Sept. 20, 1966 A. AMIRIKIAN 3,273,295

SPLIT-BEAM PRESTRESSING

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FIG. 1.

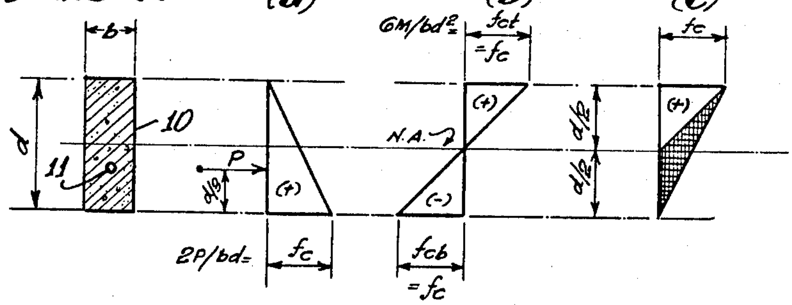

FIG. 2.

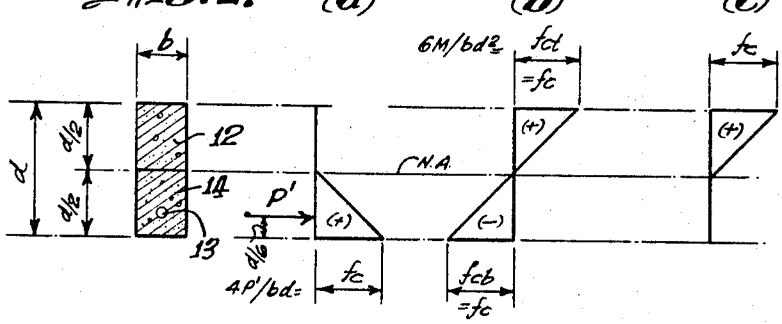

FIG. 3.

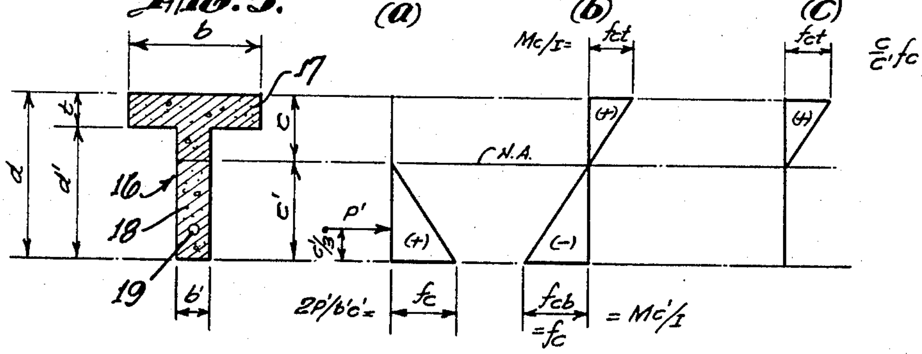

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FIG. 4.

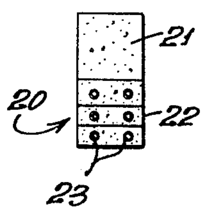


FIG. 5.

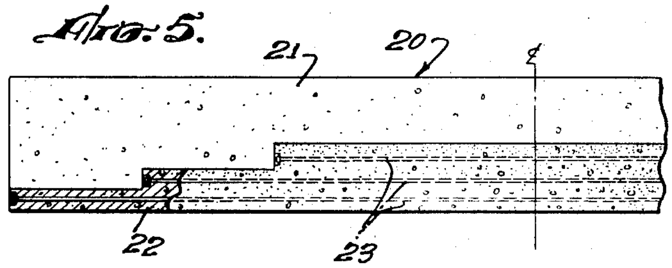


FIG. 6.

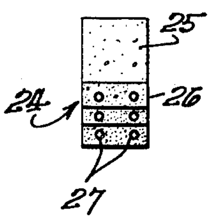


FIG. 7.

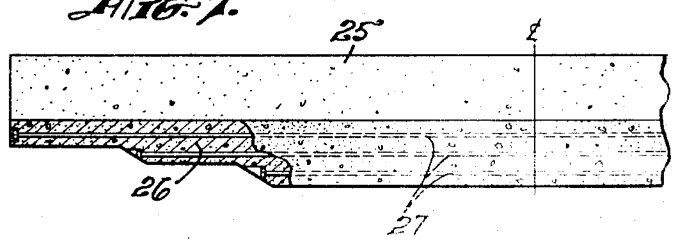


FIG. 8.

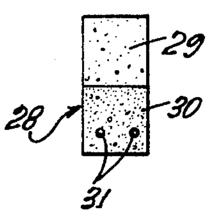


FIG. 9.

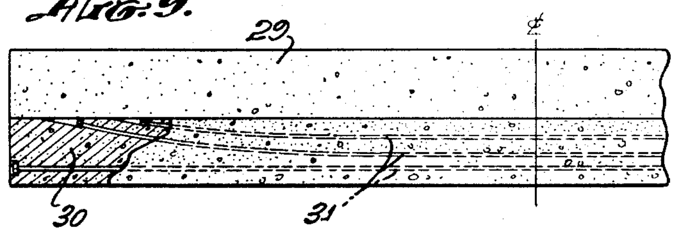


FIG. 10.

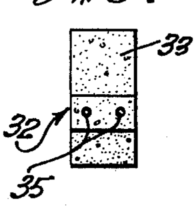
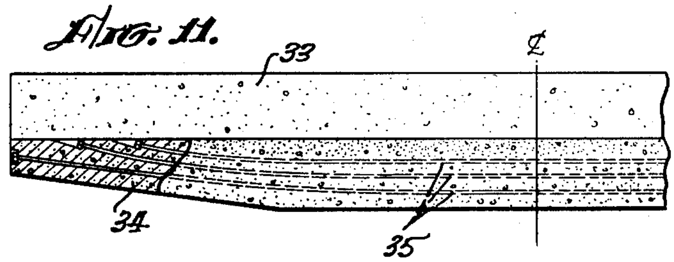


FIG. 11.



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SPLIT-BEAM PRESTRESSING

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7 Claims. (Cl. 52—223)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates generally to the prestressing of concrete structures and particularly to the method of prestressing the tension portion of the beam or structure and then later casting the compression portion after the beam structure is emplaced in its working location.

The principles of prestressing are well known and the advantages of the application of the technique in concrete construction are generally recognized. What is not known, however, is that still larger benefits could be obtained if the prestressing of a member is confined to the tension zone only and not applied to the entire section, as has been the practice heretofore. The additional gains would be in the form of reduction in the quantity of stressing steel required, up to 50% or more; savings in the quantity of cement; simplification of casting and handling; and other corollary benefits.

The principal object of this invention, therefore, is to provide a method of construction of prestressed structural concrete members which entails considerable savings in materials and greater facilities in the manufactured, transporting, and erecting such members in construction work.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings wherein:

FIGURE 1 is a diagrammatic presentation of the stress distribution on a rectangular cross section of a flexural member stressed as a unit;

FIG. 2 is a diagrammatic presentation of the stress distribution on the presetressd tension segment only of the rectangular cross section shown in FIG. 1;

FIG. 3 shows the stress distribution on the tension segment of a T-section flexural member; and

FIGS. 4 to 11, inclusive, show various types of pre- and post-stressed flexural concrete members constructed in accordance with the invention.

The basic idea of prestressing is to pre-introduce into a member compressive strains of such pattern and magnitude that would compensate the tensile strains resulting from the eventual loading. Consider, for example, the case of a simply-supported beam of rectangular cross section, having a width b and depth d, which is to resist a maximum design moment, M. If the beam is to bend as a member of uniform flexural properties, then the tension zone at each section along the length of the span must be provided with a built-in compression strength at least equal to the tension stresses resulting from flexure under maximum loading. In conventional prestressing, this is accomplished by subjecting the whole member to an internally balance compressive force, P.

The distribution of stresses on a typical rectangular cross section **10** is shown in FIG. 1(a). The triangular stress pattern of no tension and a maximum design com-

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pression of f_c at the bottom is obtained by the placing of the stressing force P eccentrically, that is, at a distance of $d/6$ below the gravity or neutral axis, NA of the section or at $d/3$ above the bottom. The stressing force P results from the tension of prestressing rod **11**. Then, the average and the maximum stresses are:

$$f\text{ av.}=\frac{P}{bd};\ f\text{ max.}=\frac{2P}{bd}=f_c \qquad (1)$$

The stress distribution due to the bending moment, M, is as shown in FIG. 1(b). Here, because of the symmetry of the section and the assumed homogeneity of the flexural properties, the compressive stresses above the neutral axis, NA, equal those of the tensile stresses at corresponding distances below the axis. The maximum fiber stresses at top and bottom are, accordingly:

$$f_t=+\frac{6M}{bd^2};\ f_b=-\frac{6M}{bd^2} \qquad (2)$$

and, since the concrete is not to be subjected to tension, in numerical value, this stress must not exceed that produced by the prestressing force P; that is

$$f_c=\frac{2P}{bd}\geq\frac{6M}{bd^2} \quad \text{or}$$

$$P\geq\frac{3M}{d} \qquad (3)$$

The resultant stress distribution due to presetressing and design loading, obtained by combining the diagrams (a) and (b) of FIG. 1 is shown in FIG. 1(c). In this latter diagram, it is of special interest to note that of the total amount of prestress applied to the section, namely P, only one-half is used or compensated by the subsequently imposed flexure. The portion that is not used is indicated by cross-hatching in the diagram (c). Obviously, this part is not needed for the basic function of prestressing and its elimination would constitute a net saving in the needed prestressing effort.

The elimination of the unused portion of prestressing is accomplished by merely divorcing the tension segment of a flexural member from that in compression and thus prestressing the former or tension segment only. After the separate prestressing of the tension segment, the compression or top segment may then be added as in conventional, non-prestressed concrete work.

In explanation, consider again the simple beam discussed above. With reference to FIG. 2, the tension segment **14** consists of the lower half of the beam located below the neutral axis, NA. To produce a triangular stress distribution on this half cross section with a maximum fiber stress of f_c, we will then need a prestressing force P′, placed at a height of $d/6$ above the bottom the segment, as at **13**, which may then be expressed as

$$f_c=\frac{4P'}{bd}=\frac{2P}{bd} \quad \text{or}$$

$$P'=\frac{P}{2} \qquad (4)$$

The stress distribution due to P′ is shown in FIG. 2(a). The flexural stresses for the design moment, M, and for the whole beam or section are given as before by Equation 2 and is redrawn in FIG. 2(*b*). Now when combining the stresses from the diagrams FIG. 2(*a*) and (*b*), that shown in FIG. 2(*c*) will result. As will be seen here, the entire prestressing is used to compensate for the flexural tension. It is to be noted further that this was accomplished by a stressing force, P′, only half as large as that needed in the preceding case where the whole member was prestressed.

If a flexural member is so proportioned that the tension and compression segments are not alike, such as a T-beam shown in FIG. 3, the two-to-one ratio of the needed prestressing forces by the above outlined two methods will no longer hold. Instead, in such case, the following relation will apply:

$$\frac{P'}{P}=\frac{A'}{2A}\cdot\frac{d}{C} \qquad (5)$$

in which A and A′ indicate the cross sectional areas of the whole member **16**, and the tension segment **18**, respectively; *d*, the total depth and C, the depth of the compression segment.

Considering the T-beam structure shown in FIG. 3, it is apparent that P will be more than .5P. However, it must also be noted that, in flexure, the compression of the fiber f_{ct} will be smaller than the tension of the bottom fiber f_{cb}. This variation is in direct ratio of the depths of the compression and tension segments of the member. Accordingly, if a concrete of allowable working stress f_c is used in the lower or prestressed part of the beam, the compressive strength of the upper segment need only be:

$$f_{ct}=\frac{C}{C'}\cdot f_c \qquad (6)$$

If we let $b'=t$; $b=5t$ and $d'=5t$ and substitute these values and those derived therefrom in Equations 5 and 6, we will arrive at the equalities:

$$P'=0.6P$$

and

$$f_{ct}=\tfrac{1}{2}f_c$$

These equalities signify that, by segmental or split beam prestressing, the stressing steel is reduced by 40 percent and that the compressive strength of the concrete in the compression segment need be only one-half of that in the tension segment. For a 6000 p.s.i. concrete, it would mean a reduction in cement of over 3 bags per cubic yard of mix—an impressive saving in itself. Also, concrete of lightweight aggregates could also be used for the compression segments with further advantages.

Split beam prestressing is equally adaptable to pretensioning as well as post-tensioning techniques. As shown in FIGS. 4 to 10, inclusive, further savings in the stressing steel may be accomplished by terminating part of the wires or cables short of the ends of the members in conformity with the bending curve of the design loading.

In FIGS. 4 and 5, the prestressed tension segment **22** is shown with its prestressing rods or cables **23**. The composite beam **20** is made up of this preformed tension segment **22** and the later added compression segment **21**. This latter segment **21** may be cast on top of segment **22** in the original mold, or better, may be cast after tension segment **22** is mounted in place in its structural positioning. The stepped arrangement of **22** indicates the saving of steel by the shortening of the presstressing rods or cables to conform to a more or less centralized loading.

In general, FIGS. 4 to 7, inclusive, are intended to illustrate prestressing by pre-tensioning. FIGS. 8 to 11, inclusive, are intended to illustrate prestressing by post-tensioning. In all figures, the lower, heavier shaded portions represent prestressed high strength concrete as first cast in the manufacturing molds with the necessary prestressing hardware. The lighter shaded portions represent the later cast or later added unprestressed compression segments made of much lower strength concrete with possible lighter weight aggregate material.

The interconnection of the complementary segments does not present a difficult problem. In most cases, insofar as horizontal shear is concerned, normal bonding with the cleaned top surface of the tension segment will suffice. For diagonal tension, some tie reinforcement, particularly near the ends of the members may be needed. This requirement can be readily met by inserting looping dowels or stirrups in the tensioned segment during its casting.

It is considered that the casting of a beam in two operations in prestressed construction constitutes an ideal arrangement. It separates factory work from that which can be done with less cost in the field. By divorcing the compression segment from the unit, the tensioning effort is greatly reduced which will be reflected in longer life and less cost of the prestressing hardware and tensioning equipment. Production facilities, presently available, would greatly increase their capacity, being able to fabricate more than twice the number of framing members previously cast. The framework of the segments would be much simplified and the reduced weights of the castings would facilitate their handling and transportation.

Having thus described my new method of forming prestressed concrete beams and the new and unique construction members formed thereby, I claim:

1. The method of constructing a structural concrete beam comprising:
- determining the neutral axis of said beam;
- considering that portion of the beam above said neutral axis as the compression segment;
- considering that portion of the beam below said neutral axis as the tension segment;
- casting the tension segment in association with a system of prestressing rods and cables;
- casting the compression segment on top of said previously cast tension segment; and
- bonding said tension and compression segments at their interface to resist any developed shear.

2. A composite structural concrete beam comprising:
- a lower prestressed tension segment which includes all of the beam below its neutral axis;
- an upper non-prestressed compression segment which includes all of the beam above its neutral axis; and
- bonding means at the meeting interface of said segments to resist any shear forces developed during normal loading of said beam.

3. A composite structural concrete beam as claimed in claim **2** wherein said prestressed tension segment may be subjected to either pretensioning or post-tensioning means.

4. A composite structural concrete beam as claimed in claim **2** further characterized by said lower prestressed tension segment being cast of high strength concrete and said upper compression segment being cast of low strength concrete.

5. A composite structural concrete beam comprising:
- a lower prestressed tension segment which includes all of the beam below its neutral axis;
- an upper non-prestressed compression segment which includes all of the beam above its neutral axis;
- bonding means at the meeting interface of said segments to resist any shear forces developed during normal loading of said beam; and
- said lower prestressed tension segment and said upper compression segment being cast of concrete of equal strength.

6. A composite structural concrete beam as claimed in claim **5** wherein:
- said lower prestressed tension segment has a plurality of prestressing rods which terminate at their ends along the bending curve for a designed load on the beam.

7. A composite structural concrete beam as claimed in claim 5 wherein:
said beam has a rectangular cross-section throughout its entire length.

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