United States Patent

Magers et al.

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[45] **Aug. 29, 1972**

[54] **PRESTRESSING APPARATUS**

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[21] Appl. No.: **49,628**

[52] **U.S. Cl.** ....**242/7.21,** 226/172, 226/195, 242/147 R

[51] **Int. Cl.** **B21f 17/00,** B21f 45/00

[58] **Field of Search**..........242/7.21, 7.22, 7.23, 7.02, 242/156, 156.2, 195, 172, 155 BN, 147 R, 75.53

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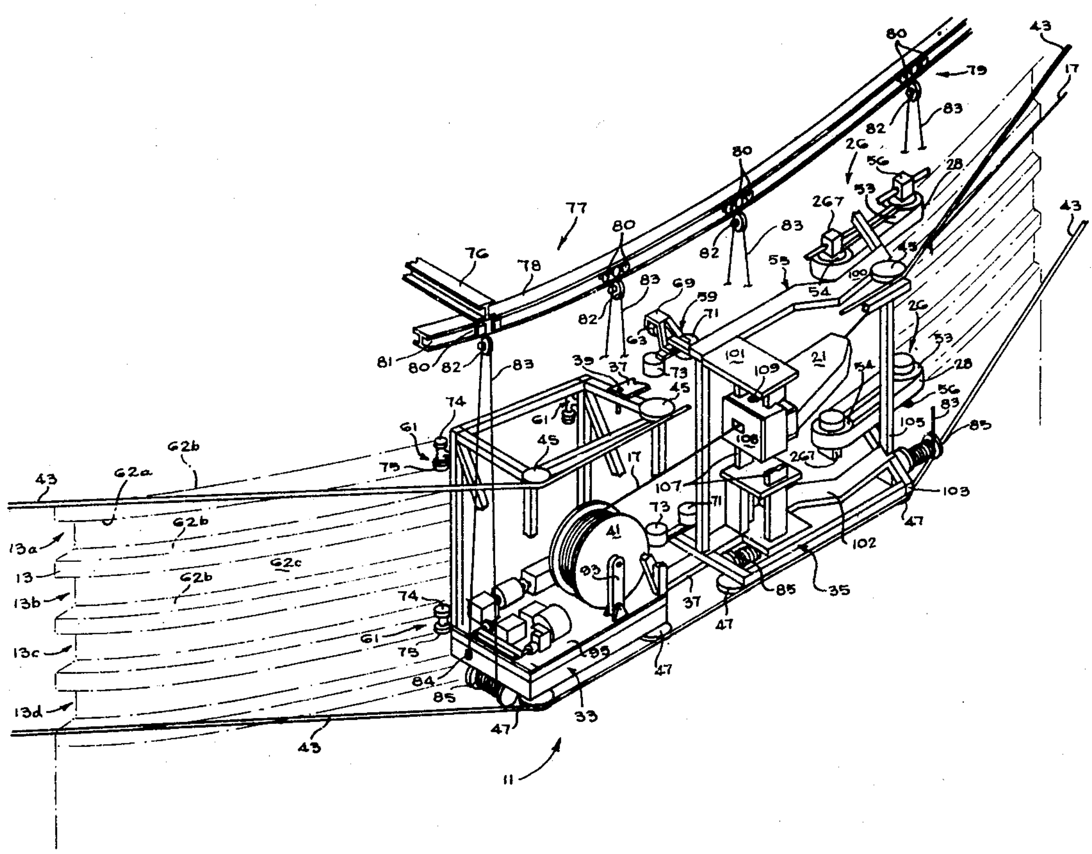
[57] **ABSTRACT**

A method of and apparatus for banding a wall of a structure with a tensioned tendon. The apparatus comprises a carriage movable about the wall of the structure and a tendon tensioning means for stressing the tendon while the tendon is held and moved along a substantially straight line path of movement aligned with a tangent to a point at which the tendon is banded on the structural wall.

27 Claims, 13 Drawing Figures



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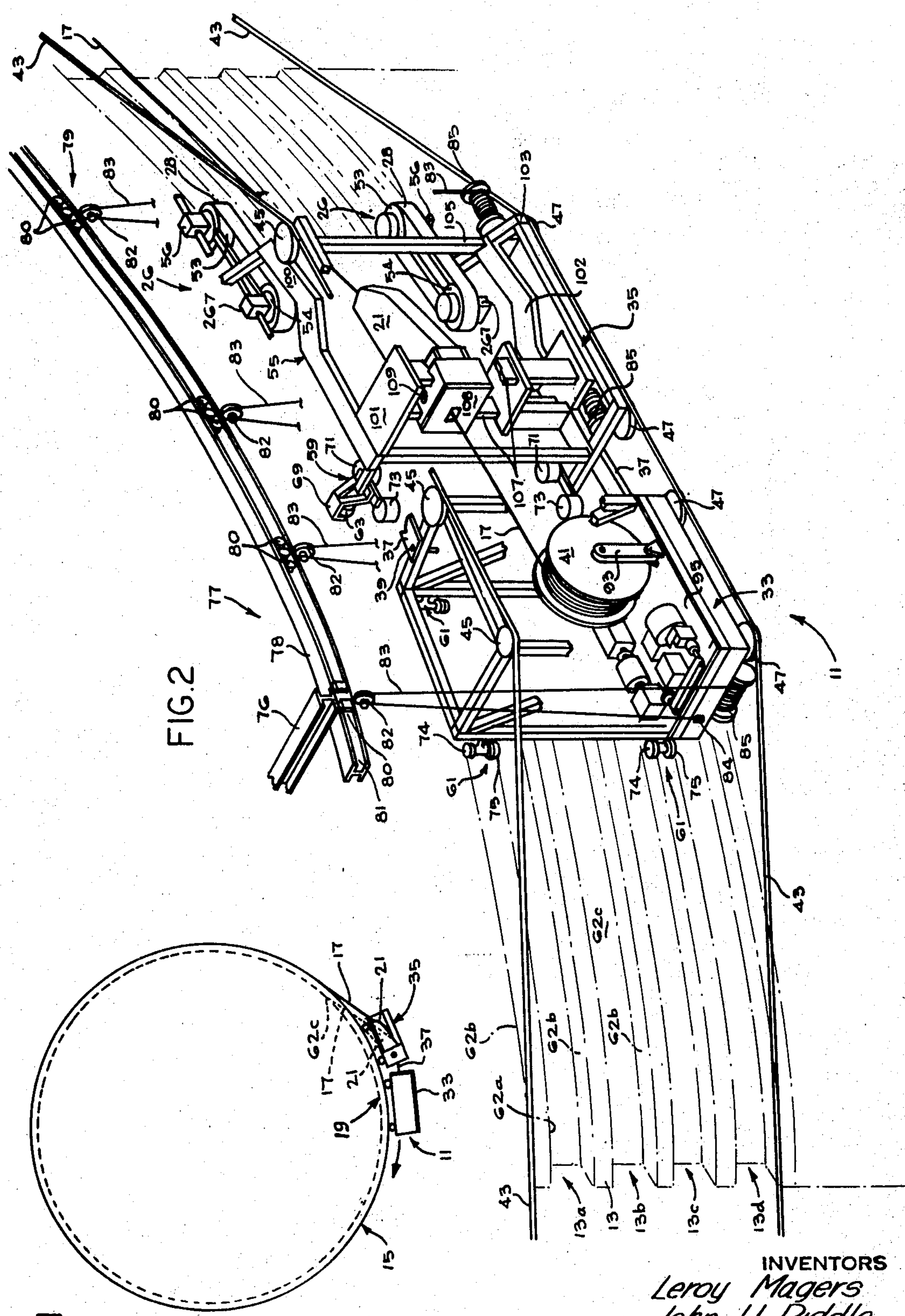

FIG. 2

FIG. 1

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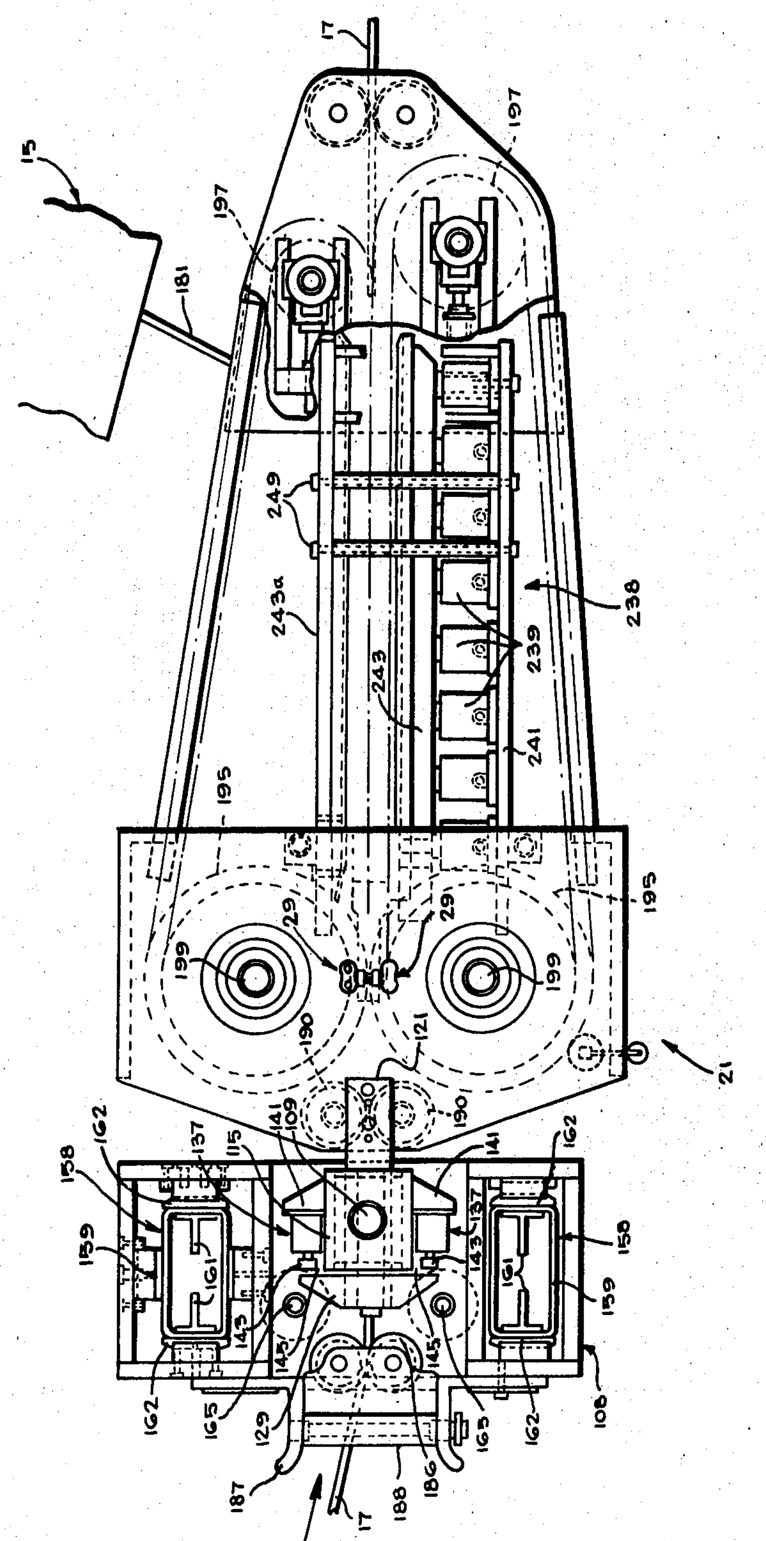
FIG.3



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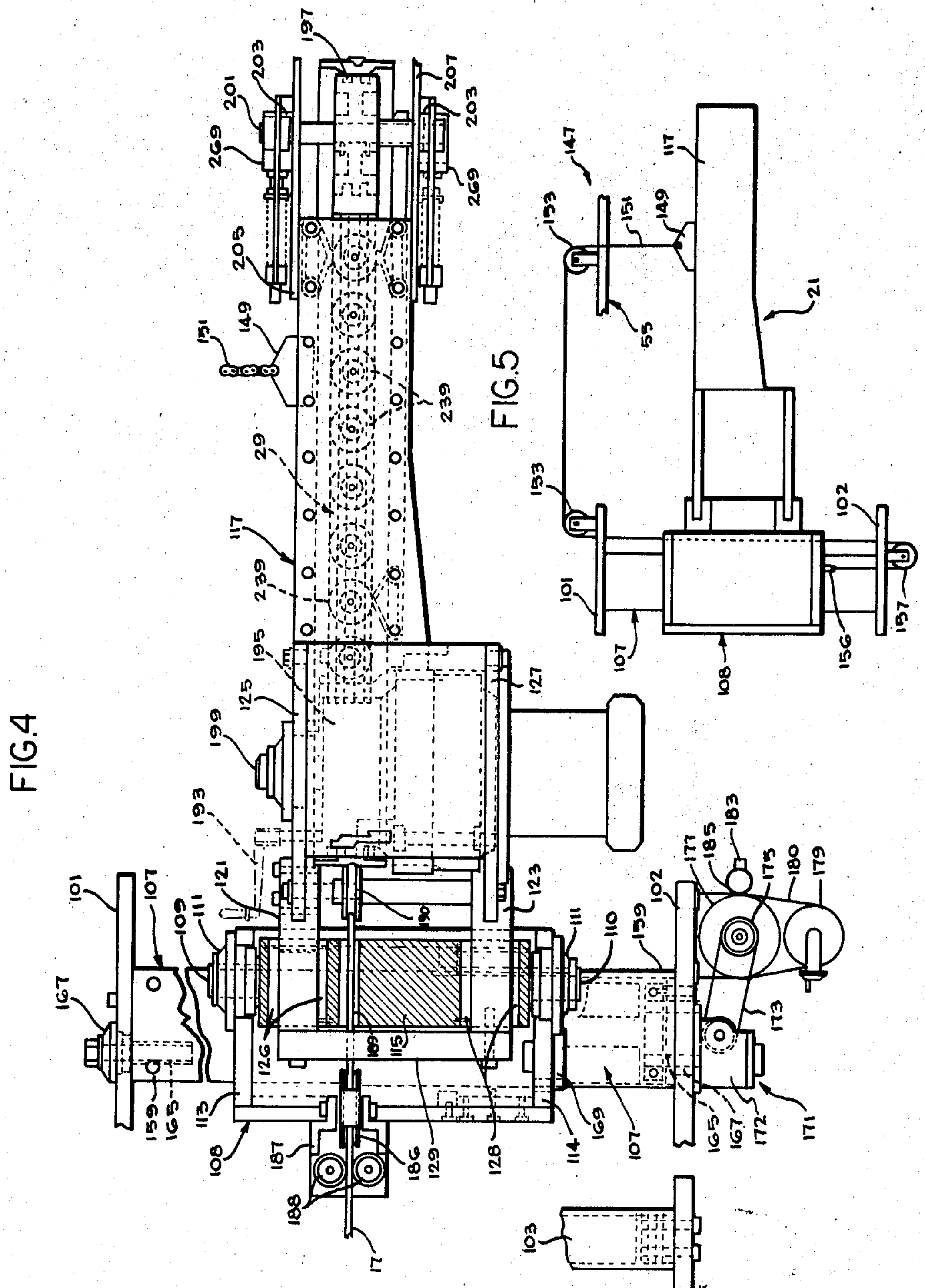

FIG.4 FIG.5

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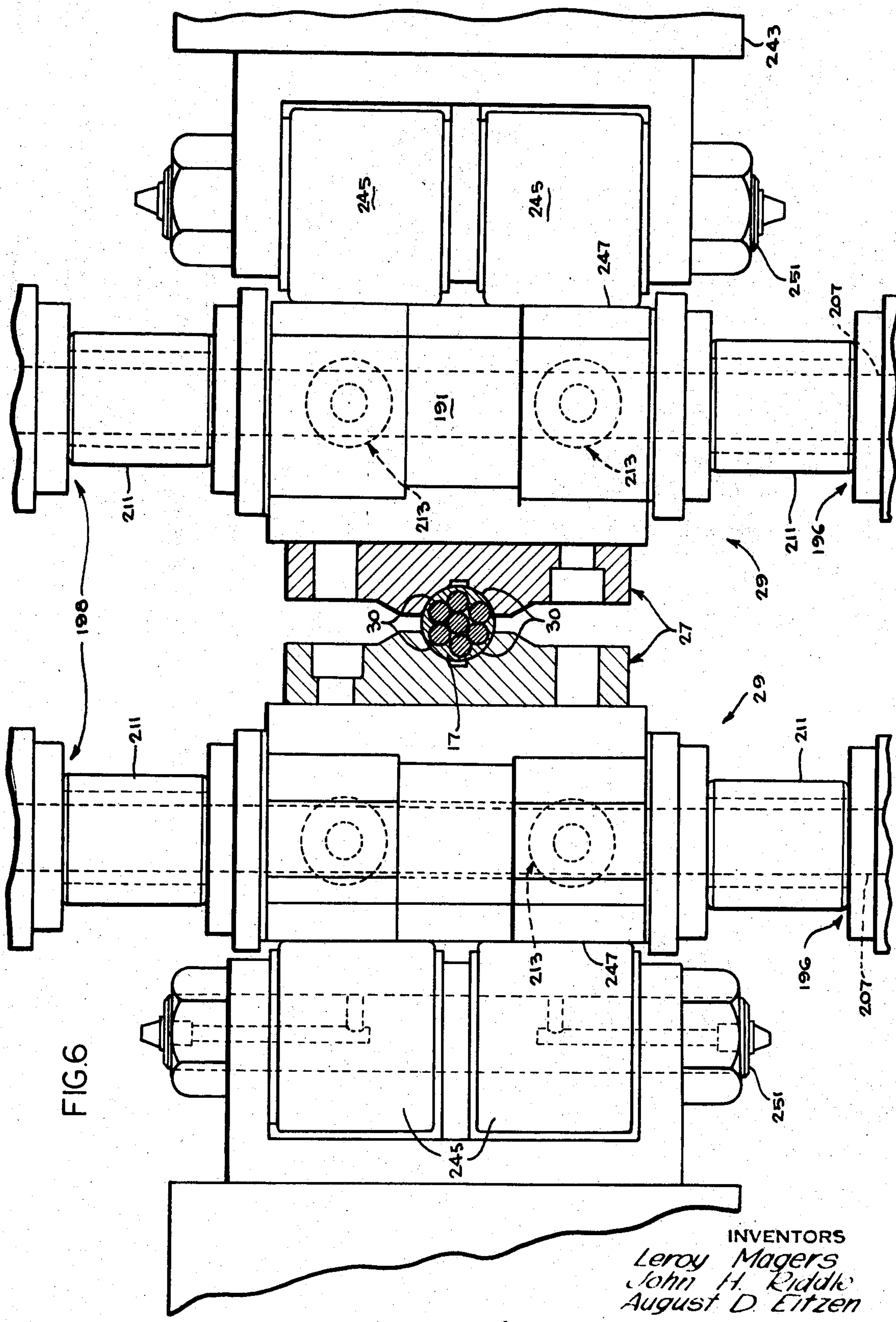

FIG. 6

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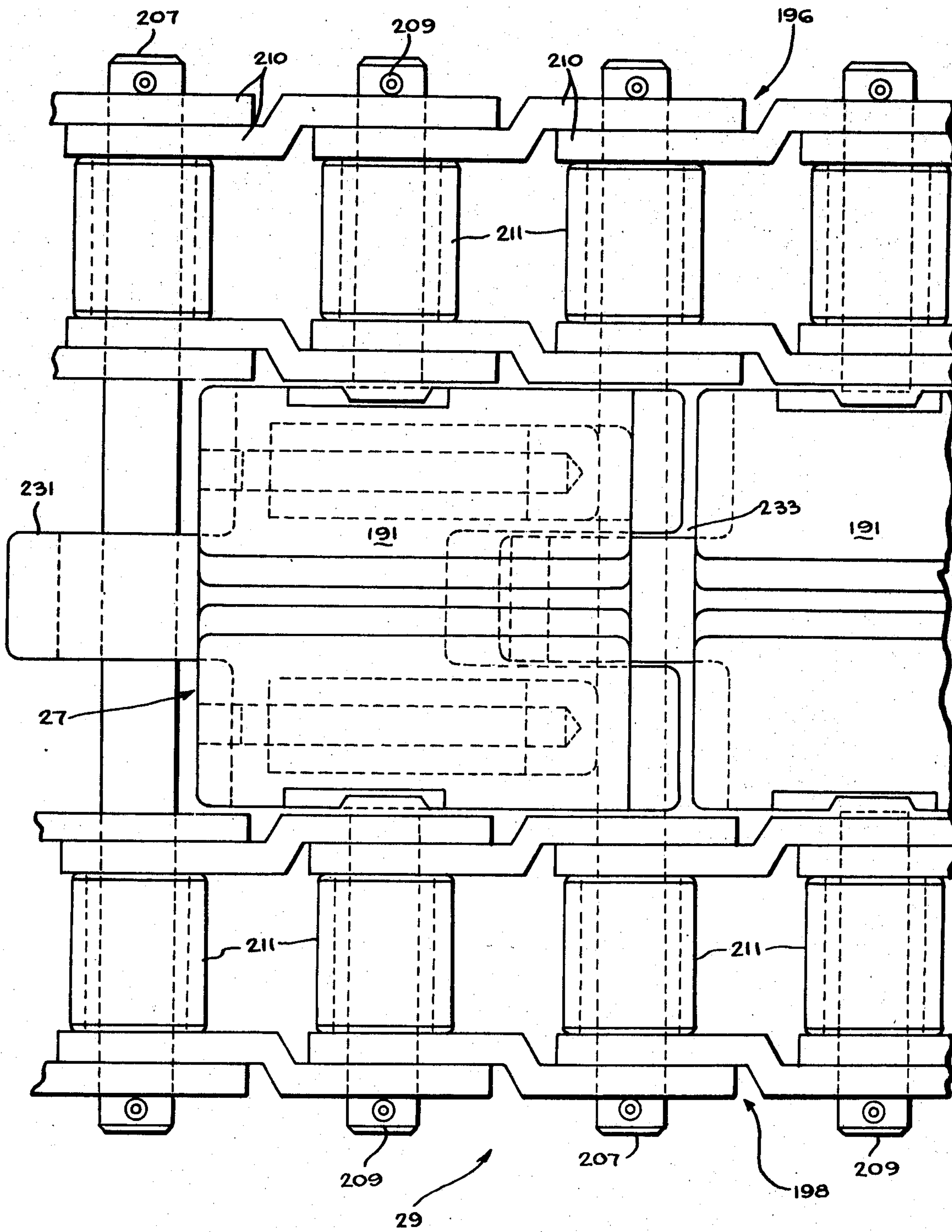
FIG.7



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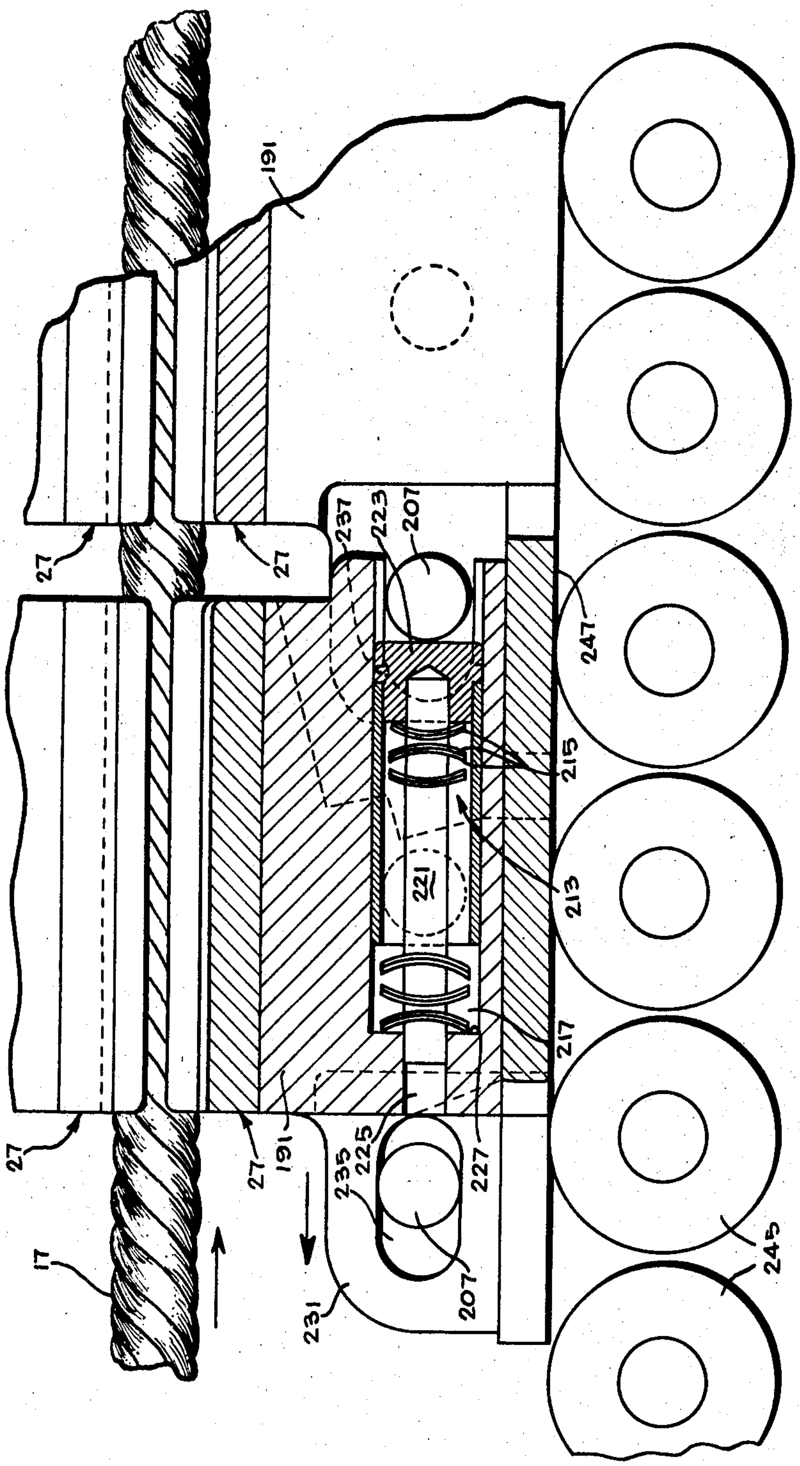

FIG.8

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FIG.9

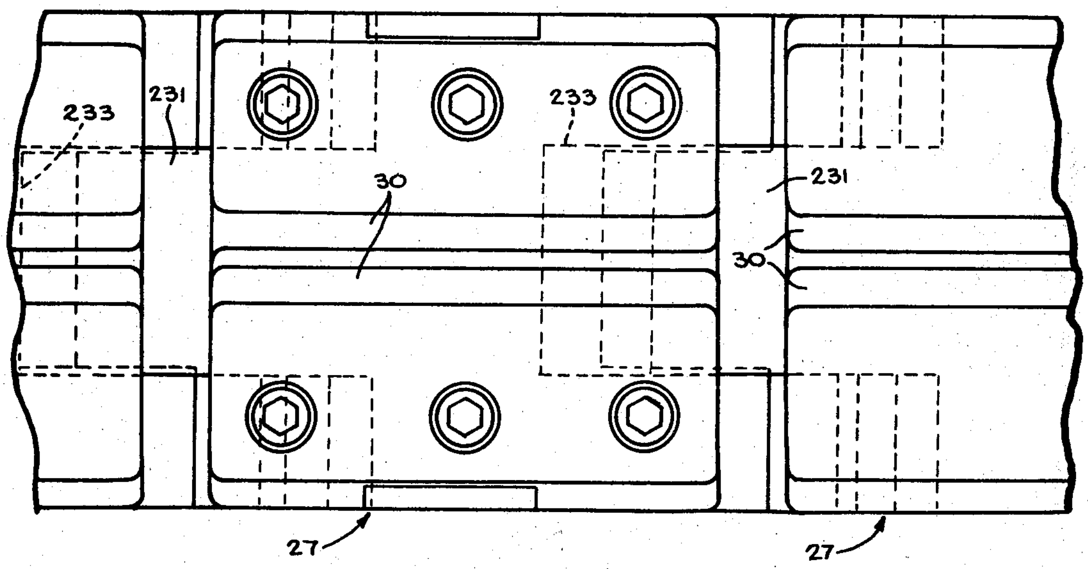

FIG.10

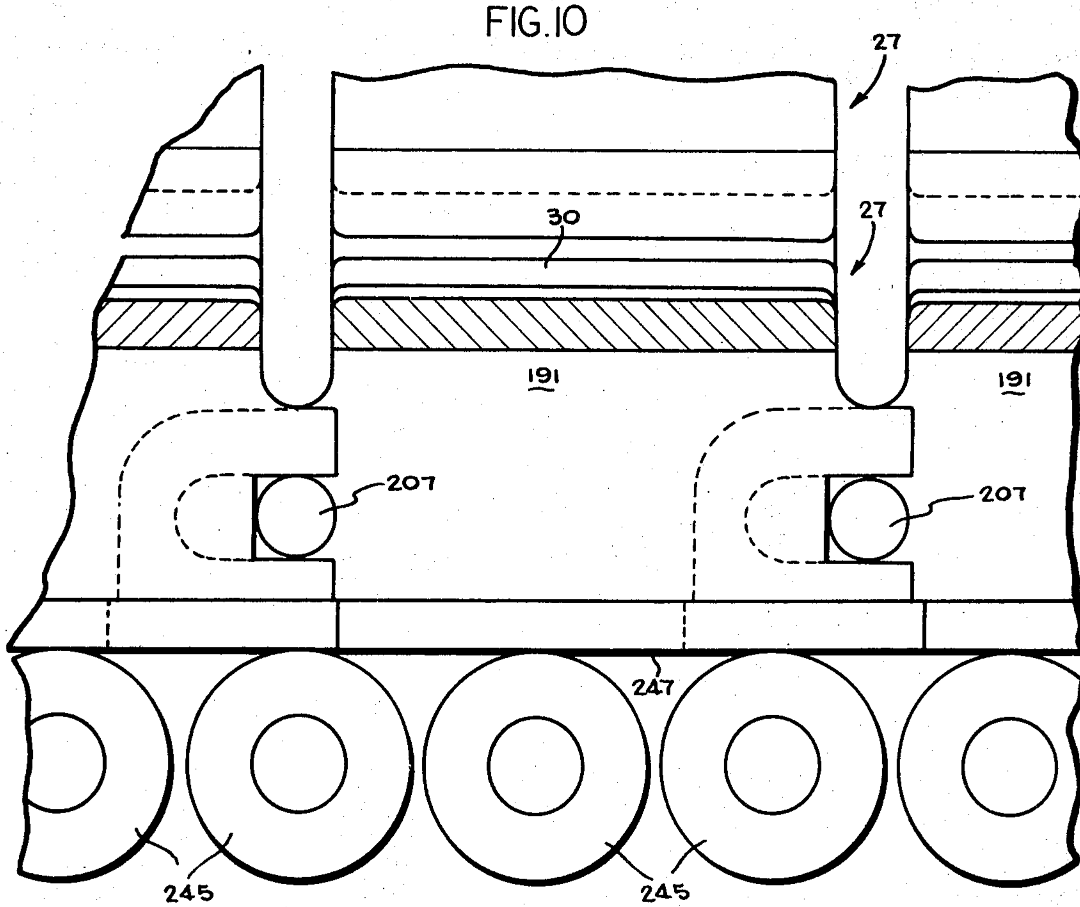

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FIG.11

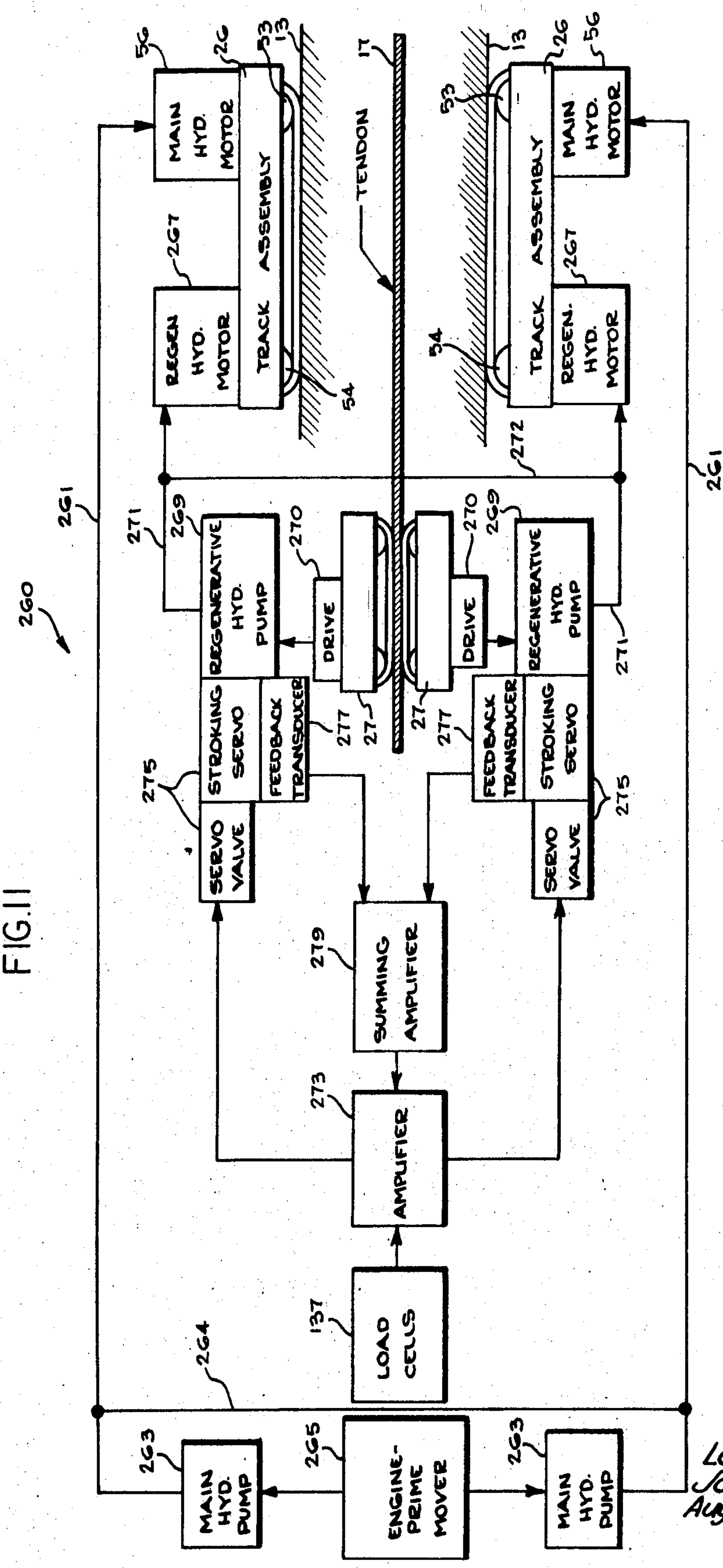

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FIG.12

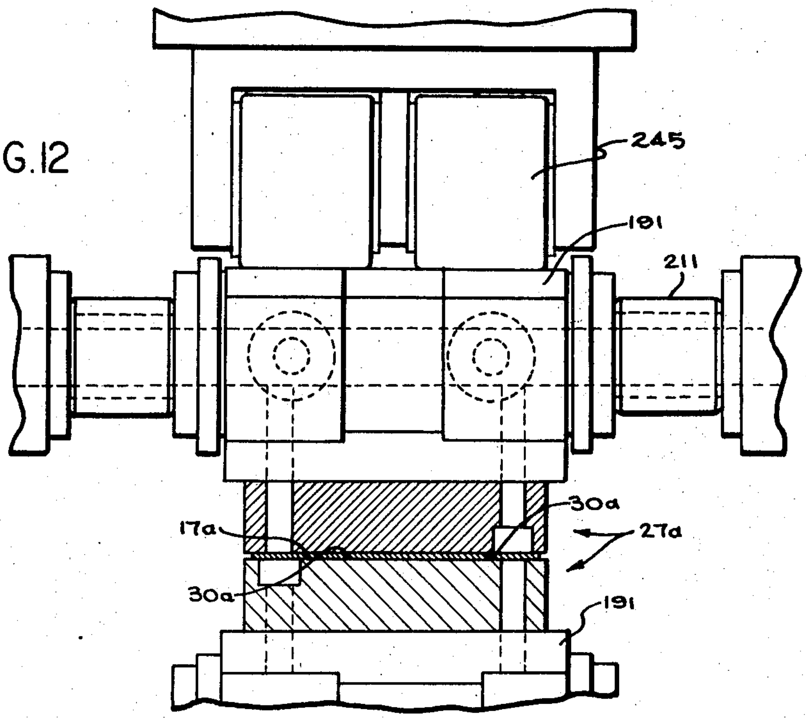
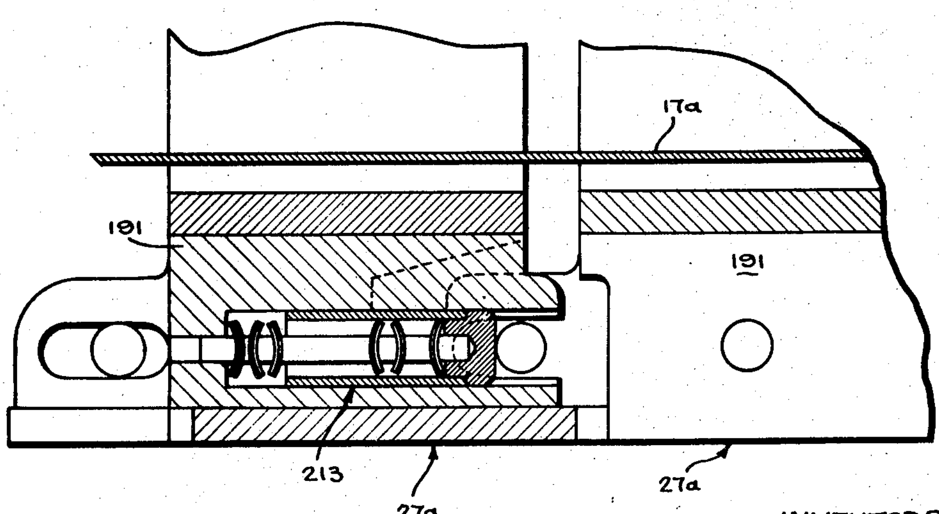


FIG.13



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PRESTRESSING APPARATUS

This invention relates to an apparatus and method for prestressing by banding continuous structures circumferentially with tensioned tendons and more particularly to an apparatus and method in which a carriage moves relative to a wall of the structure while tensioning the tendon and paying out the tensioned tendon to the structural wall.

The art of prestressing is well known, well established and has proven in many applications to be successful. In one example of prestressing, high tensile strength tendons are wrapped about a continuous wall of a structure of any suitable material, such as one made from reinforced or un-reinforced concrete or steel, with the tendons stressed in tension so that the wall of the structure is placed in compression before any substantial load is developed against the wall. When an internal load is placed against the wall, the compressive stress developed in the structure must first be overcome before the wall goes into tension and added tensile stress or tension is developed in the tendon.

Many methods have been suggested heretofore for continuously prestressing structures. In addition, various kinds of apparatus have been proposed to carry out the methods. One system involves the development of a tensile load in the tendon by means of passing it through a die to actually deform the tendon. Such a system is disclosed in U.S. Pat. No. Re. 22,762, issued June 4, 1946. Another system requires the tendon to be wrapped around a wheel or a capstan where a series of independently operated clamps grasp the tendon and develop a stress in it as it travels about the wheel or capstan. Such a system is disclosed in U.S. Pat. No. 3,229,924 to Vogt, issued Jan. 18, 1966. Another capstan or wheel system in which several convolutions of a tendon are wrapped around a wheel is found in U.S. Pat. No. 2,711,291 Kennedy, issued June 21, 1955. The wheel or capstan apparatus and methods, like the die system, cause a non-even stress development in the tendon since the outer portions of the tendon are bent and curved about the wheel or capstan and, hence are stressed to a greater degree along the outer side of the tendon than along the inner side of the tendon. This stressing during bending results in non-even distribution of stresses across the tendon.

Also, many of these prior art methods and kinds of apparatus are of limited usefulness for large size tendons and for banding large structures for which the operational speed of the apparatus becomes important. Thus, for large structures large quantities of tendon must be tensioned and payed out at fast operational speeds for a commercially feasible method.

Accordingly, a general object of the invention is to provide an improved apparatus and method for prestressing a structure.

Another and more specific object of the invention is to tension a tendon more uniformly across its cross sectional area by stressing the tendon while the tendon is moving along a path which is aligned substantially with a line tangent to the wall of the structure.

A further object of the invention is to provide an articulated tensioning mechanism on a carriage movable about the structural wall in order that the tendon may be stressed and maintained on the tangential path for different diameter structures or during a build up of successive convolutions of tendons on the structural wall.

Other objects and advantages of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings in which:

FIG. **1** is an illustrative view of a structure and an apparatus for prestressing the same and capable of carrying out the method of the invention;

FIG. **2** is a partially schematic perspective view of an apparatus in accordance with the present invention shown in relation to a continuous wall of a structure;

FIG. **3** is a top plan view of a tensioning mechanism and support of the present invention;

FIG. **4** is a partially sectional side view of the tensioning mechanism of FIG. **3**;

FIG. **5** is a schematic side view of the tensioning mechanism and vertical alignment system of the present invention;

FIG. **6** is an enlarged sectional view through the tendon and tensioning mechanism;

FIG. **7** is an enlarged sectional view showing the linkage arrangement for the restraining elements of the prestressing mechanism;

FIG. **8** is an enlarged sectional view of a means for accommodating elongation of the tendon during stressing;

FIG. **9** is a fragmentary top view of the restraining elements;

FIG. **10** is a fragmentary side view showing the interrelationship of the restraining elements;

FIG. **11** is a schematic flow diagram showing the drive arrangement for the tensioning head and track assemblies;

FIG. **12** is a view similar to FIG. **6** but showing a flat strip tendon being prestressed; and

FIG. **13** is a view similar to FIG. **8** but for prestressing a flat strip tendon.

As shown in the drawings for purposes of illustration, the invention is embodied in an apparatus **11** for banding a wall **13** (FIG. **2**) of a structure **15**, such as a restraining barrier or tank, with stressed tendons **17** which are used to develop compressive stresses in the wall and to prestress it circumferentially before an internal pressure is applied within the structure. The apparatus is particularly suited for banding very large structures, such as for example 40 ft. to 200 ft. diameter cylindrical vessels at relatively high speeds with large size tendons although the apparatus is useable with smaller or larger sizes of both tendons and structures.

Generally, the apparatus **11** includes a carriage **19** having a tendon tensioning means or mechanism **21** thereon for banding the wall **13** by the method steps of: continuously moving the carriage **19** along a path adjacent the wall **13** of the structure **15**, paying out the tendon **17** from the carriage along a straight line which is tangential to the structural wall, and tensioning and prestressing the tendon **17** while it is moving along a path substantially aligned with this straight line tangential to the wall. With the method and apparatus of this invention, the tendon is stressed without being bent or distorted while "in-line" with a tangent line from the tendon tensioning means to the point at which the tendon is banding on the wall or other previously laid tendons in one of a series of grooves **13***a* – **13***d*. Thus, with the present invention, the tendon receives a more uniform stress distribution than is achieved with conventional tendon stressing operations such as with a die or with a relatively small radius wheel or capstan about which the tendon is bent while being stressed. Such bending while stressing causes a non-even stress distribution across the diameter or equivalent dimension of the bent tendon.

Also, in accordance with the present invention, the tendon tensioning mechanism automatically adjusts its position to remain aligned with the straight line tangential path to accommodate increasing diameters caused by overlapping a series of previously laid tendon convolutions; and also to permit its use with structures having different diameters. To these ends, the tendon tensioning mechanism **21** may be pivotally mounted on the carriage **19** to swing automatically into alignment with the tangential path under forces exerted by the tensioned tendon itself. Also, the pivoting of tendon tensioning mechanism **21** on the carriage **19** advantageously assists in isolating the tendon stressing mechanism from variations in movement of the carriage toward or from the wall **13** as the carriage **19** travels about the wall.

Also, as will be explained in detail, the preferred tendon tensioning mechanism **21** may be shifted vertically on the carriage **19** so that succeeding vertically spaced wraps may be laid adjacent one another in a groove of the structural wall or in one or more of adjacent grooves **13***a* – **13***d* without shifting the carriage vertically. Means are also provided on the carriage **19** to abut the wall and hold the carriage against rotation, that is twisting or turning when the tendon tensioning mechanism **21** is shifted vertically from a centered position on the carriage **19**. The carriage **19** is driven along the wall by a traction drive means **26** which preferably includes caterpillar tracks **28** which have wide surface contact with the outer face wall **13** to distribute and reduce the load per unit of surface area and which provide good tractive force to prestress relatively large tendons while propelling the carriage at operational speeds. The traction drive means **26** also may be driven in the reverse direction to remove the tendon **17** from the wall **15**. That is, the tendon tensioning mechanism is driven in a reverse manner and the carriage is moved in the reverse direction to remove tendon from the structure while maintaining tension in that portion of the tendon not yet removed. On the other hand, in conventional kinds of apparatus the tendon becomes slack when the tendon is taken up.

Other and important features of the invention are a selective control of the prestressing of the tendon **17** by the tendon tensioning mechanism **21** in which tendon engaging holding or restraining elements **27** (FIG. 6) are carried on endless bands or carriers **29** to move into engagement with the tendon **17**, travel therewith while restraining and prestressing the tendon, and then release the tendon to return to engage another upstream portion of the tendon. The tendon tensioning means accommodates elongation of the tendon during stressing to prevent slippage of the restraining elements along the surface of the tendon, i.e., the restraining elements **27** are mounted in a manner that the restraining elements **27** may move relative to the endless bands during elongation of the tendon. Also, the tendon engaging surfaces **30** on restraining elements **27** of the restraining mechanism may be of a softer material than the tendon material to prevent damage to the surface of the tendon. Additionally, the restraining force applied by the tendon tensioning mechanism **21** may be selectively automatically controlled to obtain the desired prestressing.

Referring now more specifically to the details of the illustrated apparatus **11**, the carriage **19** (FIG. 2) is preferably formed with two units or sections, namely a supply or service section or unit **33** and a trailing prestressing unit or section **35**. The position of the units may be reversed, if desired so that the supply unit follows the prestressing unit. The units **33** and **35** are connected in tandem for simultaneous traversal along the wall **13**, preferably by means of upper and lower connectors in the form of bars **37** which are fixedly secured at one end to the prestressing unit **35** and pivotally connected to the supply unit by pivot pins **39**. The pivot pins **39** are disposed vertically in alignment to define an axis allowing the units to pivot independently in a horizontal plane and relative to each other. The tendon prestressing mechanism **21** is carried by the prestressing unit of the carriage and a supply reel **41** carrying a coil of unstressed tendon **17** is carried on the supply unit. Thus, irregularities in movement of the supply unit **33** in the horizontal plane are not directly transmitted to prestressing unit as if the units were rigidly attached to each other.

The carriage **19** is held inwardly and against the structure wall **13** by means in the form of one or more restraining bands **43** which are endless loops passing around the structure and over and through the carriage **19**. Preferably, the restraining bands **43** are held against the wall by tension and exert radial inwardly directed forces on the carriage holding the carriage against the wall **13**. The upper restraining band **43** extends across the upper and outer side of the carriage and is guided by and disposed within upper pairs of grooved sheaves **45** rotatably mounted on the respective prestressing and supply units. In a similar manner, the lower restraining band **43** extends across and is guided within a pair of sheaves **47** similarly mounted on both the prestressing and service unit. The restraining bands may be suitably tensioned by means such as a take up mechanism (not shown) on the sheaves.

The carriage **19** is propelled about the wall **13** by a traction drive mechanism which includes upper and lower caterpillar track assemblies **26** each having an endless caterpillar track or tread **28** extending between a pair of rollers **53** and **54** which are rotatably mounted on a stationary support frame **55** of the prestressing unit **35** for frictional engagement with the wall **13**. The caterpillar tracks **28** provide excellent traction and permit distribution of the load over a relatively wide surface of the wall which is of particular advantage to reduce the load per unit area on the wall **13** when stressing large tendons with relatively high tension forces. The caterpillar treads are driven by suitable motors such as, for example, hydraulic motors **56** attached to and in driving engagement with rollers **53** of track assemblies **26**. As will be explained in greater detail hereinafter a regenerative hydraulic system is used to drive the hydraulic motors **56** and the caterpillar tracks **28** although it is to be understood that a mechanical or electrical motor drive system may be substituted for the hydraulic system. In addition to the caterpillar tracks, the carriage is provided with several roller assemblies **59** and wheel assemblies **61** for rolling about the surface of the wall **13** while the carriage **19** is being driven by the respective caterpillar assemblies **28**.

To resist moments tending to twist the prestressing unit **35** and to guide the carriage in a predetermined path, in a horizontal plane in this instance, the carriage is provided with several wheels and rollers which ride on the outside surface of the wall **13** and rotate about substantially vertical axes and others which project into the grooves **13***a* – **13***d* and roll along a top wall **62***a* or bottom wall **626** of a groove. In this illustrated embodiment of the invention, the leading portion of the prestressing unit has an upper and lower roller assembly **59** each having a vertically disposed wheel or roller **63** projecting radially inwardly into a groove in the wall **13** to roll on a top or bottom groove wall **62***a* and **62***b* while turning about a horizontal axis. More specifically, the roller **63** of the upper wheel assembly **59** engages a lower groove wall **62***b* and the roller **63** of the lower wheel assembly engages an upper groove wall **62***a* and the rollers **63** roll along the outer edge of their respective grooves while turns of tendon are laid within another groove between these grooves. The spacing of the rollers **63** and their engagement with the horizontally disposed groove walls **62***a* and **62***b* resists twisting of the prestressing unit **35**. The roller **63** is mounted on a bracket **69** secured to the prestressing unit **35** and a pair of spaced rollers **71** and **73** are carried by the same bracket for turning about substantially vertical axes while rolling along the outer face wall **13** of the structure between a pair of grooves. The service unit **33** is provided with four wheel assemblies **61** which have spaced wheels **74** and **75** for riding on the outer face wall **13** between grooves. The respective roller and wheel assemblies **59** and **61** are preferably mounted on adjustable mechanisms (not shown) for moving them radially inwardly or outwardly and for moving them vertically to assure that their respective wheels and rollers are properly positioned for good rolling contact with the structure which may vary in configuration or dimensions between the top or bottom thereof. Also, this allows the same carriage to be used with different kinds and sizes of structures.

After banding several of the grooves **13a**, **13b** etc., it is necessary to displace the carriage along the wall **13** in a vertical direction to position the same for banding a next series of grooves in the wall **13**. The preferred manner of supporting and positioning the carriage **19** vertically is by means of a suspension system **77** (FIG. **2**) which is secured on the structure **15** in this instance. It is to be understood that the carriage **19** may be supported and positioned for vertical displacement on a frame or suspension system which is independent of the structure **15**. The illustrated suspension system **77** comprises an overhead track **78** in the form of a circular I beam secured to and supported at the top of the wall **13** by radially and inwardly directed beams **76**. Mounted for rolling on and along the overhead track **78** are a series of trolley units **79** having trolley wheels **80** guided for movement within an outwardly facing groove **81** in the track **78**. In this instance, front and rear trolley units support the forward and rearward ends of the respective service and prestressing units **33** and **35**. The wheels **80** will roll on a lower wall in the groove **81** of the track while the carriage is traversing about the wall **13**. Depending from the trolley units **79** are free-turning pulleys **82** about which extend support cables **83** having one end **84** anchored to the frame of the service unit **33** or the frame of the prestressing unit **35**. The other end of each of the respective support cables is wound about and fastened to power drive hoists **85** which may be driven to wind or unwind the cable thereon thereby adjusting the length of cable extending from the hoist **85** to the pulley **82** and down to the anchored end **84**. In this manner, the carriage **19** is positioned vertically and the trolley units **79** support the weight of the carriage while rolling in the track **78** while the carriage is propelled circumferentially about the wall **13** by the traction caterpillar tracks **28**.

During such movement of the carriage **19** about the wall **13**, the tendon **17** is continuously prestressed and payed out from the tendon supply reel **41** on a stand **93** carried on a floor **95** of the service unit **33**. The illustrated tendon **17**, as best seen in FIG. **6**, is of the multistranded, circular cross section kind although the apparatus **11** is capable of use with tendons of various other sizes and cross sectional shapes such as, for example, flat rectangular cross section as shown for a flat strip tendon **17***a*, as shown in FIGS. **12** and **13**. While the size of the tendon may vary considerably, the apparatus **11** is particularly useful for relatively large sizes of tendons such as the illustrated seven strand tendon **17** which, in this instance, may have a diameter of 0.6 inch. The illustrated flat strip tendon **17***a* may typically have a 6 inch width and a one thirty-second inch thickness. The length of tendons **17** or **17***a* stored on the supply reel **41** is quite long in order that large diameter structures, e.g., 40 to 200 ft. in diameter may be banded quickly without frequent stops to change supply reels. Also, long lengths of tendon on a supply reel allow the carriage **19** to maintain relatively high speeds, e.g., the minimum operating speed for the carriage in the illustrated embodiment of the invention may be as much as 100 ft. per minute for 20 ft. dia. structures and 300 ft. per minute for 80 ft. dia. structures. From the reel **41**, the tendon **17** is fed through the tendon tensioning mechanism **21** which will now be described in detail.

Referring now to the tendon tensioning mechanism **21** and more particularly to its articulation on the tendon prestressing unit **35**, this articulation assures an "in-line" path for the tendon **17** while being stressed, i.e., in-line with a tangent to the point at which the tendon is being banded to and about the wall **13**. The tendon prestressing unit comprises a box like frame **55** (FIG. **2**) having upper horizontally disposed plates **100** and **101** and a lower horizontally disposed floor plate **102** and bars **103** which are joined by upright rigid bars **105**. The tendon tensioning mechanism **21** is carried on a stand **107** fastened at its lower end to a floor plate **102** of the prestressing unit.

The tendon tensioning mechanism **21** is pivotally mounted on a carrier **108** carried on the stand **107** for pivoting about a vertical axis through a pair of vertical stub shafts **109** and **110**, as best seen in FIGS. **2**, **3** and **4** on the carrier. The stub shafts have outer ends journaled in bearings **111** fastened to top and bottom carrier plates **113** and **114**. The stub shafts **109** and **110** have inwardly projecting ends fastened to the top and bottom of a bearing block **115** (FIG. 4) which supports in cantilever fashion a supporting frame **117** for the endless chains **29** and the restraining elements **27**. More specifically, the frame **117** is cantilevered by means of a pair of vertically spaced upper and lower support bars **121** and **123** which extend between the bearing block **115** and the frame **117** with the upper support bar **121** bolted to a top frame plate **125** and the lower support bar bolted to a lower frame plate **127** of the frame **117**. As will be explained in greater detail, the tendon **17** acting through the restraining elements **27** and chains **29** exerts turning moments on its supporting frame **117** which in turn acts through the support bars to exert turning moments on the bearing block and attached stub shafts for turning the latter in the bearings **111** on the carrier **108**.

For the purpose of measuring and controlling the force of restraint applied by the prestressing mechanism, the support bars **121** and **123** are preferably slidably mounted for longitudinal movement in slide bearings **126** and **128** carried in the bearing block **115**. More particularly, load measuring cells **137**, as best seen in FIG. 3, are acted upon by and measure the force of restraint tending to pull and slide the support bars **121** and **123** to the right as viewed in FIGS. 2, 3 and 4. The load cells **137** are disposed between the non-slideable, bearing block **115** and a vertical, rear plate **129** which is attached to the right hand ends of the support bars **121** and **123** to move therewith. As best seen in FIG. 3, the bearing block **115** has a pair of horizontally extending wings **141** to which are fastened the load cells **137** with plungers **143** of the load cells extending to and abutting opposing facing surfaces **145** on the vertical plate **129**. Thus, the restraint applied to the tendon **17** will cause the vertical plate **129** to apply forces to the plungers **143** of the load cells **137** and hence measure the restraint applied thereat.

The bars **121** and **123** support the tendon restraining mechanism **21** in a cantilever manner; and the latter may be provided with a counterweight system **147**, as best seen in FIG. 5, for providing greater stability and for applying a lifting force to the outer unsupported (right) end of the tendon tensioning mechanism **21**. Fixed to the frame **117** of the tendon tensioning mechanism in a position towards the unsupported end thereof is an upstanding bracket **149** to which is connected a chain **151** which is passed around a pair of freely rotatable sprockets **153** mounted on the frame member **101** of the prestressing unit. The chain is then passed through an opening in the carrier **108** and about another sprocket **157** rotatably mounted on the floor plate **102**. The chain extends upwardly from the sprocket **147** and is secured at **156** to the under portion of the carrier. Since chain **151** is of a fixed length, it will maintain the supporting frame **117** of the tendon tensioning mechanism in substantially the same attitude with respect to the structure **15** when the carrier is shifted vertically, as will be explained. The sprockets **153** and **157** may be suitably mounted for swiveling to prevent interference with pivotal movement of the tendon tensioning mechanism **21**.

In many instances, it is desired to lay tendons **17** closely adjacent to one another in the grooves **13*a*, 13*b*, 13*c*** and **13*d*** in the structural wall; and this may be accomplished without vertically displacing the carriage **19** as the carrier **108** for the tendon tensioning mechanism **21** is mounted for sliding vertically on the stand **107** of the carriage. Also, several successive convolutions of tendons may be wrapped in the same groove by shifting the carrier **108** without displacing the entire carriage **19** vertically along the wall **13**. The vertical stand **107** is comprised of a pair of upstanding standards **158** each having an outer tubular channel **159** (FIG. 3). The standards **158** are bolted at the upper and lower ends thereof to the top and bottom frame plates **101** and **102** as best seen in FIG. 4. As best seen in FIG. 3, the carrier **108** has four slide pads **162** engaging each of the four sides of the standards **158** for sliding therealong and guiding the carrier for straight line vertical movement.

The prestressing carrier **108** is shifted vertically on the carriage **19** by means in the form of a screw or jack drive mechanism including a pair of vertically extending screw jacks **165** (FIGS. 3 and 4) spanning the top plate **101** and bottom plate **102** and journaled for turning in bearings **167** secured to the respective top and bottom plates. The screw jacks are threaded in a pair of nuts in the form of threaded blocks **169** fixed to the carrier **108** and the threaded blocks travel vertically on the screw jacks as they are turned and thereby the carrier **108** and prestressing mechanism **21** are shifted vertically along the standards **158**.

To turn the screw jacks **165**, a screw drive **171** (FIG. 4) is provided and it comprises a gear box **172** driven by a belt **173** which is connected to a take-off hub **175** of a variable speed reducer **177** which is driven by a motor **179** through a belt **180**. The illustrated motor **179** is an electric one although it may be of the hydraulic type if desired.

As the prestressing carriage **19** travels about the wall **13**, the screw jacks **165** may be rotated so that the carrier **108** is gradually lifted upwardly (when the tendon is being wrapped from the bottom upwardly.) In order to insure that the rate of rise of the carriage **19** is controlled, means to sense the position of the carriage are provided in the form of a feeler arm **181** (FIG. 3) which will ride on the bottom horizontal surface of a groove until the first convolution of the tendon is completed and wrapped about the wall. Thereafter the feeler arm **181** rides on the last convolution of the tendon which has been laid. The feeler arm **181** is an articulated arm which is attached to the free end of the stressing mechanism **21**. Also the feeler arm **181** is operatively connected to a suitable motor control device such as a micro switch **183** (FIG. 4) for an electric motor **185** which is driven in a manner to adjust the ratio of the variable speed reducer **177** to cause the rate of vertical climb of the carrier **108** to be increased or decreased as necessary.

After leaving the supply reel **41**, the tendon **17** is guided through the carrier **108** to the tendon tensioning mechanism **21** by a series of guide rollers including a first pair of vertically oriented, groove rollers **186** (FIGS. 3 and 4) rotatably mounted for turning on a bracket **187** attached to the carrier and a second set of horizontally oriented rollers **188** mounted for turning about spaced vertical axes on the bracket **187** which is fixed to the carrier. The first set of rollers **188** are mounted for rotation about horizontal axes and the second set of grooved rollers **186** are mounted for rotation about vertical axes with a pathway being defined between the grooved rollers **186** being substantially in alignment with an opening **189** in the bearing block **115**. After passing through the bearing block; the tendon travels between another set of horizontally oriented, grooved rollers **190** which guide the incoming tendon to its proper position between the chains **29** and restraining holders **27**.

In the tensioning mechanism **21**, the tendon **17** is stressed while continuously moving therethrough by means of the traveling restraining elements **27** defining a pathway for the tendon. The amount of restraint applied by the holding elements **27** to the tendon **17** determines the degree to which the tendon is prestressed and also its degree of elongation.

While the tendon **17** is passing through the tendon tensioning mechanism **21**, a series of the restraining elements **27** will simultaneously be engaging the tendon, traveling with the tendon, and exerting a restraining force on the tendon. Each of the respective tendon restraining elements has a vertically disposed block **191** which spans a pair of vertically spaced upper and lower, endless roller chains **29**, as best seen in FIGS. **6** and **7**. The chains carry the blocks **191** about an endless path including an inner run at which the tendon **17** is engaged adjacent an inlet sprocket **195** (FIG. **3**) to outlet sprocket **197** at which the restraining elements release the tendon and return along the outside paths or runs to the inlet sprockets **195**. Each of the inlet sprockets **195** is a double sprocket and each of the chains **29** is a composite chain having an upper roller chain **196** and a lower roller chain **198**. Each inlet sprocket **195** is fixed to a vertically extending shaft **199** which is journaled in bearings fixed to top and bottom frame plates **125** and **127** of the tensioning mechanism. In a similar manner, each of the outlet sprockets **197** is a double sprocket and each is attached to a common, vertically extending shaft **201** which is journaled in bearings **203** carried by stationary frame plates **205** and **207** (FIG. **4**) of the tensioning mechanism. The rotational axes of the inlet and outlet support shafts and sprockets are positioned on opposite sides of the tendon **17** so that the restraining elements **27** move along a substantially straight line, parallel paths between the inlet and outlet sprockets while engaging the tendon **17**.

The restraining blocks **191** are attached to the upper and lower chains **196** and **198** by elongated pins **207** (FIG. **7**) which extend from the upper chain through suitable openings in the blocks to the lower chain. These long pins which extend between the chains alternate with short chain pins **209** which serve with the long pins **207** to fasten the respective chain links **210** in a given chain together. Suitable chain rollers **211** are mounted for rotation on each of the respective long pins **207** and short pins **209** between chain links **210** in a familiar and conventional manner.

The restraining elements **27** are mounted on the composite chains **29** in a manner to permit the tendon surfaces **30** thereon to move relative to the chains to accommodate elongation of the tendon **17** as it is being taken from substantially zero tension to full tension but without the tendon engaging surfaces **30** slipping on the tendon during such elongation. To this end, the restraining elements **27** are mounted in a manner to shift relative to the chains and preferably to shift against the bias of a spring means **213** which permits rearward shifting of restraining elements **27** relative to the chains upon compressing the spring means **213**. In this instance, the spring means is in the form of a series of curved, spring discs **215**, as best seen in FIG. **8**, carried in a pair of bores **217** in a central part of the blocks **191** of the restraining elements **27**. The spring discs each have a circular recess through which extends a guide rod **221** on the forward end of which is a plug **223** bearing against a long chain pin **207**. The other end of the guide rod **221** is inserted in a smaller diameter bore **225** in a shoulder wall **227** against which bears the rearward one of the spring discs **215**. To assist the spring discs **215** in sliding during compression or expansion thereof, a sleeve liner may be employed with the spring discs **215** inserted therein and with the sleeve liner disposed within the bore **217**. Preferably, a pair of such spring means **213** are provided above and below the tendon path of travel as best seen in FIG. **6**.

As an alternative to the preferred embodiment of the invention, the movement of the restraining elements **27** relative to the supporting chains **29** may be limited during stress and elongation of the tendon **17** to less than that needed to accommodate the elongation of the tendon at a given tension whereby the additional displacement needed to accommodate full elongation of tendon is provided by slippage or partial yielding. For example, the spring discs **215** may be selected to bottom out at a tension load which is less than that of the given full tension load; and the tension elements may have partially yieldable surfaces **30** which will yield to provide an additional displacement needed to accommodate the total elongation of the tendon at the given tension. On the other hand, the tendon may simply slip relative to the restraining elements once the springs **215** have bottomed out and the slippage is allowed to accommodate the remainder of the elongation of the tendon. With these embodiments of the invention, however, there will be an accompanying increase in the wear rate of the tendon engaging surfaces **30**.

Preferably, each restraining element **27** is interconnected with its preceding and succeeding restraining element. More specifically, the rear portion of each block **191** of the restraining element includes a centrally disposed tongue **231** (FIGS. **7** and **8**) which projects rearwardly into a slot **233** forming a yoke on the front of the following block **191**. Each tongue has an elongated opening **235** therein through which the long pin **207** extends to permit relative movement of the block relative to the pin. Elongated openings **237** are also formed in the yokes to receive the same elongated pin **207** to permit recovery movement, i.e., forward movement of the block when the tendon is released and the spring discs are free to expand. Thus, each block **191** is connected to its preceding and succeeding block **191** and is free to move relative thereto.

To avoid damage to the tendon **17**, it is preferred that the tendon engaging surface **30** be less hard than that material of the tendon engaged thereby so that the surfaces **30** will not scratch or cut the tendon surface.

That is, the material of the tendon engaging surfaces will usually become cut or scratched before the cable surfaces. When the tendon is, for example, made of high tensile steel strands such as with seven wires, there should be no substantial change in major properties of the tendon such as for example, a change in the ultimate strength, yield point or other physical characteristics due to damage to the tendon surface by the tendon engaging surfaces **30**. Scratching or cutting is undesirable since such scratches or cuts have a deleterious effect on the mechanical properties of the tendon. In particular such scratches or cuts may serve as a substantial source of fatigue failure. Preferably, the tendon engaging surfaces **30** may be provided with a groove sized to receive therein a portion of the arcuate periphery of the tendon.

The restraining elements **27** are urged into tight gripping relation with the tendon **17** to prevent slipping therebetween during the restraint by a pressure means **238** (FIG. 3) which comprises a series of hydraulic jacks **239** which are secured at one end to a stationary frame member **241** and which apply force at their other ends to a movable back up plate **243**. As best seen in FIG. **6**, each back up plate **243** carries a series of rollers **245** which bear against a flat rear wall **247** of the blocks **191** of the restraining elements. Other alternative pressure means such as screws and/or springs or other devices may be used in lieu of the hydraulic jacks to apply pressure to the restraining elements and thereby to the tendon **17**. Only one set of hydraulic jacks may be used, if another back up plate **243***a* is secured and held to the first back up plate by tie rods **249**, as shown in FIG. 3. The rollers **245** provide reduced friction surfaces by which sufficient force may be imparted to the movable restraining elements **27** to prevent the tendon sliding on the surfaces **30** thereof. The preferred restraining elements are sufficiently long that the blocks **191** extend across at least three sets of rollers **245** with the result that the load from the hydraulic jacks **239** is distributed in a longitudinal direction along three spaced areas on each block **191**. As best seen in FIG. **6**, two vertically spaced rollers **245** are journaled on a common pin **251** to provide two vertically spaced contact areas. Thus, six rollers **245** are normally in contact with the surface **247** of each block. As will be explained in detail, the hydraulic jacks may each be subjected to the same hydraulic fluid force to provide a uniformly distributed load or a non-uniform distribution of load may be achieved. For example, the hydraulic jacks may receive progressively greater hydraulic pressures so that the tendon **17** receives a substantially linear build up in stressing from the inlet to the outlet of the tendon tensioning mechanism **21**.

In order to reduce the size of the motor used to drive the carriage about the structural wall and to prestress the tendon, a regenerative system **260** (FIG. 11) may be used in which the work developed within the tendon tensioning mechanism **21** is used to assist in driving the respective track assemblies **28** to propel the carriage **19** about the structural wall **13**.

As explained above, the upper and lower track assemblies **26** each have a roller **53** driven by a main hydraulic motor **56** which is connected by a hydraulic line **261** to a pump **263** driven by a prime mover **265** such as a diesel motor. A common hydraulic line **264** extends between the hydraulic lines **261** from the pumps **263** to provide a common system for the track drive motors **56**. To assist in driving the track assemblies, a regenerative hydraulic motor **267** is attached to each of the caterpillar rollers **54** to assist the main hydraulic motors **56** in moving the carriage **19** about the structural wall **13**. The regenerative hydraulic motors are driven by regenerative hydraulic pumps **269** which are connected by a drive **270** to sprocket shafts **199** of the tensioning mechanism and are driven thereby to pump hydraulic fluid through hydraulic lines **271** connected to the regenerative hydraulic motors **267**. A common hydraulic line **272** interconnects the hydraulic lines **271** to assure that the regenerative motors **267** are being driven equally by a common hydraulic system. Thus, the work being done by the tendon tensioning mechanism **21** is used to drive the regenerative hydraulic pumps **269** and regenerative hydraulic motors **267** to assist in propelling the carriage **19** thereby decreasing power requirements necessary for the main pumps **263** for propelling the carriage **19**.

The manner of controlling the amount of tension in the tendon **17** may also be controlled with the regenerative system **260** as by either increasing or decreasing the amount of torque allowed to be done by the regenerative hydraulic pumps **269** and motors **267**. More specifically, the load cells **137** which measure the tension in the tendon **17** may be connected to a mixing amplifier **273** which in turn is connected to servo valves **275** which regulate the angle of swash plates within the regenerative pumps **269** thus determining the torque produced by the pumps **269** for transmittal to the regenerative motors **267**.

For the purpose of insuring that the regenerative hydraulic pumps **269** are actually transmitting the desired torque to the regenerative hydraulic motors **267**, feedback transducers **277** may monitor the pumps **269** and provide outputs to a summing amplifier **279** which adds these signals together and compares their total to a reference signal for the desired load. If further correction is necessary the summing amplifier **279** causes the amplifier **273** to cause the servo valves **275** to be again changed. Therefore, the actual tension being developed in the tendon **17** is under constant and automatic surveillance and correction.

In the embodiments of the invention illustrated in FIGS. **12** and **13**, tendon restraining elements **27***a* are provided and these are similar to the above described tendon restraining elements **27** except for having flat tendon engaging surfaces **30***a* for the flat strip tendon **17***a* rather than having the grooved tendon engaging surfaces **30** for the circular cross sectioned tendon **17**. The remaining elements of the tendon tensioning mechanism shown in FIGS. **12** and **13** are substantially similar to elements above described in connection with FIGS. **1–11** and the identical reference characters have been used for these similar elements.

In operation of the apparatus **11**, the carriage **19** is propelled by the caterpillar tractive drives **28** in a clockwise direction as viewed in FIGS. **1** and **2**. With the right hand end of the tendon **17** anchored to the structure, the tendon will extend in a straight line tangential path to the wall **13** of the structure from the carriage. Within the traveling carriage tendon is being uncoiled from the reel **41** and passed through the tendon tensioning mechanism 21 at which the tendon is being stressed in tension by opposed sets of traveling restraining elements 27 on the pair of endless bands or chains 29. The restraining elements are spaced apart by a distance determined by opposite sets of rollers 245 and define a line pathway for the tendon and this pathway is aligned with the tangential line to the structural wall. Hydraulic cylinders 239 act through the rollers 245 to apply forces direct normal to the direction of tendon travel against the restraining elements 27 to prevent slippage between the latter and the surface of the tendon 17. Also, the multiple sets of restraining elements 27 provide multiple areas of holding contact to prevent slippage.

Usually, several convolutions of prestressed tendon 17 are laid vertically along each groove interior wall 62c and the inner convolutions of tendon are overlaid with several outer convolutions of tendon until the desired amount of tendon is laid within a given groove. During the overlaying of convolutions within a groove, the tendon tensioning mechanism 21 may pivot slightly in the clockwise direction, as viewed in FIG. 1 from a position, diagrammatically illustrated in dotted lines in FIG. 1 to another position, diagrammatically illustrated in solid lines in FIG. 1 to accommodate a slight difference in angle due to the difference in diameters of the respective convolutions of tendon which results in different angles for the tangent line path from the carriage to the structure. If different parts of the structure have different diameters, then the pivoting of the tendon tensioning mechanism 21 will be more pronounced for the different parts of the structure.

Advantageously, all of the restraining forces applied by the tendon tensioning mechanism 21 to the prestressing unit 35 are applied at the pivot axis of the tendon tension mechanism on the carrier 108 through the stub shafts 109 and 110. This tends to isolate the tendon tensioning mechanism 21 from radially directed movements of the prestressing unit 35 and supply unit 33 and facilitates measurement of the prestressing forces by the load cells 137.

From the foregoing it will be seen that the apparatus 11 provides a more nearly uniform stress distribution and good control of stress applied to the tendon. Also, the apparatus may operate at relatively fast operating speeds particularly for large sizes of tendons and for large sizes of structures. Additionally, a regenerative system provides economies in the amount of power consumed for the prestressing operation. Also, the ability to reverse the movement of the carriage while maintaining full tension permits correction of an error in laying without unwrapping the entire length of cable.

While a preferred embodiment has been shown and described, it will be understood that there is no intent to limit the invention by such disclosure but, rather, it is intended to cover all modifications and alternate constructions falling within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. Apparatus for prestressing a tendon and banding a circumferential wall of a structure having a longitudinally extending axis with a tensioned tendon, said apparatus comprising a carriage movable about the circumferential wall of said structure, means for moving said carriage about the circumferential wall, tendon tensioning means on said carriage having means engaging said tendon along an extended linear portion thereof for applying tensile forces thereto to stress the tendon, said means engaging said tendon and applying tensile forces thereto along a substantially straight line path of movement without substantial bending stresses being applied to the tendon, and means pivotally mounting said tendon tensioning means on said carriage with said means engaging said tendon along an extended portion thereof for turning about an axis substantially parallel to the longitudinal axis of said structure to align said tensioned linear portion with a tangent line extending from said tendon tensioning means to a point at which said tendon is banded on said structural wall.

2. An apparatus in accordance with claim 1 in which said tendon tensioning means includes a series of traveling, opposed restraining elements for engaging the tendon and for forming a pathway therebetween for said tendon, said last mentioned pathway being aligned with the tangent line to said structure wall.

3. An apparatus in accordance with claim 2 in which endless bands move about endless paths and in which said restraining elements are carried by said endless bands to engage said tendon and move along said straight line path therewith while the tendon is being tensioned and in which said restraining elements are carried into and from engagement with the tensioned tendon by said endless bands.

4. An apparatus in accordance with claim 1 in which said tendon tensioning means includes means for engaging said tendon and for displacing with elongation of said tendon during stressing thereof to prevent slipping of said means along the surface of said tendon.

5. An apparatus in accordance with claim 1 in which means are provided on said carriage for displacing said tendon tensioning means transversely to the path of carriage movement to position adjacent tendons side by side while said carriage remains in a given path of carriage movement.

6. An apparatus in accordance with claim 5 in which means on said carriage engage said structural wall at spaced locations and hold said carriage against twisting on said structural wall after a transverse shifting of said tensioning means and tendon.

7. An apparatus in accordance with claim 1 in which said means for moving said carriage includes caterpillar tracks for engaging said structural wall and for providing a propelling force to move said carriage about said wall.

8. An apparatus movable about a wall of a structure for tensioning a tendon and for applying the tensioned tendon to said wall, said apparatus comprising a carriage movable about the wall of the structure, said carriage having a supply unit and a tendon tensioning unit, caterpillar track means on at least one of said units having tractive engagement with the structural wall, means pivotally connecting said units for movement together as a tandem about the structural wall, a supply reel of tendon carried on said supply unit for providing tendon for tensioning, and means on said tendon tensioning unit for tensioning the tendon and paying out the tensioned tendon along a line substantially tangential to said structural wall.

9. An apparatus in accordance with claim 8 in which means on said carriage engage said wall at spaced points and hold said carriage against twisting on the structural wall.

10. An apparatus in accordance with claim 7 in which means are provided to shift said tendon tensioning means to permit a plurality of tendons to be applied at longitudinally spaced positions along said structural wall without shifting said carriage along said wall.

11. Apparatus for tensioning a tendon and for banding a wall of a structure with a tensioned tendon, said apparatus comprising a carriage movable in a forward or reverse direction about the wall of the structure, tendon tensioning means on said carriage for tensioning said tendon while said tendon is moving along a substantially straight line path which is along a tangent to the structural wall, said tendon tensioning means including a series of restraining elements for engaging and restraining said tendon and for traveling therewith while tensioning the same along an extended linear portion of said tendon, means mounting said tendon tensioning means on said carriage for alignment with a tangent line extending from said tendon tensioning means to said structure, said restraining elements being movable in one direction when said carriage is paying out said tendon and being movable in an opposite direction when said carriage moves in the reverse direction to take up said tendon and means for moving said carriage in the forward direction to pay out the tensioned tendon and in the reverse direction to take up the tensioned tendon while holding said tendon under a controlled, predetermined tension.

12. Apparatus in accordance with claim 11 in which said means for moving said carriage includes a motor drive and caterpillar tracks for engaging the structural wall and in which said tendon tensioning means includes a pair of endless carriers for carrying said restraining elements into engagement with said tendon to travel therewith and from said tendon for return to positions to re-engage said tendon.

13. A prestressing apparatus as defined in claim 12 wherein said restraining elements are slidably mounted and have tongue and yoke portions, said yoke portion including a pair of flanges, and the tongue portion of each element adapted to be slidably positioned within the flanges of an adjacent element.

14. A prestressing apparatus as defined in claim 12 wherein said restraining elements include a resilient member whereby the sliding movement of the restraining elements in passing through the tensioning zone is substantially equal to the elongation of the tendon in passing through said zone.

15. A prestressing apparatus for circumferentially tensioning a tendon about a continuous structure by elongating the tendon a desired extent, said apparatus comprising a support carriage movable about said structure, a tendon tensioning mechanism carried by said carriage means mounting said tendon tensioning mechanism on said carriage for articulation about an axis to align said tendon tensioning mechanism with a line tangent to said structure, and means for shifting the mechanism along a path parallel to said axis to adjust said line of tangency relative to said carriage and to said structure.

16. A prestressing apparatus as defined in claim 15, wherein the tensioning mechanism includes a pair of opposed loops each comprised of flexible links engaging a pair of spaced, rotatable sprockets fixedly positioned to maintain said loops taut, means for rotating a sprocket in each pair in timed relation whereby said loops define a pathway for the tendon and create a zone for progressively increasing the tension in said tendon as it passes through said zone.

17. A prestressing apparatus as defined in claim 16 wherein said opposed loops include a plurality of tendon restraining elements for engaging the tendon throughout its travel along the pathway defined by the opposed loops.

18. A prestressing apparatus as defined in claim 17 wherein said tendon restraining elements have a surface thereon for engaging the tendon, the hardness of said surface being less than that of the tendon.

19. A prestressing apparatus as defined in claim 16 and further including a back-up plate positioned within each loop and extending substantially the length of the pathway formed by the loops, at least one of said plates adapted to be moved whereby the pressure exerted by the restraining elements on the loops against the tendon may be varied.

20. A prestressing apparatus as defined in claim 17 wherein said restraining elements are supported by a plurality of rollers whereby the distance between the holding elements of the opposed loops is determined by the distance between the opposed rollers.

21. A prestressing apparatus as defined in claim 15, in which a movable carrier for the tendon tensioning mechanism is provided on said carriage and said tendon tensioning mechanism is supported thereon in a cantilevered condition, and in which a counterweight arrangement comprising a flexible connector of a fixed length is attached to one side of the cantilevered portion of the tensioning mechanism and passed over a roller fixed on the support carriage and attached to the carrier on the side thereof opposite the attached side of the cantilevered portion whereby said tensioning mechanism is supported by said connector as the carrier is moved relative to the carriage.

22. A tendon mechanism for prestressing a tendon without substantially bending the prestressed tendon before banding the tendon on a structure having a longitudinally extending axis comprising, a frame means, a support means, a pair of opposed, endless bands mounted on said support means for movement about endless paths, and a plurality of tendon restraining elements mounted on said endless bands for travel therewith and for forming a straight line pathway for the tendon to travel along, said restraining elements engaging the tendon during its travel along said straight line pathway, said tendon restraining elements exerting forces on said tendon to prestress the same while traveling along said straight line pathway and means pivotally mounting said support means on said frame means for pivoting thereon about an axis parallel to said longitudinal axis of the structure and relative to said structure being banded to align said tendon being tensioned with a tangent line to the structure.

23. A tendon tensioning mechanism in accordance with claim 22 in which said support means is slidably mounted on said frame means for movement in the

direction of tendon travel and in which load sensing means are operated upon by said support means moving in the direction of tendon travel to provide an indication of the prestressing force being applied to the tendon.

24. A tendon tensioning mechanism in accordance with claim **22** in which means are provided to apply force to said tendon restraining elements in a direction normal to the tendon travel to hold the tendon against substantial slippage relative to said restraining elements.

25. A tendon tensioning mechanism in accordance with claim **24** in which means are provided to allow said restraining elements to move relative to said endless bands during elongation of the tendon to prevent substantial surface slippage between the tendon and the restraining elements.

26. A tendon tensioning mechanism in accordance with claim **22** in which means are provided to allow said restraining elements to move relative to said endless bands for a predetermined displacement during tendon elongation and in which surfaces are provided on said restraining elements for partially yielding to accommodate further elongation of said tendon to its fully stressed length.

27. A method of tensioning a tendon and banding a circumferentially extending wall of a structure with the tensioned tendon by a tendon tensioning mechanism carried on a movable carriage; said method comprising the steps of: moving the carriage circumferentially about the wall, tensioning an extended linear portion of said tendon while said tendon is moving along a straight line path through said tendon tensioning mechanism without producing a substantial bending of the tendon and without drawing the tendon to produce the tension therein, aligning the tensioned linear portion of the tendon with a straight line tangent path from the tendon tensioning mechanism to the circumferential wall of the structure, paying out said tensioned tendon along said straight line tangential path to said structure, and banding said circumferential wall with said tensioned tendon.

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