Feb. 27, 1962 B. F. FRIBERG 3,022,713

PRESTRESSED CONCRETE STRUCTURES

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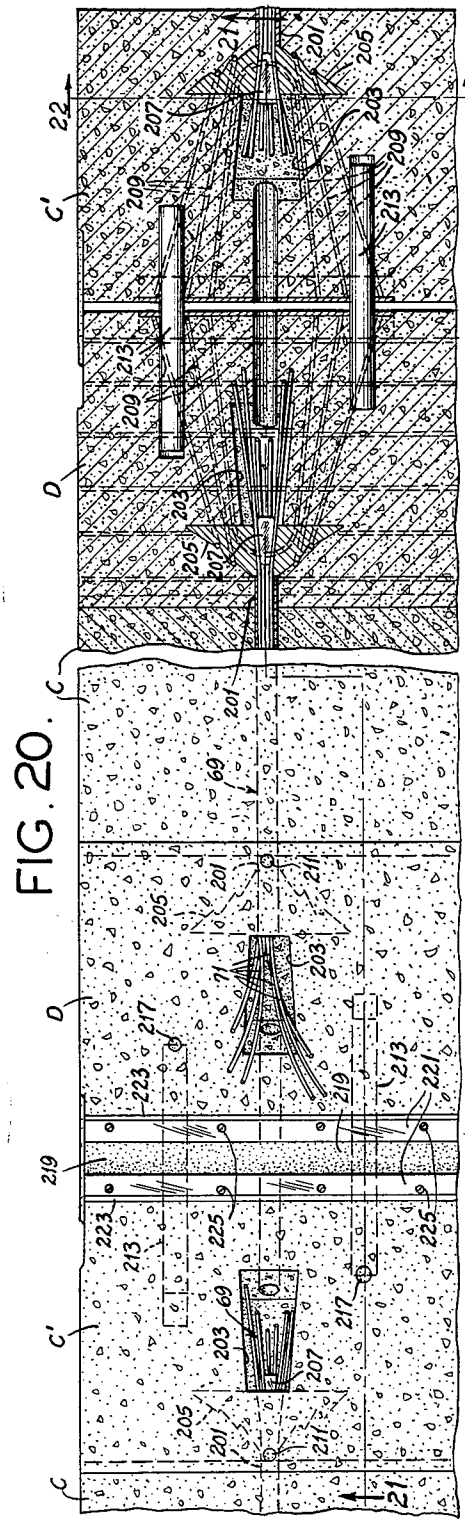


FIG. 20.



FIG. 21.

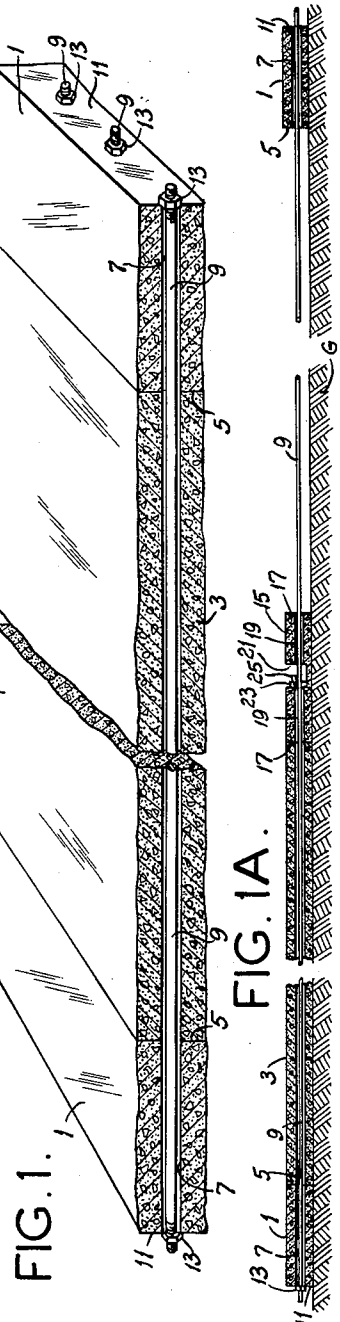


FIG. 1.

FIG. 1A.

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FIG. 2.

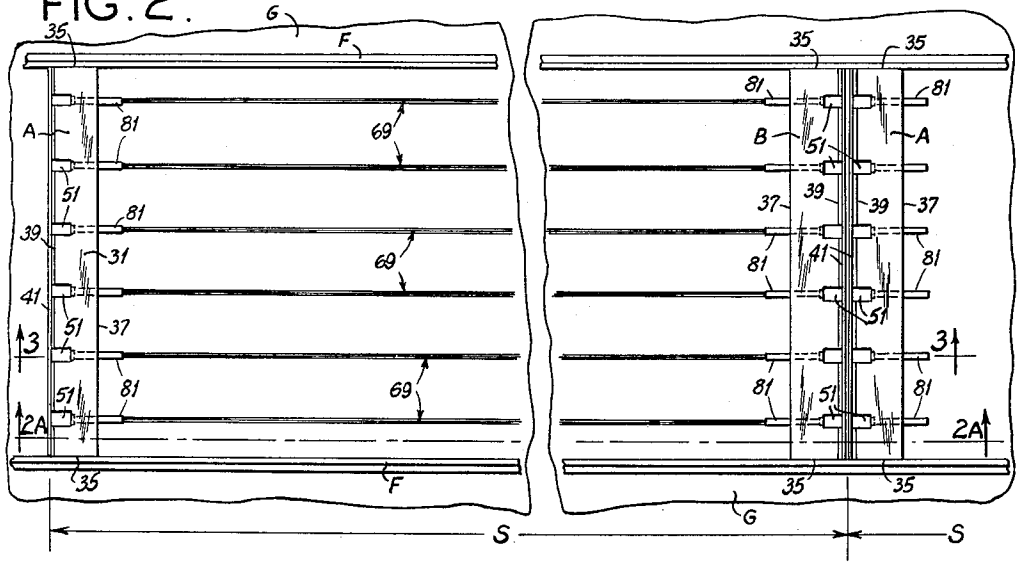
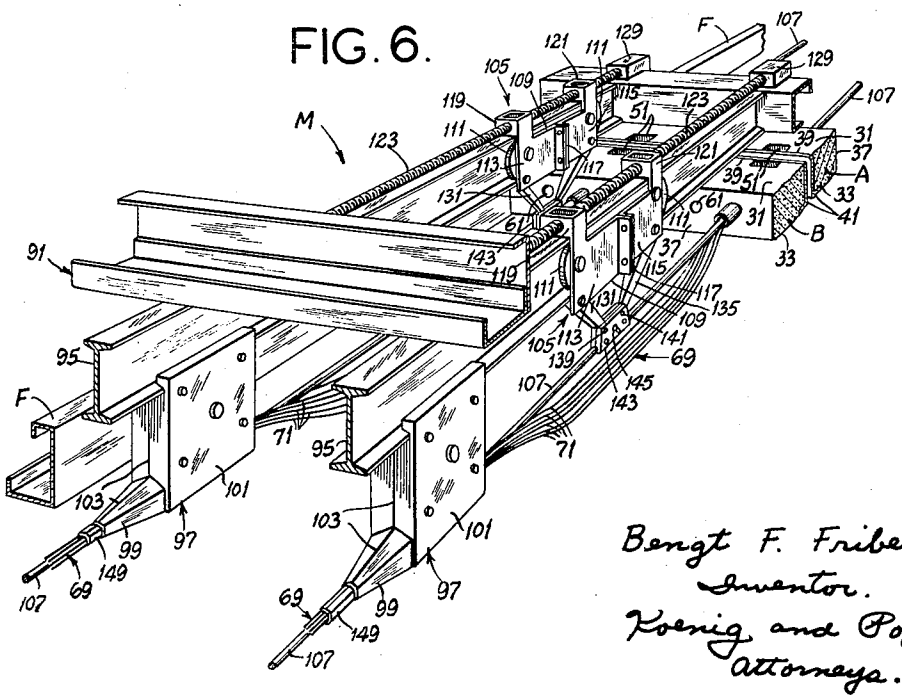


FIG. 2A.



FIG. 6.



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PRESTRESSED CONCRETE STRUCTURES

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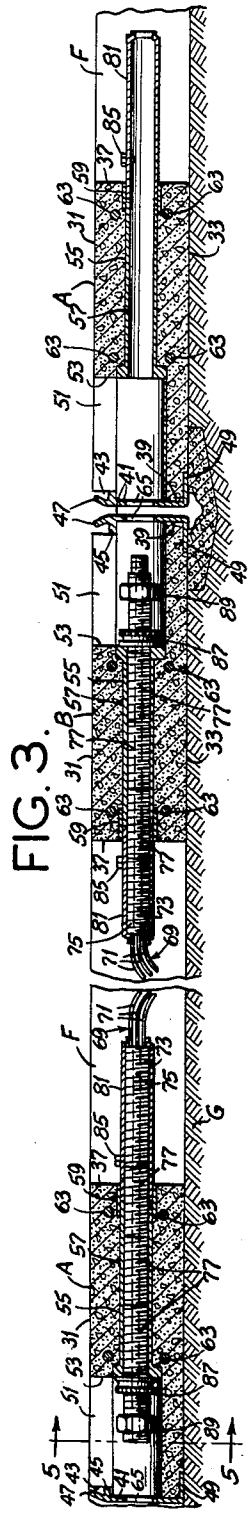


FIG. 3.

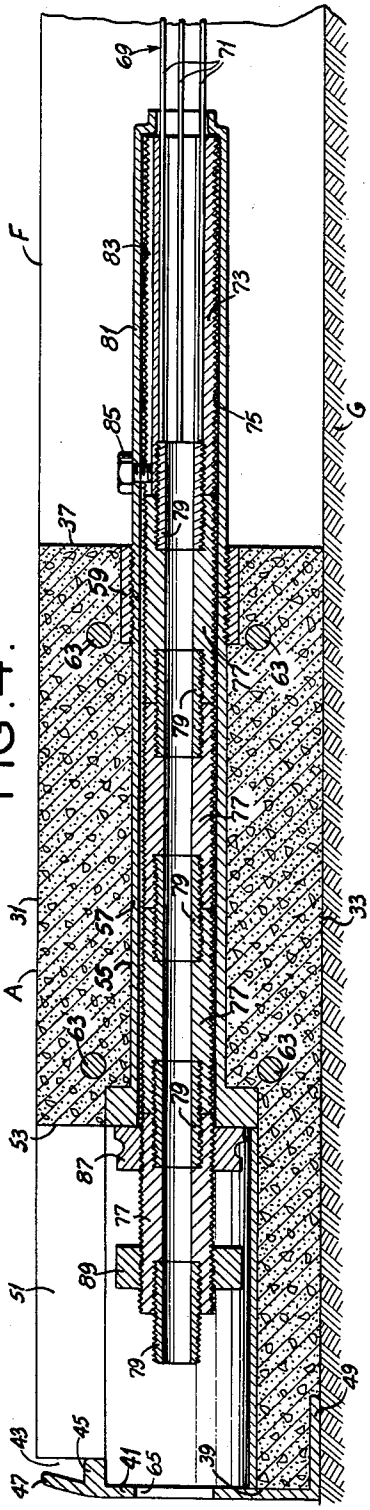


FIG. 4.

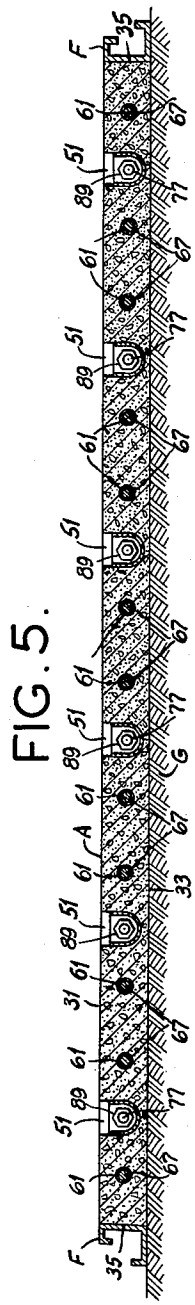


FIG. 5.

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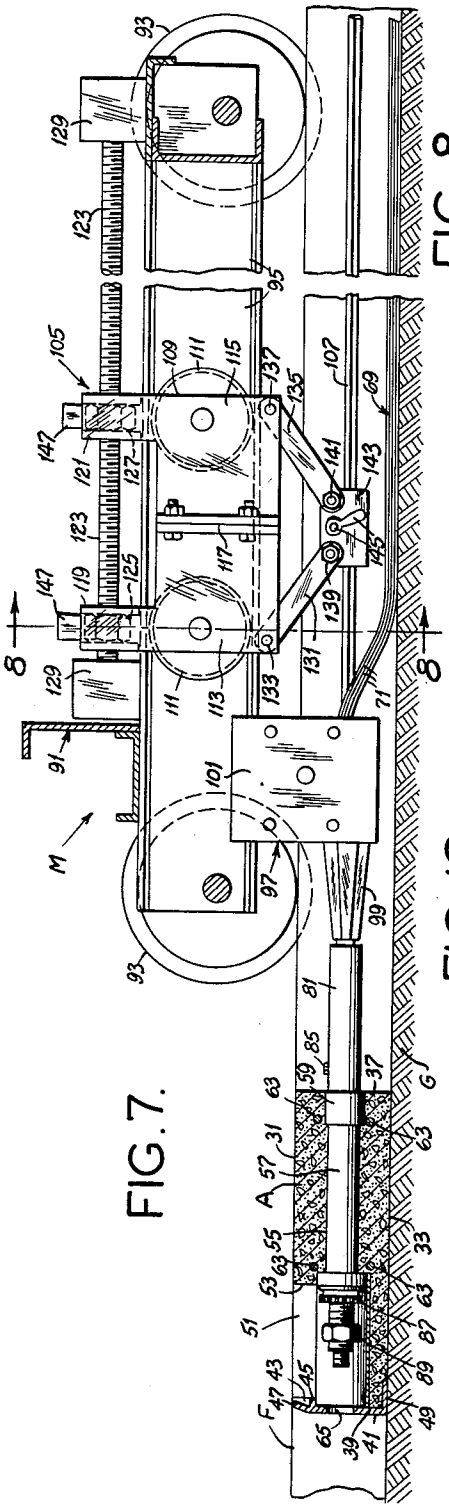


FIG. 7.

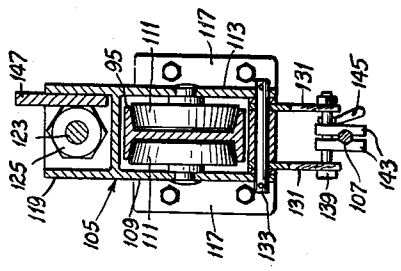


FIG. 8.

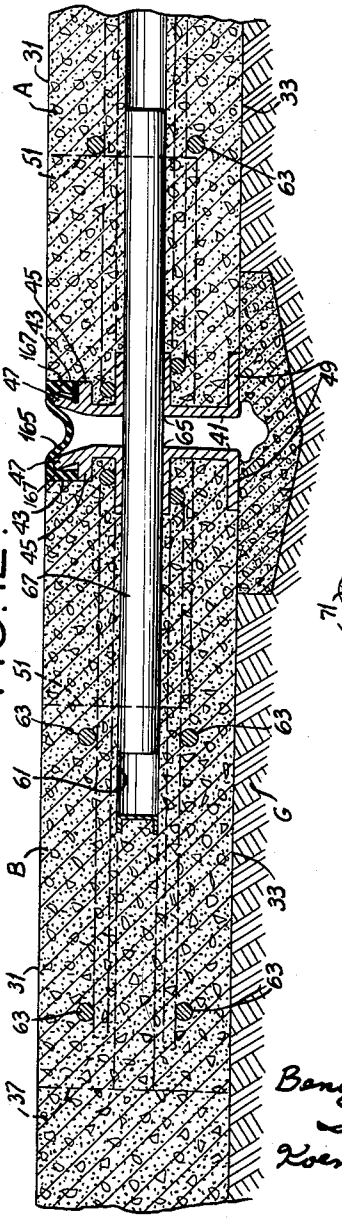


FIG. 12.

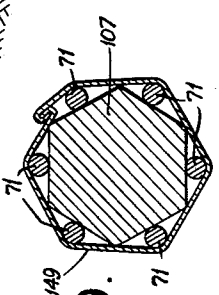


FIG. 9.

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FIG. 10.

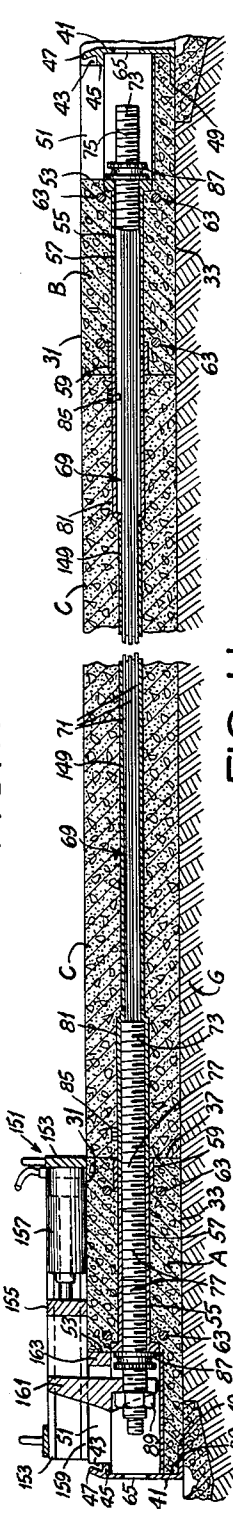
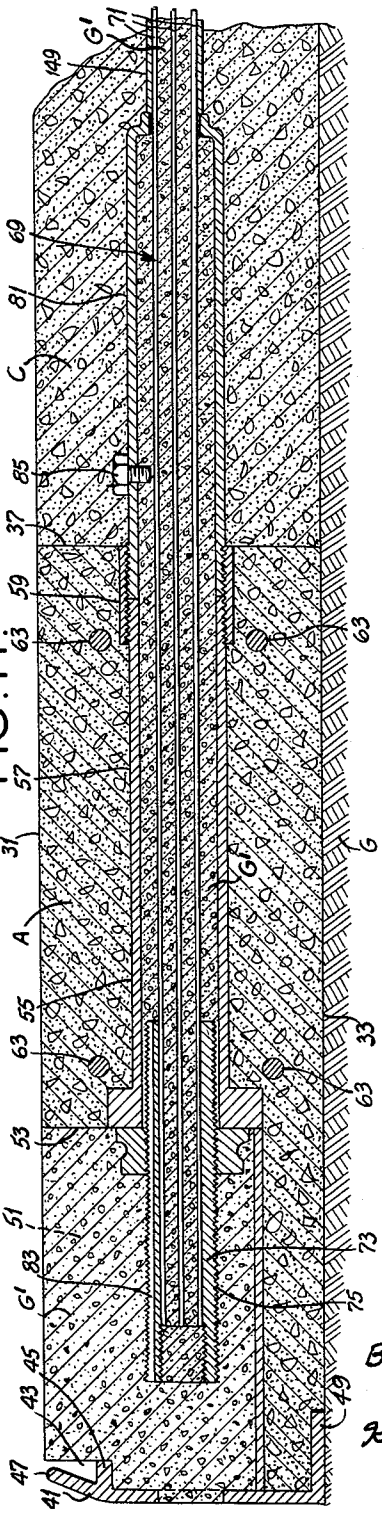


FIG. 11.



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FIG. 16.

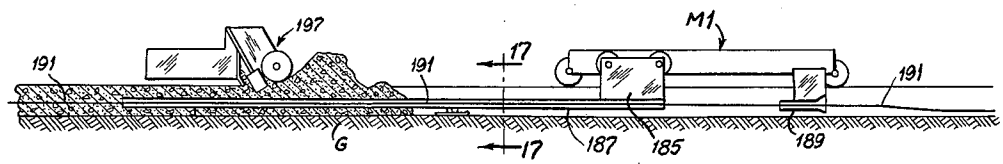


FIG. 17.

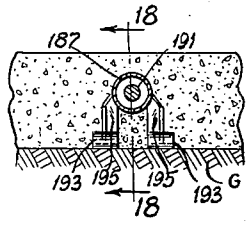


FIG. 18.

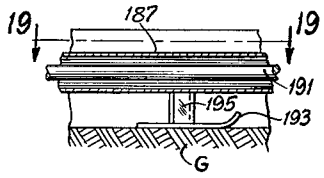


FIG. 19.

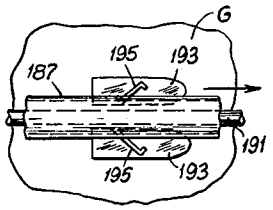


FIG. 13.

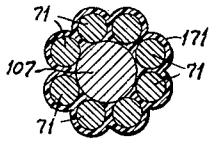


FIG. 14.

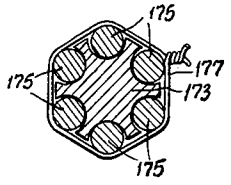


FIG. 15.

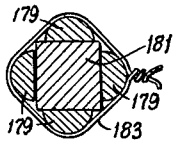


FIG. 22.

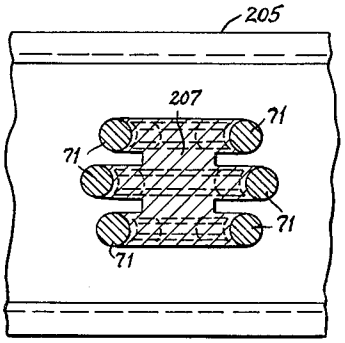
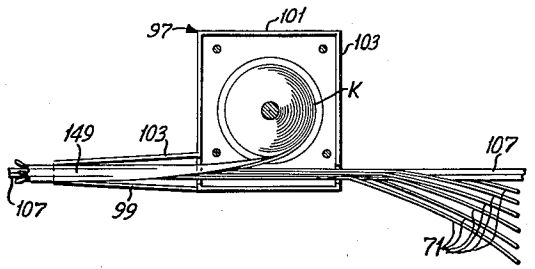


FIG. 6A.



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United States Patent Office 3,022,713 Patented Feb. 27, 1962

3,022,713

PRESTRESSED CONCRETE STRUCTURES

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Filed Nov. 26, 1954, Ser. No. 471,431
8 Claims. (Cl. 94—24)

This invention relates to prestressed concrete structures, and more particularly to prestressed concrete structures of the class having reinforcing members encased in concrete poured in place around the reinforcing members, the latter being tensioned after the deposition of the concrete ("post-tensioning") to impose prestress on the structure.

A basic object of the invention is the provision of prestressed concrete structures of the class described in which there is distribution of prestress on the concrete section. Another object of the invention is the provision of methods of and means for constructing structures of the class described wherein the reinforcing members are constituted by multi-wire cables, the method involving the formation, protection and encasement in concrete of the cables in progressive steps, the cables being tensioned after the deposit of concrete around them uniformly to impose prestress on the concrete.

The principles of the invention are particularly applicable to long prestressed structures and continuous structures. The invention is hereinafter described particularly in its application to long prestressed concrete pavement slabs and continuous highway construction, with prestress imposed at transverse joints which are spaced far apart. It will be understood, however, that the invention is not limited to pavements.

Heretofore, when reinforcing members such as steel bars, wires or cables have been employed for prestressing concrete structures by post-tensioning the reinforcing members, it has been customary to encase the reinforcing members in pipes, flexible conduits or sheet metal boxes, or to wrap or coat them to prevent bond with the concrete poured in place around them. This enables the members to be tensioned after deposition of the concrete. In all cases, it has been customary to have the reinforcing members tied and secured in place from one end to the other of the structure before deposition of the concrete. The procedure and means used have been costly, and it has been difficult to maintain the reinforcing members accurately positioned during concrete placing, and difficult to keep them from sinking or rising in concrete of different unit weight. In consequence, dislocation of the reinforcing members has frequently occurred, resulting in construction difficulties and frictional loss of prestress in the structure. In the interests of encasement economy, the reinforcing steel has been clustered into limited space, or concentrated into large members. Transfer of the highly concentrated tension in the reinforcing steel to impose compression on the concrete has been accomplished by the use at the ends of the structure of such members as washers, pads or plates. In the interest of economy, these have been given the smallest possible dimensions surrounding each reinforcing member. As a result, the prestressing forces have been highly concentrated on the ends of the structure, rather than being uniformly distributed on the concrete section. Also, the space surrounding the reinforcing steel has been severely constricted, preventing effective grouting around the steel after tensioning thereof.

This invention avoids the stated disadvantages of the prior customary construction practice, and includes among the salient features thereof the following:

Positioning the reinforcing members as the placing of concrete proceeds from one end of the structure to the other:

Progressively providing the reinforcing members with

means for preventing bonding to the concrete, preceding the placing of the concrete;

The use of reinforcing members each constituted by a cable consisting of several small reinforcing wires, the cable being formed by applying the wires around a mandrel which is of greater cross-sectional area than the cross-sectional area of the individual wires;

The protection of the reinforcing members during the placement of and finishing operations upon the concrete by means which is successively withdrawn from within completed portions of the poured-in-place concrete;

The provision of support for the individual wires and the bond-preventing means during the concrete placing and finishing stages by means which is successively withdrawn from within completed portions of the concrete, the withdrawable support extending back into concrete in its final consolidated position;

The provision of preformed end blocks with passages for the reinforcing members and mandrels in prespaced arrangement, with provision for securing the reinforcing members in tensioned condition;

The provision of the end blocks with transverse entrance through wells to the passages in the blocks so that tension may be imposed on the reinforcing members at points along a continuous concrete structure, without separation between continuous structures, or at tight joints between structures;

The provision of rigid end blocks of dimensions substantially equal to the concrete section to be prestressed, so that the tension in the spaced reinforcing members is distributed evenly over the concrete section to be prestressed;

The provision of end blocks adapted to serve as headers for the deposited concrete, assuring full contact with the concrete face and providing a firm body for distribution of prestress evenly on the fresh concrete at early age, and permitting the prestress to be imposed on the full cross section in steps, increasing with increasing strength of the concrete between the blocks, this being referred to as "Stress-Curing";

The provision of preformed end blocks that may have miscellaneous devices, such as anchor holes, ties, dowels, dowel sleeves, bases and closures, accurately incorporated therein, together with the passages and wells, during manufacture at the factory, accurate provision of such devices being impossible with job-made forms and at construction speeds.

It is recognized that the construction of prestressed concrete highway pavements in long monolithic slabs with transverse joints spaced much farther apart than in any present design practice offers the possibilities of (1) substantially reducing pavement thickness while eliminating concrete tension failures, (2) reducing the progressive subgrade deterioration and pavement failure attributable to joints and cracks, and (3) making possible a balanced design and interaction between the pavement and its subgrade for traffic loads. Heretofore, however, there has not been any practical and economical method for constructing such pavements. The invention provides a practical and economical method for the construction of pavements of the class described, the method involving post-tensioning of prestressing cables and stress-curing of poured concrete slabs, as is desirable; and further provides a method of and means for carrying out operations relating to the post-tensioning of the prestressing cables without impeding or unduly delaying the operations of pouring and finishing a slab, and allowing the latter operations to be carried out in conventional manner and with conventional equipment. The stress-curing (early application of prestress) is most advantageous to prevent transverse cracks and to provide for quick autogenous healing of incipient cracks such as

may otherwise occur due to the serious temperature decrease and shrinkage at early age of the concrete.

Other objects and features will be in part apparent and in part pointed out hereinafter.

The invention accordingly comprises the constructions and methods hereinafter described, the scope of the invention being indicated in the following claims.

In the accompanying drawings, in which several of various possible embodiments of the invention are illustrated,

FIG. 1 is a perspective view, with parts broken away and shown in section, illustrating a basic prestressed concrete structure of this invention;

FIG. 1A is a vertical section illustrating the use of an intermediate stressing block in accordance with this invention;

FIG. 2 is a plan view, broken away in the center, illustrating the construction of a pavement slab in accordance with this invention;

FIG. 2A is a vertical longitudinal section taken on line 2A—2A of FIG. 2;

FIG. 3 is an enlarged vertical longitudinal section taken on line 3—3 of FIG. 2;

FIG. 4 is an enlargement of a portion of FIG. 3;

FIG. 5 is a transverse vertical section taken on line 5—5 of FIG. 3;

FIG. 6 is a perspective, with parts broken away, illustrating a cable machine of this invention;

FIG. 6A (Sheet 6) is a detail of a tube-forming means of the FIG. 6 machine;

FIG. 7 is a view like FIG. 3 illustrating the cable machine at the start of operations;

FIG. 8 is a transverse vertical section taken on line 8—8 of FIG. 7;

FIG. 9 is a vertical cross section of a prestressing cable sheathed in a tube in accordance with this invention;

FIG. 10 is a view corresponding to FIG. 3 showing how a prestressing cable is stretched;

FIG. 11 is a view like FIG. 4, showing parts as they appear in the completed pavement;

FIG. 12 is a vertical longitudinal cross section showing other parts of the completed pavement;

FIGS. 13–15 are vertical sections illustrating modifications;

FIG. 16 is a generally diagrammatic view partly in elevation and partly in section illustrating another mode of carrying out the invention;

FIG. 17 is an enlarged vertical section taken on line 17—17 of FIG. 16;

FIG. 18 is a vertical section taken on line 18—18 of FIG. 17;

FIG. 19 is a horizontal section taken on line 19—19 of FIG. 18;

FIG. 20 is a plan view broken away in the center, illustrating a modification of the prestressed pavement structure;

FIG. 21 is a vertical section taken on line 21—21 of FIG. 20; and,

FIG. 22 is an enlarged vertical section taken on line 22—22 of FIG. 21, illustrating wire anchoring parts, other parts being omitted.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

Referring to the drawings, FIG. 1 illustrates a basic prestressed concrete structure of this invention. The structure is shown to include two spaced rigid end blocks 1 which serve as headers for a body of concrete 3 (such as a pavement slab) poured in place between the end blocks. Each end block or header is shown as consisting of a precast concrete slab having an inner face 5 continguous with the ends of the body of concrete 3. The dimensions of faces 5 correspond to the dimensions of the cross-section of the body 3 to be prestressed. Each end block is cast with passages 7 for reinforcing members 9. These passages extend from the inner face 5 of the block through the block to its outer face 11. They are preferably spaced at equal intervals laterally of the blocks. The reinforcing members 9 extend through the body 3 from one end to the other. End portions of the reinforcing members 9 extend through the passages 7 in the end blocks and project beyond the outer faces 11 of the blocks. The structure is formed without any substantial bonding of the concrete 3 and the reinforcing members 9, so that the reinforcing members are free to be tensioned though encased in the concrete 3. The reinforcing members are tensioned after the concrete 3 has been poured, and are held in tension as for example by nuts 13 threaded on the projecting ends of the members. The tensioning of the reinforcing members results in the application of concentrated forces on the outer faces 11 of the end blocks by the nuts 13. The end blocks are designed with sufficient distance between the outer and inner faces for spreading these concentrated forces so that substantially uniform distribution of pressure is attained on the ends of the body of concrete 3 at the faces 5 of the end blocks. This prestresses the body 3 substantially uniformly over its cross-sectional area. While the reinforcing members may be tensioned before or after completion of hardening of the concrete 3, it is preferable to tension them at an early age and at a rate increasing with the increasing strength of the hardening concrete for "stress-curing" the concrete.

In the case of long structures, a precast intermediate block such as indicated at 15 in FIG. 1A may be used at an intermediate stressing point between two of the end blocks 1. The intermediate stressing block 15 is shown to have oppositely directed pressure-applying faces 17 with passages such as indicated at 19 in FIG. 1A extending between the faces for the reception of reinforcing members such as indicated at 9, and an access well 21 intersecting the passages. As illustrated in FIG. 1A, the reinforcing members 9 extend from the left end block 1 through the intermediate block 15 to the right end block 1. Concrete 3 is shown as poured in place (without bonding to the reinforcing members) between the left end block and the intermediate block 15. The portion of the reinforcing members between the left end block and the intermediate block is tensioned by anchoring the members to the intermediate block as by means of temporary cooperating wedge members 23 and 25, and then stretching the reinforcing members at their left ends projecting from the left end block. The tension is held in the reinforcing members as by means of nuts 13 applied to the left ends of the members. Concrete is then poured in place between the intermediate block and the right end block (without bonding to the reinforcing members). The reinforcing members are then stretched at their right ends projecting from the right end block. During this operation, wedge member 25 pulls out of wedge member 23. Tension is held as by means of nuts applied to the right ends of the reinforcing members.

The above illustrates the basic principles of prestressed concrete structures of this invention. The construction of a single-lane highway pavement in accordance with these principles is illustrated in FIGS. 2 to 12, certain methods and apparatus of this invention also being illustrated. FIGS. 2 and 2A show side forms F in place on subgrade G for the construction of the pavement. As herein described, the pavement is twelve feet wide, but it will be understood that the invention is applicable to any pavement width. The pavement is to consist of sections S each five hundred feet long, for example, and as herein described is six inches thick. The subgrade G is prepared by conventional methods, preferably being granular at the transverse joint locations, sand or paper being used on a high-friction subgrade.

In accordance with this invention, a precast concrete end block or header A is placed on the subgrade extending between the side forms at one end of each section S

(this being the rearward end of the section as related to the direction in which paving operations proceed), and an identical precast end block or header B is placed on the subgrade at the other and forward end of the section. As shown, each end block or header comprises a concrete slab of substantially rectangular shape in plan and in cross section, and is hereinafter referred to as a "joint slab." Each joint slab has a dimension widthwise of the pavement corresponding to the pavement width (twelve feet, for example), a dimension lengthwise of the pavement of twenty inches for example, and a thickness corresponding to the pavement thickness (six inches, for example). The top face of the joint slab is designated **31** and the bottom face is designated **33**. The short side faces of the slab are designated **35**. The long sides, which constitute end faces as the slabs are used in the pavement, are designated **37** and **39**. End face **37** constitutes a pressure-applying face. End face **39** has a steel facing member **41** of special cross section. The joint slab is cast to have a groove **43** at the meeting edge of its face **39** and its top face **31**. The facing member **41** has a horizontal flange **45** extending over the bottom of this groove and an upper web portion **47** above the bottom of the groove angled in the direction toward the slab. The facing member also has a lower horizontal flange **49** underlying the slab.

At its end face **39**, the joint slab is provided with a row of wells **51** extending down into the body of the slab from its top face **31**. As herein described, there are six such wells, spaced at intervals across the width of the joint slab (transversely of the pavement). The facing member **41** closes one side of each of the wells. The opposite side of each well is designated **53**. The joint slab is formed with horizontal passages **55**, each adapted to receive a prestressing cable. Each passage **55** extends parallel to the side faces **35** of the slab from the pressure-applying face **37** of the slab to a respective well. These passages are located in the central horizontal plane of the slab. The passages are formed by casting the slab around metal sleeves **57**, and, at their ends toward the pressure-applying face **37**, around internally threaded coupling members **59** of larger diameter than the sleeves. Dowel holes **61** are also formed in the joint slab (see FIGS. 5 and 12). Reinforcing bars for the joint slab are indicated at **63**. The facing member **41** has holes **65** aligned with the passages and dowel holes. The joint slab indicated at A (the rearward joint slab of section S) is placed with its pressure-applying face **37** forward, and the joint slab at B is placed with its pressure-applying face **37** rearward. The facing members **41** of adjoining joint slabs B—A may be either butted together or slightly spaced apart to form an open joint. Adjoining joint slabs B—A are doweled together by dowels **67** inserted in the dowel sleeves (see FIGS. 5 and 12).

The joint slabs A and B of each section S serve as anchor blocks for prestressing cables, each generally designated **69**. Six such cables are shown for each section S. Each cable, as herein disclosed, comprises six steel wires. Each wire is designated **71**. Each cable has tubular end terminals **73** in which the ends of the wires of the cable are securely fastened in any suitable way. The cable terminals are of smaller diameter than passages **55**, and are externally threaded as indicated at **75**. Each cable, when unstressed, is shorter than the predetermined length for section S by an amount corresponding to the amount which the cables are to be stretched for prestressing. For example, in the case of a five hundred foot section as herein described, the cables when unstressed may be thirty-four inches shorter than five hundred feet to allow for a thirty-four inch stretch.

To bring the length of a cable **69** up to five hundred feet, so that it may be stretched in accordance with this invention, a string of tubular terminal extensions **77** is attached to the end of each cable terminal **73**. The extensions **77** are strung together and attached to the cable terminals as by means of tubular threaded fittings **79**. The extensions **77** are of the same outside diameter as the cable terminals, and are externally threaded in continuation of the threads on the terminals. Each cable terminal **73** is housed in a sheath **81** which is externally threaded at its outer end for threading in a coupling **59**. Each cable terminal is also shown as having a longitudinal keyway **83** receiving a screw **85** threaded in the sheath **81**, the screw serving as a key to prevent rotation of the terminal relative to the sheath while allowing the terminal to slide axially.

In constructing a section S, six cables **69** are payed out from a coiled condition to extend along the subgrade between the joint slabs A and B which constitute the ends of the section (see FIGS. 2 and 2A). Each cable has the string of terminal extensions **77** at its rearward end entered in one of the passages **55** of joint slab A and its terminal sheath **81** threaded in the respective coupling **59**. The string of terminal extensions **77** at the forward end of the cable is ultimately entered in one of the passages **55** of joint slab B and the terminal sheath **81** at the forward end of the cable is threaded in the respective coupling **59**. The terminal extensions **77** project into the respective wells **51**, and each extension has a terminal nut **87** and an extension nut **89** threaded on the end thereof which projects into the respective well.

Following the paying out of the cables as described (they may be allowed to rest on the subgrade and need not be accurately positioned), a special cable machine M (see FIGS. 6–8) is brought into position on the side forms F somewhat forward of the rearward joint slab A. This cable machine is adapted to travel forward in advance of conventional equipment for pouring and finishing a pavement slab C which ultimately will extend from joint slab A to joint slab B. The cable machine comprises a frame **91** having wheels **93**, the frame including six I-beams **95** (one for each of the six cables) extending longitudinally above the locations of the cables. Toward the rear of the cable machine, each beam **95** carries means **97** for forming a sheath around the respective cable. As herein shown, this means **97** is adapted to form a strip of thin gage sheet metal into a tube around the respective cable. It is shown as comprising a guide **99** extending from a housing **101**. The housing contains a coil K of sheet metal strip (see FIG. 6A). The guide is adapted to form the strip from the coil into a tube around the cable as the cable machine is advanced. The housing and guide are split into two parts on line **103**, the parts being separable so that the cable may be inserted to extend through the tube-forming means **97** at joint slab A, and so that the tube-forming means may be removed from around the cable at joint slab B. FIG. 6A shows one of the two parts removed.

Each beam **95** also carries a mandrel puller **105** for pulling a hexagonal mandrel **107**. The mandrel extends rearward from the puller through the guide **99**, the six wires of the cable being guided onto the sides of the mandrel as operations proceed, and the sheet metal tube being formed around the wires as supported on the sides of the mandrel. Each mandrel puller comprises a carriage **109** having wheels **111** riding on the lower flange of the respective I-beams **95**. The carriage is split into a rearward section **113** and a forward section **115**, detachably connected together as indicated at **117**. Above the beam, the rearward section has a box **119** and the forward section has a box **121**. As to each mandrel puller, a screw shaft **123** extends longitudinally above the respective beam through the respective boxes, and through a nut **125** in box **119** and a nut **127** in box **121**. The ends of each screw shaft are mounted as indicated at **129**. Each screw shaft is adapted to be power driven by any suitable power means (not shown to avoid detail) provided on the cable machine. For example, the shafts may be driven by an internal combustion engine provided on the cable machine, with suitable gearing and clutches connecting the engine and the shafts. Links

131 are pivotally connected at their upper ends as indicated at 133 to the rear carriage section 113, and links 135 are pivotally connected at their upper ends as indicated at 137 to the forward carriage section 115. The lower ends of the links 131 and the lower ends of the links 135 are pivotally connected at 139 and 141 to a pair of mandrel clamping jaws 143. The jaws are movable toward and away from one another, a suitable clamping bolt 145 being provided for drawing them together to clamp the mandrel therebetween.

Any one of the mandrel pullers may be moved in one direction or the other on the respective I-beam by locking both nuts 125 and 127 of the puller against rotation in boxes 119 and 121, as by the insertion of locking keys 147 in the boxes, and rotating the respective screw shaft 123 in appropriate direction. By detaching the rearward and forward carriage sections 113 and 115 of a given mandrel puller, by removing the key for one of the nuts so that it is free to rotate, and by rotating the respective screw shaft in appropriate direction, the detached carriage sections may be separated, thereby swinging the links 131 and 135 upward and raising the jaws 143. This allows the cable machine to travel over the joint slabs, if all jaws have been raised. The mandrel pullers may also be advanced singly over the joint slabs, the length of the cable machine being greater than the length of road covered by the joint slabs.

With jaws 143 of a mandrel puller clamped to a mandrel, the mandrels may be singly advanced and withdrawn from within the wires 69 and the tube or sheath 149 of the respective cable without disturbing the surrounding concrete. The mandrels may extend forward of the mandrel pullers so that they may be advanced continuously through the passages of the joint slabs. The cable machine M may move forward independently of the mandrel pullers and mandrels, during which step the wires are gathered around the mandrels and the tubes formed around the wires, the mandrels remaining stationary. As the cable machine advances, the carriages 109 approach the rearward ends of beams 95 and are then in position to be advanced singly, withdrawing the mandrels an equal distance, and all ending up near the forward ends of the beams 95, in position for the cable machine M to be advanced.

The mandrels 107 are short relative to the five hundred foot pavement section length, preferably being less than fifty feet long. As to any pavement section S, the cable machine M starts out at a position somewhat forward of the rear-end joint slab A, with the tube formers 97 located at the rear-end cable terminal sheaths 81 (see FIG. 7). As to any one of the cables 69, the rearward end portions of its wires 71 extend through the respective tube former 97 (the latter having been separated for entry of the wires and then reassembled). The respective mandrel 107 has its rearward end extending through the rear-end cable terminal 73 to support the wires, and extends forward from the rear-end joint slab A along the subgrade. At the start of operations, the mandrels 107 are free of the mandrel pullers.

The rear ends of the tubes 149 formed by the tube formers 97 are secured to joint slab A, and the cable machine is moved forward away from joint slab A far enough to permit the start of the construction of the slab C. Usually, a twenty foot advance of the cable machine is sufficient for this purpose. The construction of the slab C is carried out in conventional manner, employing a concrete mixer travelling on the shoulder, and a concrete finishing machine traveling on the side forms behind the cable machine. The advance of the cable machine is less than the length of the mandrels, as the cable machine is advanced, the six wires of each cable are guided into position on the six sides of the respective mandrel and encased in the tube 149 formed by the respective tube former 97 upon the advance of the cable machine (see FIG. 9). The mandrels hold the portions of the wires which lie on the mandrels accurately positioned both as to height above the subgrade and location laterally of the subgrade.

After the cable machine has been moved forward as described, concrete is poured in place on the subgrade between the side forms to the specified thickness (six inches, for example) behind the cable machine to start the construction of the poured slab C. The cables are embedded in the poured concrete, but the cables are sheathed by the tubes 149 to prevent bonding of the cables and the poured concrete, thereby remaining free for subsequent stretching. The mandrels support the cable wires in proper position and prevent crushing of the tubes on the wires. Then the mandrels are pulled partly out of the completed portion of the poured slab C and advanced by means of the mandrel pullers. For this purpose, all the mandrels are clamped in the respective clamp jaws 143. One mandrel puller is moved forward on its I-beam at a time to pull the respective mandrel forward and advance the mandrel a distance corresponding to the mandrel puller travel. The cable machine is held against movement by being gripped to the other five mandrels. After one mandrel has been advanced, another mandrel is advanced in the same manner, and so on until all the mandrels have been advanced. It will be understood that the mandrels are not pulled completely out of the guides 99 nor completely out of the previously poured portion of the slab C.

Then, the cable machine is advanced forward another step to permit continuation of the construction of slab C. This may be accomplished, if desired, by holding all the mandrel pullers clamped to the mandrels, and simultaneously turning all the screw shafts 123 in appropriate direction to effect relative movement between the cable machine frame 91 and the mandrel pullers, the latter being held stationary by being clamped to the mandrels, the frame 91 moving forward. The reaction due to the rotation of the screw shafts is transmitted through the mandrels to the previously poured portion of the slab C, in which the rear end portions of the mandrels are gripped with sufficient friction for the purpose. Advancing the cable machine effects formation of further lengths of the tubes 149 around the cables.

The above-described operations are repeated step-by-step until the cable machine reaches the joint slab B. At any convenient time before the joint slab B is reached, clamps 143 are shifted rearward on the mandrels to give them sufficient lead to extend through the passages 55 of joint slab B and through the passages 55 of the adjacent joint slab A which constitutes the rear-end joint slab for the next five hundred foot pavement section S. The mandrels are advanced to extend through these passages. Then, all the mandrel clamps 143 are released and raised, the carriages 109 are advanced over the two joint slabs, and the clamps are lowered and reconnected to the mandrels. The cables will have been encased in tubes 149 substantially up to joint slab B. Any small space left between the ends of tubes 149 and the rearward ends of sheaths 81 projecting rearward from joint slab B may be manually wrapped to prevent bonding of the cables with the concrete and to prevent entry of concrete into the sheaths 81. The cable machine is advanced over the adjoining joint slabs B—A into position to start operations on the next pavement section S. The pouring and finishing of the slab C of the first pavement section S is then completed up to the joint slab B. The mandrels extend back into the slab C an appropriate distance. They are subsequently completely withdrawn from the joint slab B as operations proceed on the next section S.

By the above arrangement, substantial force may be applied to any one mandrel for withdrawing and advancing it, the other mandrels serving to steady the cable machine in the process. The cable machine may be advanced and the cables formed with minimum effort, and the cable machine may be kept at an appropriate distance

ahead of the concrete placing with full freedom of movement, the distance the mandrels extend back into the concrete being independently variable. The mandrels advancing within the wires are restrained only by the friction with the wires with little or no friction restraint by the concrete. Withdrawal of the mandrels is effected with the least disturbance of the surrounding concrete, so that a smooth and full bore or passage is obtained for tensioning of the wires and easy grouting. The dimensions of the mandrel and tubing 149 may be selected so that the weight of the tubing with the wires in it is equal to the weight of concrete displaced by the tubing to prevent flotation, and at the same time provide bores or passages of adequate cross-sectional area for grouting after tensioning of the wires.

As a result of the above-described operations, and with reference to the first five hundred foot pavement section S, the six cables 69 are fully protected from bonding with the concrete by the tubes 149 throughout their lengths from the rear-end joint slab A to the forward-end joint slab B (see FIGS. 9 and 10). The tubes 149 are embedded in the six inch poured slab of concrete C, this slab extending from the pressure-applying end face 37 of joint slab A to the pressure-applying end face 37 of joint slab B. The cable terminals 73 are housed in sheaths 81 and hence are free of slab C.

Now each cable 69 is stretched for prestressing the slab C. Stretching of each cable may be effected by using a hydraulic jack such as indicated at 151 (see FIG. 10). This jack comprises a box 153 in which is slidable a ram 155. A hydraulic cylinder for the ram is shown at 157. The box has a bottom slot 159, and the ram has a head 161 which extends down through the slot for engagement with an extension nut 89 threaded on a string of cable terminal extensions 77. The box also has a downwardly extending abutment 163 for engagement with the side 53 of a well 51.

In using the jack 151, it is placed on a joint slab with its abutment extending down into one of the wells 51 in the slab and abutting the side 53 of the well, and with the head 161 engaging the extension nut 89 on the string of extensions 77 which extends into the well. Then pressure is supplied to the jack cylinder to move the head, whereby the string of extensions 77 is moved to stretch the respective cable at the respective end of the cable an amount equal to the jack travel. As this occurs, the terminal nut 87 moves away from the side 53 of the well. Prior to venting the jack cylinder, the terminal nut 87 is threaded back against the side 53 of the well to hold tension in the cable, then the jack cylinder is vented and the head 161 returned to take another pressure stroke. The extension nut 89 is then threaded back against the head, and another jacking step taken. The jacking steps are repeated until the cable has been stretched at its said end half the total stretch to be taken for prestressing. As the jacking steps are taken, extensions 77 are removed one by one as required. The extensions may be reused.

In the above case, all the cables are stretched at both ends in the manner described, but it will be understood that the cables may be given their entire stretch all at one end, where the pavement is straight and no frictional loss of prestress need be anticipated. For example, assuming that each cable is to be stretched a total of thirty-four inches, it may be stretched seventeen inches at its end at joint slab A and seventeen inches at its end at joint slab B. After stretching, the extension nuts 89 are removed, so that they may be reused. The terminal nuts 87 anchor the ends of the tensioned cables to the joint slabs A and B. The tension in the cables is transmitted through the terminal nuts to the joint slabs and applied over the pressure-applying faces 37 of the joint slabs to the poured slab C to effect prestressing by endwise compression of the slab C.

The decrease in pavement temperature as the concrete setting heat is dissipated to the air and to the subgrade may be about 30° F.; the decrease in pavement temperature due to loss of sun heat at night time, if the pavement is not protected in curing, is of the same magnitude. The corresponding contraction at each end of a 500-foot slab is about one-half inch. Without compressive force to overcome frictional resistance of the subgrade to that contraction, transverse cracks would almost certainly occur. Such cracks, once open, may become obstructed so that they cannot later close under prestress. It is therefore highly desirable to stress-cure the concrete by applying prestress during the very early age of the concrete at a rate increasing with the increasing strength of the hardening concrete. Such prestress could not be safely applied through limited-dimension washers, pads or plates, nor, because of variation in contact surfaces, through rigid blocks imposed after pouring against the ends of the slab C.

Patent 2,251,672 describes a method whereby stress-curing is accomplished by flexible pressure-imposing means. In the present invention, even and positive contact between the rigid end blocks or joint slabs and the ends of slab C is assured by the end blocks serving as forms for the slab C as poured. The end blocks are made substantially to the same dimensions as the cross section of the slab C. Thereby the full strength of the hardening concrete may be utilized for the gradually increasing prestress, commencing as early as three to six hours age if found necessary, and reaching the full value as early as twelve to fifteen hours for high temperature changes.

The end blocks or joint slabs provide firm working platforms for the prestressing operations, workers, tools and forces, before they could be taken without damage by the slab C. The blocks or joint slabs may be designed for distribution of the concentrated forces from the reinforcement in the most economical manner, yet be light enough to be placed easily by crane, and to remain effectively and accurately positioned. These precast blocks would normally be made at some central point, although they could be made in place, sufficient time in advance of general concrete placing operations. Made with accurately fabricated forms under factory or yard conditions, many refinements can be incorporated into the end blocks which could not be satisfactorily handled in the hurried and less accurate means available at the site. The blocks may be made of different and stronger or more rigid materials, to satisfy the greater demands for strength or rigidity adjacent to joints or ends. Passages, wells and dowel sleeves may be incorporated in the premade blocks with a high degree of accuracy. The blocks themselves may be prestressed in the direction of prestressing forces as well as transversely to give increased resistance to forces of continuity. Refined attachments and fittings, such as for joint closures, which could not possibly be provided effectively at the site, without great expense or delay and damage to the concrete, may be incorporated into the blocks of equal structural dimensions in section.

At any time that may be convenient following the cable-stretching operation, the wells 51 and tubes 149 are filled with grout G'. The grout is forced into the tubes 149 through the tubular cable terminals 73, and fills the terminals. In the progressively formed hollow tube 149, dimensions may be elected freely to suit construction conditions; the void around the reinforcement can be made sufficient in size for positive grouting of the longest slabs at the least expenditure of material and without construction inconvenience.

A flexible (rubber) joint top closure 165 (see FIG. 12) is applied to close the joint between adjacent joint slabs B and A. This closure consists of a strip having marginal bead portions 167 adapted to be lodged in the grooves 43 of the joint slabs, the angled upper web portions 47 of the facing members 41 retaining them in place.

When each cable is stretched the total amount at one end, the string of extensions 77 at that end of the cable

which is to be given the total stretch is made twice as long as in the case where the cable is to be stretched half the required total at both ends, no extensions 77 being needed at the other end of the cable, and the other end of the cable may be anchored in any suitable way.

It is contemplated that the cables may be ensheathed by means other than the sheet metal tubes 149. For example, the cables may be helically wrapped with paper or any other suitable material, in which case the devices 97 are wrapping devices. Instead of using such sheathing on the cables, the cables may be coated with a bond-preventing coating, such as a grease or any other suitable material, as indicated at 171 in FIG. 13. In such case, devices 97 are coating devices. Such coatings are easily damaged, and it is particularly advantageous to apply them immediately adjacent to the concrete placing operations at 97. Curing means may be incorporated in devices 97 of either heating or chemical nature. In such case, the mandrels providing support and protection would extend further back into the deposited concrete to assure against crumbling of the concrete around the formed tube. The mandrel may incorporate means such as heating elements or chemical contact agents to speed the setting of the concrete immediately surrounding the tube. To eliminate in the greatest degree damage to the surrounding concrete in withdrawing the mandrel, the central mandrel primarily sliding against the stationary prestressing wires, is particularly valuable.

A further variation of my invention involves the use of a mandrel so shaped or wires so shaped that the wires have insufficient degree of their circumference in contact with the surrounding concrete, whereby, when tension is applied to the wires, they do not bond in the concrete but break away from the wall of the formed tube. The friction between the mandrel and the wires can be sufficient to pull the wires toward the interior of the hollow space left by the mandrel to free the wires from the concrete even before tension is applied. FIG. 14 illustrates a mandrel 173 of special cross section for this purpose, using wires 175 of circular cross section, secured by wire ties 177. FIG. 15 illustrates wires 179 of special cross section for this purpose, using a mandrel 181 of square cross section, and showing wire ties 183.

The mandrels 107 need not be of hexagonal cross section. If the cables have a number of wires other than six, other mandrel cross sections may be more desirable. In some instances, the use of the mandrels 107 is dispensed with. For example, if reinforcing members such as single-wire cables are used, the central mandrels cannot be used. However, in such case, a tube-forming mandrel surrounding each reinforcing member may be used in accordance with this invention to create a void between the reinforcing member and the surrounding concrete of sufficient size for later grouting. FIGS. 16–19 illustrate the use of such an mandrel. FIG. 16 shows a cable machine M–1 having mandrel pullers such as indicated at 185 for pulling tubular mandrels such as indicated at 187, and means such as indicated at 189 for guiding cables such as indicated at 191 into the respective mandrels. The mandrel pullers are located at the rear of the cable machine, and the means 189 at the front of the cable machine. The mandrels extend rearward from the cable machine, each mandrel being supported on sled-type runners 193. Plow-shaped wings 195 may be used to force concrete firmly under the mandrel, even before the screeding and vibration of the concrete by the concrete spreader, vibrator and screed which is indicated at 197.

Even when multiwire cables are used, exterior tube-forming mandrels such as indicated at 187 may be used, together with relatively short central mandrels extending from the means 189 for supporting the wires of the cables. In this case, the means 189 is adapted to form the wires on the mandrel. The exterior mandrels would be of split construction so that they may be removed from around the reinforcement and advanced over joint slabs. While this construction would result in relatively long portions of the reinforcement adjacent to the joint slabs to be wrapped or otherwise protected, the use of exterior mandrels may be particularly suited to construction permitting short mandrels to be used. Fixed tubular exterior mandrels attached to the cable machine may be used in any case as shields to protect the cables and formed tubes through the concrete dumping location closely behind the cable machine. Such shields may have an open bottom to permit easy lifting over the joint slabs, and may have sled-type runners and plow-shaped wings.

FIGS. 20–22 illustrate a modified construction which does not require the use of the cable terminals 73 and the terminal extensions 77. The joint slabs used in this construction are somewhat modified in respect to those shown in FIGS. 3–5, and are designated C′ and D. These joint slabs C′ and D have passages 201 for the cables corresponding to the passages 55, and wells 203 corresponding to the wells 51, but in this case the wells 203 are shown as being located centrally rather than toward the outer faces of the joint slabs. The wells 203 are so formed as to allow the ends of the cables to curve upward and out of the wells, as illustrated at the right in FIG. 21. Stretching of the cables is accomplished by operating on their ends extending out of the wells. Anchoring of the cables in the joint slabs is accomplished by means of wedge anchor members 205 provided in the joint slabs and cooperating wedges 207. The wedge anchor members 205 are secured by means of the bars 209 embedded in the joint slab. Holes for grouting the cable passages are indicated at 211. Dowels are indicated at 213, dowel holes at 215, and passages for grouting the dowel holes at 217. In this modification, a flexible (rubber) joint top closure 219 is clamped in position by means of clamp bars 221 secured to face plates 223 by screws 225.

It may be advisable in some instances to provide the cable machine with an outrigger extending forward from the machine having means for supporting the cables and mandrels above the subgrade and guards overlying the cables to protect them.

It may be found that the mandrels need not be separately movable by the cable machine. Such conditions would exist where the speed of construction is slow, or where the concrete placed is so stiff as to preclude collapse of the tube walls immediately after placement or consolidation, or where the resistance to movement of the mandrels sliding against the wires or the tube walls is relatively low, or where only one or two or very few mandrels are used, so that the cable machine has sufficient tractive force to perform all the operations simultaneously. In that case the mandrel may constitute an integral part of the cable forming tool. It may still be provided so as to project forward through the passages of the end blocks.

Transverse reinforcement, such as tiebars through longitudinal joints, if it interferes with the cable machine, may be positioned in the working space between the cable machine and the concrete placing. The same would be true for stirrups, tubes or mandrels for transverse prestressing. Such appurtenances can be tied to the cables or sheathing without risk of displacement by the withdrawing of the central mandrels.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above constructions and methods without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. The method of constructing a prestressed concrete structure comprising the steps of placing two headers at

locations corresponding to the ends of the structure, laying multiwire prestressing cables to extend from one header to the other, the ends of the cables extending through openings in the headers, then, starting at one header, laying a portion of the length of the wires of each cable on a mandrel and forming a sheath around said portion, pouring concrete around the sheathed portions of the cables, withdrawing the mandrels before the concrete has set and advancing them in the direction toward the other header, laying a further portion of the length of the wires of each cable on the respective mandrel and continuing with the formation of the sheath around said further portion, pouring concrete around the further sheathed portions of the cables, again withdrawing the mandrels before the concrete has set and advancing them, repeating the sheath-forming, pouring and mandrel-advancing steps up to said other header, whereby a sheath is formed around each cable throughout its exposed length between the headers, whereby the mandrels are completely withdrawn from within the sheathed cables, and whereby the space between the headers is filled with concrete, the sheathed cables being embedded in the concrete, and then tensioning the cables and anchoring their ends to the headers.

2. In the construction of a prestressed concrete structure, the steps of placing two headers at locations corresponding to the ends of the structure, pouring concrete, starting at one header, around a portion of a reinforcing member and an elongate mandrel extending lengthwise of and contiguous to said portion, withdrawing the mandrel from within the concrete before it has set thereby substantially freeing said portion of the reinforcing member from the surrounding concrete and leaving said portion of the reinforcing member extending through a passage in the concrete and concomitantly advancing the mandrel lengthwise into lengthwise and contiguous relation with a further portion of the reinforcing member, pouring concrete around said further portion of the reinforcing member and the mandrel, withdrawing the mandrel from within the concrete before it has set thereby substantially freeing said further portion of the reinforcing member from the surrounding concrete and leaving said further portion of the reinforcing member extending through a passage in the concrete and concomitantly advancing the mandrel lengthwise into lengthwise and contiguous relation with another portion of the reinforcing member, progressively repeating the pouring and mandrel-withdrawing steps to the other header, whereby the entire length of the reinforcing member is left extending through a passage in the concrete, tensioning the reinforcing member, and anchoring the ends of the tensioned reinforcing member to the headers to apply the tension to effect compression of the concrete.

3. The method of constructing a prestressed concrete structure utilizing elongate mandrels comprising the steps of placing two headers at locations corresponding to the ends of the structure, positioning prestressing members to extend from one header to the other, the ends of the members extending through openings in the headers, then starting at one header, sheathing portions of the members and said elongate mandrels with said mandrels extending lengthwise of and contiguous to said portions, pouring concrete around said portions of said members and mandrels thus sheathed against the surrounding concrete, withdrawing the mandrels from within the concrete before it has set thereby substantially freeing said portions of said members and leaving said portions of the members extending through passages in the concrete and concomitantly advancing the mandrels lengthwise into lengthwise and contiguous relation with further portions of the members, sheathing said further portions of the members and the mandrels, pouring concrete around said further portions of said members and the mandrels thus sheathed against the surrounding concrete, withdrawing the mandrels from within the concrete before it has set thereby substantially freeing said further portions of said members and leaving said further portions of the members extending through passages in the concrete and concomitantly advancing the mandrels lengthwise into lengthwise and contiguous relation with further portions of the members, progressively repeating the sheathing and pouring and mandrel-withdrawing steps up to the other header whereby the entire lengths of the members are left extending through passages in the concrete, and then tensioning the members and anchoring their ends to the headers.

4. The method of constructing an elongate prestressed concrete slab on a base, comprising the steps of placing two headers on the base spaced apart a distance corresponding to the desired slab length, said headers having passages for the ends of prestressing wires, laying prestressing wires on the base with the wires extending from one header to the other and with the ends of the wires extending through the passages in the headers, then, in successive reaches along the length of the base between the headers, raising the wires from the base to their final height in relation to the slab to be formed, providing the wires with bore-forming means comprising mandrels for forming tubular bores for the wires in concrete poured therearound while protecting the wires from becoming bonded in the concrete with the tubular bores of larger cross-sectional area than the wires contained therein, pouring concrete on the base around the raised wires and bore-forming means, subsequently removing the mandrels from within the poured concrete leaving the wires extending loosely through said tubular bores without being bonded to the slab, and tensioning the wires and anchoring them to the headers.

5. The method of claim 4 wherein the wires are applied against the outside of the mandrels and the bore-forming means further comprises sheaths which are provided around the wires and mandrels to provide protection for the wires from becoming bonded in the concrete.

6. The method of claim 4 wherein the mandrels are tubular and the wires extend through the mandrels.

7. The method of claim 4 wherein the wires are tensioned and anchored to the headers to apply their tension to the poured concrete slab while the latter is at an early age and said tensioning being at a rate increasing with the increasing strength of the hardening concrete for stress-curing the poured concrete slab.

8. The method of constructing an elongate prestressed concrete slab on a subgrade comprising the steps of placing two precast concrete joint slabs on the subgrade spaced apart a distance corresponding to the desired pavement joint spacing, said joint slabs having passages for the ends of prestressing wires and wells extending downward and intersecting the passages, laying prestressing wires on the subgrade with the wires extending from one joint slab to the other and with the ends of the wires extending through the passages in the joint slabs into the wells, then, in successive reaches along the length of the subgrade between the joint slabs, raising the wires from the subgrade to their final height in relation to the slab to be formed, providing the wires with bore-forming means comprising mandrels for forming tubular bores for the wires in concrete poured therearound while protecting the wires from becoming bonded in the concrete with the tubular bores of larger cross-sectional area than the wires contained therein, pouring concrete on the subgrade around the raised wires and bore-forming means, subsequently removing the mandrels from within the poured concrete leaving the wires extending loosely through said tubular bores without being bonded to the slab, and tensioning the wires by operating on their ends accessible via the wells of one of the joint slabs, the ends of the wires in the wells of the other joint slab being anchored to said other joint slab.

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