lb./ft.

Total = 2,160 lb./ft.

$M = 1/8 \times 2,160 \times 70 \times 70 \times 12 = 15,870,000$ in. lb.

Total moment = 17,590,000 in. lb.

$M = 173.3 \times 24 \times 65.25 \times 65.25 = 17,700,000$ in. lb. which is satisfactory .

$A_s = 17,590,000/(18,000 \times 0.867 \times 65.25) = 17.28$ sq. in.,

Use 12-1 1/4 in. sq. bars.

Bent ups are to be the same way as in interior beams. For details see figure (36-a).

Maximum shear at support:

$V = 2,160 \times 35 + 620 \times 1.257 \times (1.59/9) + 25,200 \times 1.257 \times (1.5/9)$

$= 75,000 + 4,550 + 5,270$

$= 85,300$ lb.

$V_c = 24 \times 65.25 \times 50 \times 7/8 = 68,500$ lb.

Shear to be carried by stirrups = 16,800 lb.

$s = 20,000 \times 0.61 \times 65.25 \times (7/8) = 33.1$ in.

Space the stirrups at 24 in. all through the length of the beam.

$\Sigma o = 85,300/(125 \times 0.867 \times 65.25) = 11.95$ in.

Which is provided.

Four diaphragms are provided, two at both ends and two at 23ft. from both ends and will be 12 in. x 48 in. bellow the slab

Steel used in the design:

Dimension	Length	Lb./ft.	Total wt.
1 1/4 in. sq. bars	5,928 ft.	5.31 lb./ft.	31,500 lb.
3/8 in. round "	1,919	0.38	730
3/4 " " "	416	1.50	625
½ " " "	2,250	0.67	1,510
5/8 " " "	5,544	1.04	5,770
			40,140 lb.

Total quantities used are:

4,265 cu.ft. or 151 cu. meters of Concrete, and,

40,140 lb. or 17.92 metric tons of Steel.

2.- In the Following is the Design of a Prestressed Bridge of the Same Span asthat Designed in Ordinary Reinforced Concrete:-

Data and specifications:-

It is required to design a prestressed girder bridge for the following specifications:

Clear span	69 ft.-0 in.
Clear width	22ft.-6 in.
Live load	H-20

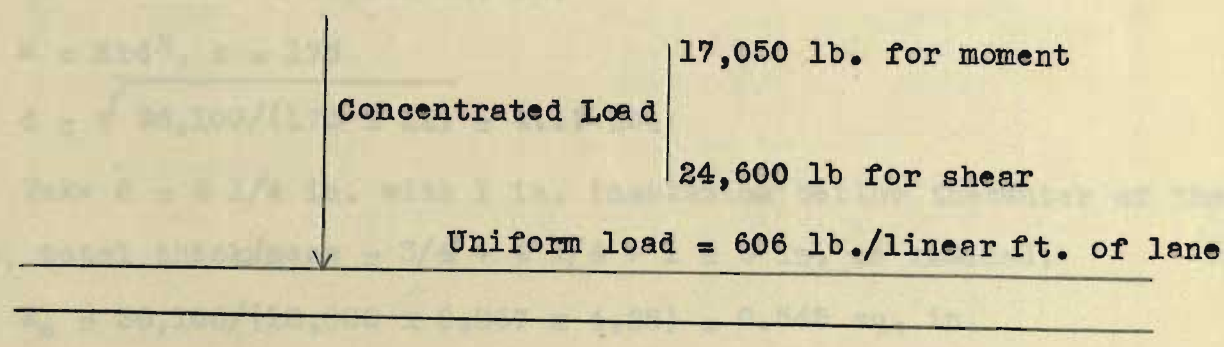
For concrete in slab: $f_c = 1{,}000$ psi; $f_s = 18{,}000$ psi; $n = 12$.

For concrete in girders: $f_c = 2{,}000$ psi; $f_s = 125{,}000$ psi. Loss of initial prestress around 16% (Using the Roebling Strand and Fittings for Prestressed concrete.)

Crushing Strength of concrete at prestress = 5,000 psi

The bridge is to consist of 2 intermediate beams and two outside beams supporting a floor slab.

Live load of H-20 for spans more than 60 ft.-0 in. and reduced 4.5% (because 22.5 ft. is 4.5 ft. more than 18 ft.)



Slab : - The slab distance will be taken as theclear distance between supports = 4 ft.-0 in. Assume the section of bridge shown in figure (36-5). Bending moment in slab is designed for 80% of the maximum bending moment of a simply supported slab of the same span.

Assume a total thickness of slab of 6.0 in. (including 3/4 in. wearing surface) and allowing 15 lb./sq.ft. for possible future protection covering, the total dead load is:

$(6/12) \times 150 + 15 = 90$ lb./sq. ft.

To find the effective width of one wheel,

$E = 0.7\ (2D + T)$, $D = 7.00/2 = 3.50$ ft., $T = 1.67$ ft., then

$E = 0.7\ (2 \times 3.5 + 1.67) = 6.06$ ft.

Therefore the concentrated load at the center of 1 ft. of strip of slab is $= 32{,}000/(2 \times 6.06) = 2{,}640$ lb., then

L. L. Moment $= 0.8(2{,}640/2) \times 4/2 \times 12$

$= 24{,}500$ in.lb.

Impact coefficient $= 0.4$

D. L. Moment $= 0.8\ (1/8 \times 90 \times 4 \times 4 \times 12)$

$= 1{,}700$ in. lb.

Total moment $= 36{,}100$ in. lb.

$M = Kbd^2$, $k = 173$

$d = \sqrt{36{,}100/(173 \times 12)} = 4.17$ in.

Take $d = 4\ 1/4$ in. with 1 in. insolation bellow thecenter of the bars, total thickness $= 3/4 + 4\ 1/4 + 1 = 6$ in. as assumed.

$A_s = 36{,}100/(18{,}000 \times 0.867 \times 4.25) = 0.545$ sq. in.

This is furnished by 5/8 in. ø at $6\frac{1}{2}$ in. c.c. Each alternate bar is bent up over the support and additional straight bars 13 in. c.c. are placed in the top of the slab continuous from outside beam to outside beam to complete the negative-moment reinforcement. Temperature and distribution stresses in the direction of the span are are provided for by placing 4-$\frac{1}{2}$ in. ø in the top and bottom of each slab panel parallel to the beams.

Beams :-

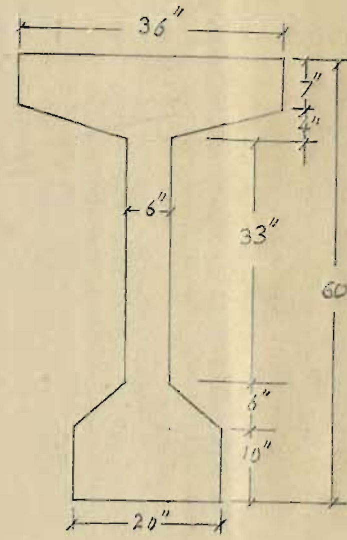
The concrete section of all the beams will be the same because, as will be seen later, the difference in moments applied at both beams, exterior and interior beams, is comparatively small and does not justify the design of another section. Also the cost in having two beams of different cross-sections will be greater than if we had only one. Assume the section of concrete shown in figure (36-5).

Area A		Static Moment Q	
36 x 7	= 252	252 x 56.5	= 14,240
15 x 4	= 60	60 x 51.7	= 3,100
43 x 6	= 258	258 x 32.5	= 8,400
20 x 10	= 200	200 x 5.0	= 1,000
7 x 6	= 42	42 x 12.0	= 504
	812 sq. in.		27,244 in.^{3}

y_b = 27,200/812 = 33.5 in.,

y_t = 26.5 in.

Moment of inertia I



252 (49/12 + 22.9 x 22.9) = 132,800
60 (16/36 + 17.1 x 17.1) = 17,500
259 (1850/12 + 2.1 x 2.1) = 40,000
200 (100/12 + 28.6 x 28.6) = 165,000
442 (144/36 + 21.6 x 21.6) = 19,500

375,000 in.^{4}

r^2 = 375,000/812 = 462 in.^{2}

e = 462/26.5 = 17.4 in.., 462/33.5 in.
= 13.8".

Interior Beams:-

Assume a 16 in. diaphragm, area = 7 x 50/12 + 612/144 ± 2π
= 18.67 sq. in.

Weight of one diaphragm = 18.67 x(16/12) x 150
= 3,730

Moment at center due to diaphragms:
= (3,730 x 2 x 35 - 3,730 x 2 x 14) x 12
= 1,880,000 in.lb.

Dead load of girder;
= 812 x 150 / 144 = 846 lb./ft.

M = 1/8 x 846 x 70 x 70 x 12 = 6,210,000 in.lb.

Moment due to 6 in. slab covering:
= 1/8 x 90 x 70 x 70 x 12 x 7 = 4,630,000 in.lb.

L.L. Moment = 7/9 (1/8 x 606 x 70 x)70 x 12 + 8,530x35x12)1.257
= 7,840,000 in.lb.

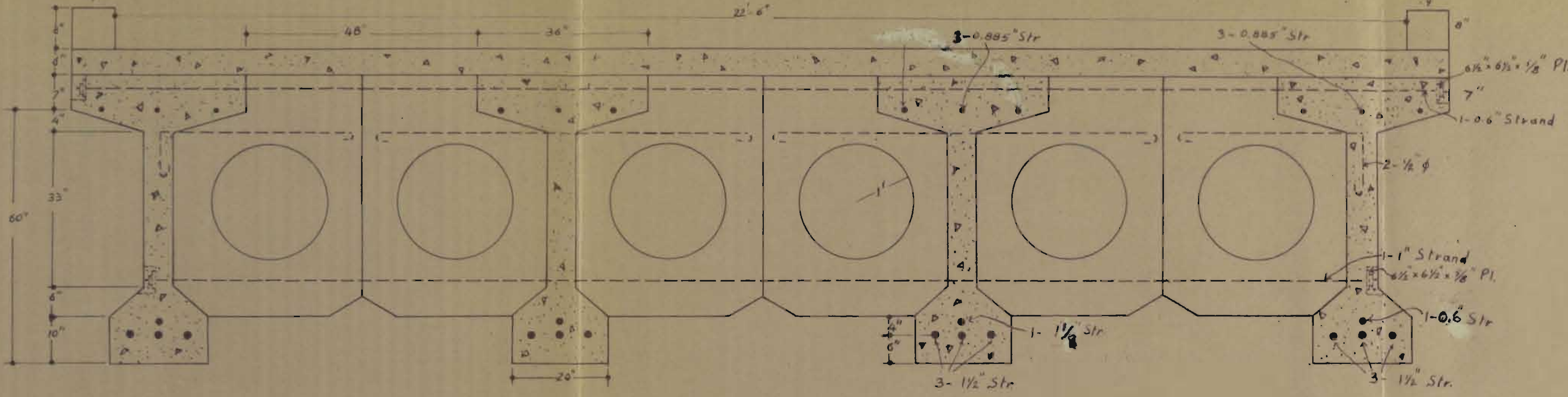


Fig. 36-5 SCALE 1/24

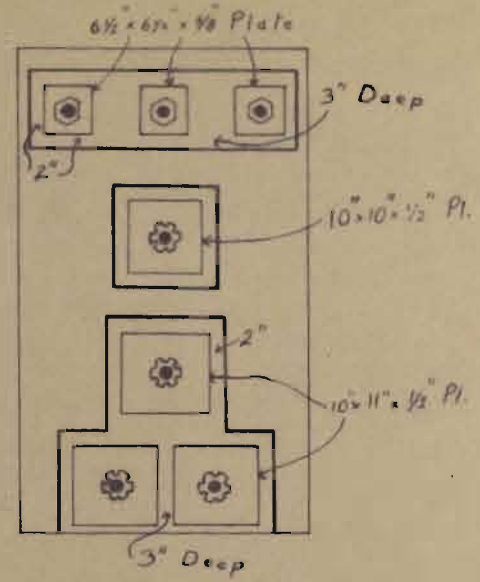


Fig. 36-6 SCL 1/24

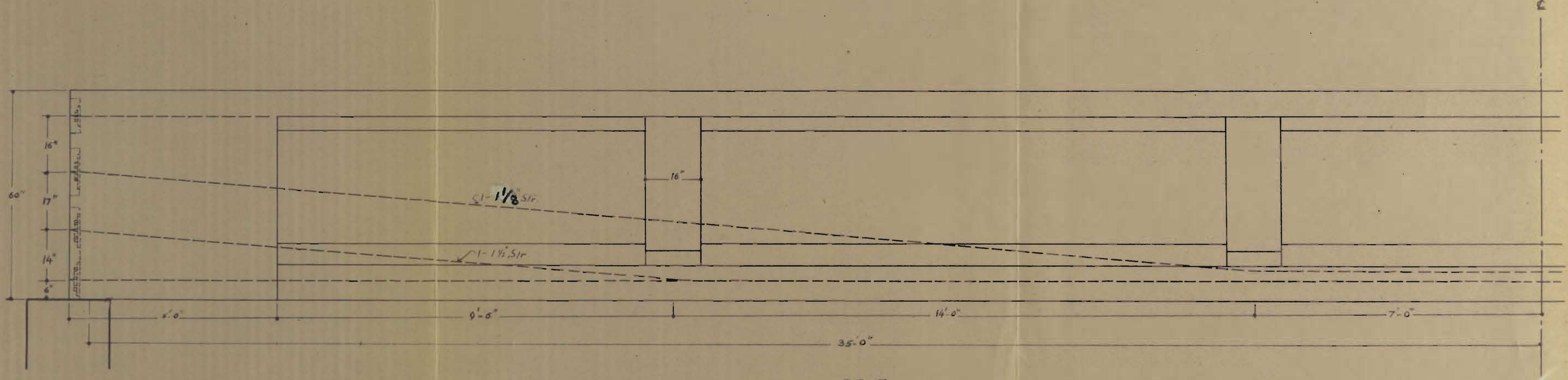


Fig. 36-7 SCALE 1/24

M_T = 20,560,000 in.lb.

P = 20,5 60,000/31.2 = 658,000 lb. *

P_b = 658,000 x 34.8/45 = 509,000 lb.

P_t = 658,000 x 102/45 = 149,000 lb.

For top steel use 3-1 1/2 in. Roebling Strand P = 429,000 lb.

and 1-1 1/8 in. " " P = 79,000 lb.

508,000 lb.

For top steel use 3-0.885 in. Strands P = 144,000 lb.

The bent up arrangement is shown in figure (36-7)

Stresses in concrete due to M_T:

f_t^t = 20,560,000 x 26.5/375,000 = 1,450 psi

f_b =- 20,560,000 x 33.5/375,000 =-1,832 psi

<u>Computation of stresses:</u>

1.- Stresses in concrete due to initial applied forces:

P = 775,000 lb.

f_t = 775,000/812 - 775,000 x 17.4 x 26.5/375,000

= 954 - 954

= 0 psi

f_b = 954 + 775,000 x 17.4 x 33.5/375,000

---

* These values are taken from the Roebling Pamphlet. See the the Appendix.

= 954 + 1,202

=2,156 psi

2.- Stresses in concrete due to prestressing forces after reduction of forces:

P = 652,000 lb.

f_t = 652,000/812 - 652,000 x 17.4 x 26.5/375,000

= 803 - 803

= 0 psi

f_b = 803 + 652,000 x 17.4 x ~~26.5~~ 33.5/375,000

= 803 + 1,014

= 1,817 psi

3.- Stresses in concrete due to prestressing and weight of girder:

M_G = 8,090,000 in.-lb.

At top : 8,090,000 x 26.5/375,000 = 571 psi

At bottom :-8,090,000 x 33.5/375,000 =-723 psi

f_b = 0 + 571 = 571 psi

f_t =-723 +1,817= 1,094 psi

After the beam is put in place the top steel is loosened and pulled out leaving only the bottom steel acting on the section.

4.- Stresses in concrete due to applied forces (with e = 26.5 in.)

P = 508,000 lb.

f_t = 508,000/812 - 508,000 x 26.5 x 26.5/375,000

= 625 - 915 = - 290 psi

f_b = 625 + 508,000 x 26.5 x 33.5/375,000

= 625 + 1,210 = 1,835 psi

5.- Stresses due to total moment:

M_T = 20,560,000 in.lb.

At top: 20,560,000 x 26.5/375,000

= 1,450 psi

At bott. 20,560,000 x 33.5/375,000

= 1,832 psi

If we combine this with step (4) we get:

f_t = -290 + 1,450 = 1,160 psi

f_b = 1,835 - 1,832 = 3 psi

<u>Exterior beams</u>:

M_G = 6,210,000 + 940,000 = 7,150,000 in.lb.

Weight of railing and curb = 300 + (14/12) x 0.75 x 150

= 431 lb./ft. of beam.

M = 1/8 x 431 x 70 x 70 x 12 = 3,170,000 in.lb.

Moment due to slab and covering:

= 4,630,000 x(4.25/7) = 2,810,000 in.lb.

M_T = 18,190,000 in.lb.

P = 18,190,000/31.2 = 583,000 lb.

P_b = 583,000 x 34.8/45 = 451,000 lb.

P_t = 583,000 x 10.2/45 = 132,000 lb.

For bottom use 3-1 1/2 in. Strand $P = 429,000$

and 1-0.600 in. Strand $P = 22,500$

451,500 lb.

For top use 3-0.885 in. Strand $P = 144,000$ lb.

595,500 lb.

Computation of stresses:

1.- Stresses in concrete due to initial applied force:

$P = 708,000$ lb.

$f_t = 708,000/812 - 708,000 \times 17.5 \times 26.5/375,000$

$= 872 \qquad - 872 = 0$ psi

$f_b = 872 \qquad + 708,000 \times 17.4 \times 33.5/375,000$

$= 872 \qquad + 1,100 = 1,972$ psi

2.- Stresses in concrete due to prestressing forces after reduction:

$P = 596,000$ lb.

$f_t = 596,000/812 - 596,000 \times 17.4 \times 26.5/375,000$

$= 734 \qquad - 734 = 0$ psi

$f_b = 734 \qquad + 928 = 1,662$ psi

3.- Stresses in concrete due to prestressing force and M_G:

$M_G = 7,150,000$ in.lb.

At top : $7,150,000 \times 26.5/375,000 = 505$ psi

At bottom : $7,150,000 \times 33.5/375,000 = 638$ psi

$f_t = 0 + 505 = 505$ psi

$f_b = 1,662 - 638 = 1,024$ psi

After the beam is put in place the top steel is loosened and pulled out leaving only the bottom steel acting on the section.

4,- Stresses in concrete due to applied forces (with $\underline{e}$ = 26.5 in.):

P = 452,000 lb.

f_t = 452,000/812 - 452,000 x 26.5 x 26.5/375,000

= 557 - 846 = -289 psi

f_b = 452,000/812 + 452,000 x 26.5 x 33.5/375,000

= 557 + 1,070 = 1,627 psi

5.- Stresses in concrete due to total moment:

Top: 18,190,000 x 26.5/375,000 = 1,285 psi

Bott:-18,190,000 x33.5/375,000 = 1,622 psi

If we combine step (4) with this step we get:

f_t = -289 + 1,285 = 996 psi

f_b = 1,625 - 1,622 = 3 psi

The steel at the top is placed so that when the steel is pulled at the start no tension at the top and no excessive compression at the bottom is produced. The top steel in the beams is pulled after the beams are placed in their final position, because the dead load of the beam has to act in order that no tension or excessive compression is produced. After the beams are placed and the top steel pulled out the stresses in the combination of steps (3) and (4) will be within the allowable and no tension occurs any where on the section. Actually step (4) does not occur by itself under any condition but has to be combined with step (3) and step (4).

The advantage of pulling out the steel is to economise on the steel used. The same top steel could be used in manufacturing the beams because all top steel in all the four beams is the same with the same cross-section.

The bent up arrangement of the exterior beams will be the same as that of the interior beams.

The beams are laterally prestressed by means of Strends:

At top : 1-0.6 in. Strand $\underline{a}$ = 0.215 sq.in.

At bottom : 1-1 in. Strand $\underline{a}$ = 0.577 sq.in.

Calculation of Shear Forces:

At support, in the interior beams:

$V = (VQ/(Ib)$ psi

$V = 846 \times 35 + 7,460 + 90 \times 35 + (606(7/9) \times 35 + 24,000 \times 7/9) \times 1.257$

$= 85,000$ lb. $\qquad Q = 8,260 \text{ in}^3$

$v = 85,000 \times 8,260/(375,000 \times 6) = 312$ psi

Stress due to prestress = 508,000/812 = 626 psi

$S_t = \sqrt{312 \times 312 + 313 \times 313} - 313 =$

$= 129$ psi which is within the allowable.

There is no need to investigate shear in the exterior beams.

Check for Deflection:

$$(\text{max.}) = (5/48) \times (7,840,000 \times 70 \times 70 \times 12 \times 12)/6,000,000 \times 375,000$$

$= 0.256$ in.

Allowable deflection = $(1/1,200) \times L = (70 \times 12)/1,200$

$= 0.7$ in.

The ends of the beams are made rectangular and have the dimensions ~~o~~of 36 in.x 60 in.x 60 in. to support the anchorage at the ends.

Design of the End Plates:

(The dimensions are taken from the Roebling Pamphlet, see Appendix.

For $1\frac{1}{2}$ in. strand, P = 170,000 lb

$$+ 2,000 + \pi\ 5.5 \times 5.5/4$$

$$= 108.7 \text{ sq. in.}$$

Use $10\frac{1}{2}$ in.x$10\frac{1}{2}$ in. plate; or 11 in. x 10 in. plate.

Thickness : 170,000/(32.2 x 12,000) = 0.44 in., use $\frac{1}{2}$ in.

For 1 7/16 in. stand, P = 155,000 lb

$$+ 2,000 + \pi 5.13 \times 5.13/4$$

$$= 98.1 \text{ sq. in.}$$

Use 10 in. x 10 in. plate

Thickness : 155,000/(29.5x12,000) = 0.438 in., use $\frac{1}{2}$ in.

For 1 1/16 in. strand, P = 83,000 lb.

$$+ 2,000 + \pi 4 \times 4/4$$

$$= 52.1 \text{ sq. in.}$$

Use 7 1/4 in.x 7 1/4 in. plate

Thickness: 83,000/(17.7 x 12,000) = 0.391 in., use $\frac{1}{2}$ in.

For 1 in. strand P = 72,000 lb.

$$+ 2,000 + \pi\ 2.25 \times 2.25/4$$

$$= 40 \text{ sq. in.}$$

Use $6\frac{1}{2}$ in. x $6\frac{1}{2}$ in. plate

Thickness = 72,000/(1.73 x 6 x 12,000) = 0.578 in., use 5/8 in.

3.- Description of Manufacturing and Placing:-

In the ordinary reinforced T-beam deck-girder bridge, forms should be constructed all through the length of the bridge in order to support the structures before it is able to support itself. Steel is placed and concrete poured. Vibrators may be used. 28 days, after pouring the last part of concrete in thebridge, the forms are removed. Specimens of concrete should be taken every now and then from the concrete used on the job for testing. The mix will be 80% course aggregate, 40% sand or fine aggregate, with 7 bags of cement (50 kgs each) per cubic metre.

In the prestressed girder bridge the beams are poured on the side of the river (if it is a river), parallel to the banks and close to the final location of the bridge. As the beams are all similar the forms may be used four times with little replacement.

The materials to be used are as follows:

Concrete: Ordinary Portland cement 8 bags of cement, in one finished cubic metre of concrete with 80% by volume of course aggregate and 40% by volume of sand or fine aggregate. This corresponds to a mix of 1:1½:3. As little water as possible is used as workability of the concrete permits. This will be determined on the job. Vibrators are used in the manufacture of beams. Specimens for testing should be taken always every, say, three mixes for an ordinary concrete mixer ... used locally. These specimens should be numbered and dated and a special diary should be kept for them.

The steel used will be the Roebling Strands ordered from the company in the required lengths accompanied with their plates and fittings.

The concrete used should be able to possess at the time of prestressing a crushing strength of about 5,000 psi, otherwise the girder should stay for another certain period of time until it possesses this strength. This will be determined by testing the specimens.

The forms are set and the steel is put in its proper place. The concrete is poured and vibrated. Special place should be provided for the lateral prestressing strands by placing rubber or steel cores of 1 in. diameter in the molds moulds and pulled out after two or three hours the concrete has been vibrated. These cores are placed at the top and bottom in the exact location of the lateral prestressing strands.

The side forms could be removed five or six days after the concrete was poured. The concrete should be cured for 28 days after pouring and should be protected from the sun or freezing temperatures and kept damp all the time.

Because the exterior beams are not expected to be as strong as the interior beams, then it is suggested to start pouring the exterior beams first, because the work at the start will be more difficult and better results will be obtained in the last beams.

After the concrete was found, by testing the specimens, to conform with the requirements stressing the steel starts. This could be done thid way: first stress the strands which are bent up. Then stress one of the top steel, take the middle one. Then stress the middle one at the bottom. Then stress one of the top strands. Then stress the opposite corresponding one at the bottom. Then stress the last one at the top. Then stress the last one at the bottom. This is done so because it should be clear that stressing all the bottom strands first may produce tension at the top which is undesirable and not in accordance with the specifications.

The beams after prestressing are ready to be lifted and placed. The weight of one beam will be = 794 x 150 = 119,100 lb. = 59.6 short tons = 53.2 metric tons. A crane is needed to carry this weight. The ties to the crane should be two and the beam should be lifted only from the end blocks. The radius of the crane that should be able to move, should be more than 15 metres. If one crane to carry all this weight is not accessible two cranes may be used each one located at one of the two sides. The radius of each should be at least 25 metres. Each one will carry the beam from one end and will carry half the weight of the beam. Actually, for safety, more than half the weight should be assumed for each, say, 35 metric tons each. In lifting the beams by means of two cranes will be ~~very~~ difficult and will take a longer time to place the beams. Caution should be taken in placing the beams in their position. The position should be exact and the diaphragms should come in almost exact contact so that the strands for lateral post-tensioning will be introduced later through the successive beams.

If it is found difficult and impractical to use cranes as those described, another method may be used to locate the beams in their place. This system is described on page 213 in "Prestressed Concrete" by Gustav Magnel in the erection of the Eecloo Bridge. The beams are poured at one side perpendicular to the direction of the river ~~(N)~~, and in the line with their final location. The furthest end is placed on rollers and the other is tied to an upward lifting cable (to the top of a vertical mast) and also tied with a horizontal pulling system. These cables are connected each to a winch on the other side of the river. The upward lifting cable is attached to a vertical mast which is tied well to the ground. First the beam is raised slightly by means of the lifting cable. The beam is then pulled horizontally by means of the pulling system. When pulling horizontally the side of the beam tied to the cables willbe lifted upward; therefore it is necessary to lengthen the lifting cable in order to keep the beam in a horizontal manner. After the beam is pulled near its horizontal location, two cranes will lift it to its final place.

After the beams are placed intheir final position, the top strands are pulled little by the jack in order to be able to loosen thenuts. The top steel is pulled out then.

When all the beams are assembled near each other the lateral strands are intoduced through their paths and stressed to the required stress. This will insure us that all the beams will act as one rigid structure.

The forms for the slab laid, the steel is placed and the concrete poured. When pouring the concrete of the beams, short mild steel bars, about one feet in length,are put at the top of the beams projecting about 3 in. to the outside. These bars will connect the slab with the beams well and will forbid any kind of motion of the slab with respect to the beams. The curb and railing are then poured. The mix used in the slab will be 7 bags of cement per one finished cubic metre of concrete.

As mentioned before the capacity of a crane, if one crane is used, shoud be 54 metric tons or more with a radius of 15 m. or more. If two cranes are used each should be able to carry 35 metric tons or more with a radius of 25 m. or more. The hydraulic jack used in prestressing should be able to pull 170,000 lbs . = 85 short tons = 76 metric tons or more.

4.- Comparison of Both Designs :

In comparing both designs the following points should be mentioned:

1) In the construction of the ordinary reinforced concrete, deck girder bridge, forms are needed all through the length of the bridge in order to support the structure before it is able to support itself and the superimposed load on it. This will require too much labour and introduces difficulty specially if the bottom of the river, or other kind of foundation, to act as a foundation to support the form is not accessible or difficult to obtain. In the construction of the prestressed reinforced concrete bridge, there is no need for forms all through the length of the bridge because the main girders will be constructed at the side and when the concrete hardness is sufficient, prestressing is obtained and then the beams are lifted by means of cranes to their proper place. After the beams are placed forms for the slab are placed on the beams themselves and the slab is poured. This will economize much on the total cost of the bridge.

2) In the construction of the ordinary concrete bridge the introduction of form may hinder the navigation in the river and closes the way for a considerable time. In the construction of the prestressed concrete bridge the path will be free all the time,

3) In the local market it is almost impossible to find ordinary reinforcing steel in the lengths required to serve as main reinforcement in the girders. The steel used will be composed of samller length that should overlap a considerable length to ensure bond. If we assume that the maximum length of steel obtained locally is 8 metres,

and in 24 m. we need, say, 4 lengths of 8 m. that will make an increase of about 33% of the original steel needed. While the steel used in prestressed concrete can be obtained in almost any length required because it is found in the form of rolls and any length can be obtained. Or the steel could be in the form of finished cables to the required lengths and no extra steel is wasted.

Materials used in the ordinary reinforced concrete bridge:-

151 cu. metres of concrete,

17.92 metric tons of mild steel.

Materials used in the prestressed concrete bridge:-

79.7 cu. metres of concrete in beams

26.2 cu. meters in curb and slab,

1.21 metric tons of high tensile steel,

3.00 metric tons of mild steel.

It is noticed that the quantity of concrete in the prestressed bridge is much less than that used in the ordinary reinforced concrete bridge. This is so because, as had been stated, a rich mixture is used, and the allowable stress in concrete in one is twice that in the other. Also high girders with thin webs contribute to make this difference.

To have a rough idea about the cost of each the following prices are assumed. Some of these prices are taken from people who are aquainted with bridge construction: -

Concrete 7 bags per cu.metre	: L.L.	66 per cu.m.
Concrete 8 bags per cu. metre	: L.L.	70 " "

Mild Steel per metric ton	: L.L.	510
High tensile steel: 510 x 2.7	: L.L.	1,380 per met.ton
Concrete 7 bags per cu.metre (in slab only)	: L.L.	56

Cost of ordinary reinforced concrete bridge:

151 x 66 = 9,960

17.92 x510 = 9,140

L.L.19,100

Cost of the prestressed Concrete bridge:

79.7	x	70	=	5,580
26.2	x	56	=	1,470
2.45	x	1,380	=	3,380
3.00	x	510	=	1,530
		L.L.		11,960

For unforseen expenses accompanied with prestressed concrete, let us add 10%. The cost will become L.L. 13,160

This big difference is due to the fact that we are dealing with girders, slab and curb only. But if all the parts of the bridge be considered auch as the abutments, covering, raling and others , then the saving will not be 37.4% or 31.1% but less.

Figure (36-4) shows the same bridge designs in the pre-tensioning system. The space between the beams is left empty and the top of the beams are covered with pre-cast blocks of reinforced concrete of 1 ft of length to hold the slab when poured. Fig. (36-2) shows different kinds of covering suggested to be used.

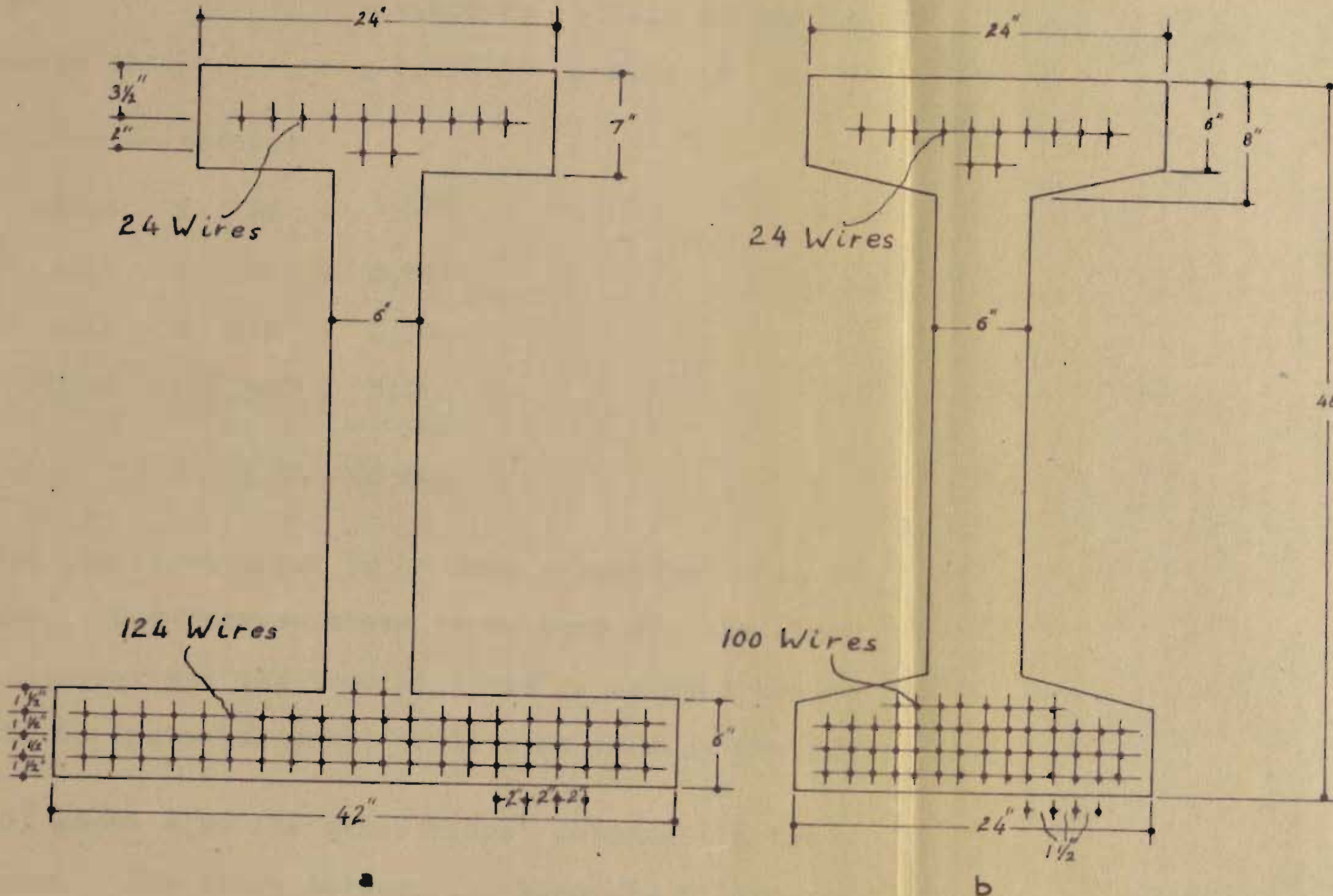
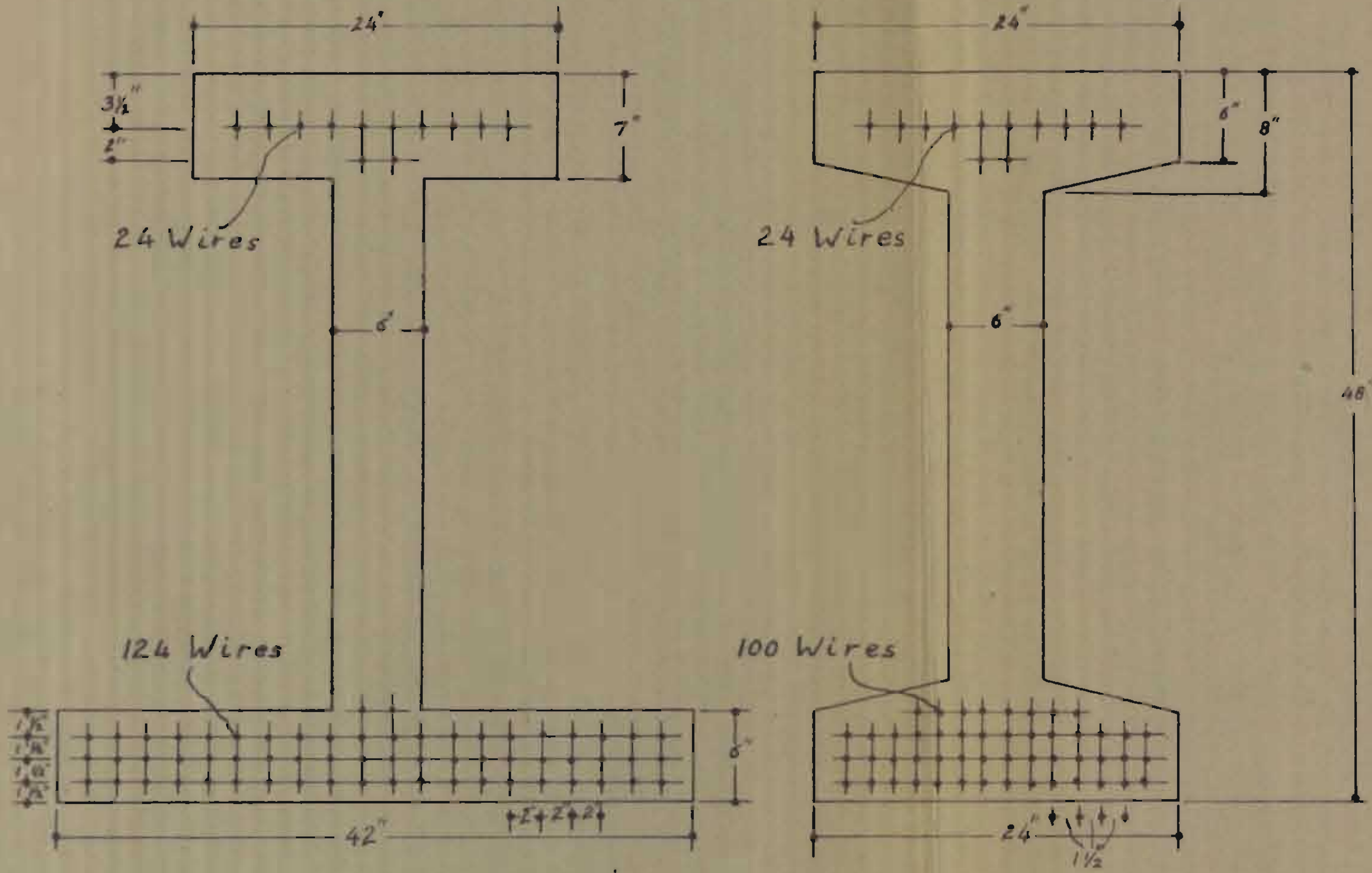


Fig. 36-1

SCALE 1/12



a b

Fig. 36-1 SCALE 1/12

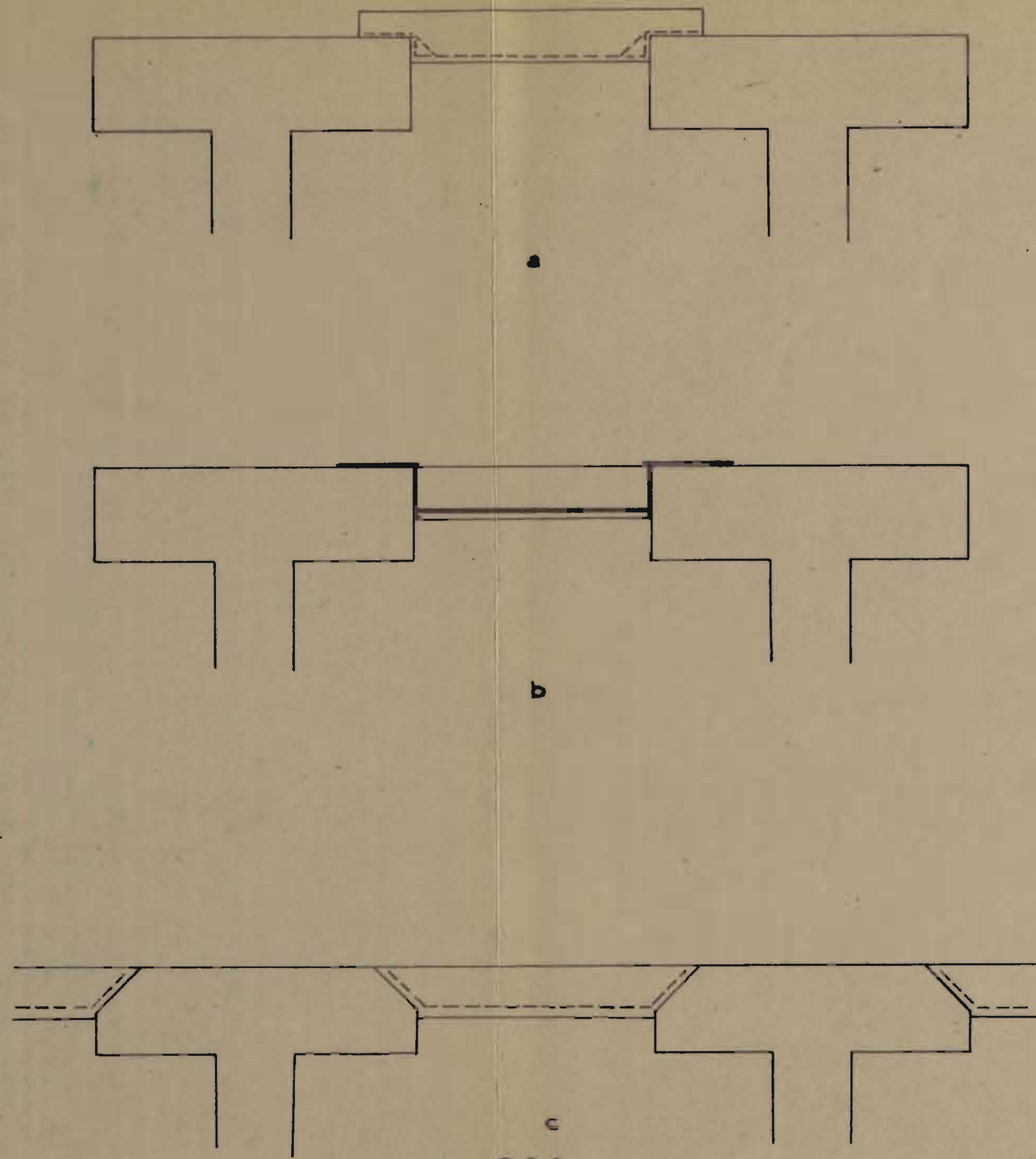
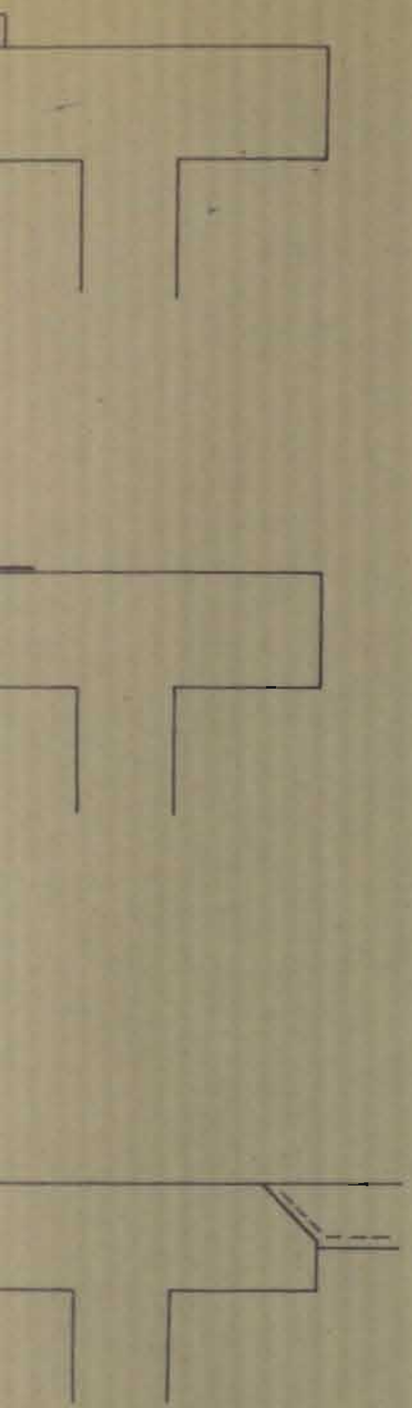


Fig. 36-2 SCALE 1/12



LE 1/12

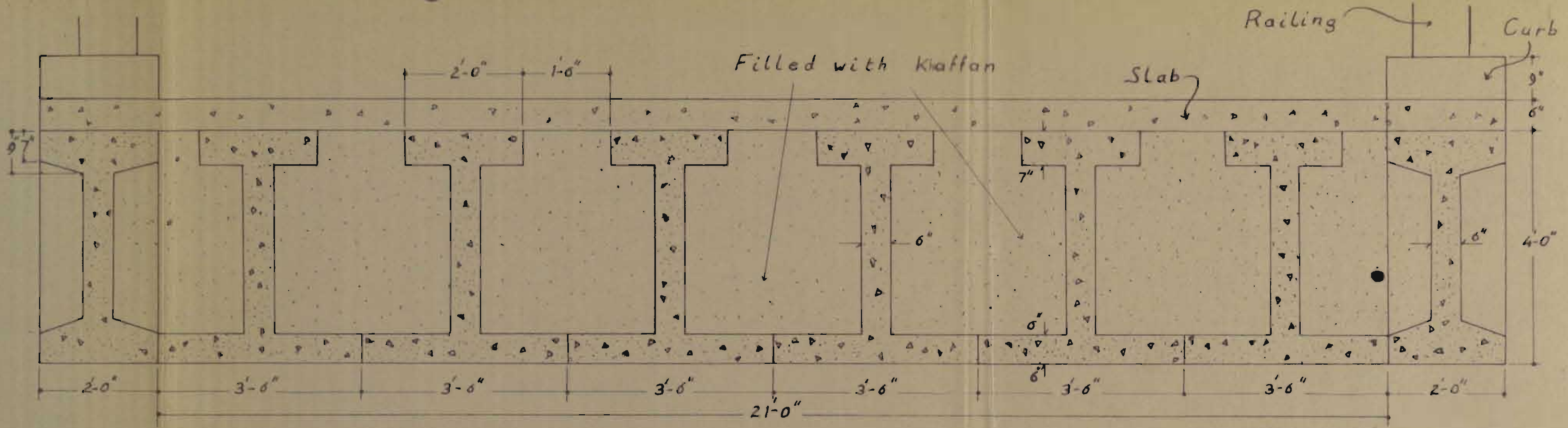


Fig. 36-3

SCALE 1/20

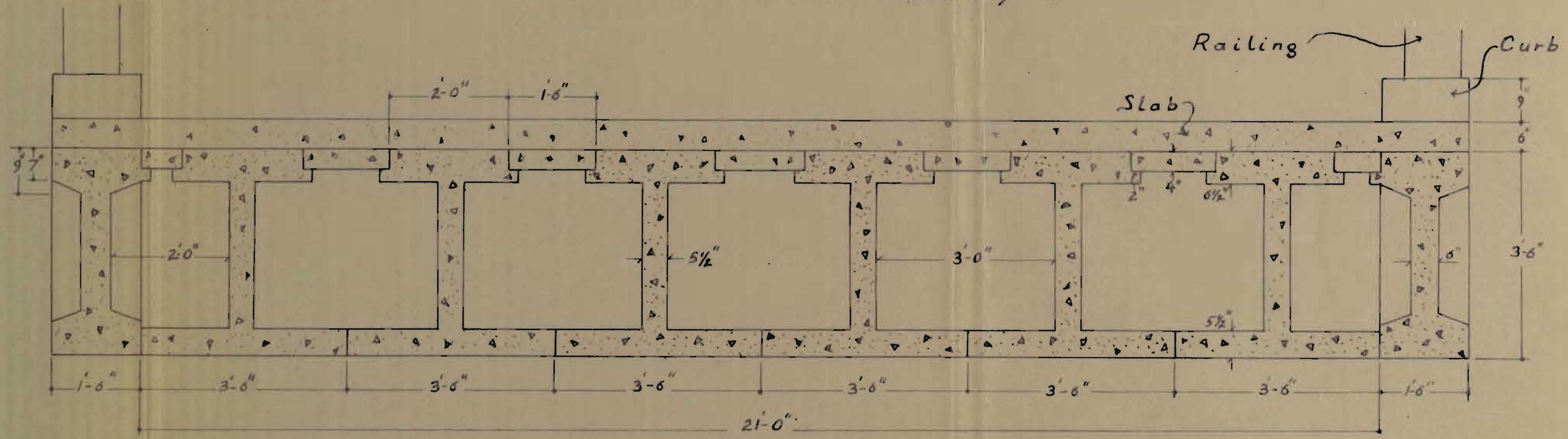


Fig. 36-4

SCALE 1/20

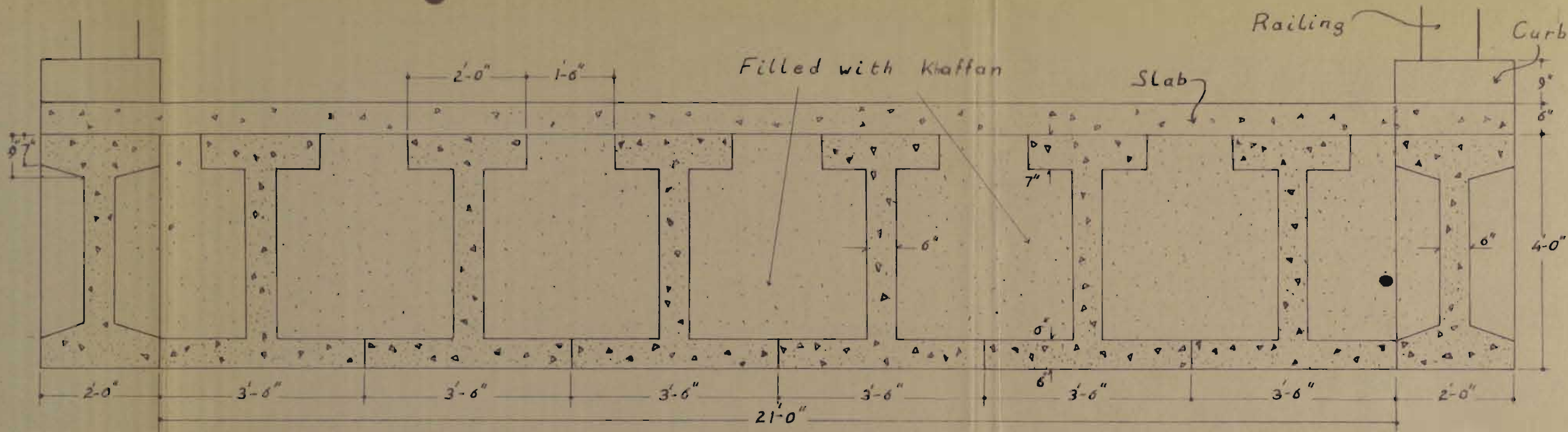


Fig. 36-3

SCALE 1/20

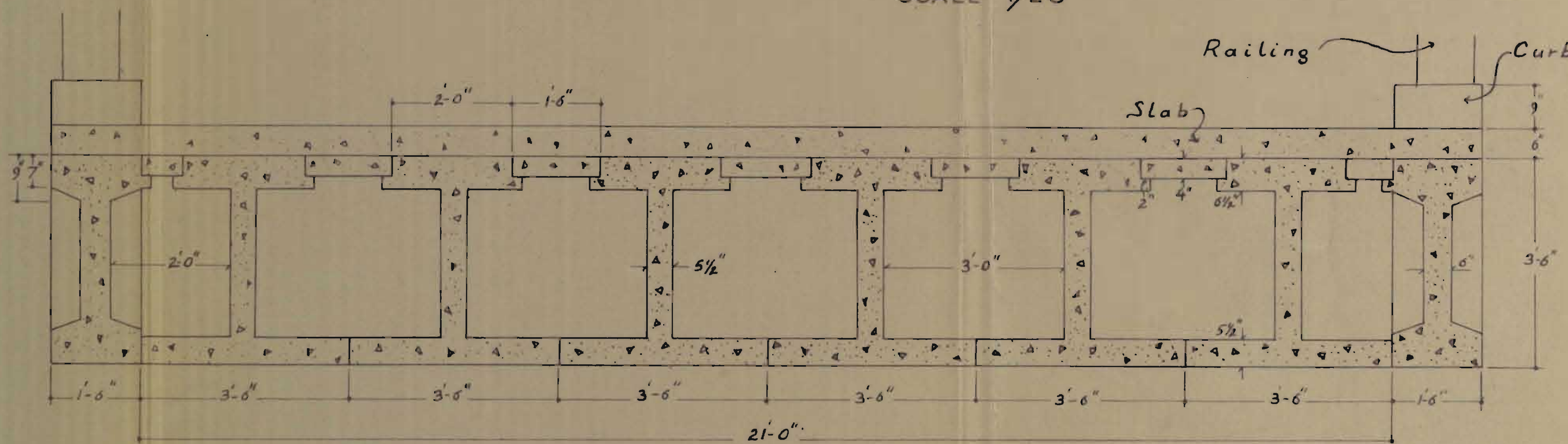


Fig. 36-4

SCALE 1/20

The quantities used are:

Concrete in slab and cover	= 1,047 ft^3	= 29.6 m^3
Concrete in beams	= 1,801 ft^3	= 51.0 "
Mild steel	= 4,830 lb	= 2.16 metric tons
High tensile steel	= 6,470 "	= 2.89 " "

Assume same prices as before:

Cost:	29.6	x	66	=	1,950
	51.0	x	70	=	3,570
	2.16	x	510	=	1,100
	2.89	x	1,380	=	3,980
				L.L.	10,500

which seems for the first sight to be more economical than the one designed before. But because there is no room for the steel to be placed in the section and the bond will not be secured the concrete section have to be increased ~~until~~ will also increas the final cost.

Fig.(36-3) shows also the same bridge designed in the pre-tensioned system. The space between the beams is filled with pumice (Khaffan).

The quantities used:

Concrete in slab	= 1,047 ft^3	= 29.6 m^3
Pumice concrete	= 3,724 "	= 105.8 "
Concrete in beams	= 2,196 "	= 62.2 "
Mild steel	= 4,830 lb	= 2.16 metric tons
High tensile steel	= 7,000 "	= 3.16 " "

Assume the same prices as before, with pumice concrete as L.L.60 per m^3, then,

29.6	x	66	=	1,950
105.8	x	60	=	6,350
62.4	x	70	=	4,360
2.16	x	510	=	1,100
3.16	x	1,380	=	4,370
				L.L. 18,130

This design seems not to be economical and also there is no room for the steel to be palced in the beam.

b.- Design of Standard Floor System and Window and Door Lintels for the purpose of Construction of Buildings on a Large Scale in Precast Prestressed Reinforced Concrete :

The plan of the house shown in Fig. (37-1) is the plan of a typical design of a house designed by Mr. Michel Naser in his Thesis "Planing of a Scheme for Palestinian Refugees Settlement in the Bekaa'" for the year 1951-52.

The dimensions of the house are changed little to suite the application of practical design to be done in prestressed precast concrete after the permission of Mr. Naser.

The design of the floor will be as followes:-

Two kinds of designs will be presented. The first is thought to be as a slab to carry another story above it, the second is thought to be applied to act as a final covering roof. Actually any of them will serve the purpose of the other. Different allowable stresses in the concrete are used in each kind, depening on the mix and other factors, for the purpose of variation in the design.

In both kinds the roof will consist of a series of prestressed precast beams of small cross-section with the space between the beams filled with precast Khaffan (Pumice) blocks, hollow concrete blocks, or hollow gypsum blocks.

Khaffan (Pumice) concrete have the characteristic of having a specific weight of 0.7. This material is found in Lebanon, and if the project is to be executed in Lebanon, it could be used in the manufacture of these blocks cheaply. Concrete blocks can be used almost

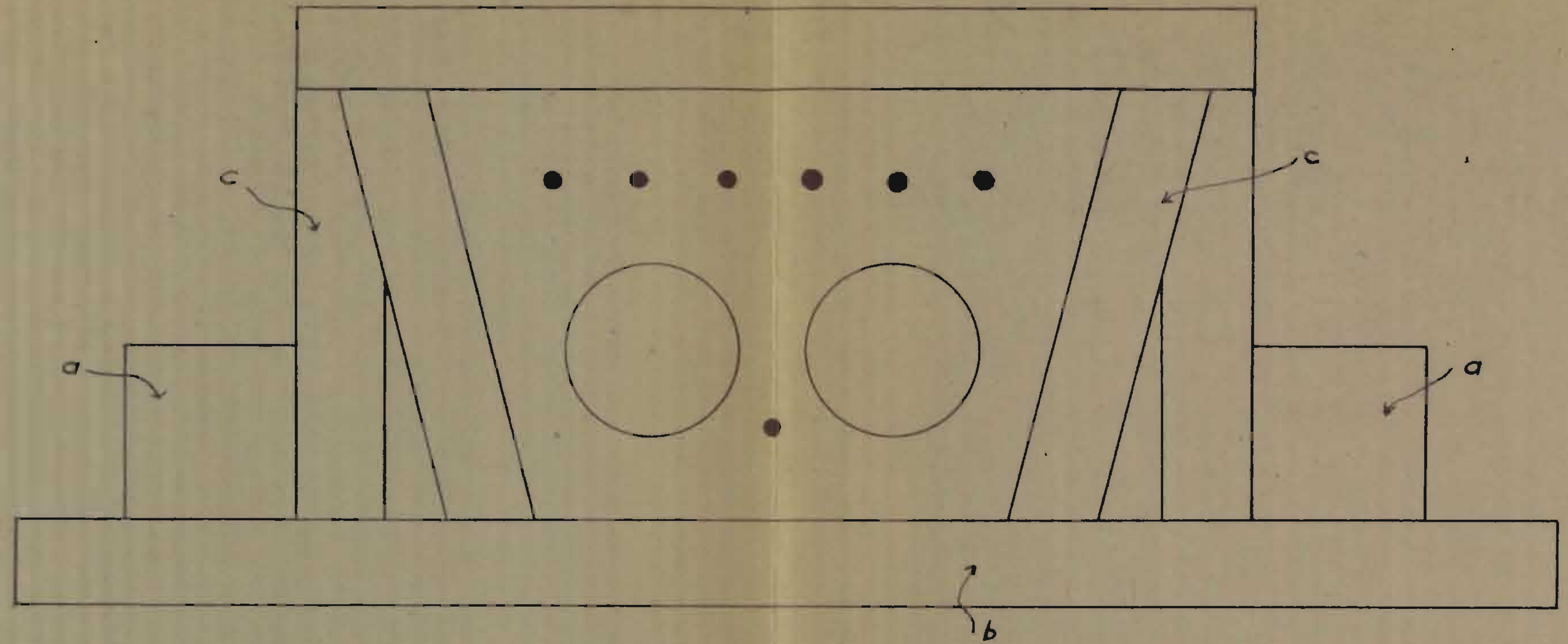


Fig. 37-6

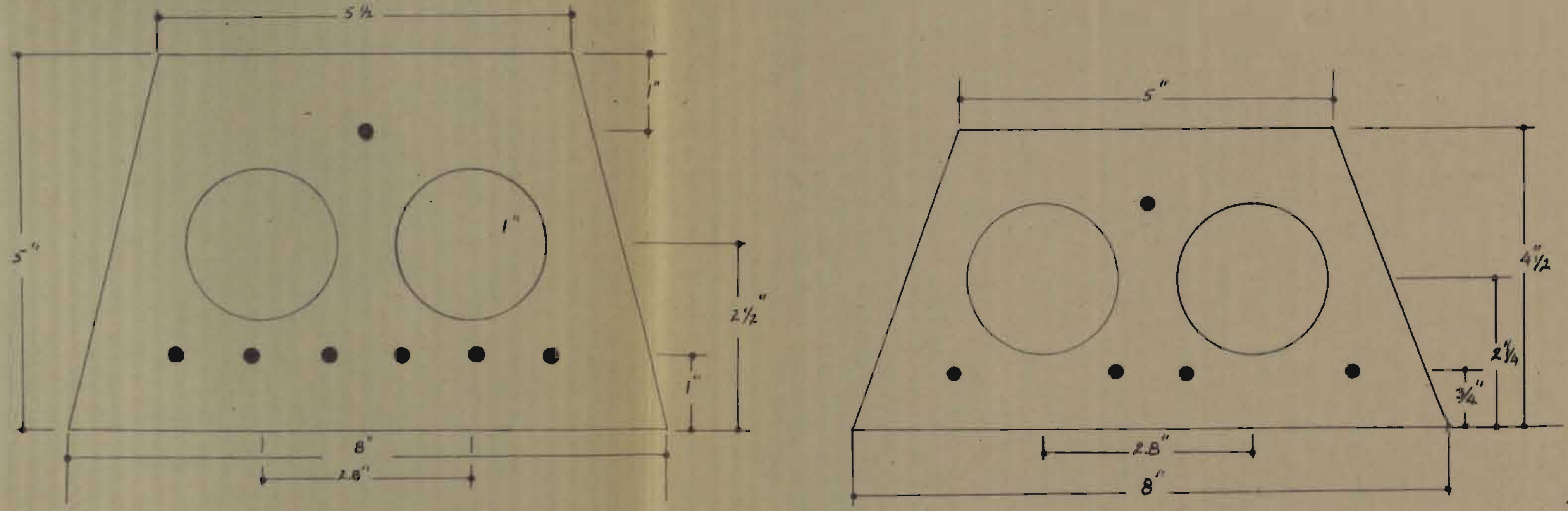


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Fig. 37-7 SCALE 1/2

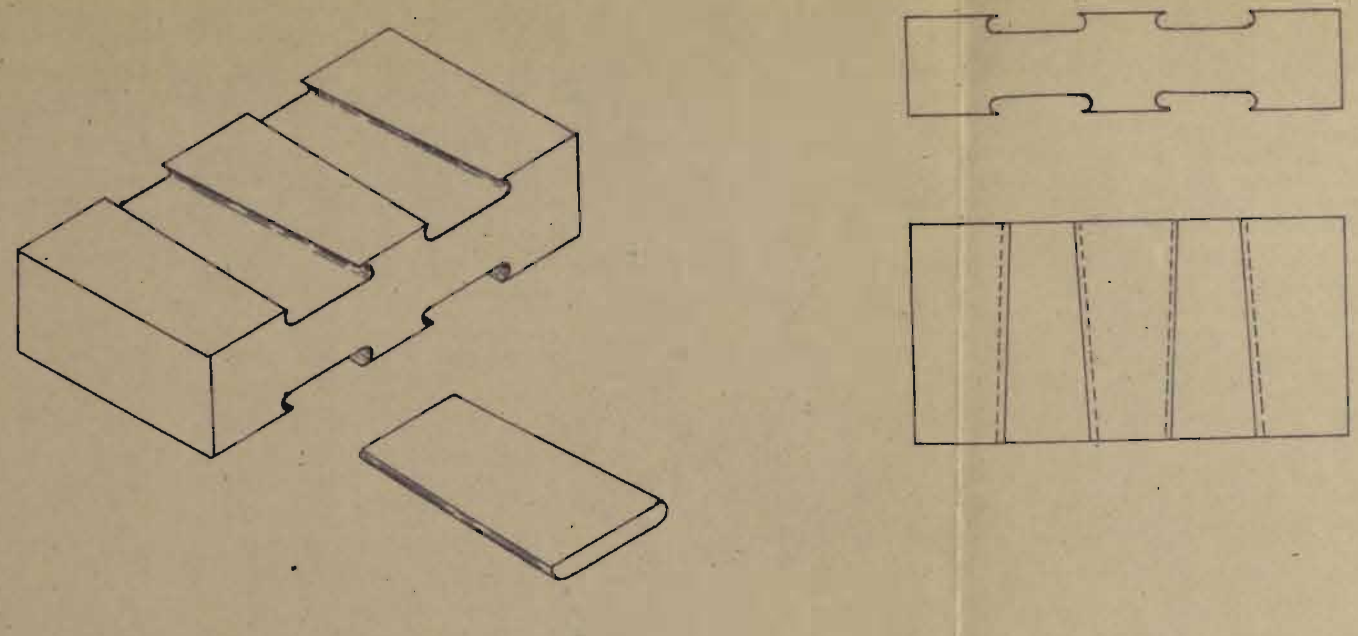
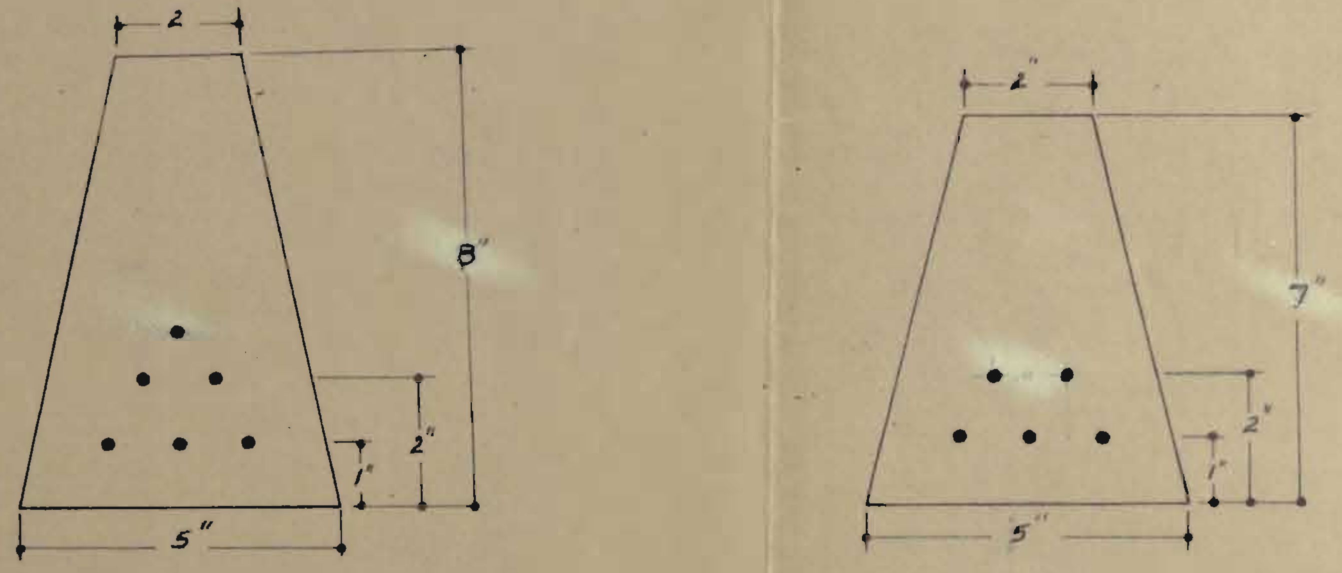


Fig. 37-8



a

b

Fig. 37-9 SCALE 1/3

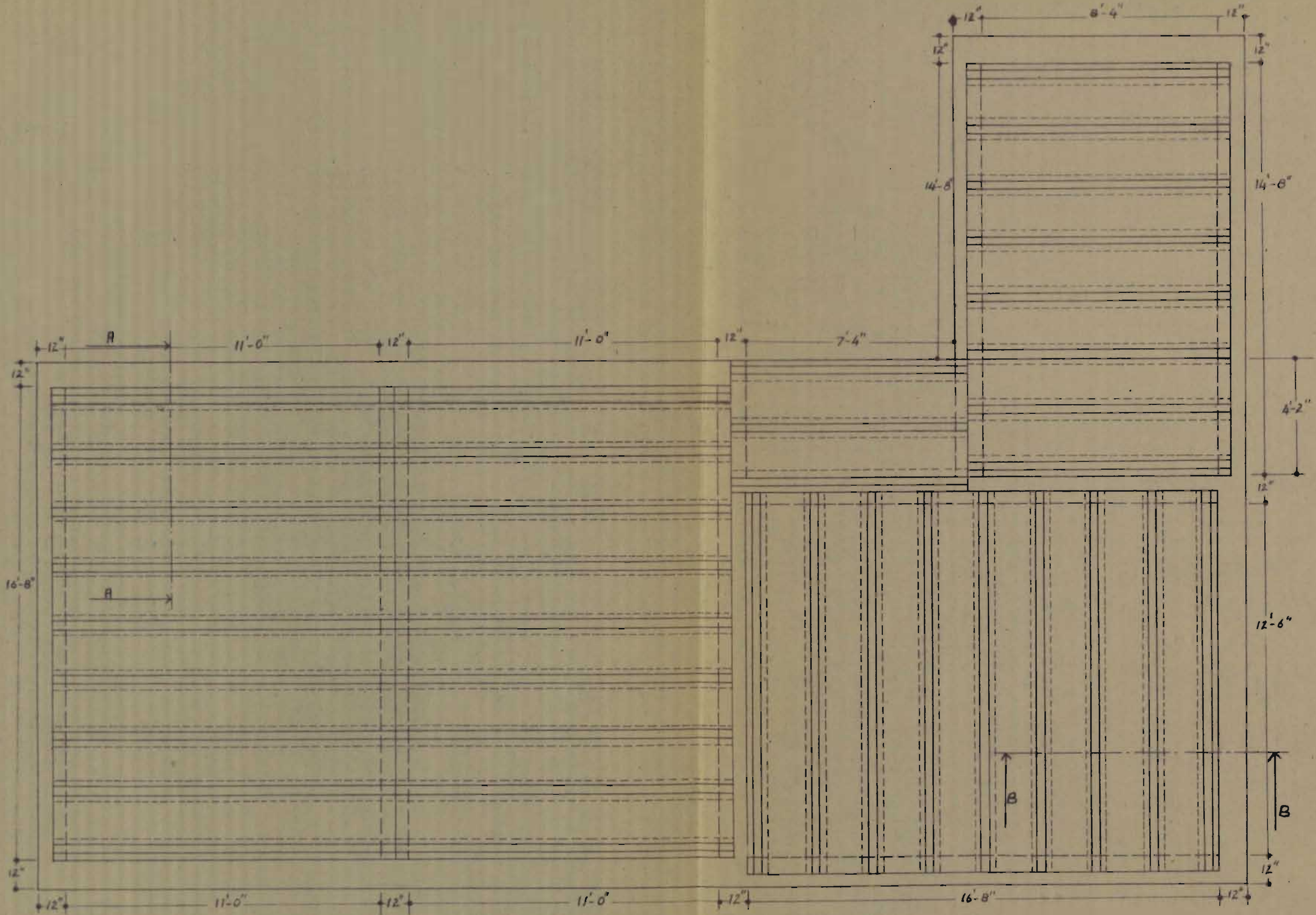


Fig. 37-1

SCALE 1/48

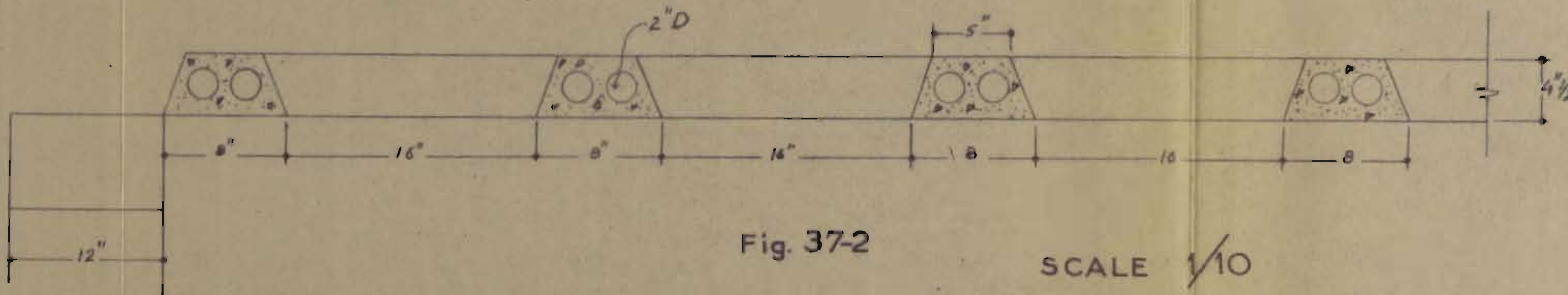


Fig. 37-2

SCALE 1/10

Section A-A

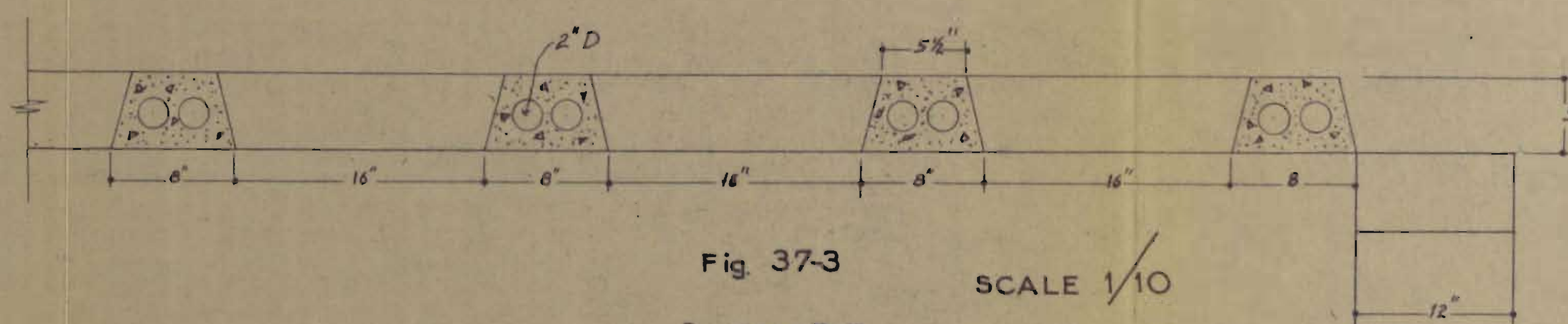


Fig. 37-3

SCALE 1/10

Section B B

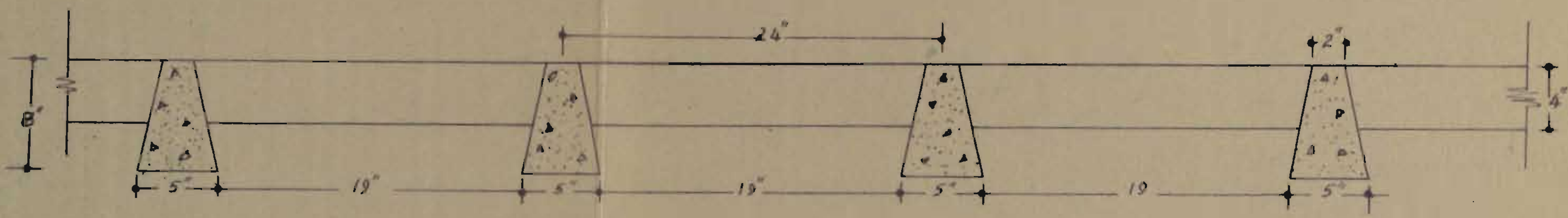


Fig. 37-4

SCALE 1/10

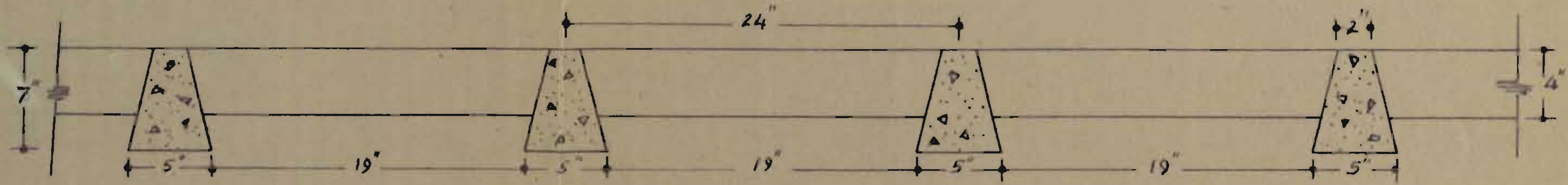


Fig. 37-5

SCALE 1/10

every where and it requires transporting the cement to the location where the project is to be executed and manufactured there. As to gypsum this material is abundant is the Syrian desert and is used there. So it is only reqired to set a factory there to produce it cheaply.

The house will be devided into five units, two of which are identical. The beams will span in the direction of the shorter dimension except for one unit.

The clear spans of the units are: 12ft.-6in., 11ft.-0in., 8ft.-4in. and 7ft.-4in. 0ft.-6in. is added to each to get the effective span.

1- <u>Design of the First System:</u>

Data and specifications

f_c = 2,000 psi; f_s = 150,000 psi; loss of initial prestress is = 20%; live load and tiles and sand = 60 lb./ft^2 .

<u>Design of the 12ft.-6in. span:</u>

Assume the section of concrete shown in figure (37-7a)

Area A		Static Moment Q	
$(5.5 + 8) \times 5/2$	= 33.7 sq.in.	$5.5 \times 5 \times 2.5$	= 68.7
$2 \times \pi$	= -6.28 "	$2.5 \times 5/2 \times 5/3$	= 10.4
	27.4 sq.in.		79.1 in.^{3}
		$2 \times \pi \times 2.5$	= 15.7
			63.4 in.^{3}

$y_b = 63.4/27.4 = 2.31$ in. ; $y_t = 2.69$ in.

Moment of inertia I

$$I_1 = \frac{25.5(64 + 176 + 30.2)}{36 \times 13.5}$$

$= 69.5 \text{ in.}^4$

$2 \times \pi/4 \qquad = 1.6$

$2 \times \pi \times 0.3 \times 0.3 = \underline{0.6}$

$\qquad 2.2 \text{ in.}^4$

$I = 69.5 - 2.2 = 67.3 \text{ in.}^4$

Allowable moment:

$M = 2{,}000 \times 67.3/2.69 = 50{,}000$ in.lb.

Load on 2 ft. strip across the beam

$= 60 \times 2 + 28.4 \times 150/144 + (24 \times 5 - 33.7) \times 0.7 \times 62.4/144$

$= 176$ lb./ft.

(Assuming the specific gravity of Pumice as 0.7)

$M = 1/8 \times 176 \times 13.0 \times 13.0 \times 12$

$= 44{,}600$ in.lb.

$r^2 = 67.3/27.4 = 2.46$ sq.in.; $\quad e = 2.46/2.69 = 0.913$ in.

$2.46/2.31 = 1.06$ in.

$P = 44{,}600/(0.8 \times 1.97) = 28{,}400$ lb.

$a = 28{,}400/150{,}000 \qquad = 0.189$ sq.in.

Number of 0.2 in. wire of an area of 0.031 sq.in. each is:

$0.189/0.031 = 6.11$, use 7 wires

$a_b = 0.189 \times 2.66/3 = 0.16$ sq.in. use 6 wires

$a_t = 0.289 \times 0.34/3 = 0.0234$ sq.in.   use 1 wire.

For details of section see figure (37-7a).

Design of the other spans:

The concrete section of the beams used in the other spans will be the same for convenience and practical considerations. A smaller section than the assumed will not be practical to use, steel will be smaller in area if more concrete section is used than needed. Assume the section of concrete in figure (37-7b)

	Area A
4.5×6.5	$= 29.3$
$2 \times \pi$	$= 6.3$
	23.0 sq.in.

$$\frac{4.5 \times (16 + 5)}{3 \times 13} = 2.42 \text{ in.}$$

$$y_t = (29.3 \times 2.42 - 6.3 \times 2.25)/23.0 = 2.46 \text{ in.}$$

$$y_b = 2.04 \text{ in.}$$

Moment of inertia I

$$I_1 = \frac{4.5 \times 4.5 \times 4.5(64 + 160 + 25)}{36 \times 13} = 48.4$$

$$I_2 = 2 \times \pi/4 + 2 \times \pi \times 0.25 \times 0.25 = 2.0$$

$$46.4 \text{ in.}^4$$

The concrete could carry:

$$M = 2,000 \times 46.4/2.46 = 37,700 \text{ in.lb.}$$

Total weight on the beam = $60 \times 2 + (24 \times 4.5 - 29.3) \times 62.4 \times 0.7/144$ + $23.0 \times 150/144$

= 168.0 lb./ft.

$r^2 = 46.4/23.1 = 2.10$ sq.in.

$e = 2.10/2.46 = 0.851$ in.

$2.10/2.06 = 1.020$ in.

Moment for 11 ft.-0 in. span:

$M = 1/8 \times 168 \times 11.5 \times 11.5 \times 12 = 33{,}300$ in.lb.

$P = 33{,}300/(0.8 \times 1.871) = 22{,}900$ lb.

$a = 22{,}900/150{,}000 = 0.1524$ sq.in.

Number of wires = $0.152/0.031 = 4.9$, use 5 wires.

See the arrangement of steel in figure (37-7b)

Moment for 8ft.-4in. span:

$M = 1/8 \times 168 \times 8.83 \times 8.83 \times 12 = 19{,}600$ in.lb.

$P = 19{,}600/1.47 = 13{,}300$ lb.

$a = 13{,}300/150{,}000 = 0.0886$ sq.in.; use 3 wires

See the arrangement of steel in figure (37-7c)

Moment for the 7ft.-4in- span:

$M = 168 \times 7.83 \times 7.83 \times 12 \times 1/8 = 15{,}450$ in.lb.

$P = 15{,}450/1.47 = 10{,}500$ lb.

$a = 10{,}500/150{,}000 = 0.700$ sq.in. Use the same steel as in the 8ft.-4in. span.

2- <u>Design of the second system</u>:

Data and specifications

$f_c = 1{,}800$ psi; $f_s = 150{,}000$ psi; loss of initial prestress is = 20%; live load and roofing = 70 lb./ft.^{2} ; space between beams is filled with hollow blocks of either concrete or gypsum.

<u>Design of the 12ft.-6in. span</u>:

Area $\underline{A} = 8 \times (2 + 5)/2 = 28.0$ sq.in.

$$y_t = \frac{8 \times (2 \times 5 + 2)}{3 \times 7} = 4.56 \text{ in.}; \qquad y_b = 3.44 \text{ in.}$$

$$I = \frac{8 \times 8 \times 8 \times (25 + 40 + 4)}{36 \times 7} = 140 \text{ in.}^4$$

Moment the concrete could carry:

M = 1,800 x 140/4.56 = 55,200 in.lb.

Assume 4 in. of concrete or gypsum hollow blocks to fill in the space between the beams. Weight of blocks: 78 lb./ft.^{3}. The weight on beams

21.5 x 4 x 78/144 = 46.6 lb./ft.

Weight of beam = 28 x 150/144 = 29.2 lb./ft.

L.L. + Plaster = 140 lb./ft.

Total load = 216.3 lb./ft.

M = 1/8 x 216 x 13 x 13 x 12 = 54,800 in.lb.

$r^2 = 140/28$ = 5.00 sq.in.

5.00/4.56 = 1.10 in.; 5/3.44 = 1.455 in.

P = 54,800/(0.8 x 2.56) = 26,800 lb.

a = 26,800/150,000 = 0.178 sq.in.

Number of wires of 0.2 in. = 0.178/0.031 = 5.71; use 6 wires

See the arrangement of steel in figure (37-9a)

<u>Design of the other spans:</u>

Assume the section of concrete shown in figure (37-9b)

Area $\underline{A}$ = 7 x 7/2 = 24.5 sq.in.

$$y_t = \frac{7 \times (2 \times 5 + 2)}{3 \times 7} = 4 \text{ in.}; \qquad y_b = 3 \text{ in.}$$

$$I = \frac{7 \times 7 \times 7 \times (25 + 40 + 4)}{36 \times 7}$$

$$= 94.0 \text{ in.}^4$$

The moment the concrete could carry:

$M = 1,800 \times 94/4 = 42,300$ in.lb.

Moment at the 11ft.-0in. span

Weight of beam = 24.5 x 150/144 = 26.5 lb./ft.

Weight of hollow blocks = 46.6

L.L. + roofing =140.0

212.1 lb./ft.

$M = 1/8 \times 212.1 \times 11.5 \times 11.5 \times 12 = 42,000$ in.lb.

$r^2 = 94/24.5 = 3.94$ sq.in.

$e = 3.94/4 = 0.985$ in.

$3.94/3 = 1.31$ in.

$P = 42,000/(0.8 \times 2.30) = 22,900$ lb.

$a = 22,900/150,000 = 0.153$ sq. in.

Number of wires = 0.153/0.031 = 4.94 , use 5 wires

See the arrangement in figure (37-9b)

Moment at the 8ft.-4in. span:

$M = 1/8 \times 212 \times 9.83 \times 9.83 \times 12 = 25,600$ in.lb.

$P = 25,600/1.84 = 13,900$ lb.

$a = 13,900/150,000 = 0.0926$ sq.in.; use 3 wires.

For the 7ft.-4in. span use the same as in the 8ft.-4in. span.

Design of Lintels of doors and Windows:

For simplicity of work all lintels of doors and windows will have the same cross-section.

The largest span is 4ft.-6in. with a distributed load of 350 lb./ft. The width of the lintel is taken as 12 in. and 12 in. will be added to the length of the lintel for support, and the lintel will project 10 in. inside the wall from each side. The height of the lintel is assumed as 4 in.

The moment the lintel can stand, if we take $f_c = 1,700$ psi, is:

$M = 1,700 \times 64/2 = 21,700$ in.lb. ($I = 64$ in.^{4})

$A = 4 \times 12 = 48$ sq. in.

$y_t = y_b = 2$ in.

$I = 12 \times 4 \times 4 \times 4/12 = 64$ in^4.

$r^2 = 64/48 = 1.33$ sq.in.

$e = 1.33/2 = 0.667$ in.

$M = 1/8 \times 350 \times 5.5 \times 5.5 \times .2 = 15,900$ in.lb.

$P = 15,900/(0.8 \times 1.33) = 15,000$ lb.

$a = 15,000/150,000 = 0.10$ sq.in. Use 4 wires.

3.- Method of manufacturing:

The beams, lintels and blocks are manufactured in a factory. This factory is to be located at the centre of the area where these houses are to be constructed or at a place where it is easy to transport to and near the place.

To manufacture the beams and lintels and the following equipment is needed:

1.- Forms made of timber,

2.- Anchorage made of steel or reinforced concrete,

3.- Device for Stretching the steel wires,

4.- Vibrators,

5.- Rubber tubes with accessories,

6.- Concrete mixers.

Rubber tubes andtheir accessories are not needed if the second system were used.

A yard is needed whose length is about 100 M (330 ft.) with a width of, say, 10 M (33 ft.) or more.

The beams will be poured in an inverse form, i.e. the top fibres at the bottom. Many beams can be poured at the same time and their steel is stretched once. This is done by placing any number of beams depending upon the length of the beams and the length of the yard. The same wires go from one beam to another and anchored at the ends of the steel wires. For example if each beam have a length of 12 ft. we can have 24 beams poured at the same time in series and their concrete is separated by pieces of timber with their steel composed of wires of one stretch of about 288 ft. long. The steel will be anchored at both ends of the wires only. When the concrete has hardened sufficiently the wires joining the beams are cut and each beam becomes a separate beam. Suggested forms are shown in fig.(37-6). The bottom piece of timber is made stationary and cleaned by a brush and washed before used again. The timber may be covered with oil or any cheap covering in order that the water may not find its way through the timber and accelerate its deterioration. When the ofrms are placed only piece "a" is nailed to piece "b" and piece "c" is put inside and clamped to piece "a" and clamped to each other at the top. After the concrete is poured and hardened piece "a" is removed first with the nails taken out, then piece "c" follows. The details are shown in fig. (37-6). These forms in this way could be used more than once. Let us assume that 5% of the timber is replaced every time the timber is used.

The anchorage used may be a steel beam hammered into the ground in a vertical direction, or a reinforced concrete heavy member, like a pile, which is deep enough. The maximum force acting on the anchorage will be:

$$7 \times 0.031 \times 150{,}000 = 32{,}500 \text{ lb.}$$

The beam should have holes located exactly at the place where the wire should be placed. The wires after being stretched are caught by means of the shandwich device described by Prof. G. Magnel and shown in fig. (37-8). The plates transfer the pull to the steel beam or the reinforced concrete member.

For stretching the wires a hydraulic jack is used. This jack will stretch two wires at a time. The force the jack is supposed to pull: 0.062 x 150,000 = 9,300 lb., say 10,000 lb. jack. The stress in the wire is measured by reading the force on the dial of the jack and by the elongation of the steel wires. If a jack is not used, a hand axle might be used and the stress will be measured by the elongation of the wire.

Tube vibrators are used which is preferable to be of the smallest size in order to be inserted through the wires. Electrical vibrators are used if electricity is available and cheap. If not pnaumatic vibrators are used. These vibrators are movalbe and have a long tube in order to be taken from one place to another.

Rubber tubes of 2 in. diameter, two of which are ~~pla~~ used in every beam, (these tubes are not used in the second system of design) are placedbefore the concrete is poured, air is forced into these tubes to a certain pressure so as not to yield to normal forces on it. The rubber tube is tightened so that air will not escape. These tubes are held in place by means of fine wires to the form. After the concrete has hardened sufficiently air is allowed to escape and the rubber tubes pulled out.

Concrete mixers have to be used and hadn mixing is not allowable. The number of men employed to carry fresh concrete depends upon the capacity of the concrete mixer.

Khaffan (Pumice) blocks, hollow concrete blocks or hollow gypsum blocks could be manufactured in the ordinary way. It is not economical to use hollow Khaffan blocks because the extra cost in making them hollow will not be equal to the gain in materials and in making them lighter.

4.- Handling, Transporting and Laying the Beams:

In handling the beams, if the beam is upside down, it should be lifted only from the middle. If the beam is in the right position it should be lifted from both ends. The maximum distance from the end of the beam should not exceed one or two feet. This is because tension may be produced at the top fibres and the beam will break. In laying the beams the same precaution should be taken. A crane, is used to lift the beams in their proper place or near that place. The weight of the heaviest beam is:

28.4 x 150/144 x 13.5 = 400 lb.

The weight in the other system is:

19.72 x 150/144 x 12 = 250 lb.

This weight if divided by two could be carried by two strong men with each at one end of the beam.

These beams are transported to the sight by truchs and layed there.

5.- Materials to be Used:

Concrete had to be mixed in the proportion of 1:1½:3, or in the metric system as 8 bags of cement per cubic meter of finished concrete. Because vibrators are used, the least amount of water is needed to produce a wet mix. The amount of water has to be fixed after certain laboratory tests are performed. The maximum size of the angular course aggregate will be 6 mm or 1/4 of an inch so that the concrete will fill in the space easier. Round course aggregate may be used also. River sand has to be used and if sea sand is used it has to be washed properly. In the first system a crushing strength of 5000 psi should be attained in 28 days.

Steel used may be the Belgium steel cold drawn wire of 5 mm No. 5-I of an ultimate strength of 210,000 psi.

In Khaffan and hollow concret blocks of 5 bags of cement (of 50 kg. per bag) per cubic meter of finsihed concrete is used.

Calcium chloride by 3% of the weight of cement used in beams may be added to the mixture in the form of solution inthe water.

In the case where calcium chloride is not used the forms are removed after 14 days when the concrete was poured. The steel is released after 28 days. If calcium chloried is used as described the forms are removed after a period of less than 14 days and the steel is released in less than 28 days. However these numbers should be determined from tests.

6.- Estimation of Cost and Comparison with Ordinary Reinforced Concrete Design:

In prestressed concrete, assume the following prices:-

Concrete (8 bags of cement)	: L.L.	70.- per cu.metre
One Khaffan block	:	1.35 per block
One concrete (or gypsum) block	:	0.90 " "
High tensile steel	:	1,380.- per metric ton.

Cost in the First System :

Steel	111 x 1.38	= 158
Khaffan block	360 x 1.35	= 485
Concrete in beams	2.3 x 70	= 161
		L.L. 804,-

If we add 10% of this for unforeseen expenses it becomes:

804 + 80 = L.L. 884.-

Lintels:

Concrete	0.647 x 70	= L.L. 45.3
Steel	12.9 x 1.38	= 17.8
		L.L. 63.1
	+ 10%	= L.L. 69.-

Total cost of roof and lintels per unit = L.L.953

Cost of the Second System :

Steel	86.5 x 1.38	= L.L. 119.5
Hollow blocks	360 x 0.90	= 324.-
Concrete inbeams	2 x 70	= 144.-
		L.L. 587.5

If we add 10% it becomes : 588+59 = L.L. 647

Lintels: L.L. 69

Total cost of roof and lintels : L.L. 716

According to the design of Mr. M. Naser of the roof in ordinary reinforced concrete the estimate of the roof and lintels was L.L.1,000

In thefirst system the saving is 5%, 13%

In the second system the saving is 28%, 35%.

Conclusions:-

As prestressed concrete is a completely new method of construction it will require some effort in applying its practice locally. People have to be convinced that prestressed concrete is better than other types of construction, specially reinforced concrete which is mostly used in this country. To show that it is better, examples of actual desings, compared with other kinds of designs, have to be presented and the saving indicated.

In the theoretical phase points which are important in the treatment of prestressed concrete are mentioned. Some of these points are ignored in the local practice of concrete. These points are essential in prestressed concrete and a better practice is required, otherwise the advantages of prestressed concrete will not be fully accomplished.

The economic service rendered to the country is appreciable, specially in importing steel. The cost of steel used in prestressed concrete, to serve the same purpose, is less than the cost in ordinary reinforced concrete. And as both are imported from outside markets, the saving in foreign exchange will serve the economy of the country.

The possibility, in prestressed concrete, to use high beams with thin webs, makes a better utilization of the concrete used. The use of less water-cement ratio with vibrators will produce a stronger and better concrete which will raise the allowable stress. These points will economize in the concrete.

For the first application of prestressed concrete, locally, some difficulty is encountered in introducing this kind of construction to the labourers. Proper supervision should be provided.

The favourable conditions to apply prestressed concrete to be economical and efficient depends upon the volume and scale of production. The structures to be built have to be big enough with heavy loads and large spans such as warehouses, airoplane hangars, cinema halls and public buildings. Or the units, if small, have to be repeated a number of times to have more advantage of the equipment used, such as anchorage and hydraulic jacks. These units have to be produced on a large scale.

In the design of the bridge, in both reinforced concrete and in prestressed concrete it is apparent that the materials used in the prestressed design is considerably less than the materials used inthe ordinary reinforced concrete design. The final cost is also less and the saving is about 31%.

In the design of the system of flooring the economy is also noticeable. Having the floor composed all of precast units is very important. It requires no forms to be set, and no time to be lost in waiting for the concrete to harden at the job, as the case in ordinary reinforced concrete.

APPENDIX :

The Roebling Prestressed Concrete Strand

The basic unit of Roebling's Americanized System is hot galvanized acid steel prestressed concrete wire. This type of wire has a high proportional limit which permits the use of strand design stresses and initial tension stresses with values of 105,000 psi and 125,000 psi. respectively.

These strands are fabricated from hot-dip galvanized wire, which assures complete protection against corrosion without further treatment.

Diameter (inches)	Weight per ft. (Pounds)	Area sq.in.	Min. Ult. Strth.lb.	Design load (pound)	Tens. Load (Pounds)
0.600	0.737	0.215	46,000	22,500	27,000
0.835	1.412	0.409	86,000	42,500	51,000
0.885	1.589	0.460	97,000	48,000	57,000
1	2.00	0.577	122,000	60,500	72,000
1 1/16	2.30	0.663	138,000	69,500	83,000
1 1/8	2.61	0.751	156,000	79,000	94,000
1 3/16	2.92	0.843	172,000	88,500	105,000
1 1/4	3.22	0.931	192,000	98,000	116,000
1 5/16	3.58	1.04	212,000	109,500	130,000
1 3/8	3.89	1.12	232,000	117,500	140,000
1 7/16	4.29	1.24	252,000	130,500	155,000
1 1/2	4.70	1.36	276,000	143,000	170,000
1 9/16	5.11	1.48	300,000	155,500	185,000
1 5/8	5.52	1.60	324,000	168,000	200,000

This table is from ROEBLING STRAND AND FITTINGS FOR PRESTRESSED CONCRETE, catalogue T-916.

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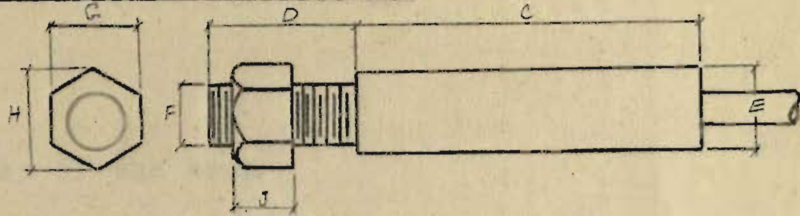
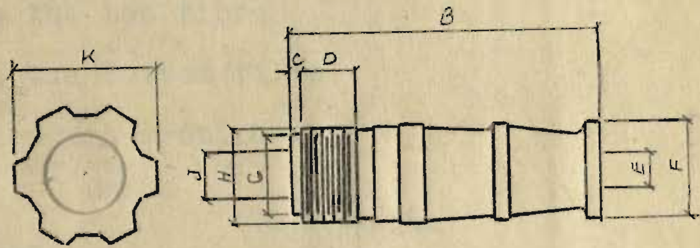
Anchor Fittings for Prestressed Concrete Strand:



Dia. Strand	C	D	E	F	G	H	J
.600	7	8	1 5/8	1 1/4-12	1 13/16	2.038	1 1/4
.600	7	3	1 5/8	1 1/4-12	1 13/16	2.038	1 1/4
.835 / .885	12 3/8	10	2 1/2	1 7/8-8	2 13/16	3.100	1 21/32
.835 / .885	12 3/8	4	2 1/2	1 7/8-8	2 13/16	3.100	1 21/32
1	13	11	2 3/4	2-8	3	3.464	1 23/32
1	13	4	2 3/4	2-8	3	3.464	1 23/32



Dia. Strand	B	C	D	E	F	G	H	J	K
1	10 7/8	5/16	1 7/8	1 3/16	3 1/2	3	3 3/8	1 3/4-1 7/8	5 3/16
1 1/16	10 3/4	5/16	1 3/4	1 1/4	3 7/8	3 3/8	3 3/4	2-2 1/4	5 11/16
1 1/8	10 3/4	5/16	1 3/4	1 5/16	4	3 1/2	3 7/8	2 1/8-2 3/8	5 7/8
1 3/16	11	5/16	2 5/16	1 3/8	4 1/4	3 3/4	4 1/8	2 1/8-2 5/8	6 1/8
1 1/4	10 3/4	5/16	2 1/16	1 7/16	4 3/8	3 3/4	4 1/8	2 1/8-2 5/8	6 3/8
1 5/16	11 1/4	5/16	2 1/4	1 1/2	4 11/16	4 3/16	4 9/16	2 1/2-2 3/4	6 11/16
1 3/8	11 11/16	5/16	2 1/2	1 9/16	4 7/8	4 3/8	4 3/4	2 1/2-3	6 7/8
1 7/16	12	5/16	2 1/2	1 5/8	5 1/8	4 5/8	5	2 5/8-3 1/4	7 1/8
1 1/2	12 5/16	5/16	2 1/2	1 11/16	5 3/8	4 7/8	5 1/4	2 3/4-3 3/8	7 5/8
1 9/16	12 13/16	5/16	2 5/8	1 3/4	5 5/8	5 1/8	5 1/2	2 7/8-3 5/8	7 7/8
1 5/8	13 1/8	5/16	2 3/4	1 13/16	5 3/4	5 1/4	5 5/8	3-3 3/4	8
1 11/16	13 3/4	5/16	3	1 7/8	5 7/8	5 3/8	5 3/4	3-3 3/4	8 1/4

Measurements in inches.

TABLE OF NOTATION :

P	=	Prestressing force
e	=	Eccentricity
A	=	Cross-sectional area of the beam
I	=	Moment of Inertia of the cross-section
M_T	=	Total moment acting on the beam
M_L	=	Live load moment on the beam
M_G	=	Dead load moment on the beam
y	=	Distance from centroid to the outside fibre
f_{cc}	=	Compressive stress in the concrete
f_{ct}	=	Tensile stress in the concrete
y_t	=	Distance from centroid to the top fibre
y_b	=	Distance from centroid to the bottom fibre
r	=	Radius of gyration of the cross-section
f_s	=	Stress in the steel
f_{si}	=	Initial stress in the steel
f_{sf}	=	Final stress in the steel
E_{st}	=	Modulus of elasticity of the steel
E_c	=	Modulus of elasticity of the concrete
n	=	E_{st}/E_c
a	=	Total area of steel
a_t	=	Area of steel at the top
a_b	=	Area of steel at the bottom
Δf_{st}	=	Change of stress of top steel due to the downward delection of the beam due to M_T
Δf_{sb}	=	Change of stress of bottom steel due to the downward deflection of the beam
ΔP_t	=	Change of force in top steel due to M_T
ΔP_b	=	Change of force in bottom steel due to M_T

y_{st} = Distance from centroid to the top steel

y_{sb} = Distance from centroid to the bottom steel

Q = Static moment

V = Shear

b = Thickness of the web or width of beam

v = Shear stress

S_t = Principal combined stress

S_x = Normal stress

M_{cr} = Momentof first crack

f_{cr} = Stress, ultimate, at first crack

δi = Instantaneous strain in concrete

δt = Strain in concrete after a time due to creep

C_c = Coefficent of creep $= \delta_t / \delta_i$

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