Sept. 1, 1964 A. M. JAMES 3,146,549

METHOD AND CONSTRUCTION OF PRESTRESSED STRUCTURES

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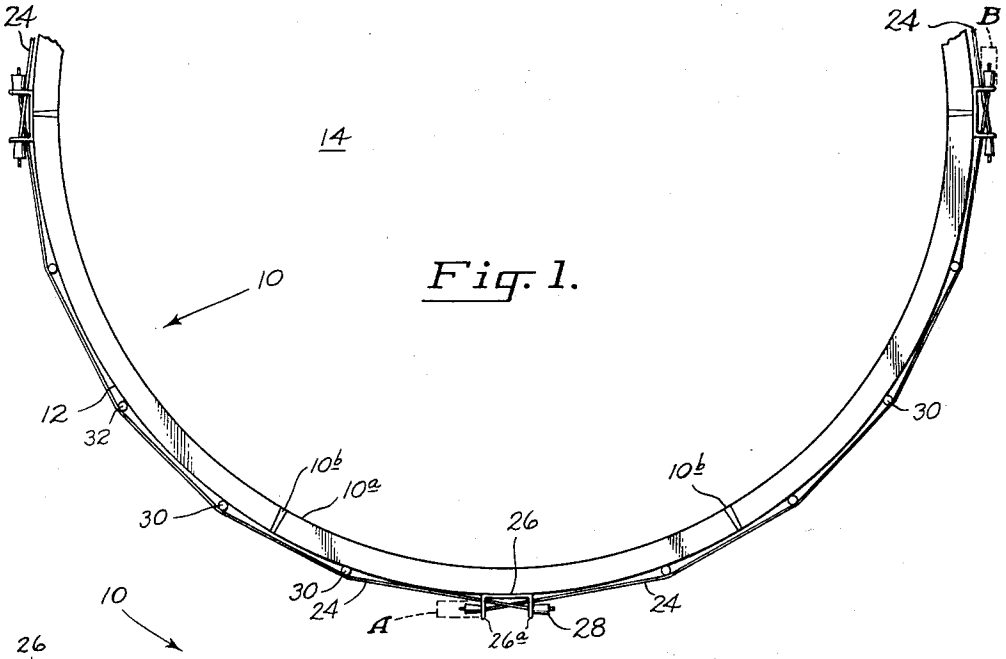


Fig. 1.

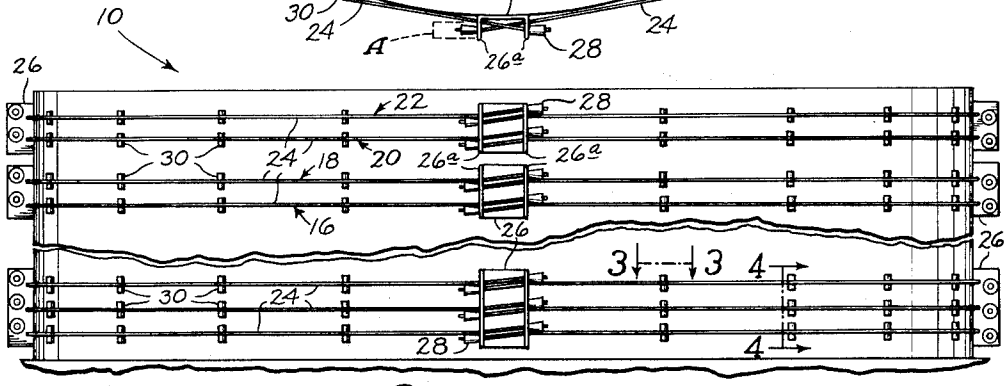


Fig. 2.

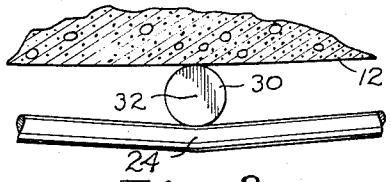


Fig. 3.

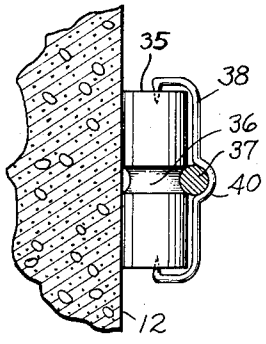


Fig. 5.

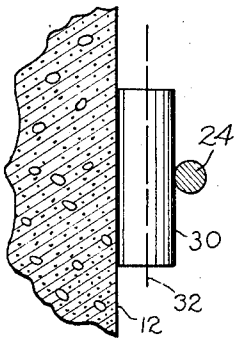


Fig. 4.

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METHOD AND CONSTRUCTION OF PRESTRESSED STRUCTURES

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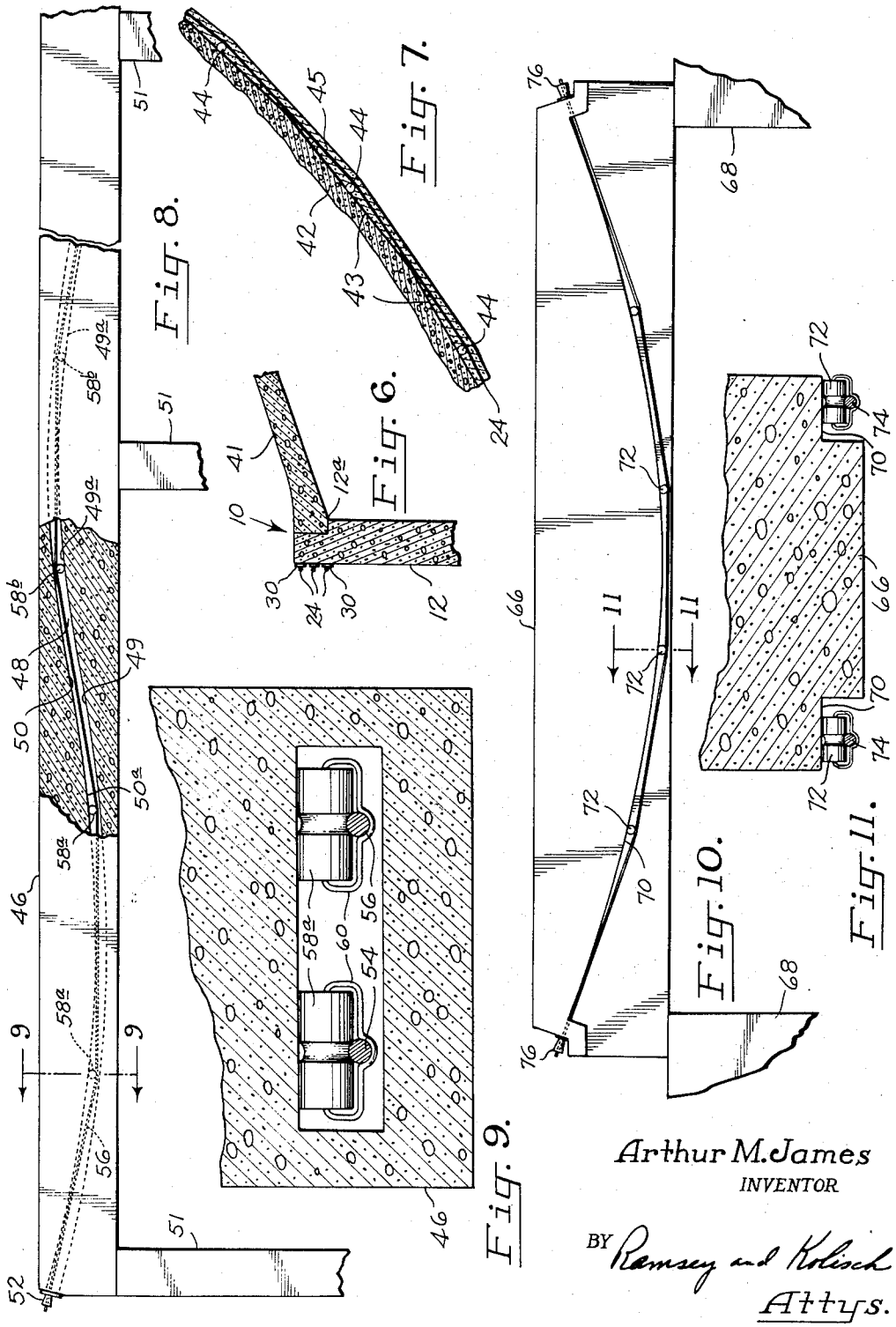


Fig. 8.

Fig. 7.

Fig. 6.

Fig. 9.

Fig. 10.

Fig. 11.

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METHOD AND CONSTRUCTION OF PRESTRESSED STRUCTURES

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5 Claims. (Cl. 50—129)

This invention relates to methods and construction for prestressed structures and more particularly prestressed concrete structures.

In general, it is an object of the invention to provide an improved method and construction for prestressing concrete, wherein the concrete is prestressed by using posttensioned members and wherein said posttensioned members are mounted in engagement with the concrete by means accommodating distribution of elongation (stretching) in the members during their tensioning.

Another general object of the invention is to provide an improved construction for prestressing concrete that lends itself to the prestressing of concrete where working space is limited.

Still another general object is to provide an improved method for prestressing concrete that permits significant reduction in the effect of friction between the tensioned members and the concrete during tensioning and elongation of the members, and wherein such is possible using mechanism that is relatively inexpensive and easily applied to ordinary forms of concrete structures without modification of their design.

One known method of prestressing concrete, that is, applying stresses to a concrete structure that oppose stresses later produced under loading, comprises subjecting the concrete to stresses through the tensioning of a member secured to the concrete after hardening thereof. Since the member is applied after setting or hardening of the concrete, this method of prestressing makes use of what is referred to as a "posttensioned" member which extends over the surface of the concrete in an angular course.

One method of applying the tensioned member is to tension the member before laying it over the surface of the concrete, so that any elongation occurring in the member due to tensioning takes place before the member comes in contact with the concrete. This method of construction is expensive because of the special type of machinery necessary and cannot be employed where there are space limitations.

Another method of applying a posttensioned member is to place a member to be tensioned over the cured concrete and apply tension after posttensioning of the member by pulling on its ends. Thus, with a cylindrical object, wires, straps, cables, bands or similar tension members are loosely placed around the object and thereafter tensioned. According to this method of construction, friction between the concrete and tensioned members, unless taken care of, inhibits movement relative to the concrete and thus interferes with the even tensioning of the members and concrete. This invention contemplates an improved construction for prestressing using the latter-described method wherein the effects of friction are markedly reduced and significant improvement is achieved in the distribution of the stresses applied to the concrete structure.

Specifically, and explaining the invention with reference to a conventional cylindrical object or structure, the object is prestressed by girdling it at locations on its perimeter spaced along its longitudinal axis with plural tension means which are held out of contact with the surface of the object by rolls or rollers extending transversely of the tension means. The rolls are mounted so that their rotation axes are free to translate in paths parallel to the curved outer surface of the object as the tension

means undergo elongation (tensioning), this translation occurring in the direction of elongation. Each tension means has its own rolls or rollers whereby the means are separately tensioned and secured in place one alongside the other.

A specific object of the invention, therefore, is to provide means for prestressing concrete that includes a tension member and means spacing the member out of contact with the surface of the concrete, said means comprising rolls having rotation axes free to translate in paths parallel to the surface of the concrete. The rolls may be supported on the surface of the concrete with the rolls directly contacting the surface. This construction has the special advantage of requiring no special surface design for the concrete, except a surface which is sufficiently smooth to permit the rolls to roll. A roll size is selected that permits the rolls to move freely over the concrete surface. Since the rolls are supported on the surface of the concrete, they provide the maximum clearance possible between the tension member and the concrete surface without the necessity of special structure holding the rolls away from the concrete.

Another object and feature of the invention is to provide for a concrete structure a series of tension means disposed side by side, each of said tension means having a separate series of rolls for supporting it out of contact with the concrete. By using a separate series of rolls for each tension means, the rotation axes of each are free to translate without restraint caused by tightening of adjacent tension means.

The invention also lends itself to the prestressing of elongated beams and similar structures. Thus to prestress a beam that in operative position is to be supported at its ends, the beam is provided with a curved surface that extends along the beam and curves in a direction corresponding to the deformation tending to be produced in the beam under load. Elongated tension members may then be anchored to the ends of the beam, said tension members extending over the curved surface. Such tension members may be provided with plural rolls extending transversely of the tension members and mounted with their axes free to translate in paths parallel to the curved surface. These rolls accommodate elongation of the tension members during tensioning, with the elongation being distributed throughout the length of the tension members.

According to the invention, a minimum of criticality in the placement of the rolls to obtain suitable clearance of the tension members is required. The amount of clearance obtained may be regulated by proper selection of roll diameters. On a curved surface, the stressing produced tends to be directed radially of the surface prestressed, since the rolls contact the surface along lines that lie in planes extending tangentially of the surface. This is true even after translation of the rolls, and is most important in obtaining balanced prestressing. It should also be noted that the use of freely mounted rolls permits a wide selection in the number of contact locations possible between a tension member and the concrete. Thus the construction enables the use of a large number of rolls and the provision of a larg enumber of roll contact locations where pressure is applied to the prestressed members. The determination of how many rolls should be used may readily be made at the site of prestressing. As a corollary to the above, the construction permits distribution of the pressure applied to a prestressed concrete structure over a large area, and permits close control of the level of pressures applied to a structure at any given location.

The invention provides a simple and inexpensive way of obtaining excellent distribution of tension forces along the length of a tension member. Considering any tension

member, the relationship of the tension forces between two points separated by a length of member L may be expressed by the following formula: $F_1=(F_0)(e^{-KL+u\theta})$ where F_0 and F_1 are the tension forces at the two points respectively, e is the base of the natural system of logarithms, K is a constant allowing for a wobble effect (lateral shifting of the tension member during elongation), θ is the angle between the two points F_0 and F_1 expressed in radius, and u is the coefficient of friction. From the above formula it will be seen that if the wobble effect (K) is substantially eliminated, and the coefficient of friction (u) is substantially reduced, forces F_1 and F_0 approach equality. This is a condition that is closely approached by the invention. Thus the invention makes possible curved prestressing over large angle changes and substantial savings in labor and equipment costs are achieved.

The objects and advantages attained by the invention are described in greater detail hereinbelow in conjunction with the accompanying drawings, wherein:

FIG. 1 is a plan view of an embodiment of the invention, showing a portion of a cylindrical tank structure with tension members applied thereto as contemplated by the invention;

FIG. 2 is a side view of portions of the tank illustrated in FIG. 1;

FIG. 3 is an enlarged view along the line 3—3 in FIG. 2, illustrating details of how a roller spaces a tension member out of contact with the concrete surface;

FIG. 4 is a side view of the roller illustrated in FIG. 3;

FIG. 5 illustrates a modification of the invention, wherein a roller is provided with an annular groove intermediate its ends, operable to seat a tension member, and a clip rotatable on the roller ends that holds the tension member to the roller;

FIG. 6 shows a detail of the top of the dome of a tank according to the invention;

FIG. 7 illustrates another modification of the invention wherein the outer surface of the prestressed object has polygonal outline;

FIG. 8 illustrates another modification of the invention, wherein the tension members are applied to a beam;

FIG. 9 is a section view along the line 9—9 of FIG. 7, slightly enlarged, illustrating details of the tension members and rolls within the beam;

FIG. 10 illustrates another modification of the invention, wherein the tension members are applied to a beam and mounted externally of the beam; and

FIG. 11 is a section view along the line 11—11 of FIG. 9.

Referring now to the drawings, and more particularly to FIGS. 1, 2, 3 and 4, in this embodiment there is shown a large, cylindrical concrete tank 10, such as might be used for water storage or the like. In a typical installation, such a tank may have a diameter ranging from about fifty to three hundred feet or more. Tank 10 may be constructed by pouring concrete in forms at the job site or, as is now quite common, assembled at the site from preformed sections 10*a* joined together by grouts 10*b*. The finished structure has an enlarged, substantially cylindrical and continuously curving convex outer wall, or bounding surface, indicated at 12. The tank has a hollow interior 14, which in service confines material which exerts outward pressure. To prestress the tank, stresses are applied to the outer surface of the tank that oppose the radially outwardly directed stresses produced when the interior of the tank is filled.

There are provided around the perimeter of the tank and spaced along its longitudinal axis a series of elongated tension means, indicated generally at 16, 18, 20 and 22 in FIG. 2, each of which encircles or bounds the tank. Specifically, each tension means comprises elongated wires or tension members 24, anchoring mountings 26 and collets or ferrules 28. The connections at adjacent ends of members 24 are made by passing the ends

through suitable bores provided in outstanding flanges 26*a* of mountings 26, and wedging the collets over the ends of members 24 using suitable wedges inserted within the collets (the latter wedges being obscured in the drawings). The connections are made after suitable tensioning mechanism has drawn adjacent ends past one another to produce the desired tension in the tension members. It will be seen that in the embodiment illustrated each tension means comprises four tension members 24, and these have their ends anchored in place at 90° spacings about the tank. By providing multiple tension members in each tension means so that tensioning is produced by applying force at points spaced about surface 12, the total curvature of each member between its ends is reduced. This has the effect of distributing more evenly the tension in each tension member.

The mountings and collets constitute adjustment mechanisms permitting adjustment in length of a tension means, and are positioned at regularly spaced intervals around the perimeter of the tank depending on its size. Adjustment mechanisms are provided on diametrically opposite sides of the perimeter of the tank so that equalizing tension may always be simultaneously exerted on opposite sides of the tank.

The means for applying tension to members 24 may be any suitable mechanism such as jacks, indicated schematically in dotted lines A and B in FIG. 1, which are temporarily connected to pull against each other at opposite ends of a member 24. The jacks form no part of the completed structure but serve only as means for imparting the desired degree of tension to the members, whereupon the members are secured in place in the previously mentioned manner and the jacks removed for tensioning of another member. The number and positioning of the jacks employed may be varied depending upon the size of the structure and the amount of tensioning needed.

Spacing each tension member of a tension means from the curved outer surface of tank 10 are a series of rolls or rollers indicated at 30. These are disposed about outer surface 12 at distances sufficient to keep the tension members out of contact with the surface of the tank. The rolls are mounted with their rotation axes, indicated at 32, extending transversely of the tension members. The rolls are freely mounted under the tension members and supported on the outer surface of the tank, and thus on rotation (such as accompanies elongation of a tension means) their rotation axes are free to translate, with translation occurring in the direction of elongation. This translation is in a curved sweep that parallels the curvature of the tank.

By providing rolls 30, the friction produced between the tension members and the surface of the prestressed structure during elongation is reduced substantially from that resulting using conventional methods. It has also been observed that "wobble" effect, that is, the tendency of a wire to wander laterally during elongation, tends to be reduced. Thus the tension in a tension member tends to be distributed evenly throughout the member and as a corollary, the elongation in the member also tends to be distributed evenly throughout the length of the member.

It should also be noted, with reference to FIG. 2, that each tension means is supported on a set of rolls 30 separate from the set of rolls supporting the other tension means. One tension means may be stretched and secured in place, with such stretching having the effect of locking the rolls for the tension means in a fixed position. An adjacent tension means may then be tensioned, with its supporting rolls moving freely. If a single roll were used for both tension means, the rolls would render only sliding and not rolling support for the tension means, thereby effectively reducing the amount of tension that could be distributed through the second means.

The roll construction according to the invention has other advantages. Maximum clearance is provided each wire, since the rolls are supported entirely on the exterior

of the surface. The rolls may be placed at any desired location about the surface of the structure, without the necessity of any special changes or adaptations in the design of the tank. The rolls may be spaced at close intervals, with the number of locations where pressures are applied being increased proportionally. The pressure applied to a tank through each roll may be regulated by varying the number of rolls used.

It should further be noted that since the rolls move over the convex surface of the structure, contact of the rolls with surface of the structure is always along lines that lie in planes tangent to the convex curved surface. Thus the rolls exert pressures on the structure directed radially inwardly of the curved surface. This is so regardless of any shift which occurs in the rolls.

By way of example, in order to illustrate the amount of elongation and consequent tensioning it is possible to achieve according to the invention, the following was observed in the pre-stressing of a circular concrete tank 20 feet high, 60 feet in diameter, and having a wall thickness of 6½ inches. The tension members were high-tensile, stress-relieved prestressing wires having a diameter of about 0.2 inch. Each wire was elongated over mild steel rollers having a diameter of about a half-inch and length of about two inches. A suitably prestressed condition was attained in the tank when the total elongation of a wire over an angular distance of 90° was about four inches at one end of the wire.

Referring now to FIG. 5, in this figure a modified form of roll is shown. In the modification, a roll **35** has an annular groove **36** extending thereabout intermediate its ends. This annular groove receives a tension member **37** passing thereover. Further, rotatably mounted on the ends of the roll and passing between these ends is a clip **38**. Clip **38** has an intermediate portion **40** that clamps onto an outer portion of tension member **37**. In such a construction wobble effect in member **37** is further minimized. Most important, the tension member may be applied to a surface with the roll supported on the tension member before mounting the member about the surface. This is helpful in assembling a tension member with rolls properly in position.

FIG. 6 shows top or dome **41** (frequently of saucer shape) of tank **10** resting on a shoulder **12***a* formed in the upper end of wall **12**. Tension members **24** surround in closely adjacent relationship outer wall **12** of the tank at the points where dome **41** engages wall **12**. When members **24** are elongated (tensioned), wall **12** as well as dome **41** are put under stress. In this manner prestressing according to the invention may be utilized simultaneously to stress the wall and dome of the tank.

Referring to FIG. 7, in the modification of this figure a structure **42** is prestressed that is bounded by regularly recurring multiflat sides **43**. In such a construction, rolls **44** are supported on sides **43**, with their rotation axes free to translate over the sides **43**. As in the previous embodiments discussed, a separate set of rolls is used with each tensioning means, and the number of rolls used is determined by the clearance required and the maximum pressures to be generated at points of roll contact.

After a structure has been placed under a desired stress, the tension means may be covered by spraying concrete **45** or some other suitable substance thereover. This serves not only to give a finished appearance to the structure but assists in protecting the tensioning means from the elements, as such structures are usually outdoors.

The spacing of adjacent tension means around a structure will depend on the amount of tension necessary for the particular structure. In some large structures plural layers of means, one mounted on top of the other, may be necessary.

FIGS. 8 and 9 disclose a modification wherein an elongated beam **46** is provided with a channel **48** extending through the length thereof. This channel has bottom and top walls **49**, **50** that curve in a direction corresponding to the deformation occurring in the beam after it is mounted on supports **51** and subjected to loading. Thus top wall **50** first curves convexly at **50***a*, then concavely, and then convexly, progressing from right to left in the figure, and bottom wall **49** curves in a complementary manner, i.e., first concavely, then convexly at **49***a*, then concavely. Portions **50***a*, **49***a* constitute a pair of convexly curved surface portions spaced along the length of the beam.

Extending through the beam and anchored as at **52** at the ends thereof, are tension members **54**, **56**. These tension members have rolls **58***a*, **58***b* interposed between the tension members and the convexly curving surface portions of the channel and supported on these surface portions. One set, indicated, at **58***a* in FIG. 8, is disposed on one side of members **54**, **56**, and the other set (**58***b*) is disposed on the opposite side of members **54**, **56**. In this embodiment, as in the previous ones discussed, the rolls or rollers are mounted with their rotation axes extending transversely of the tension members, and so that these rotation axes are free to translate with elongation of the tension members. In this embodiment, the use of clips **60** is particularly important, such clips aiding in the proper placement of rollers **58***a*, *b* within channel **48**

In FIGS. 10 and 11, another form of construction is shown. In these figures, beam **66** is supported at its ends on supports **68**. A curved surface **70** is provided each side of the beam, such surfaces being external surfaces. Extending over the curved surfaces are tension members **74**, with rolls **72** interposed between the surfaces and the members. The tension members are anchored at **76** in suitable support flanges provided on the beam. Rolls **72** have rotation axes extending transversely of the tension members, such rotation axes being free to translate with elongation of the tension members.

The method of prestressing, according to the invention, is well suited for cylindrical objects, such as the tank of FIG. 1, and other objects resembling it in form. These may be solid or have hollow centers, and be cylindrical over only portions of their length. The form of prestressing is particularly useful for large structures having relatively thin walls, wherein anything recessed into the walls would weaken the walls. The prestressing according to the invention is readily done on structures where working space is limited because a minimum of room exterior the structure is necessary for working space to apply the tension means. In this connection, it should be noted that the invention is particularly useful for the prestressing of cylindrical objects disposed on their sides, where the bottom sides are at or near the ground. It should be borne in mind that the invention is not only applicable to substantially cylindrical objects, but also to the prestressing of elongated beams such as shown in FIGS. 8 through 11.

It is appreciated that changes may be made in the parts and their organization without departing from the invention, and it is desired to cover all modifications and variations that would be apparent to one skilled in the art and that come within the scope of the appended claims.

It is claimed and desired to secure by Letters Patent:

1. Mechanism for prestressing a concrete structure a portion of which is bounded by a curving wall, said mechanism comprising an elongated, flexible tension means adapted to be placed over said curving wall, means for connecting opposite ends of said tension means to the structure after tensioning of the same, and plural rollers supported on the tension means spaced along the length thereof, each of said rollers having a clip means holding the roller to the tension means with the roller extending transversely of the tension means and its axis free to translate thereon.

2. The mechanism of claim 1 wherein said rollers have annular grooves intermediate their ends, said grooves receiving portions of the tension means extending thereover.

3. The combination of a surface, an elongated flexible line extending over the surface, a roller positioned between said line and surface extending transversely of said line, said roller spacing the line from the surface whereby the two are out of frictional contact, and clip means holding said roller on said line with said roller free to traverse on rotation of the roller in a direction extending longitudinally of said line.

4. In the prestressing of a concrete structure with an elongated tension member and a rolling agency that supports the tension member, where said tension member is placed in an angular course over the structure and then tensed, the method comprising placing the rolling agency against the tension member with its rotation axis extending transversely of the member, mounting the agency on the tension member with the rotation axis of the member free to translate relative to the tension member, positioning said tension member in its angular course over said wall surface, and positioning the rolling agency through positioning of the tension member against the wall surface with the rolling agency disposed beneath the tension member and resting on said surface, tensing the tension member, and upon tensing of said tension member shifting said agency both with respect to said surface thereunder and the tension member thereover by rolling the agency over said surface with its rotation axis translating in the direction of elongation of the tension member.

5. In the prestressing of a concrete structure with plural tension members where the tension members are placed so that each extend in an angular course about the structure and are then tensed, the method comprising preparing a convexly curved wall surface for the structure, positioning said tension members with each extending in its angular course over said surface, spacing the tension members from the wall surface by placing rolling agencies beneath the tension members and resting on said surface with the rolling agencies of one member separate from the rolling agencies of the other tension members, tensing each tension member independently of the other members by pulling on the ends thereof, and upon tensing of the tension members shifting the rolling agencies of each tension member independently of the agencies for the other members, both with respect to the surface thereunder and the tension member thereover, by rolling the agencies over the surface with their rotation axes translating in the direction of elongation of the tension member.

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