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Landenberg, Pa.
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Division of Ser. No. 712,796, Mar. 13, 1968,
Pat. No. 3,513,609. Continuation-in-part
of application Ser. No. 623,709, Mar. 16,
1967, now abandoned.
[45] Patented **May 25, 1971**
[73] Assignee **E. I. du Pont De Nemours and Company**
Wilmington, Del.

[50] **Field of Search**..... 52/223,
698, 741, 230; 24/126 (W), 129 (W); 264/228;
29/155 (R), 155 (C), 452

[56] **References Cited**
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550,267 12/1942 Great Britain..... 24/129

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Assistant Examiner—James L. Ridgill, Jr.
Attorney—George W. Walker

[54] **METHOD FOR POST-TENSIONING TENDONS**
5 Claims, 36 Drawing Figs.
[52] **U.S. Cl.**..... 52/741,
29/155, 29/452, 52/230, 264/228
[51] **Int. Cl.**..... E04c 3/29,
E04c 5/01, E04g 21/12

ABSTRACT: An anchoring system is provided wherein the end of a post-tensioned tendon extending from a concrete structure is encased in a metallic sheath and the sheath is crimped in a series of reversals of increasing angularity in the direction away from the concrete structure.

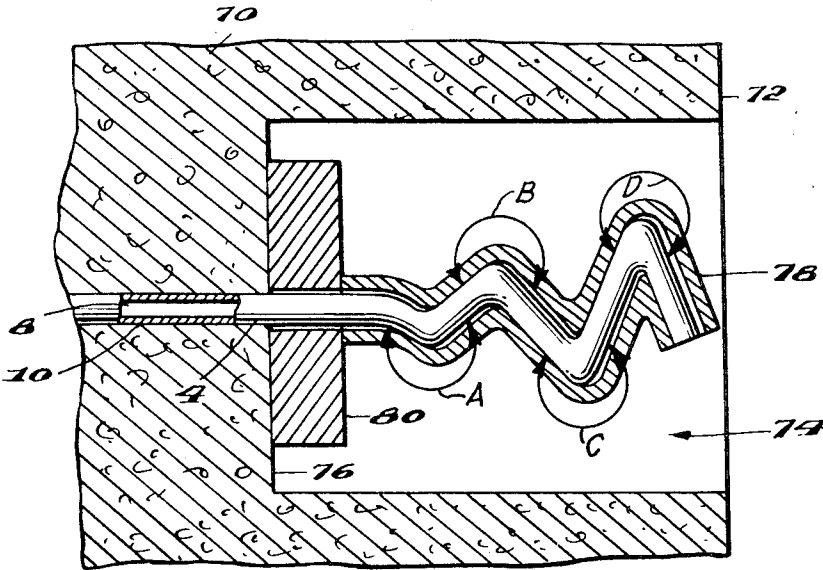


Fig. 1.

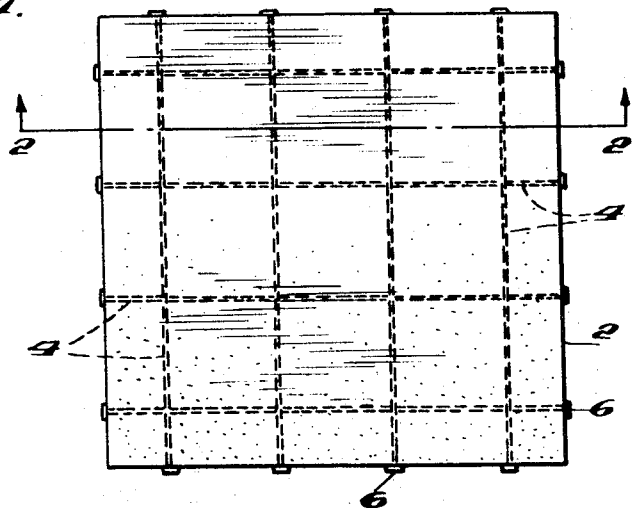


Fig. 2.

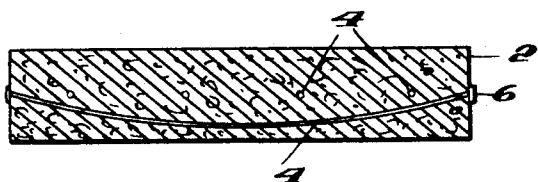


Fig. 3.

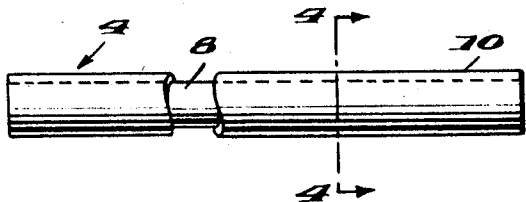


Fig. 4.

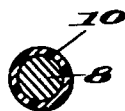


Fig. 5.

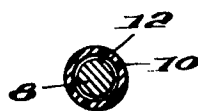


Fig. 6.

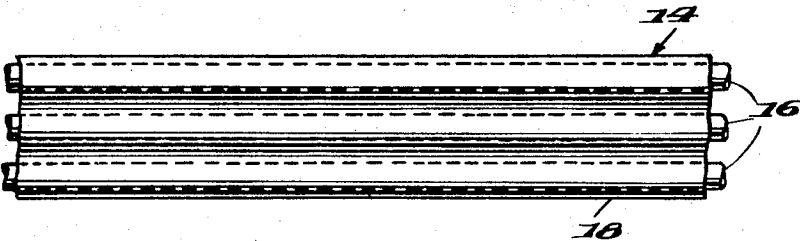


Fig. 7.

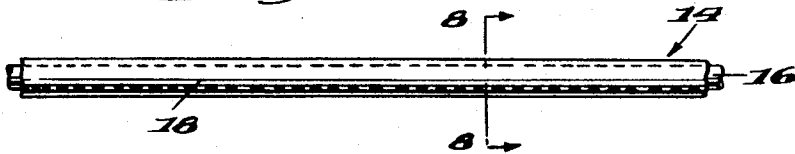


Fig. 8.



Fig. 9.



Fig. 10.

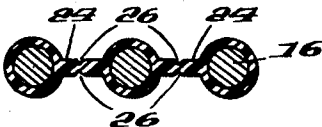


Fig. 11.



Fig. 12.

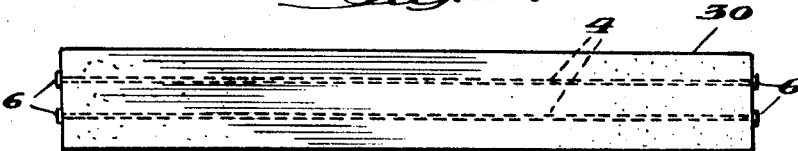


Fig. 13.

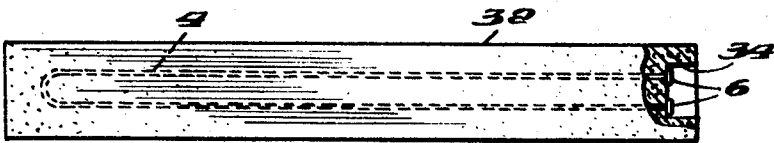


Fig. 14.

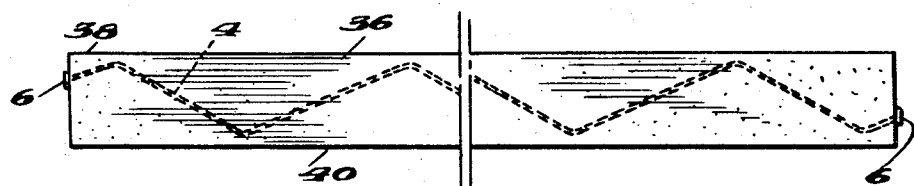


Fig. 15.

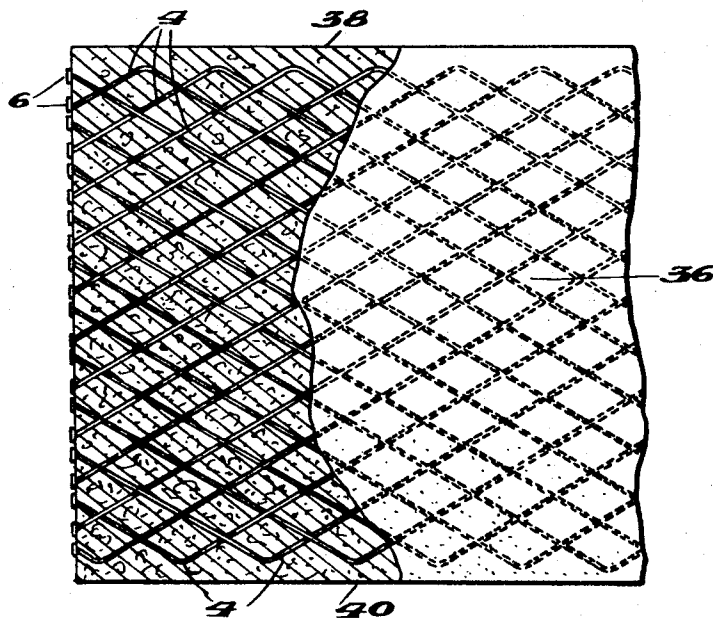


Fig. 16.

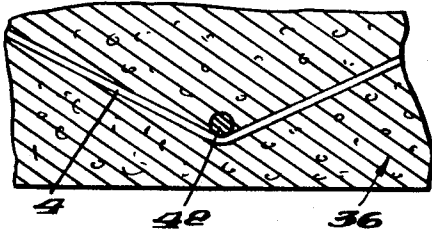


Fig. 17.

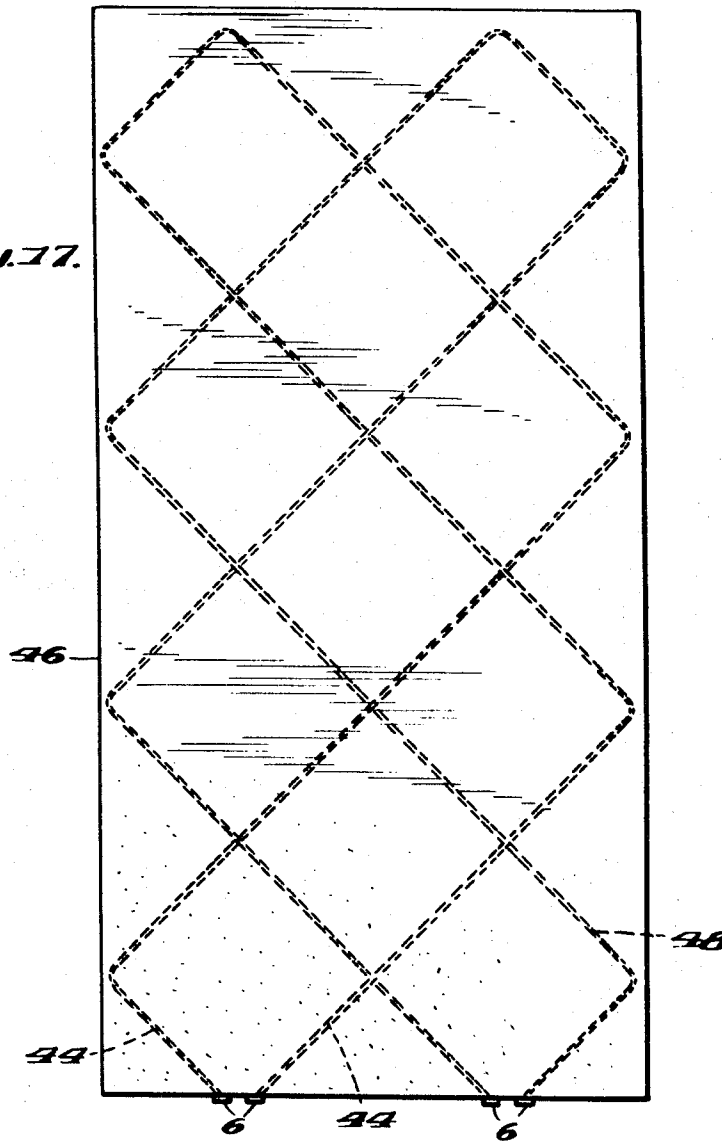


Fig. 18.

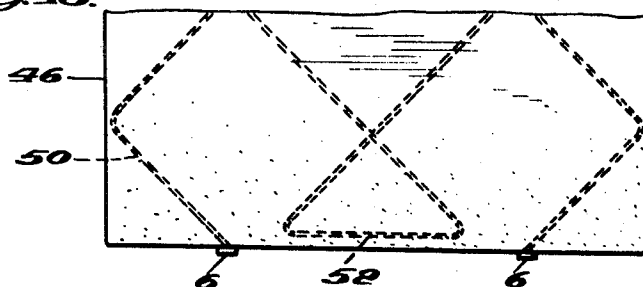


Fig. 19.

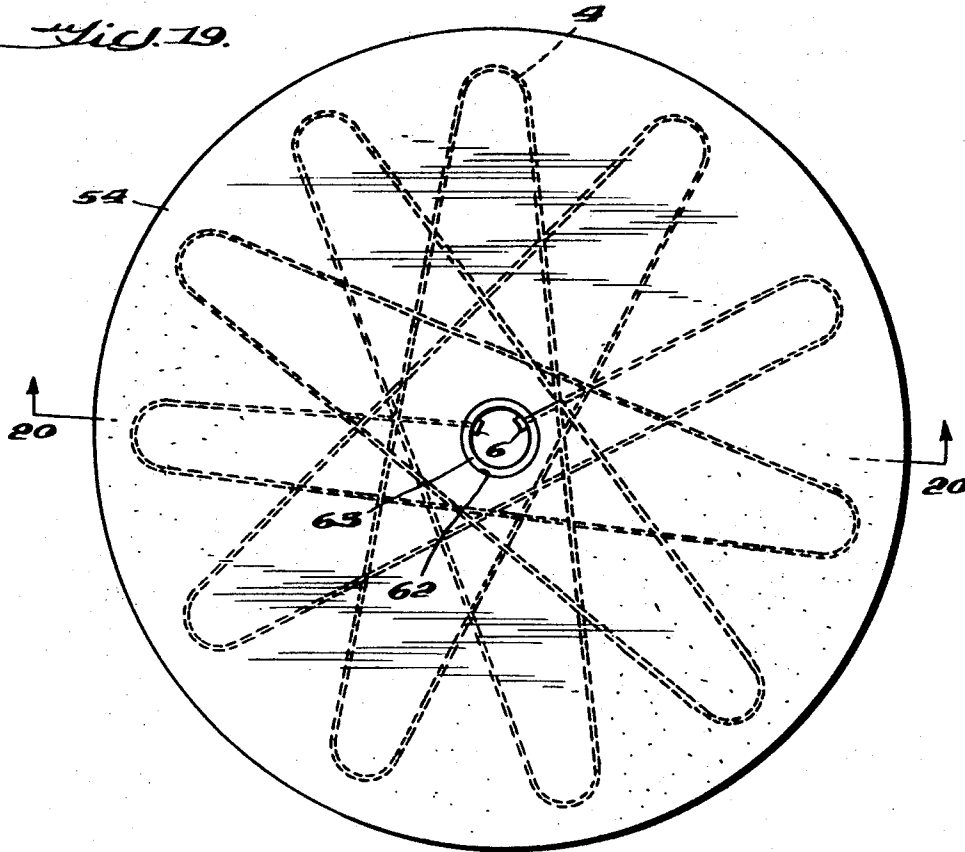


Fig. 20.

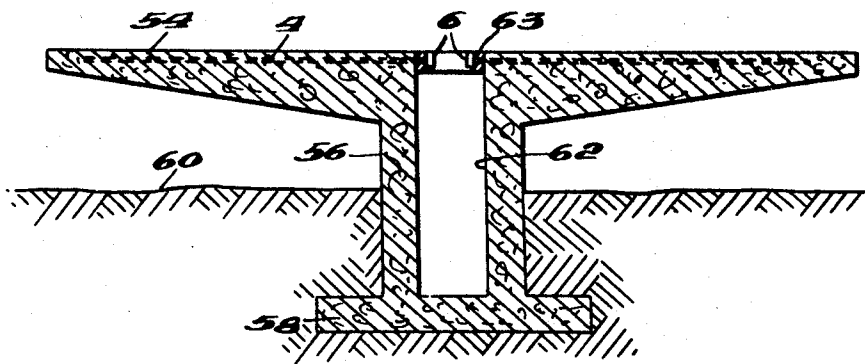


Fig. 23.

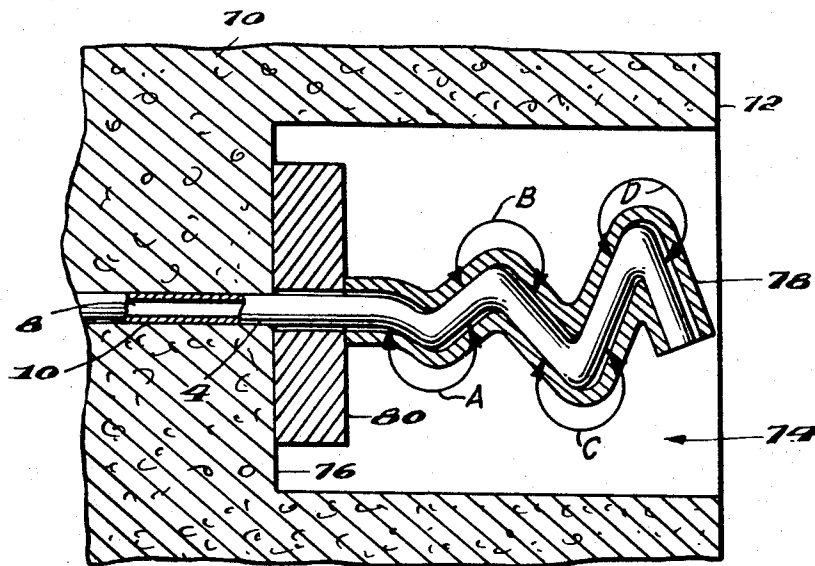


Fig. 24.

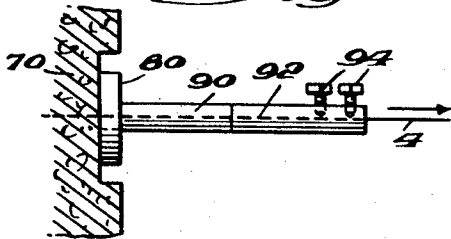


Fig. 25.

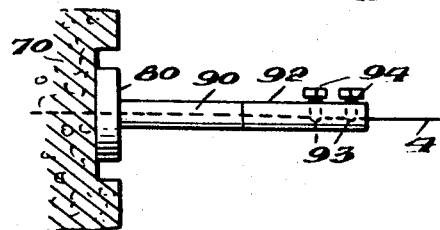


Fig. 26.

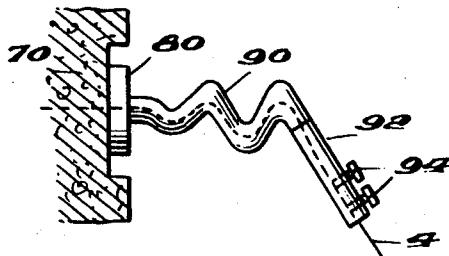


Fig. 21.



Fic. 22.

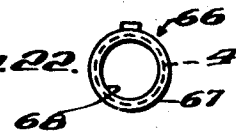


Fig. 27.

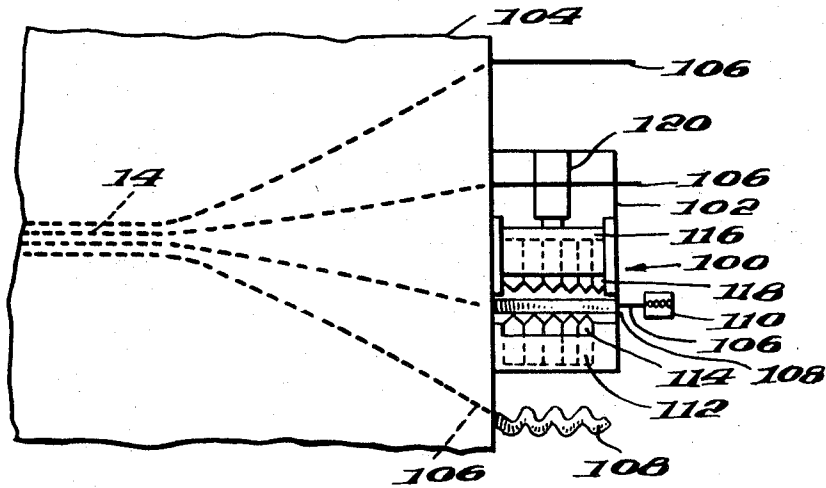


Fig. 28.

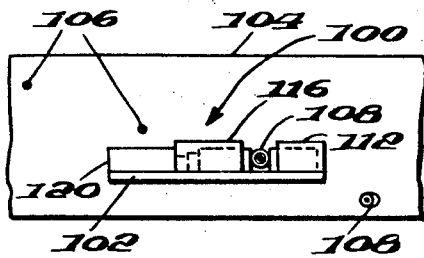


Fig. 29.

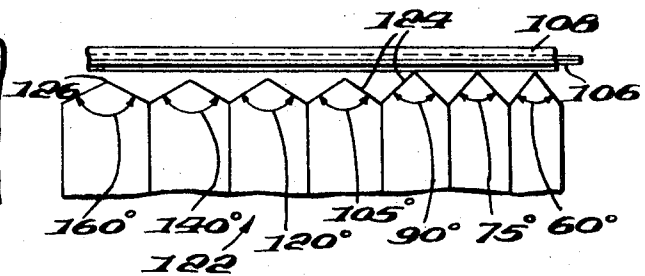


Fig. 30.

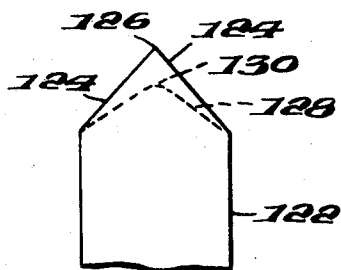


Fig. 31.

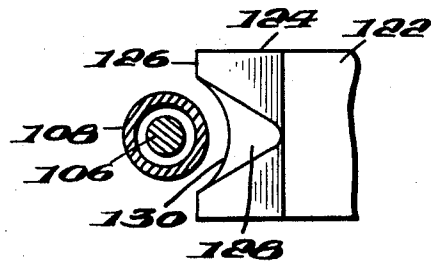


Fig. 32.

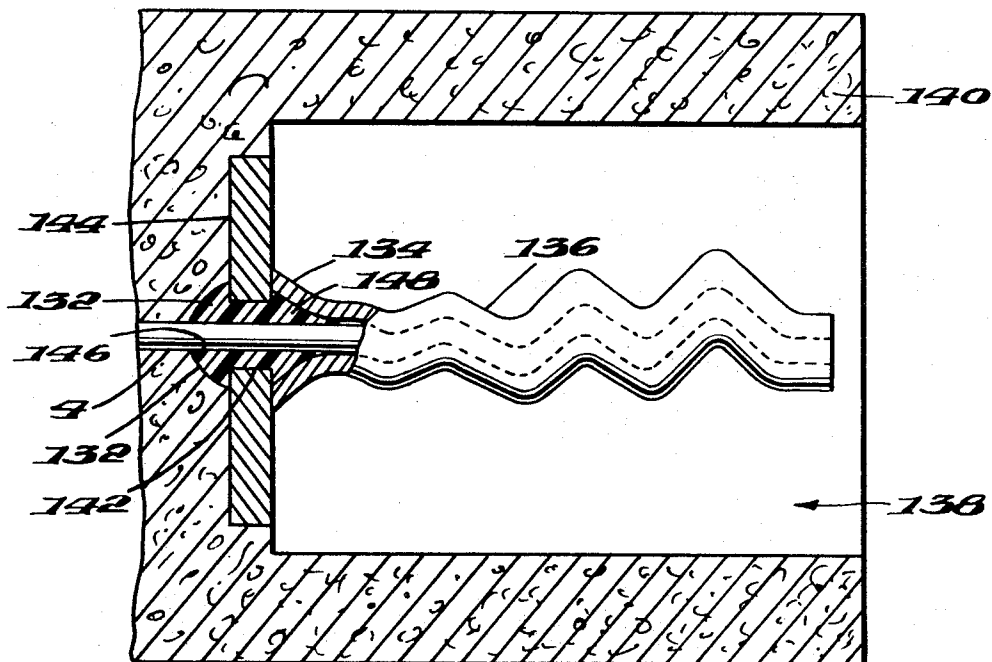


Fig. 33.

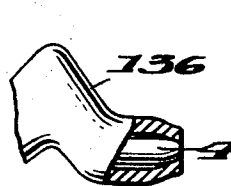


Fig. 34.

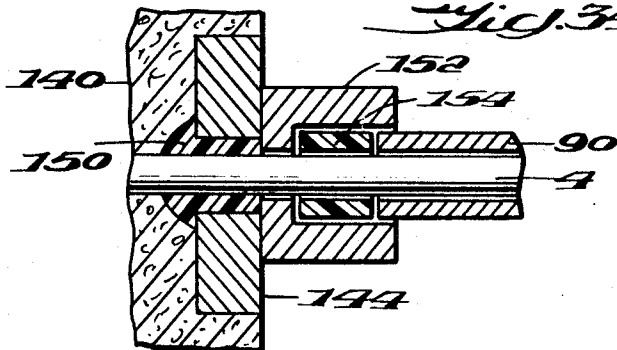


Fig. 36.

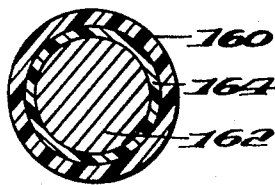
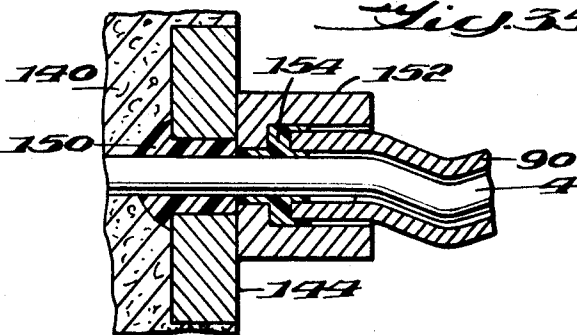


Fig. 35.



METHOD FOR POST-TENSIONING TENDONS

This application is a division of application Ser. No. 712,796, filed Mar. 13, 1968 granted May 26, 1970 as Pat. No. 3,513,609 by the same inventor, which in turn is a continuation-in-part of application Ser. No. 623,709, filed Mar. 16, 1967 now abandoned, by the same inventor.

This invention relates to concrete structures in which the concrete is maintained in compression during use so as to prevent failure in tension, and to tendons and anchoring systems for maintaining this concrete under compression.

In the post-tensioning method of prestressing concrete, concrete is poured into a form which defines the shape of the structure desired and which contains tendons extending across the form. After the concrete has sufficiently hardened, the tendons are elongated to a point within their elastic limit, and their ends are held by fasteners that rest against the concrete or against a bearing plate which rests against the concrete. In this manner, the tensile force in the tendons produce a compressive force in the concrete and, as a result, increases the load carrying capacity of the concrete.

Important to the success of post-tensioning is the requirement that the tendon be free to move within the concrete during post-tensioning so that the elongation is as evenly distributed as possible along the length of the tendon. One approach for accomplishing this result has been to move the tendon back and forth in the concrete during its hardening to make a chase (U.S. Pat. No. 3,029,490 to Middendorf). Another approach has been to form the tendon from a grease-coated bundle of rods which is then helically wrapped with plastic or paper tape and embedded in the concrete. After the concrete hardens around the tape, some movement between the rods and the tape can occur during post-tensioning. The same principle is employed for a tendon composed of rods or cable which has been threaded through a metal or plastic tubing. Special tubing has been designed for this purpose (U.S. Pat. No. 2,677,957 to Upson and U.S. Pat. No. 3,212,222 to Wittfoht). These approaches have one or more disadvantages, e.g., the presence of relatively high friction which causes nonuniform elongation of the tendon during post-tensioning, the presence of measurable voids (between the tube or tape and the rod or cable) which expose the tendon to corrosion, and the requirement for tendons of relatively large cross section which are difficult to transport and handle in the field. While precautions are taken to minimize some of these disadvantages, e.g., grouting as shown in U.S. Pat. No. 3,114,987 and U.S. Pat. No. 3,060,640 to Harris, these precautions require extra expense and still the other disadvantages remain.

The present invention provides a tendon which overcomes the disadvantages of previous tendons. One embodiment of the tendon of this invention comprises a wire and plastic material tightly and uniformly coating said wire. In this embodiment, the plastic material should be such that it provides a coefficient of friction between the coating of plastic material and wire of not greater than 0.09. In another embodiment, a lubricant is present at the interface between the wire and uniform tight coating of plastic material to produce the coefficient of friction of not greater than 0.09. The aspects of low friction and tight coating in these embodiments appear anomalous in that one aspect would be expected to defeat the other. This does not occur, however, in the present invention wherein the wire is a single wire of small diameter generally no greater than 0.3 inch and has a smooth, regular surface and wherein the coating closely conforms to this surface and has a uniform thickness generally no greater than about 0.05 inch. The low coefficient of friction enables the elongation of wire in post-tensioning to be substantially uniform so that it is more efficiently used than tendon systems having a higher coefficient of friction. The coating is sufficiently tight, however, that the wire cannot be threaded into the coating for any useful distance. Instead, the coating is molded about the wire from the molten state. This tightness precludes voids and thus markedly reduces corrosive elements, e.g., air and moisture from reaching the wire. This, together with additional corrosion

protection if necessary, which may be provided by suitable coating on the wire, enables wire of small diameter and high tensile strength to be safely used for post-tensioning.

The tendons of this invention overcome the transportation and handling awkwardness of a relatively heavy gauge tendon in that the tendons of this invention can be supplied on a reel of convenient diameter. No advance prefabrication of the tendon, such as outfitting with end fastening hardware, is necessary. The use of separate tubing through which rod or cable is threaded is not required. Instead, the tendon of this invention is a prepackaged post-tensioning assembly. The tendon of this invention is merely unreel within and across the form for the concrete, laid in position, severed to appropriate length and then outfitting with appropriate end fastening hardware. No special steps are necessary during the hardening of the concrete. When the concrete has hardened, the plastic coating is stationarily embedded therein. However, the wire is free to move and therefore can be uniformly post-tensioned.

In another embodiment, a plurality of the foregoing described tendons of this invention are integrated in the form of a ribbon, with the individual tendons being in a common plane and being severable from one another. This composite tendon has the same advantages of the individual tendon of this invention and additionally the advantage of providing simultaneous handling for a plurality of tendons.

Another embodiment of this invention relates to anchoring systems for post-tensionable tendons. Various anchoring systems for the ends of post-tensionable tendons are known, such as disclosed in U.S. Pat. Nos. 2,371,882 and 2,270,240, both to Freyssinet; U.S. Pat. No. 2,609,586 to Parry; U.S. Pat. No. 2,728,978 to Birkenmaier et al., and U.S. Pat. No. 3,216,162 to Gerber et al. These systems suffer from one or more of the disadvantages of requiring prefabrication of the tendon or the anchoring system before reaching the construction site, thereby reducing flexibility of application and increasing expense, of causing excessive localized stresses in the post-tensioned tendon, of requiring multiplicity of parts, of holding by friction rather than by positive engagement, and/or of failing to provide corrosion protection to the anchored end of the tendon. The present invention provides an anchoring system for the ends of post-tensionable tendons which alleviates or overcomes these disadvantages. The anchoring system comprises a crimpable metallic sheath for encasing a protruding end of the tendon, with the sheath having one end in force transmitting relationship with the concrete structure being placed under compression by the post-tensioning operation and with the body of the sheath being deformed in a series of reversals of increasing angularity in the direction away from the concrete structure to engage positively the protruding tendon to prevent its withdrawal from the sheath. This maintains the tendon under tension and thereby, the concrete structure under compression.

In another embodiment of anchoring system, anchoring of the post-tension tendon is accomplished by bonding of the wire along its length to the coating of plastic material embedded in the concrete structure. This bonding is effected by a curable plastic material present between the wire and the coating, which is cured after the tendon is in place within the concrete and post-tensioned.

These and other embodiments will be described more fully hereinafter with reference to the drawings, in which:

FIG. 1 shows a plan view of a concrete structure incorporating features of this invention;

FIG. 2 shows a cross section taken along line 2-2 of the structure of FIG. 1;

FIG. 3 shows in indeterminate length one embodiment of tendon of this invention with a section of its coating removed;

FIG. 4 shows a cross section taken along line 4-4 of the tendon of FIG. 3;

FIG. 5 shows a cross section of another embodiment of tendon of this invention;

FIG. 6 shows a plan view of a length of composite tendon of this invention with the wire component partly exposed;

FIG. 7 shows a side view of the composite tendon of FIG. 6;

FIG. 8 shows a cross section taken along line 8-8 of the composite tendon of FIG. 7;

FIG. 9 to 11 show in cross section other embodiments of composite tendon;

FIG. 12 shows in plan view one form of concrete structure post-tensioned with a particular pattern of tendons of this invention;

FIG. 13 shows a partially cut away plan view of a concrete structure similar to that of FIG. 12 employing a different post-tensioned tendon pattern;

FIG. 14 shows in indeterminate length and plan view another form of concrete structure post-tensioned with still another pattern of tendons of this invention;

FIG. 15 shows an enlarged partially cutaway plan view of one end of the concrete structure of FIG. 14 with the pattern of tendons in greater detail;

FIG. 16 shows in still further enlargement a cutaway plan view of a region of the concrete structure of FIG. 15 showing a reversal of a tendon therein;

FIG. 17 shows in plan view a concrete structure post-tensioned with still another pattern of tendons of this invention;

FIG. 18 shows in plan view one end of the concrete structure of FIG. 17 with a variation of the pattern of tendon therein;

FIG. 19 shows in plan view a cantilever concrete construction utilizing a tendon of the present invention;

FIG. 20 shows a cross section of the cantilever concrete construction taken along line 20-20 of FIG. 19;

FIG. 21 shows in indeterminate length a pipe post-tensioned with a tendon of this invention;

FIG. 22 shows a cross section of the pipe taken along line 22-22 of FIG. 21;

FIG. 23 shows in fragmentary cross section one embodiment for anchoring the ends of tendons of this invention;

FIG. 24 to 26 show schematically the steps for obtaining the anchoring depicted in FIG. 23;

FIG. 27 shows schematically a plan view of apparatus suitable for anchoring a post-tensioned tendon in a concrete structure;

FIG. 28 shows a side elevation of the apparatus and end of the concrete structure of FIG. 27;

FIG. 29 shows an enlarged fragmentary plan view of a series of crimping elements of a jaw suitable for use in the apparatus of FIG. 27;

FIG. 30 shows a still further enlarged plan view of one of the crimping elements of the jaw of FIG. 29;

FIG. 31 shows a side elevation of the crimping element of FIG. 30;

FIG. 32 shows in fragmentary cross section one end of a concrete structure incorporating another embodiment of anchoring by end fastening, of this invention;

FIG. 33 shows the extremity of the anchored assembly of FIG. 32 after radial compression for sealing the extremity from moisture;

FIG. 34 shows in fragmentary cross section one end of a concrete structure incorporating still another embodiment of end fastening system in which the tendon is maintained under tension by external means;

FIG. 35 shows the embodiment of FIG. 34 after crimping and after release of the tendon by the external means; and

FIG. 36 shows in enlarged cross section an embodiment of bonded tendon of this invention.

LOW FRICTION TENDON

Referring now to the drawings, FIG. 1 shows a concrete slab 2 which is held under compression by substantially uniformly elongated post-tensioned tendons 4 of the present invention arranged in a conventional crisscross pattern, with the ends of the tendons being secured by end clamps 6 which can include bearing plates. The tendons 4 are spaced from one another at a distance which gives the desired amount and distribution of compression to the slab 2, which can be in the form of pavement, floor, wall, roof, siding, i.e., shingles, and tabletops. The

tendons 4 can be in a draped disposition as they extend through the slab 2, as shown for one tendon in FIG. 2.

The tendon 4, as shown in FIG. 3, comprises a wire 8, which is elongated during post-tensioning, tightly and uniformly coated with plastic material 10, which remains fixedly embedded in the concrete during post-tensioning. The wire has a smooth outer surface, and the coating 10 has its inner surface in close conformation with the outer surface of the wire as shown in FIG. 4. Thus, there are no irregularities between the coating and the wire to interfere with the elongation of the latter.

The diameter of the wire is generally no greater than 0.3 inch and usually no greater than 0.2 inch. The smallest diameter wire that can be used will primarily depend on the size of the concrete shape being post-tensioned; for example, music wire measuring about 0.02 inch in diameter is useful in post-tensioning small concrete shaped, for example, which are of tabletop size. Generally however, the diameter of the wire will be at least 0.05 inch. With respect to coating 10, it is continuous and of uniform thickness. Generally no greater than 0.05-inch thick coating is required. However, the coating thickness usually need be no greater than 0.015 inch. As a general rule, the coating thickness is no greater than 25 percent and preferably no greater than 12 percent of the diameter of the wire. The thinness of coating 10 about wire 8 aids in maintaining the integrity of the coating under transverse loading by minimizing the tendency of the coating to cold flow, possibly exposing the wire. The tightness of the coating about the wire minimizes corrosive elements such as air and moisture from contacting the wire.

In order to attain the low coefficient of friction between the wire and the coating, their mating surfaces should be smooth, even and uniform with respect to each other. Some plastic materials, e.g., tetrafluoroethylene polymers, i.e., homopolymers and copolymers thereof with small proportions of other copolymerizable monomers, preferably perfluorocarbon monomers, generally provide a coefficient of friction of 0.09 or less. For other plastic materials it may be necessary to provide a lubricant at the interface between the wire and the coating. Such a lubricant should be noncorrosive to the wire and should have sufficient "film" strength to prevent direct contact between the wire and the coating of plastic material. The magnitude of the "film" strength required will depend on the amount of transverse stress placed on the tendon during post-tensioning. Coefficients of friction of no greater than 0.05 are attainable for tendons of the present invention. Such tendons are particularly useful in reversal patterns within the concrete. For example, for an amount of reversal (total angle of curvature) of about 180°, a coefficient of friction of no greater than 0.05 between the wire and the coating is desirable. As the amount of reversal increases, even lower coefficients are desired. Coefficients of friction decreasing from 0.02 to 0.009 are desirable for angles of curvature increasing from about 540 to 1300°. However, coefficients of friction of 0.09 to 0.03 are generally useful in this range as well as at smaller angles of curvature. The elastic limit of the wire is not exceeded in bending the wire to form any of the reversal patterns herein described.

Lubrication can be accomplished by the incorporation of slip-producing agents in the coating of plastic material, such agents including graphite, molybdenum disulfide and oils. A particularly advantageous coating is polyamide blended with from about 1 to 5 percent silicone oil, with the polyamide preferably being 610 nylon. In another embodiment, the lubricant can be disposed as a separate layer 12 between the outer surface of the wire 8 and the inner surface of the coating 10, as shown in FIG. 5. Preferably, the lubricant of layer 12 has at least some solid lubricating material present therein, particularly on the occasion when the tendon is to be used for reversal patterns. Representative solid and liquid lubricants for layer 12 include the mineral oils, hydrocarbon oils, graphites, fluorocarbon polymers such as high molecular weight polymers or telomers derived principally from

tetrafluoroethylene used alone or in combination. A particularly useful lubricant layer 12 is composed of a solid fluorocarbon coating such as obtained with the polytetrafluoroethylene dispersions disclosed in U.S. Pat. No. 2,612,484. Preferably, a corrosion inhibitor is present between the wire 8 and coating 10 consisting (i.e., in layer 12) e.g., of a chemical reducing agent such as sodium nitrite or high molecular weight organic amines such as lauryl amine. Along with the corrosion inhibitor, a dispersing agent is preferably also present, such being selected from a wide variety of commercially available water soluble emulsifying agents, such as inorganic salts of sulfonated petroleum or sulfonated hydrocarbons, the aryl sulfonamides and high molecular weight fatty acids, i.e., aliphatic monocarboxylic acids or water soluble salts thereof, especially fatty acids having from 12 to 20 carbon atoms. The corrosion inhibitor and dispersion agent are conveniently applied in the form of an emulsion of hydrocarbon oil in water. Most of the water is driven off during the application of coating 10. A particularly useful corrosion inhibitor-lubricant which is useful for applying to the wire 8 prior to coating is the aqueous dispersion of 45—47 percent water, 19—21 percent hydrocarbon oil, e.g., mineral oil, 15—16 percent amine, e.g., ethanolamine, 8—9 percent of a fatty acid, e.g., oleic and 7.5—10 percent of sodium nitrite (percent's are by weight). Most of the water of this dispersion is driven off during the application of the coating 10 and the residue mixture provides both lubrication and corrosion protection. This dispersion can be used in combination with other lubricants hereinbefore described. Mixtures of this dispersion with polytetrafluoroethylene dispersions provide a layer 12 with both lubrication and corrosion protection properties. Generally the benefits of either dispersion become apparent when as little as 10 percent by weight of either dispersion is present in the combination thereof. The lubricant layer 12 can also include a first coating of lubricous plastic material such as polytetrafluoroethylene applied directly to the wire, with lubricant of the layer 12 being provided between the first coating and coating 10, whereby the first coating is elongated with the wire while the coating 10 performs the same function as hereinbefore described. Liquid lubricants, such as the corrosion inhibitor-lubricant described can be present between the first coating and coating 10, as a part of layer 12.

The layer 12 of lubricant, when present is generally no greater than about 0.012 inch in thickness, usually no greater than 0.005 inch, and is uniform along the length of the wire. Preferably, the thickness of layer 12 does not exceed 0.002 inch. The tight coating 10 of plastic material maintains the lubricant at the wire-plastic coating interface during handling and in post-tensioned use.

The plastic material from which coating 10 is made can consist essentially of any plastic resin which can be formed into a coating about the wire and which is compatible with the particular lubricant present, if any. The plastic material can be applied as a uniform and tight coating to the wire by extrusion of the plastic material in the form of continuous tubing around a wire which is moving in the direction of the extruded tubing and by drawing the continuous tubing down by vacuum onto the moving wire. When the wire is to be coated with lubricant and/or corrosion inhibitor, this can be done, such as by dipping or spraying or otherwise applying the lubricant onto the wire prior to the extrusion coating step with the extrusion coating herein described not removing the previously applied lubricant or corrosion inhibitor coating from the surface of the wire. This kind of extrusion coating can be carried out with what is generally referred to as a tubing die, such as is described in Paper No. 603 entitled "Wire Jackets of Nylon" by E. C. McKannan and R. E. Shaw published by the E. I. du Pont de Nemours and Company. When the layer of lubricant has sufficient integrity prior to the coating with plastic material step, a pressure-type extrusion die can be used to form the coating 10. Suitable plastics include the polyamides, especially hexamethylene adipamide (66 nylon), polycaprolactam (6 nylon) and hexamethylene subaceamide (610 nylon) and

copolymers and terpolymers thereof, polyolefins including the alpha-monoolefins having from 2 to 10 carbon atoms, especially polyethylene and polypropylene, the polystyrenes, the ABS resins, ionomers such as described in Canadian Pats. 674,595 and 713,631 both to Rees, halogenated polyolefins such as vinyl chloride polymer, oxymethylene polymer and copolymer and polyethylene terephthalate.

The wire used in the tendons of this invention, will generally be any filamentary material that has an elastic limit (stress) of at least 150,000 p.s.i. The wire may be of metal such as cold drawn carbon steel or of fiber glass. The wire can include a surface treatment which improves corrosion resistance but does not significantly impair strength; an example of such a surface treatment is a coating of zinc powder which can be held in place by a phosphate binder. A particularly useful tendon of this invention is one in which the wire is the carbon steel and measures 0.08 inch in diameter, which is coated with a lubricant oil containing tetrafluoroethylene polymer particulate solids dispersed therein to a thickness of about 0.0005 inch, which is in turn tightly and uniformly coated with 610 nylon or olefin polymer having a thickness of 0.01 inch.

In another embodiment of tendons of this invention, a composite tendon 14 can be made of a plurality of wires 16, which are similar to wires 8, covered by a uniform and tight coating 18 of plastic material, which is similar to coating 10 hereinbefore described. As shown in FIGS. 6 and 7 the wires are disposed in a common plane whereby the composite tendon 14 is in the shape of a ribbon. The individual wires 16 of the tendon 14 are integrally connected by a relatively thin bridge 20 of the same plastic material as the coating 18. This tendon can be applied in concrete construction from a reel in the same manner as tendon 4 with the additional advantage of simultaneous handling of wires 16 being present.

Should it be desired to separate one coated wire 16 from another such wire of the tendon 14, either for the purpose of providing individual ends of the tendon for purposes of end fastening, the junction between the coating 18 of each of the wires can be in the form of a sharp V-shape 22 as shown in FIG. 9. In another embodiment, as shown in FIG. 10, the bridge 20 may be in the form of a web 24 between coated wires 16 with opposing V-shape grooves 26 dissecting the webs 24 to assist in separation of one coated wire 16 from the other.

In still another embodiment of composite tendon in ribbon form, a plurality of tendons shown in FIG. 4 can be coated with an outer coating of plastic material 28 which forms the junction between the individual tendons 4. The configuration of the coating 28 at the junction of the tendons 4 can be varied as desired such as to resemble the junctions depicted for the embodiments of FIG. 8 to 10.

The composite tendons of this invention can be made of the same materials and have the same frictional characteristics and coatings 12 as discussed hereinbefore with respect to tendon 4.

In addition to the crisscross application of tendons of this invention as depicted in FIG. 1, tendons of this invention may also be used for unidirectional post-tensioning of concrete structures, particularly those which have much greater length than width. For example, a plurality of tendons 4 can be used to post-tension such a concrete structure 30 which can be in the shape of a railroad tie. Tendons 4 are held at their ends by end clamps 6 as shown in FIG. 12.

Because of the light gauge and low frictional characteristics of the tendons of this invention, a similar elongated concrete structure 32 can be post-tensioned by a tendon 4 which is disposed in a loop pattern within the structure and which requires the use of end clamps at only one end thereof. In this embodiment the end clamps are situated within a cavity 34 in one end of the concrete structure 32 which can also be used as a railroad tie. In this embodiment, it is apparent that only half as many ends of the tendon 4 need to be end-clamped as compared to the embodiment of FIG. 12. The point at which the looped tendon 4 of FIG. 13 can be terminated can be varied to the location desired. For example, one or both ends of the ten-

don 4 can be made to terminate in a cavity (not shown) which is intermediate the ends of the concrete structure 32.

Another tendon pattern which is useful for post-tensioning concrete structures having greater length than width is the zigzag pattern of tendon 4 in an elongated concrete structure 36 (FIG. 14) which is useful, for example, as a highway or airport runway slab. Such a tendon can be positioned within the form for the slab by a concrete paving machine just prior to filling of the form with concrete. By having a reel of the tendon move transversely in response to longitudinal movement of the paving machine, the zigzag pattern is obtained. In this zigzag pattern, tensioning of the tendon 4 is done at opposite ends of the concrete structure 36, but the tendon essentially always travels at an angle first to one side 38 and then to the other side 40 and so on, reversing its direction at a point proximate to the sides as the tendon passes from end to end of the structure 36. Upon post-tensioning of the tendon 4, the structure 36 is placed under both longitudinal and transverse compression. In practice, a plurality of the tendons 4 are used forming reversals spaced along the length of the structure and in opposing sequence, i.e., opposing reversals at the sides 38 and 40 as shown in FIG. 15.

Pins 42 may be disposed in the concrete form in which the particular concrete structure is to be made and the tendon, such as tendon 4, is passed around such pin prior to pouring of the concrete in the form. The pin 42 has a sufficiently large radius that the elastic limit of the wire is not exceeded in bending (reversing) about the pin. The pin can remain buried in the concrete structure, such as shown in FIG. 16. This pin or similar device can be used in any of the reversal tendon patterns described herein. Another pattern which can be produced with tendons of the present invention is similar to that of FIGS. 14 and 15, except that the ends of the tendons all protrude from, and are thus clamped at, one end of the concrete. This embodiment is shown in FIG. 17, wherein one tendon 44 extends in one direction in a zigzag path within concrete structure 46 and then at the end thereof, reverses itself to form a similar return path and provide side-by-side ends for end clamping with clamps 6. Another tendon 48 extends in an opposing course through the structure 46 to also have its ends terminate side-by-side as shown. In a variation on the tendon pattern in FIG. 17, a single tendon 50 can be used to establish essentially the same pattern as shown in FIG. 17 for concrete structure 46, by uniting the pattern with segment 52 of the single tendon, whereby only two ends require post-tensioning and fastening with end clamps 6. Tendons 44, 48 and 50 are similar to tendon 4. In practice, a plurality of tendons, having their ends and reversal points spaced from that of other tendons, will be used to form the tendon pattern of FIGS. 14 and 15.

Another pattern which can be formed of tendons of this invention is a pattern of circumferentially displaced radially-extending loops of either one or a multiplicity of tendons. An example of this pattern is shown in FIG. 19 and FIG. 20 in which a deck or flooring 54 extends in cantilever fashion from a central tubular section 56, which in turn is supported by a footing 58 which is buried in the ground 60 or is otherwise supported. The deck 54 is circular in plan view and is positioned symmetrically about the tubular section 56. Embedded in the deck 54 is a tendon 4 entering from the interior 62 of the tubular section 56 and exiting within the same tubular section 56 and exiting within the same tubular section and secured therein by end clamps 6. Within the deck 54, the tendon 4 forms a series of substantially radially extending circumferentially displaced loops uniformly generated about the tubular section 56. The ends of tendon 4 extend through apertures in a steel ring 63. Upon post-tensioning, the deck 54 is compressed inwardly, with the steel ring serving to transmit the tensile force in one end of the tendon to the other end thereof. End clamps 6 maintain the tendon in the post-tensioned condition. In this pattern as in previous patterns, a plurality of tendons spaced one from the other, will be used.

Tendons of this invention can also be used for post-tensioning concrete pipe and the like by disposing the tendon, e.g., tendon 4, in a helical path within the wall of a pipe 66, held in the tensioned condition by end clamps 6 as shown in FIGS. 21 and 22. Although only one tendon is shown, normally a plurality of such tendons will be used with the ends terminating at spaced points or about the outer surface of the pipe as shown for tendon 4 or about the ends 69 of the pipe. The helix angle of each tendon will depend on the angle of wrap desired for the particular tendon used. For low coefficients of friction, e.g., 0.009, a relatively large angle of wrap can be employed which means for a given length of pipe, the helix angle of the tendon can be less than for tendons having a higher coefficient of friction. Each tendon need not go from end-to-end of the pipe but can terminate at an intermediate point, with other helically disposed tendons starting progressively later and extending progressively further along the length of the pipe. The post-tensioned concrete pipe is made, for example, by arranging a wire mesh cylinder within the form for the pipe and concentrically about its longitudinal axis, helically winding the number of tendons desired about this cylinder, pouring the concrete in the form, allowing the concrete to harden sufficiently, followed by post-tensioning and end clamping the tensioned wires. Preferably the tendons within the wall of the pipe 66 are closer to the outer surface 67 than the inner surface 68 thereof.

Composite tendons such as shown in FIGS. 6 through 11 can be used in each of the patterns depicted herein. For patterns entailing a reversal in the direction of travel of the tendon, the plane of the composite tendon need only be made parallel to the pin 42 at the point of reversal and wound therearound similar to the manner shown for tendon 4 in FIG. 16.

As is evident from the tendon patterns of FIGS. 13, 14, 17, 18 and 19, the tendons of this invention can be used in patterns requiring extreme reversal conditions. For example, when the total angle of wrap for a tendon having a coefficient of friction of about 0.009 or as high as 0.02 is 180°, the variation of stress along the length of the wire is barely noticeable. Patterns in which the angle of wrap is 1,000° or more can be employed in which the stress at one end of the tendon is within at least 70 percent, preferably at least 80 percent, of the stress at the opposite end. The path of the tendon from reversal point to reversal point can be substantially straight; however, the path can be draped as well. By tensioning the wire at both ends instead of just one end, the angle of wrap (curvature) is reduced by one-half (the example angles of curvature hereinbefore recited and the coefficients of friction desirable thereat refer to tensioning at one end). Thus, for the pattern of FIG. 19, while the tendon 4 undergoes sufficient reversals to total about 2,000° for the pattern, each end of the tendon need only be tensioned around about 1,000° angle of wrap. Preferably, however, the pattern of FIG. 19 is made with two tendons so as to provide four ends for tensioning; this can be done by interrupting the single tendon shown in FIG. 19 at or near its midpoint and having the resultant ends extend through the steel ring 63. The consistency of stress and thus uniformity of elongation can be determined experimentally using the "belt" formula, which is $F_2 = F_1 e^{\mu \theta}$ wherein F_1 = jacking end tension, F_2 = tension at other end of wire and μ = coefficient of friction and θ is the total angle of curvature or wrap of tendon, and e is the natural logarithm base. The coefficients of friction recited herein are determined by using this formula. For further explanation of the formula, reference is made to T. Y. Lin, Design of Prestressed Concrete Structures, Second Edition, 1963, page 110.

Any of the anchoring systems of the prior art which is effective on small diameter tendons may be used to anchor tendons of this invention. A suitable end clamp is shown, for example, in U.S. Pat. No. 3,137,971 to Rhodes.

ANCHORING SYSTEMS

Another anchoring system which may be used, but which use is not limited to the tendons of this invention, is that which is shown in FIG. 23. In this FIG. is shown a portion of a concrete structure 70 terminating in an outer surface 72 which has a cavity 74 therein. Protruding from the recessed surface 76 of the cavity is a tendon which for illustrative purposes is an end of a tendon 4 in the elongated condition but could be the end of any known tendon or an individual tendon of the composite tendon or an individual tendon of the composite tendon of FIG. 6. The protruding portion of tendon 4 is crimped in a series of reversals which increase in angularity, that is, a progressive increase in the size of angles A, B, C and D in that order (the bends in the tendon become sharper) in the direction away from the surface 76. Running coextensively with crimped portion of the tendon 4 is a tubular metallic sheath 78. The sheath 78 confines the crimp of the tendon 4 to prevent it from withdrawing into the concrete structure 70 and relieving the compression on the concrete. The degree of bending in the crimp is sufficiently high so that the axial stress required to withdraw the crimped tendon into the concrete member 70 at all times is greater than the operating stress on the tendon (wire 8), generally at least 30 percent greater; therefore, this withdrawal does not occur. Generally, the bend angle of the reversals is not sufficient to destroy the continuity of the plastic jacketting, if such jacketting is present, thereby maintaining its integrity for corrosion protection purposes. The compressive force on sheath 78 is transmitted to concrete structure 70 through apertured bearing plate 80 positioned therebetween for load distribution purposes. If desired, cavity 74 can be filled by grouting after completion of the post-tensioning and anchoring to form a smooth continuation of outer surface 72.

The anchoring system shown in FIG. 23 can be achieved, for example, by elongating the protruding end of tendon 4 by conventional hydraulic jacking procedures with the protruding end having been previously inserted through sheaths 90 and 92, with the sheath 92 having clamping nuts 94 in threaded engagement with apertures in the sheath wall, as shown in FIG. 24. After elongation of the wire, the clamping nuts 94 are threaded into and against the tendon 4 to engage it with high friction and to press it into corresponding recesses 93 in sheath 92. When the jacking force is removed (FIG. 25), the clamping action of nuts 94 maintain the tendon in the elongated condition and leaves the protruding end of the tendon 4 free to move with the crimping of the sheath 90 as shown in FIG. 26. Upon completion of this crimping, the clamping nuts 94 can be unthreaded from the sheath 92, the sheath 92 slid over the free end of the tendon 4 and the tendon trimmed back to the outer extremity of the crimped sheath 90, which would then resemble the crimped sheath 78 of FIG. 23, confining the remaining protruding end of tendon 4 in the crimped condition and transmitting a compressive force to the concrete structure 70 through apertured bearing plate 80.

The deformations and load carrying capacity in the crimped portion of the tendon are distributed along the length of crimping instead of being localized. The stepwise increase in severity of the vending in the direction away from the concrete structure leads to each bend in the tendon 4 carrying a portion of the tensile load of the post-tensioned tendon. This is a positive end anchor that depends on the deformation of the tendon and sheath rather than frictional engagement between the tendon and sheath. While each deformation of the tendon is a stress riser, the progressive increase in bend severity and thus stress riser moving away from the concrete is inverse to the variation in tensile load along the crimped portion of the tendon. The highest tensile load is at the bend closest to the concrete structure, but that bend is the least severe and therefore the lowest stress riser. The outermost bend is the highest stress riser, but the tensile load at that point is the lowest, increments of the tensile load having been assumed by preceding bends.

The number of reversals required for the crimped portion of the tendon and the crimped sheaths will depend on the tensile stress in the tendon and on the sharpness with which the tendon and sheath are bent. Generally, it is desirable to have the bend of each angle of the crimp progressively decrease by at least about 5° moving in the direction away from the concrete structure. "Bend angle" means the included angle formed by the crimped tendon.

Equipment which is suitable for simultaneously forming all of the crimps in the tendon end and sheath is shown in FIGS. 27 to 31. The apparatus 100 comprises a support structure 102 for positioning against the side of a concrete structure 104 from which the end of a post-tensionable tendon protrudes. In the embodiment of FIG. 27, the tendon is the composite tendon 14 of FIG. 6 but consisting of four tendons 106, with the tendons 106 being fanned-out within the concrete structure, so as to individually protrude from the side thereof. A sheath 108 is slipped over an end of one of the tendons 106 and the tendon is post-tensioned using jaws 110 of a jack (not shown). The apparatus 100 is provided with a fixed holding structure or jaw 112 for a series of crimping elements 114 on one side of the sheath 108 and on the other side of the sheath, a movable holding structure or jaw 116 for crimping elements 118. The crimping elements 114 and 118 are arranged such that when jaw 116 moves towards jaw 112, the sheath is crimped into a series of reversals rather than pinched. This movement is accomplished by a jack 120 mounted to the support structure 102 and operating on jaw 116. This operation is repeated for each tendon 106; as shown in FIG. 27, the operation has been completed for one tendon 106. As shown in FIG. 28, the ends of the tendons 106 protrude in a staggered pattern from the concrete structure 104 to enable the apparatus 100 to fit between the tendons.

The change in bend angle along the length of the crimp is accomplished by the configuration of the surfaces of the crimping elements contacting the sheath. FIG. 29 shows a representative series of crimping elements 122, each of which have converging faces 124 terminating in an edge 126 directed towards the longitudinal axis of sheath 108 containing tendon 106 to be crimped. This series is useful in opposing relationship like elements 114 and 118. The angles between the converging faces of each crimping element 122, viz., tooth angle, increases step-wise from right to left from 60° to 160° as indicated, with the largest tooth angle being closest to the concrete structure. The larger the tooth angle, the less sharp is the bend caused in the sheath. Generally, the bend angle in the sheath will correspond to the tooth angle.

As shown in FIGS. 30 and 31, the faces 124 and edge 126 of each crimping element 122 have a concavity 128 therein, forming a rounded forward edge 130 where element comes into contact with the sheath 108.

All of the protruding ends of tendons 106 can be contained within a single cavity formed by the concrete structure, such as cavity 74 of FIG. 23, or separate such cavities can be provided for each tendon end. The relative sizes of the crimping apparatus and the cavity will control whether the former can be used within the cavity. If the crimping apparatus does not fit within the cavity, the apparatus can be used in abutting relationship with the outer surface of the concrete structure, e.g., surface 72 of FIG. 23, with the crimped sheath-tendon being allowed to withdraw into the cavity of the concrete structure, followed by grouting. While this withdrawal somewhat relieves the tensile force of the tendon, such relief would be insignificant for long tendon lengths and moreover can be adequately compensated for by a corresponding increase in the tensile stress applied by post-tensioning.

While the foregoing method and apparatus for anchoring the end of post-tensioned tendons has been described for tendons 106 which are the same as the tendon of FIG. 3, this method and apparatus can be used for post-tensionable tendons in general, so long as the tendon is crimpable in the series of reversals described. The heavier the gauge of the tendon, the heavier is the crimping apparatus required. Thus, use of

tendons of the present invention, e.g., of FIG. 3, is preferred, since the corrosion protection provided by the ingredients of layer 12 and coating 10 of plastic material enable light gauge tendons to be employed.

The tubular metallic sheath that is useful in the anchoring system of this invention can be of any metal and dimension which is sufficiently deformable to undergo crimping without fracture and which retains the crimp. Preferably, the sheath is corrosion resistant so as to protect the crimped portion of the tendon from corrosion. Annealed stainless steel tubing, e.g., No. 304 or 410 stainless steel, is preferred. By way of example, a crimping apparatus similar to that of FIG. 27, containing opposing series of crimping elements of FIG. 29 is used to crimp a No. 410 stainless steel tubing 5 inches long $\times$ 0.1875 inch O.D. $\times$ 0.125 I.D. about an end of 0.080 inch diameter high tensile wire extending through a concrete slab and under a tension of 850 lb. The crimp is accomplished using a crimping force on the movable jaw of the apparatus of 8,960 lb. After crimping, the sheath exhibits bend angles closely approximate those of the crimping elements. The tensile force remaining by the wire after crimping is about 835 lb.

With the crimped sheath encasing the protruding end of the tendon, the anchoring system of this invention lends itself to complete protection, independent of grouting, of the protruding end of the tendon from corrosion and failure resulting from such corrosion. Such complete protection can be obtained by providing sealing means at each end of the crimped sheath for sealing the junction between the sheath and the concrete and any open space between the ends of the sheath and the tendon encased thereby. In one embodiment, as shown in FIG. 32, part of this sealing is obtained by providing a waterproof gasket 132 compressed between a flared section 134 of a crimped sheath 136 and a post-tensioned tendon, e.g., tendon 4, extending into a cavity 138 in a concrete structure 140. The sheath 136 resembles sheath 90 (FIG. 24) prior to crimping, except for the presence of the flared section 134 which is preformed thereon. The angle which the flared section makes with the precrimped longitudinal axis of the sheath is such that the flared section does not flare further to any appreciable amount when the tensile load of the wire is placed on the sheath. Generally, the flare angle should be between about 10° and 30°.

The gasket 132 has a circumferential groove 142 intermediate its ends for retaining itself in an aperture in bearing plate 144 and a passage 146 extending therethrough to permit the tendon to pass through the gasket. The outwardly directed section 148 of the gasket has a tapered surface for mating with the inner surface of the flared section 134 of the sheath. The volume of the outer section 148 is sufficiently large, however, that the flared section 134 compresses it against the bearing plate and the tendon when the sheath 136 assumes the tensile load of the tendon, thereby preventing the intrusion of corrosive elements, e.g., moisture. The gasket sealing arrangement can be used with tendons on which no plastic coating is present. The particular configuration of the gasket is unimportant so long as it is one which is compressed by the flared sheath to seal the junctions indicated. Suitable gasketing materials include rubber, natural and synthetic and plastics.

The extremity or outer end of the crimped sheath 136 can be made self-sealing by deforming the sheath into the tendon. For example, as shown in FIG. 33, the end of the sheath 136 is uniformly and radially deformed into the tendon 4 slightly deforming it, whereby the plastic coating on tendon 4 fills all space between the sheath and the wire of the tendon. The cavity 138 can also be filled with a waterproofing material such as grouting.

Another sealing arrangement for use with the crimping technique for anchoring the ends of tendons according to the present invention is shown in FIG. 34 and 35, wherein a tendon, e.g., tendon 4, extends through an aperture in a gasket 150 which is locked in place within an aperture in bearing plate 144 in concrete structure 140. A cuplike member 152 having an aperture in its bottom through which tendon 4

passes is positioned adjacent the bearing plate, followed by a sealing bushing 154, and a sheath 90. The tendon 4 is then tensioned and the sheath and crimped such as in the form shown in FIG. 23. Upon release of the tensioning force, the tendon withdraws slightly into the cuplike member 152, causing the crimped sheath to compress the bushing 154, which, in turn, flows to fill the space between the aperture in the cuplike member and the tendon and the spaces between the tendon and sheath and sheath and cuplike member, as shown in FIG. 35. This achieves a moistureproof seal of the tendon and the gasket 150, a cuplike member 152, and sheath 90. The bushing 154 is made of moistureproof material which is deformable under the conditions described. When the tendon is plastic coated, as is tendon 4 in the embodiment discussed, the material from which bushing 154 is made is preferably softer than the plastic coating on the tendon so as not to impair the integrity of the coating or of the layer 12 underneath. Thus, for example, when the coating is nylon, the bushing can be polyethylene, and when the coating is polyethylene, the bushing can be a softer polyethylene, e.g., one of lower molecular weight.

Although the anchoring systems discussed herein in detail have been illustrated at one end of tendons only, these systems are equally applicable to the opposite ends or to other means for end fastening at such opposite ends.

BONDED TENDON

Another embodiment of the present invention resides in the provision of a post-tensionable tendon which is applied in the manner of other post-tensionable tendons except that only temporary anchoring of the ends of the tendon are required to retain the concrete structure under compression. This embodiment of tendon, as shown in FIG. 36, consists of an outer covering 160, a core 162, which is the post-tensionable part of the tendon, and a layer 164 of a lubricious, curable bonding material, the covering 160 and layer 164 being present along the length of the core. The material of layer 164 is lubricious to permit the core to be post-tensioned while the covering 160 remains embedded in the concrete structure and is curable to bond the tensioned core to the covering and thus to the concrete structure along the length of the core. The tensioning force on the core is then released. Because of the bond of the core to the concrete structure, the core remains elongated and the concrete structure remains under compression.

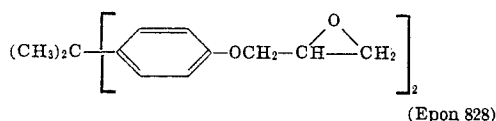
The covering 160 can be the same as coating 10 previously described, with the tightness thereof being desired in this embodiment for achieving the bond uniformly along the length of the core. The uniformity in the coating thickness and interior surface desired for tendon 4 is not as necessary for the embodiment of FIG. 36, however, unless low coefficients of friction are desired. Thus, in some applications in which some sacrifice in coefficient of friction can be tolerated, covering 160 can be of tape wrapped such as in helical fashion about the layer 164 on core 162.

The core 162 can be the same as wire 8 of the tendon of FIG. 3, of any diameter desired, or can be a multiple strand tendon.

The material of layer 164 can be one which is curable in situ to change from a liquid to a solid which bonds the core to the covering. The material of layer 164 should not cure at room temperature so as to be storage stable, but is heat activatable so as to be cured when desired by heating. Typically, curable plastic materials (resins) can be used. For example, epoxy resins can be cured from the liquid to the solid form by heating in the presence of a curing (hardening) agent. Thus, the layer 164 can be made of a blend of epoxy resin and curing agent which do not interact until some predetermined temperature is reached, e.g., 100 to 18020 C. This temperature can be reached by connecting the post-tensioned core to form a resistance portion of an electrical circuit, to cause the wire to heat, thereby heating the epoxy resin-curing agent blend, causing it to cure and bond the core in the elongated condi-

tion. Solid lubricants can be present in the blend to aid in the uniform posttensioning of the core, but not to interfere with the subsequent curing process.

Suitable epoxy resins include the hydrocarbon polyepoxides, i.e., epoxides having more than one epoxy group per molecule. These include epoxides containing ether linkages and both symmetrical and asymmetrical epoxides. Also included are the epoxides (commonly available as "Epon" resins) prepared by reacting a polyhydric phenol with a polyfunctional halo-epoxy alkane. Curing agents include polyfunctional amines (commonly available as "Epon" curing agents), acids and acid anhydrides. Examples of suitable epoxy resins and some high temperature curing agents are disclosed in U.S. Pat. Nos. 2,500,600; 2,695,894 and 2,829,124. Specific epoxy resins include vinyl cyclohexane diepoxide (Unox 206), dipentene dioxide (Unox 269), and



The curing agent can be supplied adsorbed in molecular sieves (synthetic crystalline metal aluminosilicates known as zeolites) blended with epoxy resin to form layer 164, which isolates the curing agent from the epoxy resin until released from the sieve, which can be accomplished by heating. This enables lower temperature curing agents to be used. These chemically loaded molecular sieves, containing agents for curing epoxy resins, are described in Union Carbide publication, "Chemical-Loaded Molecular Sieves in Rubber and plastics," Nos. F-2675 and F-2767.

ADDITIONAL SPECIFIC EMBODIMENTS

EXAMPLE 1

Details illustrating one application of one embodiment of low friction tendon of this invention are as follows: a form for the pouring of a concrete slab measuring 120 in. $\times$ 12 in. $\times$ 3 in. is prepared having 3 in. angle iron extending along each 12 in. dimension. The angle iron has apertures at $\frac{3}{4}$ in. spacing extending along a line which is 1 $\frac{1}{2}$ in. from the bottom surface of the form. Nineteen tendons are laid out in separate straight and parallel paths within and along the length of the form, with the ends of the tendons protruding through the apertures in the angle iron and tensioned with 100 lb. per tendon. Each tendon consists of a cold drawn carbon steel wire of 0.08 inch in diameter and having an elastic limit of 240,000 p.s.i., a uniform layer of about 0.0007 inch in thickness of the corrosion inhibitor-lubricant hereinbefore described, blended with (50:50 mixture) a polytetrafluoroethylene dispersion containing 60 percent by weight solids, and a tight and uniform coating of 610 nylon of 0.01 inch in thickness applied by a tubing type extrusion die. The coefficient of friction between the wire and the coating is 0.08. Concrete which has a compressive strength of about 5,000 p.s.i. upon curing is poured into the form and allowed to harden. Metal sleeves measuring .0125 I.D. are then positioned about each protruding end of each tendon; each sleeve has four setscrews threaded therein along its length. The setscrews of the sleeves extending along one end of the slab are all tightened against the corresponding protruding ends of the tendons. The opposite protruding ends are individually jacked (jack grips bare wire of tendon) to a tensile reading of 1,000 lb., thereby imposing a stress of 200,000 p.s.i. on each wire. While the stress is maintained the metal sleeve is moved to abut the angle iron, and the setscrews are tightened against the tendon to maintain the stress (except for diminishment due to creep) upon release of the jacking force. To test the load carrying capacity of the slab, it is supported from its ends by 4 inch $\times$ 4 inch $\times$ 4 inch blocks and loaded at the center. The slab resting on the blocks supports a load of 425 lbs. prior to initial cracking and 750 lbs. before failure of the concrete.

EXAMPLE 2

In another application, a form for a slab measuring 32 inch $\times$ 64 inch $\times$ 1 $\frac{1}{2}$ inch is constructed and two tendons are disposed therewithin to form the tendon pattern shown in FIG. 17 in a plane about midway in the 1 $\frac{1}{2}$ inch direction. Each tendon consists of a cold drawn carbon steel wire of 0.050 inch in diameter having an elastic limit of 300,000 p.s.i., a uniform layer of the corrosion inhibitor-lubricant/polytetrafluoroethylene dispersion blend hereinbefore described measuring about 0.005 inch in thickness, and a tight, uniform coating of 610 nylon of 0.010 inch in thickness. The reversals (totaling 450° for each tendon) in the tendon pattern are formed by passing the tendons around six inch diameter tubes. Concrete which has a compressive strength of about 5,000 p.s.i. is poured into the form and allowed to harden. The tendons are tensioned and clamped as described in the preceding paragraph, with the jacking force of 470 lb. at one end of each tendon producing a force to about 400 lb. at each of the opposite ends thereof. These two tendons add 117 lb./ft.² to the uniform load carrying capacity of the concrete slab. When the number of like post-tensioned tendons is increased to 20 in a pattern like that shown in FIG. 15, except that the tendons return to the starting end of the slab as shown in FIG. 17, the uniform load carrying capacity of the slab is increased by 11.7 lb./ft.².

EXAMPLE 3

These examples are repeated using polyethylene in one instance and ethylene/methacrylic acid copolymer partially neutralized with metal ion to form ionic copolymer such as described in U.S. Pat. No. 3,264,272 to Rees, in another instance, in place of the nylon coating, to obtain substantially the same results.

EXAMPLE 4

In still another example, the low coefficient of friction between wire and coating of plastic material was obtained by applying a 2 mil coating of polytetrafluoroethylene enamel to the wire, followed by baking, coating with corrosion inhibitor-lubricant, and coating with plastic material.

EXAMPLE 4 (Bonded Tendon)

A high-tensile steel wire 0.105 inch in diameter and having a breaking strength of approximately 2,500 lb. corresponding to a tensile strength of 300,000 p.s.i. was coated with a viscous layer of blend of "Epon" 828 epoxy resin containing a curing agent active at temperatures above 100° C. The viscous epoxy and activator was formulated in the following manner: The blend is prepared by mixing together 70 parts by weight of the epoxy resin with 30 parts by weight (solids bases) of the curing agent which is a benzoguanamine formaldehyde normal butanol condensation product prepared under slightly acid conditions (66 percent solids by weight). This blend was milled together with 25 percent by weight of finely ground polytetrafluoroethylene solid lubricant resin (granular) to form a homogeneous mixture. The resultant blend was then applied to the wire to form a layer averaging 0.003 inch in thickness surrounding the wire. The coated wire was then dried and was helically wrapped with three overlapping layers of 1 inch wide ethylene/vinyl acetate copolymer coated polyester film having a total thickness of 0.0015 inch. This wrapped tendon was then heated sufficiently at 95° C. To melt the ethylene/vinyl acetate copolymer coating on the polyester film to bond one layer of the film to the next, thereby creating an impervious polymer jacket.

The resultant tendon was positioned across a wooden concrete form of the type used for reinforced concrete construction. Concrete was poured into the form and cured, followed by jacking of the ends of the wire to produce a desired axial stress in the wire of 2,000 pounds. An AC-DC welding machine of a conventional type was connected to the wire and the welding machine was energized to cause low voltage DC

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electrical power to flow through the wire causing electrical resistance heating of the wire. Prior to pouring of the concrete thermocouple leads were connected to the wire at a point within the wooden form. The amperage delivered to the wire by the welding machine was adjusted to give a thermocouple reading indicating a temperature of 170° C. , which was held for 60 minutes. After allowing three hours for cooling, the jacks were disconnected from the ends of the wire. No noticeable drawback of the wire into the concrete occurred. The 2,000 pound axial force in the wire was transmitted to the concrete structure by the bond of the cured epoxy resin between the film wrapped covering and elongated wire. To demonstrate the bond, one end of the wire extending from a 40 inch long section of the concrete was jacked to produce an axial stress slightly less than the breaking strength of the wire; the wire could not be extracted.

As many apparently widely different embodiments of this invention may be made without departing from the spirit and scope thereof, it is to be understood that this invention is not limited to the specific embodiments thereof except as defined in the appended claims.

I claim:

1. A process for anchoring an end of a post-tensioning tendon which protrudes from a concrete structure so as to place

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said structure under compression, comprising encasing said end of said tendon in a sheath, tensioning said tendon and crimping said sheath and said tensioned tendon encased thereby in a series of reversals of increasing angularity in the direction away from said concrete structure sufficiently to maintain said tendon in the tensioned condition upon release of said tensioning.

2. In the process of claim 1 placing a bearing plate between the sheath and the concrete structure to distribute the compressive force.

3. In the process of claim 1 using a tendon which is made of steel wire having an elastic limit of at least 150,000 p.s.i. and using a sheath which is a tubing of annealed stainless steel.

4. In the process of claim 1 using a tendon which is made of cold drawn carbon steel wire having an elastic limit of at least 150,000 p.s.i. and using a sheath which is a tubing of annealed stainless steel No. 410.

5. In the process of claim 1 using a tendon which is made by tightly and uniformly coating a steel wire having an elastic limit of at least 150,000 p.s.i. with a plastic material, there being a coefficient of friction no greater than 0.09 between the wire and the coating, and using a sheath which is a tubing of annealed stainless steel.

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