

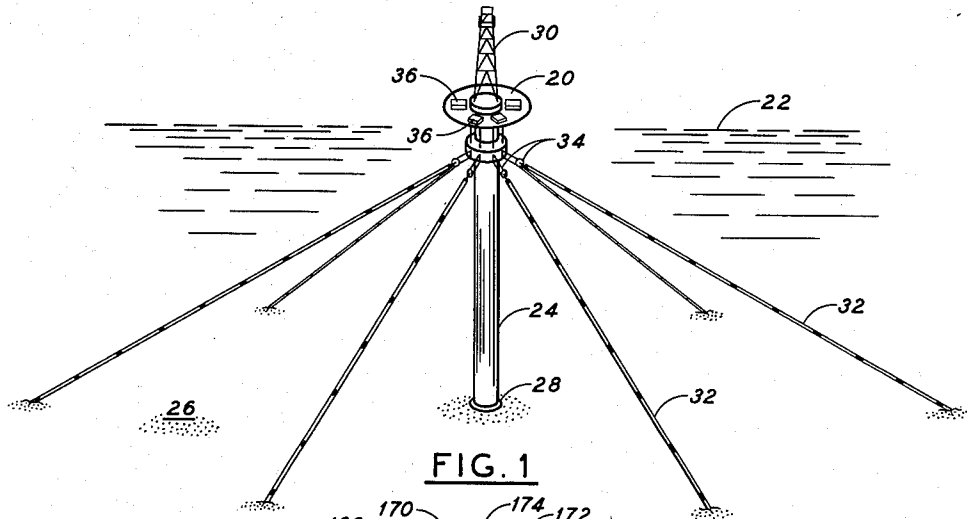
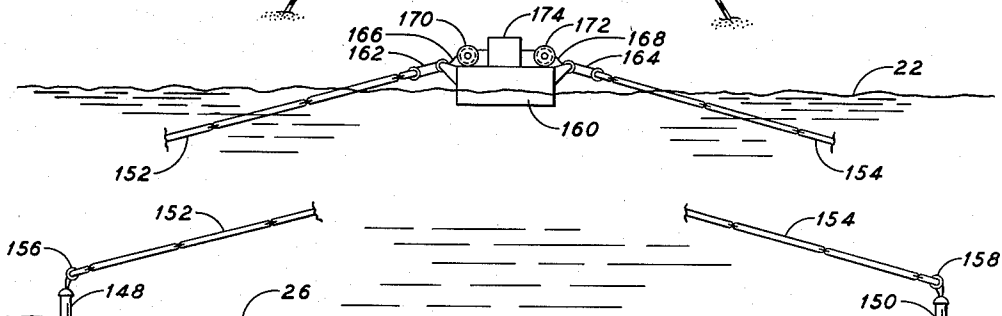
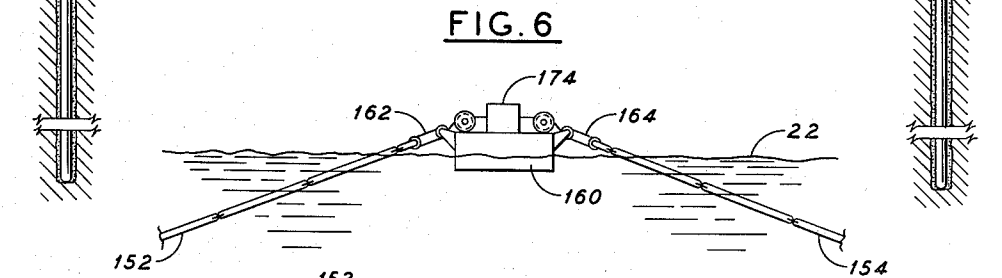
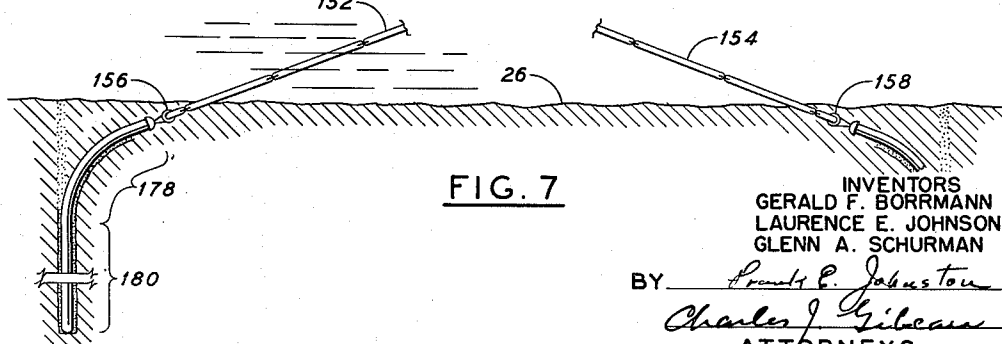
June 20, 1961

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ANCHORING METHOD AND APPARATUS

2,988,893

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4 Sheets-Sheet 1



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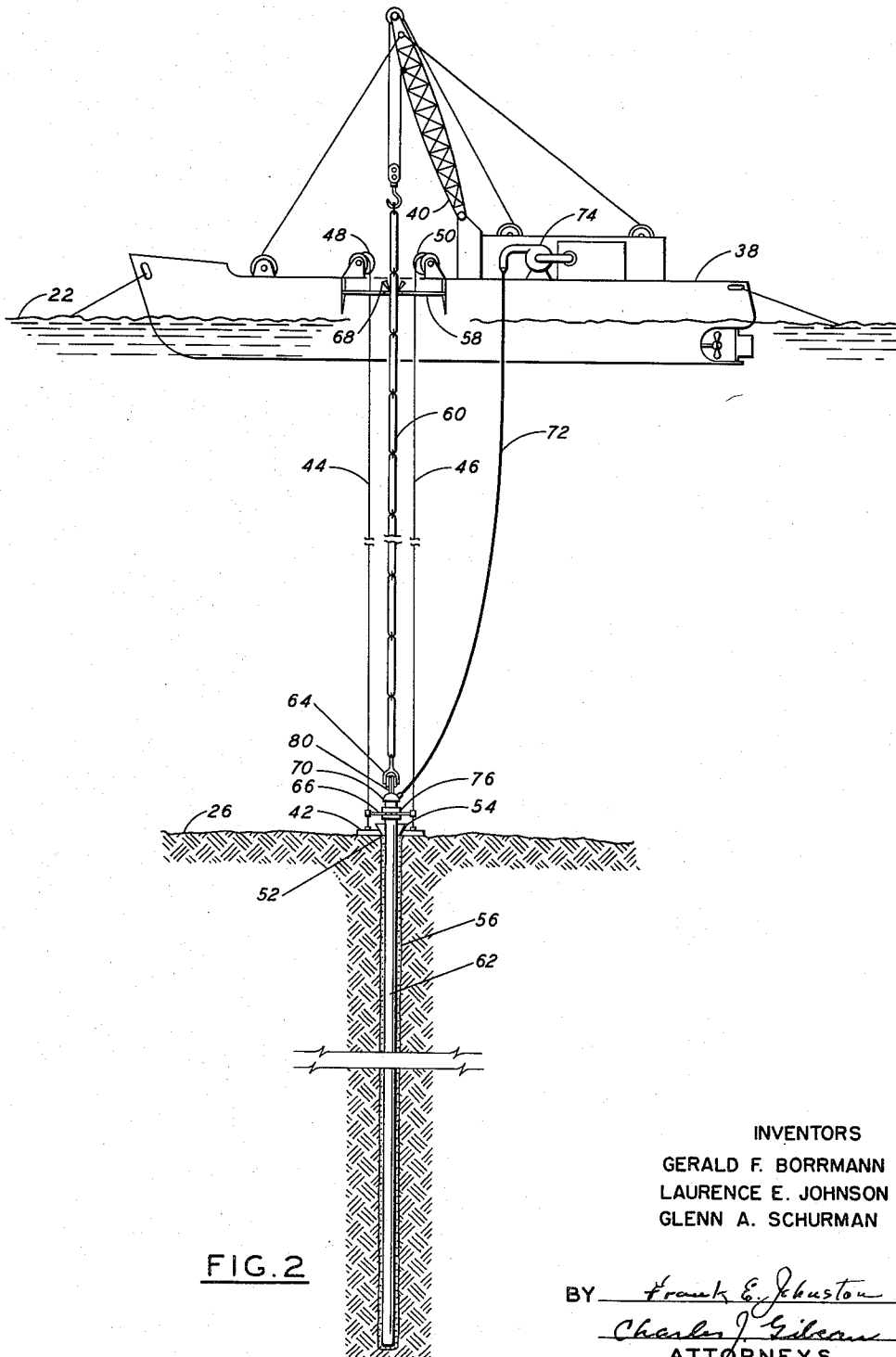
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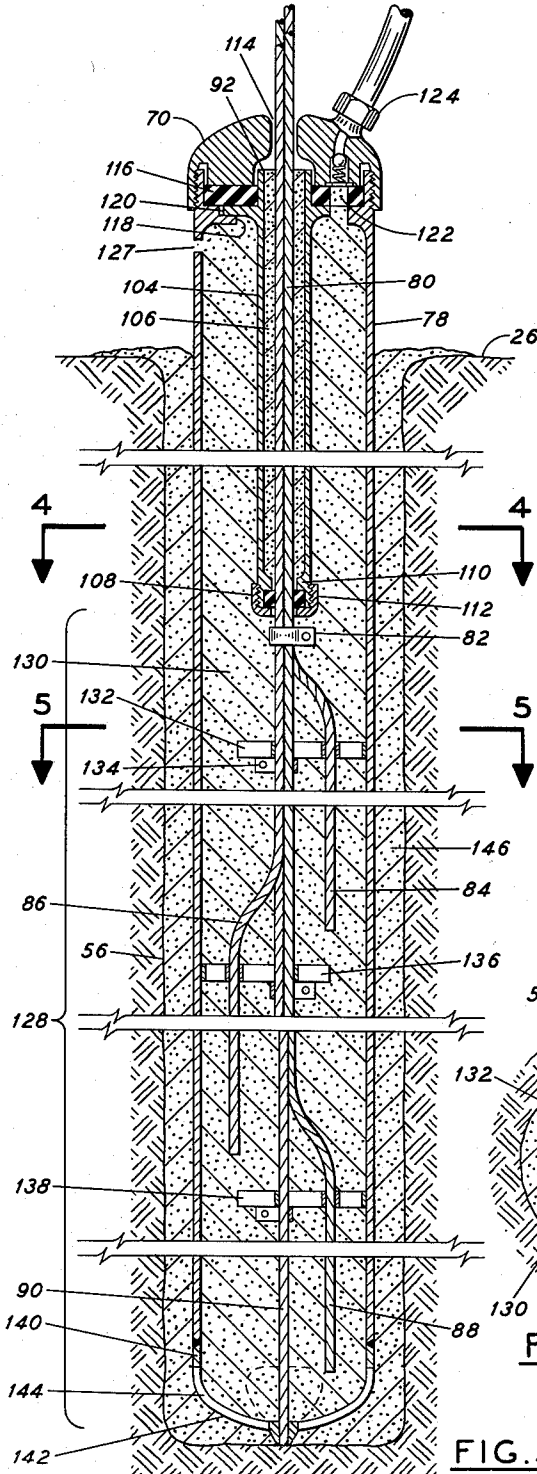


FIG. 3A

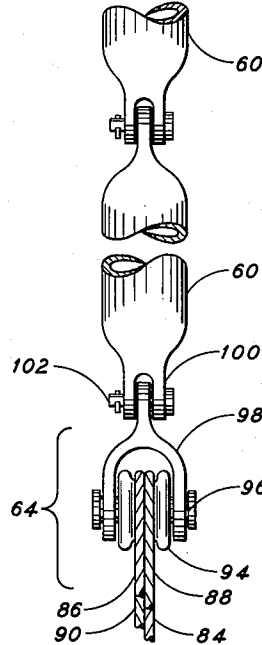


FIG. 3B

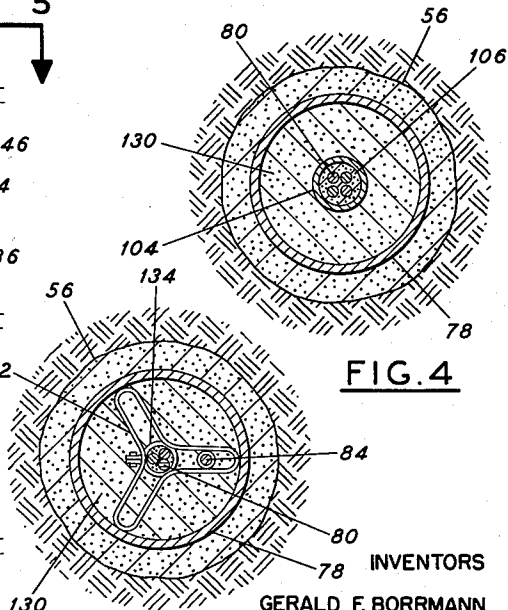


FIG. 4

FIG. 5

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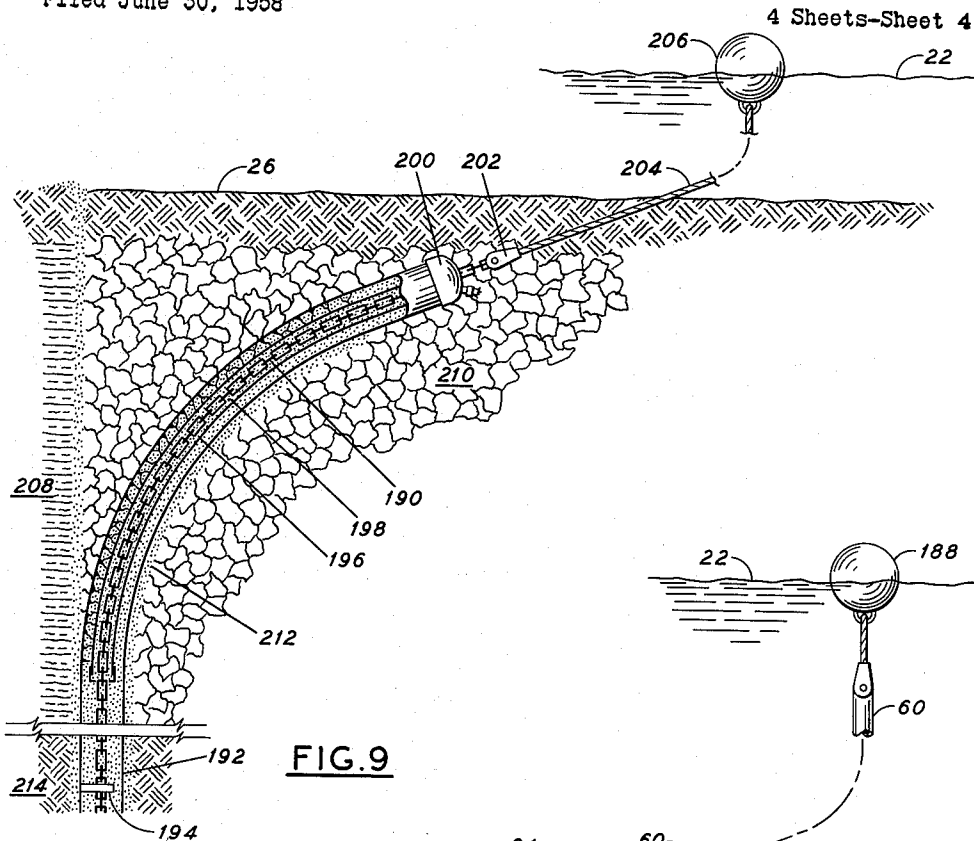
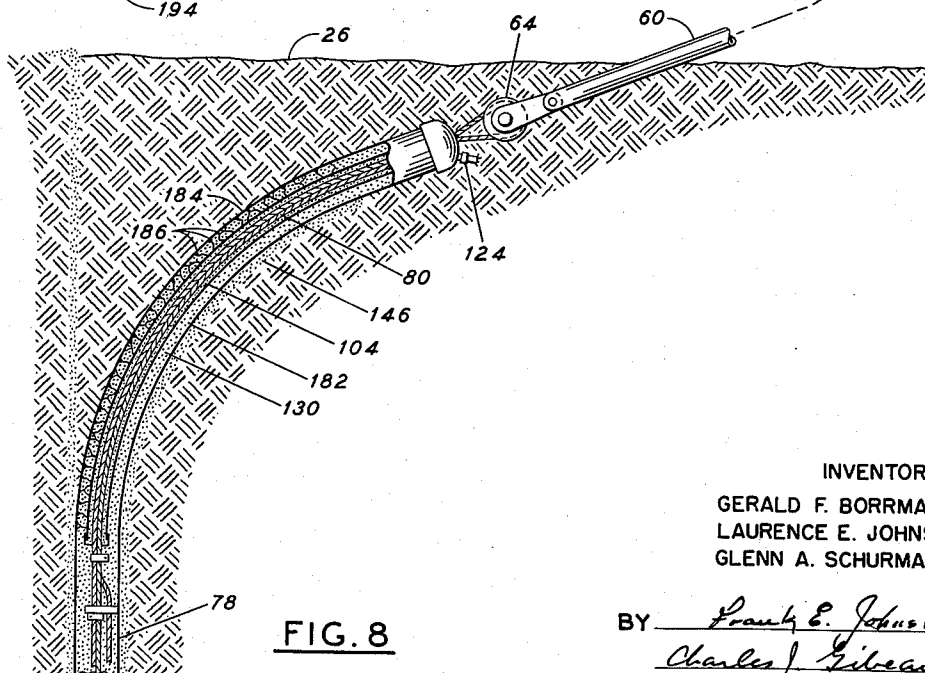
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ANCHORING METHOD AND APPARATUS

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This invention relates to anchoring means and more particularly to a method and apparatus for making a fixed lateral anchor for a marine structure.

The problem of anchoring a marine structure against transverse movement when it is exposed to severe wind and water forces has received much attention over a long period of time. The magnitude of this problem increases with the size of the structure to be anchored, and it is well known that large ships, for example, experience difficulty by dragging their bottom anchors under storm conditions. For vessels anchored in the open water, it may be only an inconvenience to have them displaced laterally from their moored position due to anchor drag. However, when such vessels must be anchored over a fixed site, as is the case for petroleum tankers which are loading or unloading at offshore stations, it becomes necessary to keep the vessel restrained to a particular location if the operation is to be completed successfully.

The anchoring problem becomes more difficult for such structures as offshore drilling platforms, which must be maintained in a substantially fixed position over a submerged well site against the wind and water forces to which they are exposed. It has been proposed heretofore that marine structures be anchored by attaching them to massive bottom anchors of sufficient weight to create enough friction on the ocean bottom to prevent anchor drag. It has been proposed, also, to anchor offshore structures to piles driven into the bottom of the water and to make the piles with sufficient strength and area to prevent their bending, or causing the earth into which they are driven to be displaced by the transverse loads imposed on it, either of which circumstance leads to anchor failure.

The economic considerations related to an anchor system are of considerable practical importance. The cost of the system increases approximately in direct relation to its holding power. For a large drilling structure anchored by one of the systems familiar to the art, the cost of the anchor system alone may well exceed a million dollars. Therefore, to make offshore drilling economically feasible, it is important that an anchor system be devised which can be installed and operated for the least amount of money without sacrificing any of its structural strength or desirable operating characteristics.

It is an object of this invention to provide a novel anchor means an method for forming it.

A further object of this invention is to provide a novel anchor means which is fixed to the earth and which will not be displaced from its fixed position by the loads imposed on it by the structure it anchors.

A still further object of this invention is to provide an anchor means which is cemented into the earth and which is preformed in situ to receive in an axial direction the anchoring forces imposed on it by a laterally disposed anchor line subsequently connected to it.

Another object of this invention is to provide a means for affixing an anchor assembly in a vertical bore hole in the earth and thence forming the top portion of it in a particular curve within the earth and in alignment with the direction of pull of the anchor line attached to it to provide an anchor which will not be displaced by the transverse forces imposed on the structure which it anchors.

The means for achieving these, and other objects of

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the invention will become apparent as the description of it proceeds, in conjunction with the accompanying drawings which form a part of this application.

This invention employs an anchor which comprises an outer casing and an inner tensile member assembled together in a particular manner and designed to be formed in a particular configuration after it is set in the earth. The tensile member extends into the casing for substantially the whole length of the latter and projects from the top of it, where it terminates at a flexible connector. The lower portion of the tensile member is affixed to the lower portion of the casing throughout a longitudinal extent of the parts, while the upper portion of the tensile member is maintained in a spaced relationship with the inner walls of the upper portion of the casing by means which permits a relative longitudinal motion between these portions of the assembly.

The casing is set vertically in the earth with a portion of its upper section extending above the earth's surface and is cemented in place. An anchor line is attached to the flexible connector at the top of the tensile member and is disposed laterally from the anchor in substantially the direction it will assume when it is attached to the structure to be anchored. A tensile force is applied to the anchor line, and the force is increased to bend the upper portion of the anchor assembly in a curve which will extend into the earth and be tangent at one end with the vertical lower portion of the assembly and in alignment with the direction of pull of the anchor line at its other end. The force on the anchor line is increased to an amount above that which will be placed on the anchor during normal operation to shape the anchor assembly in a conformation which will not be changed by the loads imposed on it later.

As the upper portion of the anchor assembly bends, it will displace the earth against which it bears in a transverse direction and also cause it to be compacted. The upper portion of the casing is proportioned with respect to the particular characteristics at the anchor site to present a sufficient bearing area to the earth to produce a smooth curve of a predetermined form as the upper portion of the anchor assembly is bent.

When the anchor assembly is shaped into its final form, the forces of the anchor line are transmitted to and in alignment with the upper portion of the tensile member, and these forces are resisted primarily by the fixed vertical lower portion of the tensile member and transmitted to the earth by the casing cemented to it.

Several embodiments of the anchoring system are illustrated in the accompanying drawings, in which:

FIG. 1 is a schematic representation in elevation of an offshore drilling structure anchored in position by the anchoring means of this invention, as an exemplification of its use.

FIG. 2 illustrates schematically a means for establishing an anchor assembly in a submerged location.

FIG. 3A is an elevational view partly in section illustrating details of an anchor assembly cemented in the earth and prior to shaping it in its final form.

FIG. 3B is an elevational view illustrating details of a connector for attaching an anchor line to the anchor assembly.

FIG. 4 is a plan view of the assembly taken along the line 4—4 of FIG. 3.

FIG. 5 is a plan view of the assembly taken along the line 5—5 of FIG. 3.

FIGS. 6 and 7 are schematic illustrations of steps of a method for shaping the anchors.

FIG. 8 is an elevational view partly in section of a completed anchor installation.

FIG. 9 is an elevational view partly in section of a

modification of an anchor made in accordance with this invention.

To exemplify an installation of an anchoring system in accordance with this invention and show how the parts function to restrain the lateral movement of a marine structure, it will be described as applied to offshore drilling apparatus. However, it will be apparent that the utility of the anchor means is not confined to this specific use.

As illustrated in FIG. 1, the drilling apparatus may comprise a drilling platform 20 which is supported above the surface of the water 22 by a column structure 24, the lower end of which is seated at the bottom of the water 26 at a footing 28 which holds the bottom of the column at the drilling site. Drilling structures of this type are intended for use primarily in relatively deep water in the range of depth, for instance, from 350 to above 1,000 feet. The support column is a slender structure and may have a ratio of length to diameter in the order of 20-1 to 40-1.

As will be understood in the art, such a structure may be built on land with buoyancy chambers incorporated in it along its length so that it may be floated in a horizontal position to the drilling site. The column is placed in a vertical position by flooding the buoyancy chambers in its lower section while maintaining those in its upper portion filled with air. The column is then towed to the drilling site, and its buoyancy is controlled to cause it to swing in a vertical position until its bottom is seated on the submerged earth. The chambers in the lower portion of the column are then filled with a dense material, such as sand or cement, to hold it firmly seated on the earth while the upper chambers remain buoyant. Such a manipulation of the buoyancy chambers not only assists in maintaining the column in a vertical position but also produces a tension through the middle portion of the column, thus increasing its load-carrying ability.

A plurality of conductor casings are incorporated in the column structure and extend from the drilling platform through the base of the column. The conductor casings are used to guide drill strings into the submerged well bores and serve also as an extension of the well bores to the surface of the water where well control equipment can be assembled on them. The derrick 30 is of the known type which includes laterally movable crown blocks to enable a plurality of wells to be drilled from the single derrick setting.

The anchor system illustrated in FIG. 1 comprises a plurality of similar anchor arrangements disposed in equi-angular relationship around the circumference of the column and extending therefrom in a generally radial direction. Each anchor arrangement comprises an anchor line 32 which extends between a fixed bottom anchor, which will be described hereinafter, and the top portion of the column. The anchor line is connected to the column by a means which enables the tension on it to be controlled. As illustrated schematically in FIG. 1, each anchor line may be connected to a respective block-and-tackle system 34 which is affixed to the upper portion of the column and actuated by a corresponding winch 36 on the drilling platform. This mechanism enables the tension on the anchor line to be adjusted. Alternatively, a jacking device or similar means may be used to adjustably connect the anchor lines to the column.

During normal water conditions, when the waves may have a maximum total amplitude of 6 to 8 feet, the upper portion of the column structure will have imposed on it transverse forces of a few hundred thousand pounds per foot. However, under storm conditions the waves may have a total amplitude in the range of 50 feet and impose several millions of pounds of force per foot on the upper portion of the structure. The anchoring system, therefore, must be made strong enough to restrain the drilling structure in its upright position under the forces imposed by storm conditions. For a column of the type described heretofore, this may require that each anchor line be able

to sustain a force of approximately one and one-half million pounds' tension. The anchor system of the present invention is designed to accept a tensile load of this magnitude without being moved from its installed position in the earth.

FIG. 2 illustrates a method for establishing one of the anchor assemblies in a submerged offshore location. When the location for an anchor has been selected, a drilling vessel 38 on which is mounted a derrick 40 is anchored over this site, and a weighted templet 42 is lowered from the vessel to the bottom of the water on guide lines 44 and 46, which are paid out from respective winches 48 and 50. The templet has an opening 52 through its central portion which is surrounded by a guide funnel 54. A drill string and bit are guided down the guide cables and through the openings in the templet until the bit is in contact with the earth, and a bore hole 56 of sufficient diameter to accept the anchor assembly is drilled by rotating the drill string by a rotary table mounted on the platform 58 affixed to the vessel. The depth of the bore hole is controlled to position the anchor assembly in the proper relationship to the surface of the earth for a purpose to be described hereinafter.

When the bore hole is completed, the drill string and bit are removed from it and returned to the drilling vessel. An anchor line 60 is attached to the anchor assembly 62 by a flexible connection 64, and the assembly is lowered from the vessel by the derrick 40 and guided along the guide lines 44 and 46 by guide arms 66 into the well bore. If the anchor line is formed of interconnected sections as illustrated herein, preferably it passes through the rotary table opening in the platform 58 and may be held by slips 68 while sections are added to it as its length increases.

The upper portion of the anchor assembly is closed by a cap 70 to which is connected a flexible hose 72. The hose is attached to the assembly prior to lowering it through the water and is paid out from the vessel as the assembly is lowered. This hose is connected to a pump 74 aboard the drilling vessel, which is used to force a cementing material, such as grout, into the interior portion of the anchor assembly and between the outer casing of it and the walls of the bore hole to cement the components together and to the earth in a manner to be described in more detail hereinafter.

After the anchor assembly is cemented in place, the hose 72 is disconnected from the cap and retrieved, and the templet 42 is raised to the vessel by the guide lines 44 and 46. The guide arms 66 are attached by shear pins to a collar 76 which frictionally engages the anchor assembly, and will become disconnected from the collar when the templet is forced against them. The opening 52 in the templet is made with sufficient diameter to clear the cap 70 and the connection 64 as the templet is raised.

Referring now to FIG. 3A of the drawings, the anchor assembly comprises the outer casing 78 within which is positioned a tensile member 80. In the embodiment of the invention illustrated, this tensile member may comprise a plurality of galvanized wire cables which are clamped together in a bundle as by the ring 82. The number and size of the cables will, of course, depend on the load the anchor assembly is designed to hold. For example, for a column structure as described heretofore for use in 1,000 feet of water, the tensile member in each anchor may be made up of 10 cables, each of which is 2 3/4" in diameter. However, for purposes of illustration, FIG. 3A shows the tensile member as made up of four cables, numbered 84, 86, 88 and 90.

The tensile member extends through the upper end 92 of the casing 78 and terminates in the flexible connector 64 to which the anchor line 60 is attached. As indicated in FIG. 3B, the connector 64 may be formed as a spool 94 which is mounted on an axle 96 supported in a yoke 98. The yoke is pivotally connected to a clevis 100 on the end of anchor line 60 by a pin 102. The tensile

member is made up of lengths of cable wrapped over the spool with each end of each length disposed within the casing 78.

The upper portion of the tensile member within the casing is surrounded by a sleeve 104 which is proportioned to provide an annular space 106 between the circumference of the tensile member and the inner wall of the sleeve. This annular space is closed off at the bottom of the sleeve as by a packing material 108 which is positioned between the sleeve and the tensile member and placed under compression between the inwardly projecting shoulder 110 formed on the sleeve and a cap 112 screw-threaded on the end of it to provide a fluid-tight connection between the parts. This packing occludes the cementing material from the annular space. Preferably the annular space 106 is filled with a material which will assist the upper portion of the tensile member to move relative to the upper portion of the casing 78 when the anchor assembly is bent. Materials suitable for this purpose may be, for instance, a bituminous substance which will flow under the loads which will be imposed on it, a heavy lubricant, packed sand, a plastic polymer or some similar substance.

In the present modification of the invention, the cap 70 is attached to the upper end of casing 78 by screw threads. It has an axial opening 114 large enough to permit the tensile member to move freely through it. A packing material 116 is placed under the cap between the inner wall of the casing and the outer wall of the sleeve and is placed under compression between the cap and shoulders 118 and 120 projecting from the sleeve 104 and casing 78, respectively, to provide a fluid-tight connection between these parts. A conduit 122 is inserted through the cap and packing to provide a communication between the interior of the casing and the connector 124 for the flexible hose 72. A check valve 126 is placed in the conduit to permit the flow of cementing material into the casing and prevent a return flow. The casing is vented, as at 127, to permit the entrapped air to escape as the interior of the casing becomes filled with the cementing material.

In accordance with the concept of this invention the lower portion of the tensile member 80 is secured to the lower portion 128 of the casing to transmit the loads from the tensile member to the casing and thence from the casing to the surrounding earth. As illustrated in FIG. 3A, the individual cables are separated progressively from the bundle throughout the lower portion of the casing and spread apart so that each will be surrounded by and bonded to the cementing material 130 which subsequently fills it. Thus, for example, the cable 84 is separated from the bundle and held away from it by a spider 132 to which it is attached. The spider is set transversely of the axis of the assembly and is affixed to the central tensile member, as by clamp 134. It is formed with openings to permit the cementing material to pass downwardly through it to lower portions of the casing. Likewise, the cables 86 and 88 are separated from the bundle at lower positions and held apart from it by the corresponding spiders 136 and 138. A sufficient length of each cable is separated from the bundle to provide an area of it bonded to the cement which will permit the cable to operate at its full tensile strength. For the example mentioned heretofore, each cable may require a separated length in the range of 12 feet to develop the necessary resistance to shear at the cement bond.

In the modification of the invention described heretofore, where the anchor assembly is put together at the surface of the water and thence lowered into the bore hole, one cable 90 may be attached to a spider 140 which is affixed to the lowermost portion of the casing to thereby support the component parts in their assembled positions and enable the assembly to be lowered as a unit. However, under some circumstances it may be desirable to form the anchor assembly by first positioning the outer casing of it in the bore hole and subsequently inserting the

tensile element into it. In this latter circumstance all of the individual cables are spread from the bundle by spiders similar to that described previously with respect to cable 84, and the spiders are made to have sufficient clearance with the inner wall of the casing to permit them to be inserted into it to their predetermined positions.

Preferably the lower end of the casing is rounded, as at 142, to assist it in entering the bore hole. The openings 144 provided in the spider 140 permit the cementing material to flow from the interior of the casing and into the bore hole 56.

When the components of the anchor are assembled and it is positioned in proper relationship to the surface of the earth, as will be described hereinafter, a cementing material is forced downwardly under pressure through the hose 72 and into the interior of the casing. This cementing material fills the casing to the top packer 116, being excluded from contact with the top portion of the tensile member 80 by the sleeve 104. The cementing material surrounds the separated cables in the lower portion of the assembly, as indicated by the numeral 130, and thence flows outwardly through the openings 144 into the annular space between the exterior of the casing 78 and the wall of the bore hole 56, as indicated by the numeral 146. Sufficient cement is forced through the casing to flush any contaminating substances from it and from the bore hole to provide a good bond between the cement and the surfaces it contacts. If the bore hole and the anchor assembly are filled with a drilling mud or some like substance, as may be the case when the bore hole is drilled with a drilling mud, then preferably the assembly and the bore hole are flushed with a wash fluid prior to forcing the cement into the parts, in accordance with the cementing practice followed in oil field operations. The sheath of cement surrounding the upper portion of the casing increases the effective diameter of it and affects the curvature it will assume when it is placed under a transverse load. This factor is one of the design parameters of this anchor arrangement.

The length and diameter of the anchor assembly are major factors in determining the amount of resistance to displacement it will develop and the configuration its upper portion will assume when bent through the earth into its final form. These factors are dependent on the characteristics of the subterranean formations in which the anchor is cemented. For example, if the outer casing of the anchor has a diameter of 2 feet and if the soil has an angle of internal friction of zero degrees, cohesion of 100 pounds per square foot, and a submerged unit weight of 35 pounds per cubic foot, an anchor assembly approximately 610 feet long will be required to anchor the structure illustrated in FIG. 1. In this assembly, approximately 338 feet of the lower portion of the casing will remain vertically disposed in the earth when the upper portion of the anchor is shaped into its final form. The major resisting forces of the anchor will be developed around this lower portion. The upper portion of the anchor assembly, which is approximately 272 feet long, is designed to be bent in a curve which is tangent at one end to the vertical lower portion and in alignment at the other end with the direction of force in the attached anchor line, as explained heretofore. For the soil and loadings described, the uppermost part of the anchor will be displaced horizontally approximately 180 feet from its initial vertical position, and the curve which this upper portion of the anchor forms will be tangent to the lower vertical portion of the anchor at a depth of approximately 178 feet below the surface of the earth.

For the above-described conditions, the anchor assembly is set in the earth with approximately 94 feet of it extending above the earth's surface and is cemented in this position. Subsequently, the anchor line 60 is disposed to extend laterally of the anchor and is placed in tension to curve the upper portion of the anchor assembly in the manner described heretofore. When this curve

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reaches its final conformation, the flexible connection 64 will be buried within the earth so that the complete anchor assembly will be embedded, with the anchor line 60 extending diagonally upwardly from it to the surface.

The flexible connection 64 permits a transverse load to be transmitted from the anchor line to the anchor assembly without causing kinks or small-radius bends to be developed in the parts. It will be appreciated that the thickness of the walls of the casing 78 and sleeve 104 relative to the lengths of these parts subjected to the bending force enable them to bend as smooth curves under the lateral loading involved. It is within the concept of this invention to make the casing of the upper portion of the assembly, and the sleeve contained therein, of a relatively flexible material, such as thin-walled steel pipe, a resinous polymer, or a ductile material which bends under transverse loading.

As another example of the variations of anchor dimensions with soil conditions, if the outer casing of the anchor assembly has a diameter of 3 feet and if the soil has an angle of internal friction of 35°, cohesion of zero pounds per square foot, and a submerged unit weight of 50 pounds per cubic foot, the anchor will require a casing 272 feet long. Approximately 192 feet of this length of casing will comprise the lower section which is cemented to the earth and remains vertical. The upper portion will comprise 80 feet of the casing length. The casing will be cemented in the bore hole with approximately 26 feet of it extending above the surface of the earth. When this upper portion is bent through the earth by the lateral loading of the anchor line, as described heretofore, the top part of it will be displaced in a horizontal direction approximately 51 feet and will be buried within the earth. The curve of the upper portion will be tangent to the vertical lower portion of the casing at a depth of approximately 54 feet within the earth.

FIGS. 6 and 7 illustrate a method for forming in situ anchors which may be used to anchor a structure such as that illustrated in FIG. 1 of the drawings. For this arrangement, six anchors are used, spaced in equiangular relationship around the base of the column. For the column structure described heretofore for use in 1,000 feet of water, each anchor may be displaced in a radial direction 2,500 feet from its base.

For the symmetrical system illustrated, selected individual anchors will be disposed on diametrically opposite sides of the column site. As shown in FIG. 6, two oppositely disposed anchor assemblies 148 and 150 are cemented into the earth with their topmost portions projecting above its surface, as described heretofore. The upper ends of the respective anchor lines 152 and 154, which were attached to the respective flexible connectors 156 and 158 when the anchor assemblies were lowered into place, are connected to a barge 160 by respective block-and-tackle arrangements 162 and 164. The barge is placed between the anchor sites, in a position to be occupied by the drilling structure. The live lines 166 and 168 from the respective block-and-tackle systems are connected to respective drums 170 and 172 of a winch mechanism 174 mounted on the barge. The winch drums are operated in synchronism to place equal tensions on the lines 152 and 154. Thus, in effect, the anchor assemblies are loaded simultaneously against each other.

FIG. 7 illustrates the curved form 178 into which the upper portion of the individual anchor assemblies are bent as the load is placed on them. As explained heretofore, the effective radius of this curve is predetermined by the dimensions of the anchor assembly and the characteristics of the soil into which it is embedded. The lower portion 180 of the assembly remains vertical.

The tension in the anchor lines is increased to an amount above that which will be imposed on them when they are connected to the drilling structure. The excess load is held for a period of time which may range up to

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several days to assure that the anchor assembly is stabilized in its final form and with respect to the earth which bears against it. Preferably, the tension is then released from the anchor lines, and they are subsequently again loaded and held under tension for a period of time as described hereinabove. This cyclic loading process may be continued for as long as is necessary to assure that the anchor has reached a stabilized condition. When the anchors are shaped into their final form, they will remain rigidly fixed in the earth under the loads imposed on them by the drilling structure.

When the forming process for a pair of anchors is completed, the upper ends of the anchor lines 152 and 154 are disconnected from the barge 160 and buoyed to the surface of the water while other opposing anchors are similarly formed. Subsequently the column structure is positioned at the drilling site and the anchor lines are attached to it and brought up to their operating tension.

When the drilling platform is set on a column structure, it is desirable that the structure be anchored rigidly in position so that it will have relatively little lateral movement under wave action. Toward this end, anchor lines are used which are substantially neutrally buoyant and which, under tension, will be disposed as straight lines between the fixed bottom anchors and the column to act as tensile members as distinguished from catenary members. Such neutrally buoyant anchor lines may be made of hermetically sealed lengths of pipe joined together by flexible connections as indicated in FIGS. 2 and 3B of the drawings. Alternatively, the anchor lines may be made of wire cable which is buoyed at intervals along its length to achieve the effect of neutral buoyancy, or the cables may be covered with a buoyant material, such as a cellular plastic material, for this purpose.

FIG. 8 illustrates the disposition of the parts in the upper portion of the anchor assembly of FIGS. 3A and 3B after it has been shaped into the configuration described heretofore. The sleeve 104 which surrounds the upper portion of the tensile member 80 extends substantially down to the location where the curve becomes tangent with the lower vertical portion of the anchor. The sleeve has prevented the upper portion of the tensile member from becoming bonded to the transversely adjacent portions of the anchor assembly and has permitted it to move longitudinally of the assembly as the curve is formed. As the curve develops, the cementing material 130 within the upper portion of the casing 78 is placed under compression along the radially inwardly disposed wall 182 of it, and under tension along the radially outwardly disposed wall 184. Thus transverse fissures or cracks 186 develop in the cement which permit the radially outer wall of the casing to stretch as the bend is made.

It is important in the concept of this invention that the radially inwardly directed surface 182 of the upper portion of the anchor assembly retain its full bearing area against the earth as it is bent, so that it will react with the earth in a predetermined manner to produce a pre-designed curve. The cementing material pressing against the wall of the casing achieves this result in the above-described embodiment of the invention. However, other means, such as reinforcing the radially inwardly directed surface with additional metal, or using a flat plate for this surface, may be employed.

The cementing material 146 which surrounds the upper portion of the outer wall of the casing along its radially inwardly directed surface will adhere to the casing as it is bent and increase the effective bearing area of the casing on the earth. The earth is compacted by the transverse movement of the casing through it and ultimately forms a firm mass to support the curved casing without further displacement under the loads which the anchor line places on the anchor assembly when it is connected to the drilling structure.

The method for forming the anchors in situ as discussed heretofore has been directed principally to the situation where the anchor means are symmetrically distributed around a drilling structure. However, in accordance with this invention a single anchor may be formed separately, or any plurality of anchors distributed in a nonsymmetrical pattern, may be formed separately or in groups. Thus a plurality of anchors designed to restrain a boat in position may be made by fixing the anchor assemblies vertically in the earth, in a manner similar to that described heretofore, and placing a transverse force on them individually by an anchored vessel or from a shore installation which is made to produce a greater pull on the anchor line than will the boat to which the anchor ultimately is attached. Thus in FIG. 8, for example, a single anchor is illustrated in which the anchor line 60 is connected to a buoy 188 at the surface of the water where it can be retrieved and connected to any structure it is desired to anchor.

FIG. 9 illustrates a modification of an anchor made in accordance with this invention. In this modification the tensile element of the anchor comprises a chain 190, the lower portion of which is positioned coaxially with the lower portion of the casing 192 by spiders 194, and is cemented to the casing in a manner similar to that described heretofore. A sleeve 196 surrounds the upper portion of the chain and contains a material 198 which will permit this portion of the chain to move longitudinally relative to the upper portion of the casing. The chain extends from the upper portion of the anchor assembly through an opening in the cap 200 and terminates in a flexible connection 202 to which the anchor line 204 is attached. The upper end of the anchor line is supported at the surface of the water by buoy 206.

In this modification the anchor assembly is shown as being set in a location where there is a relatively firm stratum 208 at the surface of the earth. Under these conditions, if a transverse force is applied to the top of the anchor assembly it will cause an abrupt bend approximately in the location where the anchor casing enters and is cemented to earth. Hence the stresses in the assembly will be concentrated at this location rather than being distributed throughout its length, and the function of the apparatus of this invention will not be achieved.

In accordance with this invention and to produce the smooth curve of the upper portion of the anchor assembly as described heretofore, the earth is broken up in a selected environment at the anchor site prior to setting the anchor assembly in place, as indicated at 210. This may be accomplished, for example, by drilling a plurality of holes at the anchor site and in the direction of the anchor line pull and fracturing the earth with explosive charges prior to drilling the bore hole 212 to receive the anchor assembly. This preparation permits the upper portion of the anchor assembly to be bent through the earth in the configuration described heretofore. This expedient may be used also to break up firm subterranean strata which would interfere with development of a smooth curve in the upper portion of the anchor assembly. The lower strata 214 of the earth, to which the vertically disposed lower portion of the assembly is cemented, is left intact, except for the bore hole 212.

It is apparent that many modifications can be made to this invention, particularly in the form of the tensile member of the anchor assembly, the materials and techniques used for preventing the upper portion of the tensile member from being bonded to the cement, and in the selection of varying casing diameters to accommodate strata of varying firmness at a particular anchor site. For example, the upper portion of the tensile member may be wrapped with a substance which will prevent the cement from adhering to it, and the casing may be made of connected lengths of different diameters which ultimately will produce a smooth curve through nonhomogeneous earth formations to achieve the result described heretofore.

Therefore, it is desired that the described exemplary embodiments of the invention be accepted as illustrative and not limiting and that the scope of the invention be limited only by the definitions of the appended claims.

We claim:

1. A method for anchoring an offshore structure at a fixed site in the water in a manner to prevent substantial movement of said structure under the impact of wind and water forces comprising drilling a plurality of bore holes into the submerged earth in positions surrounding said site and laterally spaced apart therefrom, inserting a respective elongated anchor member into each of said bore holes to extend from substantially the bottom of said bore hole to adjacent the submerged surface of the earth, affixing each said elongated anchor member to the earth in its respective bore hole, connecting a respective laterally disposed anchor line to the top of each said elongated anchor member by a flexible connection, connecting the laterally disposed anchor lines from two of said anchor members located on opposite sides of said site to a loading means for placing tension in the anchor lines, locating said loading means at the surface of the water at said site, simultaneously loading in tension the anchor lines from the said two anchor members to bend the upper portion of the said two anchor members within said submerged earth and toward said site, cyclically increasing and decreasing the tension in the anchor lines to amounts respectively greater and less than that which will be imposed by the offshore structure and forming the upper portion of said elongated anchor members in a permanent curve the shape of which will not be substantially changed by forces imposed on the said anchor members by the offshore structure anchored thereby, repeating the cyclic loading for all of the oppositely disposed anchor members around said site, disconnecting the said anchor lines from said loading means, positioning the offshore structure at said site and connecting the said anchor lines to said offshore structure.

2. A method for anchoring a marine structure at a fixed site in the water in a manner to prevent substantial movement of said structure under the impact of wind and water forces comprising drilling a plurality of bore holes into the submerged earth in positions surrounding said site and radially spaced apart therefrom, inserting a respective casing member into each of said bore holes to extend from substantially the bottom thereof to a position above the submerged surface of the earth, inserting a respective tension element into each of said casing members in substantially coaxial relationship therewith and extending to substantially the bottom end thereof, affixing the lower portion of said tension elements to the lower portion of their respective casing members through a longitudinal extent thereof, providing packing means within the upper portion of said casing member to prevent said tension element from becoming rigidly attached thereto, affixing said casing members to the walls of their respective bore holes throughout a longitudinal extent thereof, connecting respective anchor lines to the top of a selected pair of tension elements located on relatively opposite sides of said site and to a loading means which will apply equal tension to said anchor lines simultaneously, loading said anchor lines in tension in an amount greater than the tension imposed on said anchor lines when they are connected to said marine structure to bend the upper portions of each of said selected pair of tension elements and the respective casing members associated therewith in a curve of permanent form which will not be substantially changed by the forces imposed on the assemblage by said marine structure and which is tangent at one end to the lower fixed portion of the said casing member and in alignment at its other end with the direction of tensile force in its respective anchor line, connecting respective anchor lines to other pairs of tension elements and to said loading means and sequentially loading the said other pairs of tension elements, discon-

necting the said anchor lines from said loading means, positioning a marine structure at said site and connecting the said anchor lines to said structure.

3. A method for anchoring a marine structure at a fixed site in the water in a manner to prevent substantial movement of said structure under the impact of wind and water forces comprising drilling a plurality of bore holes into the submerged earth in positions surrounding said site and radially spaced therefrom, inserting a respective casing member into each of said boreholes, inserting a respective tension element into each of said casing members and substantially coextensive therewith, affixing the lower portion of said tension element to its respective casing member, providing means within the upper portion of said casing members to prevent a respective tension element from becoming affixed thereto, affixing said casing members to the earth throughout a longitudinal extent of said casing member, connecting respective anchor lines to the top of selected respective tension elements located on relatively oppositely disposed sides of said site and to a means for applying tension to said anchor lines, applying tension to said anchor lines simultaneously to bend the upper portion of each of said selected tension elements and the upper portion of said casing members in a curve of predetermined form which is precalculated from the natural characteristics of the said earth in which said anchor element is embedded and the designed characteristics of said anchor element to merge gradually from a tangent at one end thereof with the lower portion of the casing member fixed to the earth to an alignment at the other end thereof with the respective anchor line connected thereto, which curve is designed to transmit anchor line forces as tensile forces to the said lower portion of said casing member without imposing substantial transverse forces on the earth in contact with the curved upper portion of said casing member, disconnecting said anchor lines from said means for applying tension thereto, positioning a marine structure at said site and connecting the said anchor lines to said structure.

4. A method for anchoring a structure at a fixed site on the earth in a manner to prevent substantial movement of said structure under the impact of transverse forces imposed on it comprising drilling a plurality of bore holes into the earth in positions laterally spaced apart from a site of a structure to be anchored, inserting a respective elongated anchor member into each of said bore holes to extend from substantially the bottom of said bore hole to adjacent the surface of the earth, connecting a respective laterally disposed anchor line to the top of each said elongated anchor member by a flexible connection, connecting each said laterally disposed anchor line to a loading means for placing tension in the anchor lines, locating said loading means at said site, loading in tension each said anchor line to bend the upper portion of said anchor member connected thereto within said earth and toward said site, cyclically increasing and decreasing the tension in each said anchor line to amounts respectively greater and less than that which will be imposed on said anchor line by said structure and forming the upper portion of each said elongated anchor member in a permanent curve the shape of which will not be substantially changed by forces imposed on said anchor member by the structure anchored thereby, disconnecting each said anchor line from said loading means, positioning a structure at said site, and connecting the said anchor lines to said structure.

5. A method for anchoring a structure at a fixed site on the earth in a manner to prevent substantial movement of said structure by transverse forces imposed on it comprising drilling a plurality of bore holes into the earth in positions laterally spaced apart from a site of a structure to be anchored, inserting a respective casing member into each of said bore holes to extend from substantially the bottom thereof to a position above the surface of the earth, inserting a respective tension element into each of

said casing members in substantially coaxial relationship therewith and extending to substantially the bottom end thereof, affixing the lower portion of said tension elements to the lower portion of their respective casing members throughout a longitudinal extent thereof, providing packing means within the upper portion of casing member to prevent said tension element from becoming rigidly attached thereto, affixing said casing members to the walls of their respective boreholes throughout a longitudinal extent thereof, connecting respective anchor lines to the top of each of said tension elements and to a loading means for placing tension in said anchor lines, loading said anchor lines in tension in an amount greater than the tension imposed on said anchor lines when they are connected to said structure to bend the upper portions of each of said tension members and the respective casing members associated therewith in a curve of permanent form which will not be substantially changed by the forces imposed on the assemblage by said structure and which is tangent at one end to the lower fixed portion of the said casing member and in alignment at its other end with the direction of tensile force in its respective anchor line, disconnecting the said anchor lines from said loading means, positioning said structure at said site and connecting said anchor lines to said structure.

6. A method for anchoring a structure at a fixed site on the earth in a manner to prevent substantial movement of said structure by transverse forces imposed on it comprising drilling a plurality of boreholes into the earth in positions laterally spaced apart from said site, inserting a respective casing member into each of said boreholes, inserting a respective tension element into each of said casing members and substantially coextensive therewith, affixing the lower portion of said tension element to its respective casing member, providing means within the upper portion of each said casing member to prevent a respective tension element from becoming affixed thereto, affixing said casing members to the earth throughout a longitudinal extent of said casing member, connecting a respective anchor line to the top of each said tension element and to a means for applying tension to said anchor lines, applying tension to each said anchor line to bend the upper portion of each said tension element and the upper portion of said respective casing member in a curve of predetermined form which is precalculated from the natural characteristics of the said earth in which an anchor element is embedded and the designed characteristics of said anchor element to merge gradually from a tangent at one end thereof with the lower portion of the said casing member fixed to the earth to an alignment at the other end thereof with the respective anchor line connected thereto, which curve is designed to transmit anchor line forces as tensile forces to the lower portion of said casing member without imposing substantial transverse forces on the earth in contact with the curved upper portion of said casing member, disconnecting said anchor lines from said means for applying tension thereto, positioning said structure at said site and connecting the said anchor lines to said structure.

7. A method for forming an anchoring device in situ within an earth formation for securing a structure at a fixed site on the earth spaced from the position of said anchoring device comprising the steps of drilling a borehole into the earth at a position laterally spaced from said fixed site, inserting an elongated anchor member into said borehole to extend from substantially the bottom of said borehole to adjacent the surface of the earth, securing said anchoring device to the walls of at least the lower portion of said borehole, connecting a laterally disposed anchor line to the top of said elongated anchor member by a flexible connection, connecting said laterally disposed anchor line to a loading means for placing tension on said anchor line, locating said loading means at

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said site, loading said anchor line in tension to bend the upper portion of said anchor member within said earth and toward said site, and cyclically increasing and decreasing the tension in said anchor line to amounts of tension respectively greater and less than that which will be imposed on said anchor line by said structure so as to form the upper portion of said elongated anchor member in a permanent, smooth, continuous curve the shape of which will be substantially unchanged by forces imposed

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on said anchoring device by said structure secured thereby.

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