June 6, 1961 G. F. BORRMANN ET AL 2,986,888

METHOD AND APPARATUS FOR ANCHORING MARINE STRUCTURES

Filed June 25, 1958 3 Sheets-Sheet 1

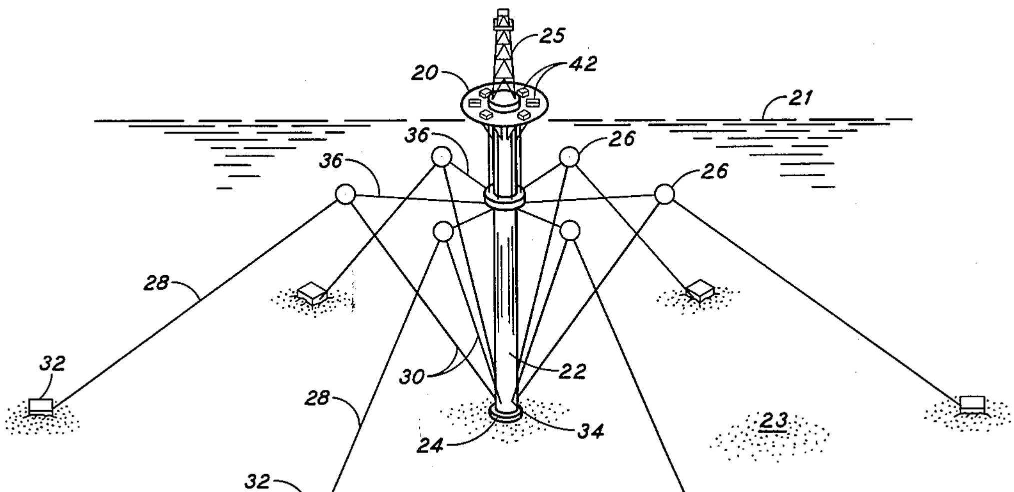

FIG.1

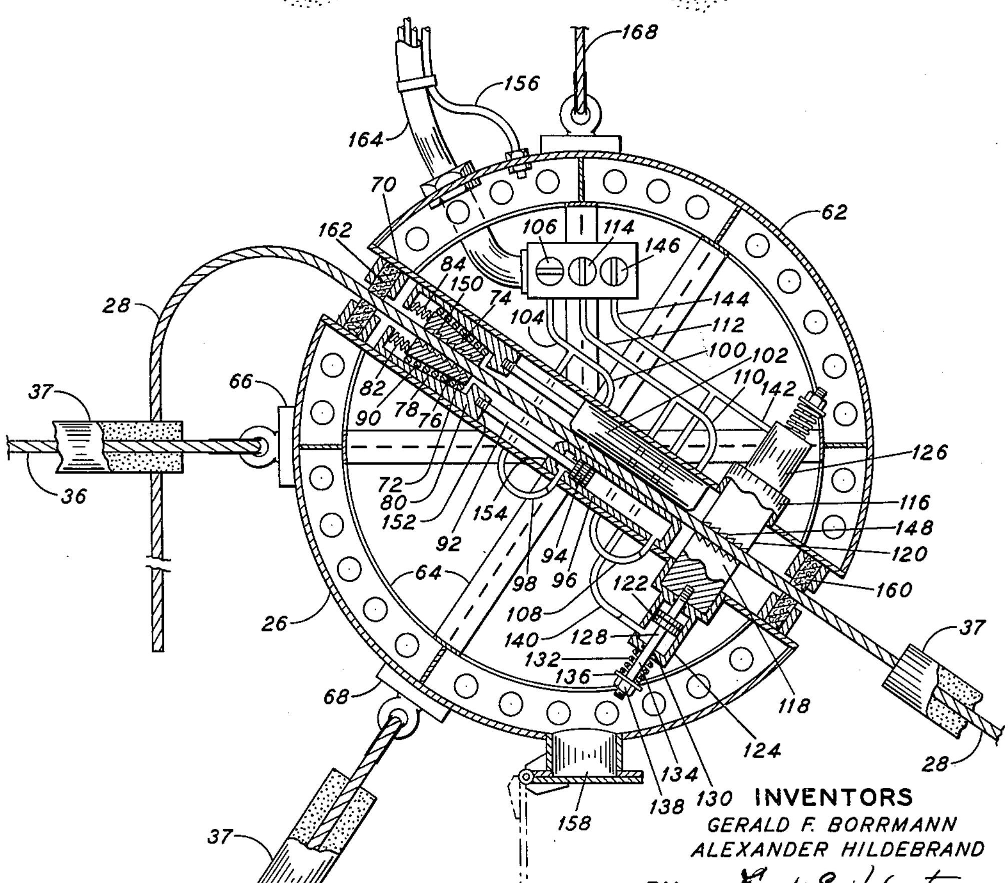

FIG.5

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METHOD AND APPARATUS FOR ANCHORING MARINE STRUCTURES

Filed June 25, 1958 3 Sheets-Sheet 2

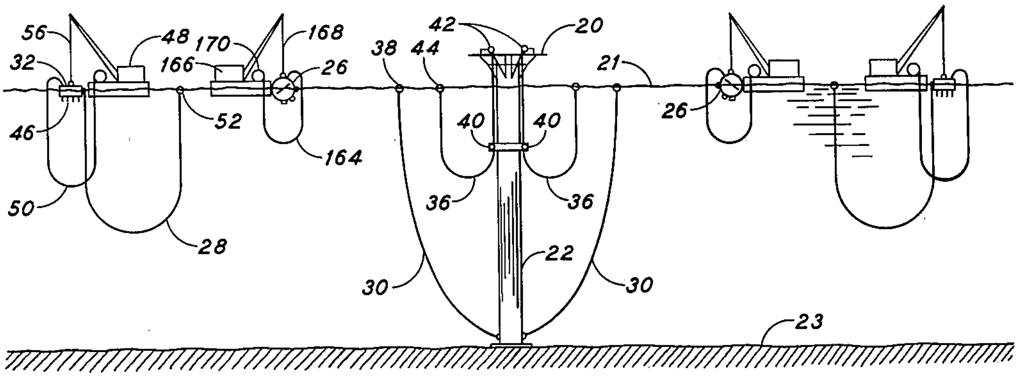

FIG. 2

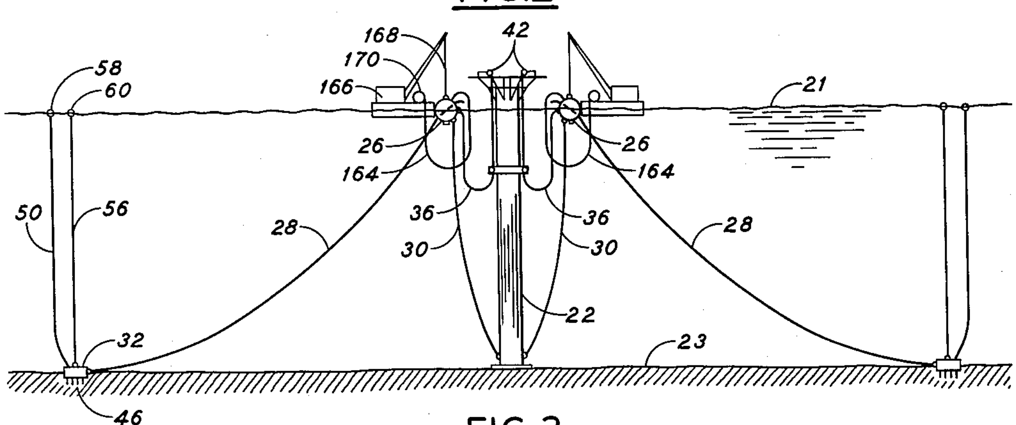

FIG. 3

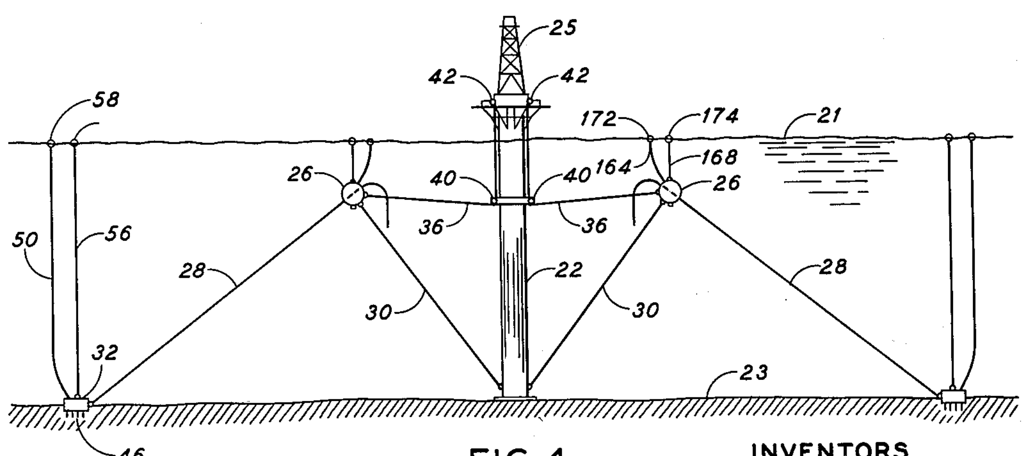

FIG. 4

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METHOD AND APPARATUS FOR ANCHORING MARINE STRUCTURES

Filed June 25, 1958 3 Sheets-Sheet 3

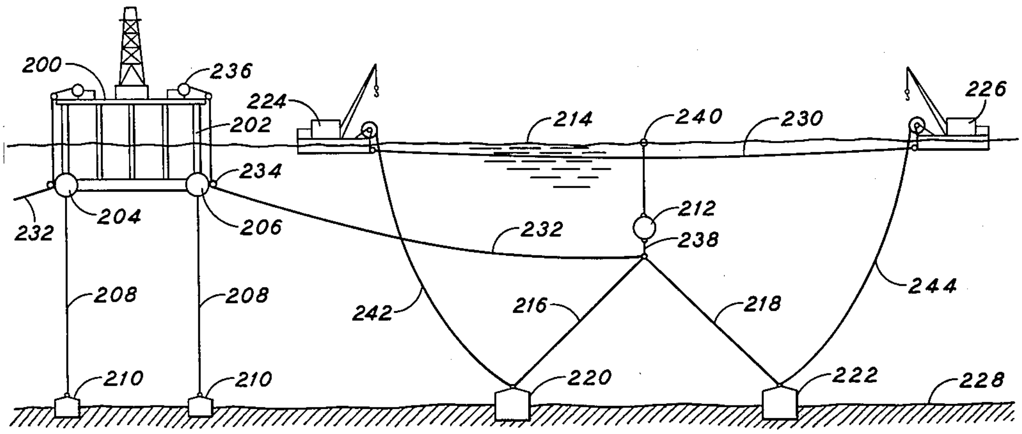

FIG. 8

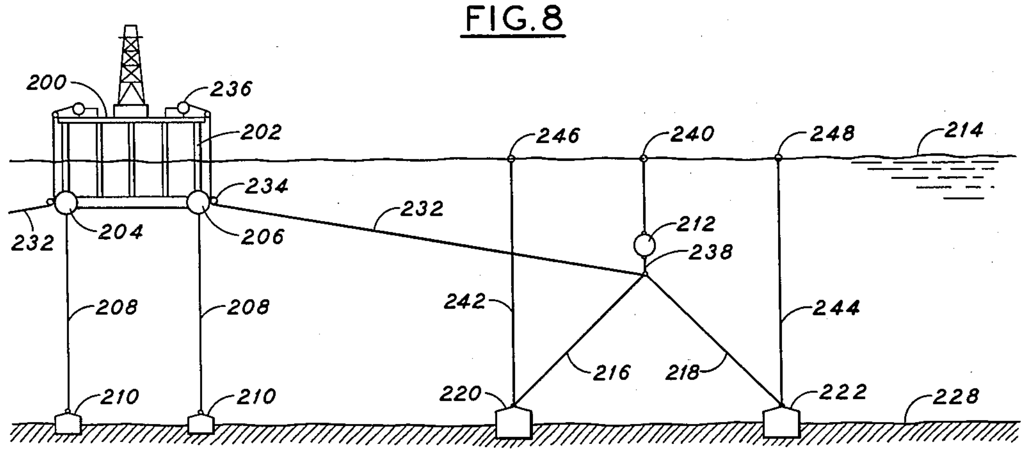

FIG. 9

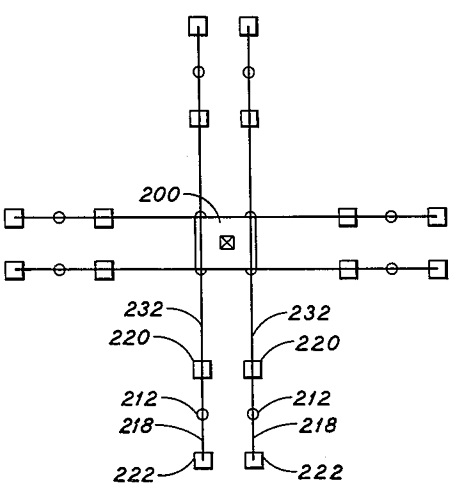

FIG. 7

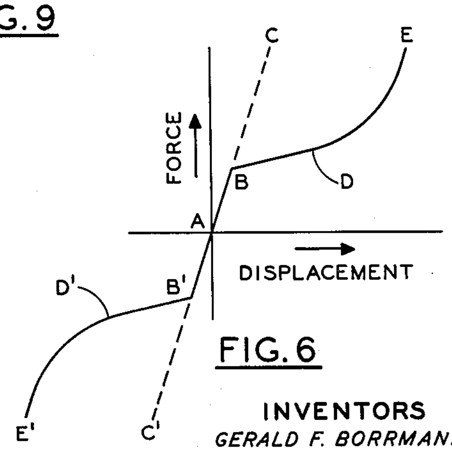

FIG. 6

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METHOD AND APPARATUS FOR ANCHORING MARINE STRUCTURES

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10 Claims. (Cl. 61—46.5)

This invention relates to structures for drilling wells in offshore locations and, more particularly, to a method and apparatus for anchoring such structures in a fixed location by apparatus which will hold the structure relatively stationary against the wind and water forces normally encountered at offshore drilling sites, but will permit a predetermined movement when the structure is exposed to excessive forces to thereby control the stresses placed on the structure and on the anchoring apparatus.

As offshore drilling progresses into deeper water, the problems involved in erecting a marine structure to hold the drilling platform and anchoring it in a stationary position at the drilling site become increasingly more severe, and the cost of such structures rises accordingly. Of the several methods which have been employed or proposed heretofore for offshore drilling, those that require a structure to be anchored in a fixed position relative to the bottom of the water by an anchoring system which is, for the most part, external or auxiliary to the structure itself are of particular pertinence for the purposes of the present invention. Such a drilling structure may, for instance, comprise a drilling platform supported on submerged buoyant members and held in position at the well site by anchor lines extending to fixed anchors at the ocean bottom. Another such structure may comprise a slender column or mast which is seated at its bottom end on the ocean floor and extends vertically through the water to support a drilling platform above its surface. The latter structure is held in a vertical position primarily by anchor or guy line means which extend outwardly from the top portion of it to a fixed anchor at the bottom of the water. In this latter case, the anchor or guy line means become component parts of the support structure and act as tensile members which restrain the column from being displaced from a vertical position by the transversely directed wind and water forces acting on it, especially those forces acting on its uppermost portions.

An effective anchoring system for a deep-water drilling structure must be capable of restraining the structure from movement arising through the action of the several separate forces which act on it simultaneously. One of these obviously is the periodic wave motion of the water surface. However, this motion by itself would not be too significant under ordinary fair weather conditions. For instance, with a freely floating structure such as a barge, or a boat, the structure would have approximately the same amplitude of motion about a central point as would a particle of water. Thus, if the water surface was disturbed only by periodic six-foot waves, a particle of water on the surface would have an orbital motion about a central point of approximately six-foot total amplitude, and a freely floating structure would follow the motion of the water particle. This oscillation of the drilling structure would not be too significant in deep water drilling.

Of more significance perhaps, under normal conditions, are the effects of wind and water forces which constantly bear on the drilling structure from a transverse or lateral direction. A tidal current, for instance, would soon carry a floating drilling structure far

off the drilling site, if it was not anchored in place, or cant a column from a vertical position if it was not restrained by anchor lines. Therefore, in order to maintain a structure in position over the well site, it is necessary to anchor it there.

The anchors, while necessary, inherently produce a complication in that they, together with the structure they restrain from movement, form an elastic system which is susceptible to forced vibrations under periodically applied forces. The resonant frequency of this system can be within the frequency of wave motions ordinarily encountered in ocean waters, and this phenomenon has been experienced on anchored ships. As applied to a drilling structure, if an attempt is made to solve this problem by slacking off the anchor lines, the structure is given enough leeway to move off the drilling site. This is, of course, objectionable, and if the drilling platform is permitted to migrate too far from its position above the well bore, the equipment connecting the drilling platform with the well bore will be damaged or destroyed. Obviously, also, slacking off the anchor lines of a slender column would permit it to tilt at an angle from the vertical and make drilling from the drilling platform it supports impossible.

If the attempt is made to change the vibration characteristics of the system by tightening up on the anchor lines, the elastic system becomes resonant at a higher frequency and hence more susceptible to forced oscillation by the smaller water waves of higher frequency. Furthermore, such a procedure places a greater stress on the anchor lines and puts more force on the anchors, necessitating the use of heavier equipment. The cost of a lateral anchoring system is almost proportional to its holding capacity, and, other considerations aside, it becomes economically unattractive to make an anchoring system strong enough to withstand directly all of the forces imposed on the drilling structure, including that of forced oscillation, to hold it stationary in place, under all of the conditions of wind and water forces it is likely to encounter.

It is an object of this invention to provide a novel anchoring system for an offshore drilling structure to hold the structure relatively stationary in place at the drilling site during normal conditions of wind and water and permit it to move with a controlled oscillation when abnormally severe wind and water forces are imposed on it.

A further object of this invention is to provide a novel anchoring system for an offshore drilling structure which automatically will control the stresses placed in the anchoring lines to hold them below a predetermined maximum amount.

A further object of this invention is to provide anchoring means which are operatively integrated with a marine structure to make in combination with the structure an elastic system of controlled forced vibration characteristics.

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

The objects of this invention are achieved by providing for a marine structure an anchoring system which comprises similar submerged float means distributed around the periphery of the structure and spaced apart from it and from each other. Each float means is held below the surface of the water by a plurality of spaced apart bottom anchors to which it is attached by buoyed anchor lines which extend angularly in relation to each other as substantially straight lines between the connected components to hold the submerged float means substantially stationary at a predetermined position under normal water conditions and prevents the float means from rising to a higher elevation in the water than its anchored position while permitting it to be moved to a position of lower elevation in the water when a transverse force exceeding a preselected value is imposed on the anchored structure. Each float means is connected to the marine structure by a buoyed anchor line which extends between these parts in a substantially straight line. One of the plurality of float-restraining anchor lines is disposed in a vertical plane which passes through the anchor line connecting the float means to the marine structure, and the bottom anchor for this float-restraining anchor line is positioned horizontally at a greater distance from the marine structure than is the float means. Thus, in effect, the principal anchoring force on the marine structure is derived from the latter said bottom anchor through the anchor line connecting it with the float means and thence through the anchor line connecting the float means with the marine structure.

When the marine structure is in an equilibrium position, the anchor lines are placed under tension between the structure and the float means and between the float means and its bottom anchors so that they will all assume a straight-line position between their ends and act as rigid tensile members as distinguished from catenary members.

The float means are selected to have a sufficient buoyant capacity to place a restraining force on the marine structure sufficient to hold it stationary under normal operating conditions. Under these conditions the buoyed anchor lines will function substantially as if they were rigidly attached between the marine structure and a fixed bottom anchor. However, when the transverse or lateral forces on the marine structure exceed the forces which obtain under normal operating conditions, the increased tension induced in some of the anchor lines connecting the structure with the submerged float means acting together with the increased tension induced in the anchor line connecting the submerged float means with its outermost bottom anchor will cause the float means to be displaced downwardly in the water. The buoyant force of the submerged float means remains constant, and as the angular relationship of the anchor lines changes due to a lateral displacement of the marine structure the buoyant force of the submerged float causes the tension in the lines to increase as a trigonometric function of the changing angle and hence increases the resultant restoring force on the structure. Thus the float means acts to control the amount of stress which is placed in the anchor lines by a displacement of the marine structure from its equilibrium position.

The combination of the anchoring apparatus and the structure which it anchors forms an elastic system which will have definite resonant frequencies. However, if a forced vibration should build up in the system and tend to produce oscillations of magnified amplitude, when the tensions in the anchor lines on one side of the structure become greater than that imposed by the submerged float the latter will be pulled deeper into the water and impose the restraining force described heretofore. Simultaneously the anchor lines connected to the opposite side of the structure, that is, the side in the direction of movement, will be relieved of tension and the effective total buoyant force of the submerged floats to which they are attached will be transferred to the bottom anchor lines which hold these floats in their substantially stationary submerged positions. Thus the buoyant force of these floats is quite abruptly removed from the anchor lines connecting them with the structure, and these lines go slack. Thus the vibration characteristics of the system in which the forced oscillation was induced changes abruptly, and the system will no longer be in resonance with the periodically applied forces.

The anchoring system including the buoyed anchor lines, the bottom anchors and the submerged float is designed to anchor the marine structure at the desired location under all foreseeable wind and water conditions. This does not means, however, that it is intended to hold a drilling structure, for instance, rigidly stable under storm conditions against the tremendous forces imposed on it, nor is it anticipated that conditions on the drilling platform during a storm will be sufficiently quiescent to permit normal drilling procedures to be pursued. However, the system is designed to hold the structure at the drilling location without damage to any of its component parts.

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

FIG. 1 is a schematic representation of a column structure supporting a drilling platform above the surface of the water and anchored in position by an anchoring system of this invention.

FIGS. 2, 3 and 4 illustrate steps of the method for installing the anchoring system shown in FIG. 1.

FIG. 5 represents a sectional view of a float means which may be used in the anchoring system of this invention, and illustrates in a schematic manner details of the apparatus contained in it.

FIG. 6 is a diagrammatic illustration of the relationship between force and displacement in an anchoring system of this invention.

FIG. 7 is a schematic representation in plan view of the anchoring system as applied to a floating drilling platform.

FIGS. 8 and 9 illustrate steps of a method for installing the anchoring system shown in FIG. 7.

As illustrated in FIG. 1, the drilling platform **20** is supported above the surface of the water **21** by a column structure **22**, the lower end of which is seated at the bottom of the water **23** in a footing **24** which holds the bottom of the column at the drilling site. Drilling structures of this type are intended for use primarily in relatively deep waters 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 to 1 to 40 to 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 permit it to sink 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 bottom 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 is incorporated in the column structure and extends from the drilling platform through the base of the column. The conductor casings are used to guide a drill string into the submerged well bore and serve also as an extension of the well bore to the surface of the water where well control equipment can be assembled on it. The derrick **25** 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 anchoring system illustrated in FIG. 1 comprises a plurality of similar anchor arrangements disposed in equiangular relationship around the circumference of the column and extending therefrom in a generally radial direction. The anchoring arrangements all impose equal restraining forces on the column when it is in an equilibrium position. However, if the top portion of the column moves in a transverse or lateral direction from the vertical only those anchoring arrangements on the side of the column away from the direction of motion will impose a restoring force on it while simultaneously the anchoring arrangements on the side of the column toward the direction of transverse motion will no longer apply a force on the column.

In this illustrative embodiment of the invention the anchoring system comprises six similar float means **26** which are submerged below the surface of the water and restrained in a submerged position by respective anchor lines **28** and **30** which are attached to fixed anchor means at the bottom of the water. The anchor lines of each separate anchoring arrangement are disposed in a respective radial plane projected from the column structure, and the bottom anchors **32** to which the lines **28** are attached are placed at a greater horizontal distance from the column than are the float means **26**, which in turn are placed at a greater horizontal distance from the column than is the bottom anchor for the line **30**. Thus the anchor lines **28** and **30** for each anchoring arrangement are disposed in angular relationship to each other with the apex of the angle adjacent the respective float. In the present embodiment of the invention the line **30** from each float means is fixedly attached to the lower portion of the column, as by an eye connection **34**. Each float means is attached to the column structure by a similar anchor line **36** which is mounted on the structure in a manner to permit the tension of the line to be regulated.

Pursuant to this invention each anchor line is buoyed so that it will assume a substantially straight-line position between its ends when it is placed under moderate tension. For example, neutrally buoyant anchor lines may be used formed of interconnected sections of steel tubing with each section hermetically sealed and properly weighted to have a density substantially equivalent to that of the water at the depth at which a particular section will be positioned when in operation. Alternatively, the anchor line may be a continuous metal tube sealed at its ends to form a buoyant chamber within it and having a wall thickness varying with depth to achieve substantially neutral buoyancy throughout its length. For some installations it may be desirable to use a steel cable surrounded by a covering of buoyant material **37** to form a buoyed anchor line as indicated in FIG. 5, or the anchor line may be buoyed at spaced intervals along its length to achieve the effect of neutral buoyancy. The components of the anchoring system are designed to place the anchor lines under sufficient tension to cause them to be disposed as substantially straight lines when the marine structure is anchored in its equilibrium position.

A method for establishing an anchoring system for a marine column structure is illustrated in FIGS. 2–4 of the drawings which show the procedural steps for the placement of two of the radially disposed anchoring arrangements. Preferably the bottom ends of all the anchor lines **30** are attached to the bottom of the column structure while the latter is on the surface of the water, before the column is upended. The upper ends of these anchor lines are attached to buoys **38** which will keep them on the surface of the water, where they will be accessible for subsequent connection to other components of the system.

The anchor lines **36** are connected to the column by apparatus which will permit these lines to be let out or taken up and provide a means for adjusting the tension in them. As illustrated schematically in FIG. 2, each anchor line **36** may be mounted over a respective pulley **40** secured to the outer shell of the column **22** and thence pass upwardly to a corresponding winch **42** on the drilling platform. The pulleys **40** preferably are placed on the column in a position where the restraining force of the anchor lines **36** acting on them will best stiffen the column and reduce its tendency to flex under load or to vibrate through the action of periodic transverse wave forces. On long columns set in deep water the optimum position for these pulleys may be at a considerable depth below the surface of the water. For example, a column structure designed to support a drilling platform above the surface in 500 feet of water may have the pulleys located at a depth of 80 feet below the surface. It may be desirable in such a circumstance, and necessary in those cases where the location of the pulley connection exceeds the water depth in which a diver can operate efficiently, to mount the anchor lines **36** on their respective pulleys **40** prior to the time the column structure is seated on the bottom of the water. The free ends of the anchor lines **36** are buoyed to the surface as by buoys **44** in a manner similar to those of anchor lines **30**.

The respective bottom anchors **32** for the anchor lines **28** may be of any type which will remain fixed in position at the bottom of the water. For example, an anchor which is drilled into the ocean bottom and cemented in place would be suitable for this purpose. In the present instance the anchors illustrated are of the type which contain a buoyancy chamber to enable the anchor to be floated on the surface of the water to a position vertically above its desired bottom location. As is understood in the art, the buoyancy chamber of such an anchor is subsequently filled with water to cause the anchor to sink to the bottom and then is filled with a weighting material such as sand to give the anchor maximum holding force. The gripping power of the anchor may be improved by providing it with projections **46** on its bottom which will penetrate into the earth at the bottom of the water and prevent the anchor from slipping or creeping. The anchors are towed to their respective, predetermined positions surrounding the well site and thence are connected to derrick barges **48** by appropriate air, water and sand lines **50** by which the buoyancy of the anchor will be controlled as it is lowered through the water and seated on bottom.

Prior to lowering the anchor the bottom end of the anchor line **28** is attached to it to be pulled to the bottom by the anchor. The free end of this anchor line is buoyed to the surface as by buoy **52** for the purpose described heretofore, or alternatively this anchor line may be let off from a winch aboard the drilling barge as the anchor is lowered. With the anchor line **28** attached, the anchor **32** is lowered through the water by the derrick lines **56** while its buoyancy is controlled from the barge through the hydraulic and pneumatic lines **50** until it is seated on bottom. It is then filled with the weighting material to hold it firmly in place.

When the anchor is in place on bottom, the lines **50** are cast off from the barge and buoyed to the surface by the buoy **58**. These lines may later be recovered and connected to appropriate sources of power on a service boat to remove the weighting material and buoy the bottom anchor to the surface. This latter procedure is desirable if the column structure is to be moved to another drilling location, since the bottom anchors are a costly item for an installation of this type. Also, line **56** by which the anchor was lowered to the bottom is cast off from the derrick barge and buoyed to the surface by buoy **60** so that the line may be recovered and used to lift the anchor off bottom.

A column structure of the type represented in FIG. 1 for use in 500 feet of water may have a diameter of approximately 28 feet and present a considerable area in the region of the surface of the water in the environment exposed to the greatest wind and water forces. In normal water conditions the wave forces may not exceed a few hundred thousand pounds on the upper portion of the column. However, during storms the waves may have a total amplitude in the range of 50 feet and the wave forces on the structure increase to several million pounds. To hold the column stationary against normally occurring transverse forces, a tension in the range of 300,000 pounds may be required in each of the six anchor lines illustrated. Under storm conditions, however, a restoring force in the range of 600,000 pounds may be required in each anchor line to maintain a controlled oscillation of the column structure about its equilibrium position.

The restraining force on the column structure in the system of the present invention is derived primarily from the buoyant effect of the float means acting on the anchor lines. For the installation described heretofore, these float means may be rigidified steel spherical shells having a diameter of approximately 28 feet and filled with air to supply the necessary buoyancy to create the required restaining forces. In the present modification the various anchor lines are connected to the float means in a manner which will cause the forces of the lines to be transmitted in a radial direction when the float means is established in its normal operating position. Thus the sphere will not have any significant tendency to rotate about its center as the relative tensions in the connected anchor lines change, and hence these tensions will not be affected by a circumferential displacement of the point at which the anchor line is affixed to the float.

FIG. 5 illustrates a float means which may be used in the anchoring system of this invention. The spherical shell **62** is reinforced by internal strengthening girders **64** which are positioned on diametrical planes passing through the points of anchor line attachment. The attachments **66** and **68** for the anchor lines **36** and **30**, respectively, are secured on the exterior of the shell to form with the inner strengthening girders a mechanical connection capable of withstanding the anchor line loads without distorting the spherical float means.

The anchor line **28** is passed through a diametrically disposed conduit **70** which is placed through the sphere in alignment with the operating position of the anchor line. The conduit is sealed at both ends to the shell **62** in a fluid-tight manner. Incorporated with the conduit is a mechanism for adjusting the position of the float means on the anchor line.

As exemplified in the illustration of FIG. 5, the adjusting mechanism may take the form of a pair of gripping jaws **72** and **74** having a tapered outer surface **76** which is complementary to a tapered inner surface **78** formed in a carriage **80** in which the jaws are mounted. The complementary tapered surfaces cause these jaws to approach each other when they are moved relative to the carriage in a direction radially inwardly of the sphere and to recede from each other as they are moved relative to the carriage in a direction radially outwardly of the sphere. The jaws are biased to a closed position by the respective compression springs **82** and **84**, and antifriction bearings **90** are placed between the tapered surfaces to prevent frictional forces from interfering from the relative movement of the jaws and their carriage.

The carriage is constructed to slide longitudinally relative to the conduit **70** and is connected by a plurality of rods **92** to corresponding pistons **94** within respective hydraulic cylinders **96** which are disposed within and parallel to the longitudinal axis of the conduit. Each end of each cylinder is connected to a hydraulic fluid line, and the hydraulic lines from corresponding ends of different cylinders are manifolded together so that the pistons can be made to move in unison in the same direction under hydraulic pressure. Thus the lines **98** and **100** from the radially inwardly disposed ends of the cylinders **96** and **102**, respectively, are connected to a common line **104** controlled by a valve **106** and the hydraulic lines **108** and **110** connected to the radially outwardly disposed ends of the respective cylinders **96** and **102** are connected to a common line **112** controlled by a valve **114**.

When the anchor line **28** is placed between the jaws **72** and **74** of this mechanism the springs **82** and **84** will force them into contact with its surface. If the cylinders **96** and **102** are now powered to move the carriage **80** radially outwardly with respect to the sphere, the wedging action between the jaws and their carriage will cause them to grip the anchor line tightly so that they become relatively fixed to it. The continued application of hydraulic pressure to the cylinders will thus force the spherical float to move relative to the gripping jaws along the anchor line to a new position on it.

The float is held in this new position by a holding mechanism **116** which is exemplified by a pair of clamping jaws **118** and **120** each of which is powered by a respective piston **122** reciprocating in corresponding hydraulic cylinders **124** and **126** placed in opposed relationships transversely of the conduit **70**. The pistons are connected to their respective clamping jaws by corresponding rods **128**, each of which is continuous through its piston and passes through the associated cylinder head **130** through an appropriate fluid-tight packing. A compression spring **132** is placed around the exposed portion **134** of the piston rod and held in place on it by a washer **136** and a nut **138**. The cylinders **124** and **126** are connected to hydraulic fluid lines **140** and **142**, respectively, which are connected to a common line **144** controlled by a valve **146**. Application of hydraulic pressure to line **144** causes the pistons to move toward each other simultaneously and thus causes the clamping jaws **118** and **120** to close. The springs retract the clamping jaws away from the anchor line when there is no hydraulic pressure in the cylinders. When hydraulic pressure is applied through the lines **140** and **142**, the pistons force the jaws **118** and **120** against the anchor line and clamp them to it. Serrations or teeth **148** may be placed on the anchor line engaging surfaces of the jaws to increase their holding effect.

While the float means is held in its new position by the clamping mechanism, the hydraulic pressure is released from the lines **108** and **110** of the respective cylinders **96** and **102**, and the hydraulic lines **98** and **100** are placed under pressure. Thus the hydraulic fluid entering the cylinders moves the pistons **94** toward the other ends of their respective cylinders and forces the carriage **80** radially inwardly with respect to the spherical float. The wedging action between the carriage and its contained gripping jaws is relieved, and the jaws tend to move relative to the carriage in a direction to release their grip on the anchor line. The springs **82** and **84** are constructed to exert only enough compressive force to assure that the anchor line engaging surfaces of the jaws contact the anchor line with sufficient frictional force to cause the wedging action between the gripping jaws and their carriage to occur. When the carriage is powered in a direction to relieve the wedging action, the springs permit the jaws to disengage their tight hold on the anchor line and move relative to it. The gripping power of the jaws may be aided by placing serrations or teeth **150** on their anchor line engaging surfaces.

After the carriage **80** of the gripping mechanism has been retracted radially inwardly the full stroke of its connected pistons, hydraulic pressure is released from the lines **98** and **100** and applied to the line **112** to again power the mechanism to move radially outwardly along the conduit **70**. At the same time the hydraulic pressure is released from the line **144**, and the clamping jaws **118** and **120** retract from the anchor line. Thus the float means will be forced along the anchor line **28** to a new position where it again will be held by the clamping means. This sequential operation of the gripping and clamping mechanisms will be continued until the float means **26** reaches the desired position on the anchor line **28**. When this position is reached, the carriage **80** is retracted to its radially inwardly position and then powered radially outward a sufficient amount to cause the jaws **72** and **74** to firmly grip the anchor line. The hydraulic pressure is now eased off from the cylinders, and the tension of the anchor line acting through the gripping jaws will move the carriage inwardly until the end surface **152** of the carriage **80** is in abutment with the end surface **154** of the cylinder assembly. The tension in the anchor line continues to maintain the wedging action of the jaws on it so that the float means will be anchored in its submerged position.

If the drilling structure is designed to be moved to other well sites, it is desirable to construct the float means to be raised from its submerged position to the surface of the water along anchor line **28** as a convenient method for retrieving it.

It is intended that this float means can be operated either by remote control from a surface boat or by a diver within it. An air line **156** connects the interior of the float with an air supply on a surface boat, permitting the air pressure within the float to be varied and controlled. An airlock **158** is provided to permit entry into the float means by a diver while it is submerged. Water is excluded from the interior of the conduit **70** by sealing the radially outer ends of it with packing means **160** and **162** through which the anchor line passes in a fluid-tight, slidable connection. Preferably these packing means are hydraulically operated packers such as are used in oil well drilling procedures and constructed to withstand the mechanical loading and fluid pressures associated with such equipment.

The hydraulic lines **104**, **112** and **144** are continued beyond their respective valves and pass through the shell **162** in a fluid-tight connection to the surface boat. Preferably these lines and also the air line **156** are bundled within a wire-reinforced, high tensile strength covering **164** which will both afford them protection from physical damage and support their weight. The lines are connected to appropriate sources of hydraulic fluid on the surface boat, and interposed valves on the boat permit remote control of the mechanisms contained in the float.

Referring now to FIG. 3 of the drawings, the plurality of float means **26** are towed to positions adjacent the column structure and positioned around it in angularly spaced relationship in conformance with the disposition of the anchor lines **36** thereon. The float means is supported from the derrick on the barge **166** by the line **168** and is attached to the barge by the air and hydraulic fluid lines, indicated as the bundle **164**, which can be payed off from a reel **170** on the barge as the float means is lowered through the water. The buoyed ends of the anchor lines **30** and **36** are retrieved and connected to their respective connectors **68** and **66** on the float. The free end of the anchor line **28** is passed through the conduit **70** in the float means and between the jaws of the gripping and clamping mechanisms therein, which have previously been described. These mechanisms are placed in operation by remote control from the derrick barge to force the float means to progress downwardly along the anchor line **28** to a submerged position in the water. As the float means is being submerged, the anchor line **36** is payed out from its winch **42**.

As the float submerges, the anchor lines **30** and **28** are pulled taut by its buoyant force, and the float continues to move downwardly through the water in a circular path about the radius formed by the line **30** until it is submerged below the surface to a predetermined depth. When it is in this position the anchor line **28** is secured within the float means in the manner described heretofore.

The anchor lines **28** and **30** extend as angularly related substantially straight lines between the float and their respective bottom anchors and during normal operating conditions hold the float substantially stationary at a predetermined position within the water and under all operating conditions prevent the float from rising to a higher elevation above the water bottom than its predetermined position. They do, however, permit the float to be submerged a greater distance under the action of extraordinary forces imposed on it. The arrangement of the float and the anchor lines which connect it to the bottom of the water in a manner to remain substantially stationary under normal operating conditions forms a means to which a marine structure can be connected to control its displacement under the action of transverse forces. For simplicity of description, the float means **26** and its associated anchor lines **28** and **30**, together with their bottom anchors, will be called an anchoring station.

As explained heretofore, and as illustrated in FIG. 1, this modification of the invention employs six anchoring stations which are distributed in equiangular relationship around the column structure. After the anchoring stations are established as previously described with relation to FIGS. 2, 3 and 5, and with the ends of the plurality of anchor lines **36** attached to their respective float means, the winches **42** are operated simultaneously to take the slack out of these anchor lines and place in them the amount of tension which has been calculated to supply the designed restraining force to the column structure. The mechanism within each float means **26** and the winches on the marine structure permit the adjustment of the position of each individual submerged float and of the tensions in the anchor lines connected to it if a bottom anchor **32** should slip or creep under the forces imposed on it.

When all of the anchoring stations are established in their predetermined positions and the marine structure anchored to them by the plurality of anchor lines **36**, the derrick barges **166** may cast off the lines **164** and **168** connecting them with the submerged floats and buoy the upper ends of these lines on the surface as by buoys **172** and **174**, respectively. Subsequently, these lines can be picked up by a service boat and connected to appropriate power sources aboard it to actuate the mechanism within the float means to adjust the position of the float in the water or to bring it to the surface.

After the marine structure is restrained in position by its pretensioned anchoring system as described heretofore, the derrick **25** and other apparatus required for drilling a well bore are mounted on the drilling platform **20**. The buoyant force of the float means and the angular disposition of the anchor lines connected to it are designed to produce a resultant force at the pulley mounts **40** to hold the assembled drilling structure substantially stationary against any transverse force which will be imposed upon it by the normal action of the wind and the water.

For example, for the column structure mentioned heretofore designed for use in 500 feet of water a restraining force of approximately 380,000 pounds may be required in each of the six anchor lines attached to it to hold the drilling platform substantially stationary against normally occurring transverse wind and water forces. If, for such an installation, the anchor line **28** is made with a length one and one-half times the distance of its horizontal projection, that is, one and one-half times greater than the distance between a point on a horizontal water bottom vertically beneath the float **26** to the bottom anchor **32**, the float means **26** is submerged a distance of 80 feet below the surface of the water, the anchor line **36** has a length of 315 feet between the float and the column, and its pulley mount **40** is 100 feet below the surface of the water, a buoyant force of 252,000 pounds will be required to supply the necessary tension in anchor line **36**.

When the column is in equilibrium condition, part of the buoyant force of the float means is imposed on anchor line **30**. The initial movement of the column will increase the tension in anchor lines **28** and **36** which, since they are disposed as straight lines, will stretch as tensile springs, and further movement will cause the anchor line

36 to pull the float means downwardly in the water in a circular path with the anchor line 28 as a radius, at the same time relieving the tension in line 30. As the float means moves downwardly through the water, the angle included between the anchor lines 36 and 28 increases, and the restraining force placed in the anchor line 36 through the action of the anchor line 28 and the float means 26 increases also, since the tension in line 36 varies approximately as the cosine of the angle which is supplementary to that included between the lines 36 and 38. For example, for the configuration described heretofore, if the column structure should move in a transverse direction 25 feet, the vertical component of float movement would be approximately 38 feet, and the tension in line 36 would increase from the initial amount of 380,000 pounds to approximately 504,000 pounds, assuming the buoyant force of the submerged float remains constant. Thus, in accordance with the present invention the tensions in the anchor lines are controlled primarily by the buoyant force of the float means as it acts on the changing geometry of the anchor system and permits the use of less massive anchoring equipment than would be required if simple guy lines were attached directly between the column structure and fixed bottom anchors.

When the column structure in the arrangement shown in FIGS. 1 and 4 has a transverse force imposed on its top portion which cause it to move in a lateral direction, the tension will be increased in the anchor lines 36 and 28 on the side of the structure opposite to the direction of movement, and the buoyant means attached to these lines will be pulled downwardly through the water. The amount of tensile force imposed by the float means in the anchor lines 28 will be a function of the displacement of the float means from their initial positions as explained heretofore. For any given amount of float displacement, the anchor lines will impose a constant restoring force on the top portion of the column structure to oppose the displacement of it caused by the transverse force. At the same time the anchor lines 36 disposed on the side of the column in the direction of transverse movement will have the effect of the buoyant force of the float means removed from them, since the floats will be held in a substantially stationary position at the predetermined minimum submerged distance by the lines 28 and 30, and will go slack. Thus, there will be no tension in these anchor lines to add to the transverse force which caused the movement of the column structure.

It will be appreciated that the storm waves which cause lateral displacement of the column structure are periodic in nature and may have periods in the range of 11 to 15 seconds, for instance, for 50-foot waves. Thus, as the wave passes the column and its peak force diminishes, the constantly acting restoring force of the active anchor stations will move the structure back to its vertical position.

It will be apparent from the arrangement of the anchor lines illustrated in FIG. 1 that a transverse movement of the top portion of the column structure will place at least two of the anchor lines connected to it under sufficient tension to depress the corresponding float means, and in most cases three of the anchoring stations will be restraining the structure with a force related to the geometric arrangement of the various anchoring stations in relation to the direction of the applied force. For example, if we assume a force sufficient to move the top portion of the mast transversely a distance of 25 feet is applied in the direction of one of the anchor lines 36 connected to the mast, the corresponding anchor lines on either side of it obviously also will be affected. As explained heretofore, a 25-foot displacement of the column structure will cause the tension in the anchor line 36 in alignment with the transverse force to increase from the initial amount of 380,000 pounds to a value of approximately 504,000 pounds. The tensions in each of the other anchor lines on either side of this anchor line will increase to 450,000 pounds, and the component of this tension in the direction of column movement will have a value of 225,000 pounds. Thus, the anchoring system will apply a restoring force of 954,000 pounds to the column structure to return it to its vertical position.

In the arrangement illustrated in FIG. 1, as explained heretofore, the anchor lines are buoyed to extend as straight lines between their connected ends and normally are operated under tension. The column itself, although rigid enough to support the drilling structure mounted on its top, is susceptible to some flexure under transverse forces. The combination of the column, the supported drilling apparatus and the anchor lines forms an elastic system which inherently will have particular vibration characteristics.

Transverse forces of two kinds normally will be imposed on the structure. These comprise in one group such transverse forces as those induced by the wind or a current of water or eccentric loading of the drilling platform which act on the structure from a single direction for a relatively long period of time, and in another group, periodic wave forces.

Under normal operating conditions the periodic wave forces may occur with a frequency which is resonant with a natural frequency of the column-anchor system and hence set up a forced vibration in the structure. If the anchor lines were rigidly attached between the structure and fixed bottom anchors, as has been suggested in the prior art, the forced vibration under resonant conditions can build up in magnitude to a degree to impose forces on the system greater than its designed limits, and cause the system to fail.

FIG. 6 is a graphical illustration of the force-displacement relationship which can be encountered in an elastic system. In an anchoring system as described immediately heretofore in which the anchor lines extend as straight lines from a fixed connection on the column to a fixed bottom anchor, the anchor lines act as tensile springs, and the force-displacement characteristic has a straight-line relationship as indicated by the line A—C. In such a system, as the top portion of the column tends to be displaced by transverse forces imposed on it, the force in the anchor lines builds up proportionately. These transverse forces may be those induced by a resonant vibration of the column-and-anchor system under periodic wave forces, as well as the directly imposed forces. Under these conditions the forced vibrations set up in the system may produce stresses which are more significant than those resulting from the more directly imposed forces. Hence, the anchoring system must be made strong enough to withstand the forces from both sources, or the structure will fail under the loads induced in it.

The line A—B—D—E of FIG. 5 illustrates the force-displacement relationship of the system of the present invention. As has been noted heretofore, the anchor lines connected to the column structure are preloaded by the buoyant means of the anchoring station to which they are connected. This loading causes the anchor lines 36 to produce a resultant force at each of the respective pulley supports 40, and the component of this force directed radially outwardly relative to the column will hold the column relatively stationary under applied transverse forces below a predetermined amount. When this predetermined amount is not exceeded, the anchor lines will act as tensile springs, and the transverse forces imposed on the column will cause the anchor lines to stretch in a straight-line force-displacement relationship as indicated by the line A—B. However, when the transverse forces on the column exceed the force corresponding to the point B of the graph, the anchor lines under the greatest tension will depress their attached float means in the manner explained heretofore, and for a given displacement the float means will impose a constant load on the anchor lines of an amount less than that which would occur in a simple guyed system. Therefore, an initial displacement of the column structure causes the float means to apply a slightly increasing load to the anchor lines as indicated by the line B—D. As the displacement increases and the float means is depressed more deeply in the water, the anchor lines 28 and 36 approach a collinear relationship and the force-displacement relationship of the system approaches that of the simple guyed system, as represented by the increasing slope of the line D—E. Hence, the force-displacement relationship of the elastic system changes and assumes the characteristic indicated by the line B—D—E of the graph.

It will be noted that the vibration characteristics of the present system change abruptly when a lateral force above the predetermined amount is placed on the column structure. If this lateral force is caused by a synchronous vibration which produces a forced oscillation in the elastic system, when the vibration characteristics of the system change at the point B it is no longer in synchronism with the periodic forces which induced the vibration, and the column structure does not respond with forced oscillation. Thus, with the present system, the anchor lines and bottom anchors used can have a capacity less than that which would be required by a rigidly connected anchoring system and still maintain the drilling structure at the well site without structural damage when it is exposed to the large wave forces produced by storm conditions.

FIGS. 7, 8 and 9 illustrate a modification of the anchoring system of this invention applied to a floating drilling platform and a method by which the anchoring system may be installed.

The drilling structure comprises a platform 200 which is mounted through appropriate structural members 202 on pontoons 204 and 206. The pontoons are positively buoyant and are pulled below the surface of the water and held there by a plurality of lines 208 which are attached to corresponding anchors 210 on the bottom. The pontoons thus are maintained in position below the water surface and out of the environment of the forces occurring at the water surface. The structure is restrained in position over the drill site by anchoring it to a plurality of laterally disposed anchors, all of which is familiar to the art.

The illustration of FIG. 7 shows the drilling structure anchored at the well site by eight laterally disposed anchoring arrangements. It will be appreciated that more or less lateral anchors may be used, depending on the physical characteristics of the structure to be anchored and the amount of restraint to be imposed on it. This modification of the anchoring system may, for instance, be applied to a boat or a barge to restrain it from lateral displacement while permitting it to move in a vertical direction in response to water forces.

FIGS. 8 and 9 illustrate the method for installing the anchoring station for one of the lateral anchor lines. In this modification of the invention an hermetically sealed float means 212 may be used, restrained in a substantially stationary position submerged below the surface of the water 214 by anchor lines 216 and 218 which are attached to respective bottom anchors 220 and 222. The float means and the bottom anchors may be connected together by the anchor lines 216 and 218 while all of the components are on the surface of the water, the bottom anchors being supported by respective derrick barges 224 and 226. The barges are aligned with the marine structure in the vertical plane in which the anchoring station is to be disposed and at a distance from each other which will cause the bottom anchors 220 and 222 to land on the bottom 228 spaced from each other a predetermined distance. The distance the derrick barges must be spaced apart on the surface of the water to accomplish this result is calculated beforehand, and the barges are connected by a line 230 to maintain this distance.

Prior to lowering the components of the anchoring station into the water, one end of the anchor line 232 is connected to it at the point where the anchor lines 216 and 218 are connected to the float. The other end of the anchor line 232 is connected to the floating drilling structure by a connection which will permit this anchor line to be slacked off or taken up. As exemplified in the drawings, the anchor line is mounted over a pulley 234 affixed in alignment with it to the pontoon and thence passes upwardly to a winch mechanism 236 on the drilling deck. The winch permits the line to be slacked off or taken up and placed under a predetermined tension.

In the present modification of the invention the float means 212 is connected to the common juncture of the three anchor lines associated with it by a connecting linkage 238. Thus, in an equilibrium position the float means exerts a force on all of the anchor lines through the common connection.

All of the anchor lines of the lateral anchoring system are constructed to have substantial neutral buoyancy in the water so that they extend as substantially straight lines when placed under tension, in the manner described heretofore with respect to the modification of the invention exemplified by FIG 1.

After the float means and its associated bottom anchors are connected together at the surface of the water and the end of anchor line 232 is connected to the assemblage, the bottom anchors 220 and 222 are lowered through the water from their respective derrick barges. The anchor lines connecting the bottom anchors with the float means pull the latter downwardly through the water to a submerged position. During the lowering procedure, the derrick barge 226 is held in a position on the surface of the water which will place the bottom anchor 222 at a predetermined lateral distance from the drilling structure and in an alignment with it described heretofore. The bottom anchor 220 preferably is seated on the bottom at a distance from the bottom anchor 222 which will cause the angle included between the anchor lines 216 and 218 to be substantially 90°. The lengths of these latter anchor lines are predetermined to hold the float means 212 in a substantially stationary position at the desired submerged elevation above the bottom of the water.

A marker buoy 240 is attached to the float means prior to lowering it and after the bottom anchors 220 and 222 are secured on the bottom of the water the lines 242 and 244 respectively, by which they were lowered may be cast off from the derrick barges and buoyed to the surface as indicated by the buoys 246 and 248. Subsequently, these lines may be recovered and reconnected to derrick barges to retrieve the bottom anchors and the interconnected components of the anchoring station.

During the time the anchoring station was being established in position, the anchor line 232 was slacked off from the drilling structure so that its tension would not interfere with the operation. When the float means is secured in its submerged location, the anchor line 232 is reeled in on the winch mechanism 236 until a predetermined tension is imposed on it to provide the desired restraining force in the lateral anchoring system. All of the eight anchoring stations indicated in FIG. 7 are established in position prior to taking the slack out of the anchor lines 232 connecting the drilling structure to them. The winches associated with the respective anchor lines are operated substantially simultaneously to bring the plurality of anchor lines 232 under tension uniformly without imposing an unbalanced transverse loading on the drilling structure.

The anchoring system of the present modification of the invention functions in a manner similar to that described heretofore in relation to FIGS. 1 and 4. When the drilling structure is in an equilibrium position, the float means 212 is at its maximum elevation above the bottom of the water and is held there in a substantially stationary position by the anchor lines 216 and 218 which are both in tension. The buoyant force of the float means and the disposition of the anchor lines connected to it, including the anchor line connecting it to the drilling structure, determine the restraining force to lateral movement which the anchor system will impose on the drilling structure. This initial restraining force is designed to hold the drilling structure relatively stationary in position over the well site against normal wave forces. When the drilling structure is exposed to wave forces exceeding the normal, the tension in the anchor lines 232 and 218 will be increased on those sides of the structure exposed to the excessive forces while simultaneously the tensions in the remaining anchor lines will decrease. As the tension in anchor line 232 increases above the amount it was loaded for equilibrium conditions, a force is placed on the float means 212 which causes it to move downwardly through the water in a circular path which has the anchor line 218 as its radius. At the same time the anchor line 216 goes slack.

As explained heretofore, the restraining force exerted on the drilling structure by an anchoring station is a function of the buoyant force of the float means and the angular relationship of the anchor lines 218 and 232. The force-displacement characteristics of this modification of the anachoring system are similar to those described heretofore with relation to FIG. 6. It may be noted against that when tension is released from an anchor line 232, the full buoyant force of the float means is taken up by the anchor lines 216 and 218 which hold the float means at its predetermined, substantially stationary, submerged position in the water and prevent it from moving upwardly through the water to continue to impose a force on the anchor line 232. Under this condition the anchor line 232 does not impose a lateral force on the drilling structure. Hence, if the structure moves laterally, the anchor lines on the sides of the structure opposite those on which the transverse force is imposed go slack and do not apply an additional transverse force which would aggravate the situation.

If the floating drilling platform should respond to periodic wave forces with a synchronous oscillation, the force-displacement characteristics of the elastic system will change abruptly when the tension induced in the anchor lines 232 and 218 causes the float means 212 to move downwardly through the water, and the system will no longer be in resonance with the periodically applied forces. Hence, as in the case of the first-described modification, this anchoring system permits the use of less massive anchoring equipment that would be required in a simple anchoring system and yet restrains the drilling platform at the well site against the aggravated transverse forces experienced during storms.

It is apparent that many modifications can be made and equivalents substituted for the various components of the anchoring systems illustrated herein. Therefore, it is desired that the described exemplary embodiments of this 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. Means for anchoring a marine structure against substantial lateral displacement comprising a marine structure positioned in a body of water, a plurality of float means placed circumferentially around said marine structure, a respective pair of bottom anchor lines for each float means of said plurality, a respective bottom anchor means for each anchor line of said respective pair and placed in spaced apart relationship to each other and in mutual alignment with said structure, means connecting each said anchor line of said respective pair to the corresponding said each float means and to the corresponding said respective bottom anchor means with said respective pair of anchor lines proportioned in length to hold the corresponding said each float means submerged below the surface of said body of water in a substantially stationary normal operating position, a respective third anchor line means connecting said each float means with said marine structure and extending as a substantially straight line between the corresponding said each float means and said marine structure, and means to adjust the tension in each said third anchor line means to apply a predetermined anchoring force to said marine structure while maintaining said each float means at its said substantially stationary normal operating position.

2. Means for anchoring a marine structure comprising a marine structure positioned at an offshore location, a plurality of float means disposed in angularly spaced relationship circumferentially around and spaced horizontally from said marine structure, a respective plurality of first anchor lines connected to each float means and holding said each float means submerged in the water in a respective substantially stationary normal operating position with at least one anchor line of said respective plurality extending outwardly from the corresponding said each float means relative to said marine structure and disposed as a substantially straight line along its length, respective second anchor lines connecting each of said float means to said marine structure, means for placing each of said second anchor lines under tension to dispose said second anchor lines as substantially straight lines between said each float means and said marine structure, and means for adjusting the tension in each of said second anchor lines to apply a restraining force of a predetermined amount on said marine structure when said marine structure is in an equilibrium position and while maintaining said float means in said substantially stationary normal operating position.

3. A means in accordance with claim 2 wherein the buoyancy of the said float means in selected and the tension in each of said second anchor lines is adjusted to the amount required to hold said marine structure relatively stationary when exposed to wave forces below a predetermined minimum force and to permit said structure to move transversely when exposed to wave forces above the predetermined minimum force.

4. A means for anchoring a marine structure in a fixed location in a body of water comprising a plurality of float means disposed around a marine structure at an off-shore location and spaced apart therefrom and from each other, a plurality of respective first anchor lines affixed to each float means and restraining said each float means in a substantially stationary submerged position, at least one of said first anchor lines affixed to a bottom anchor positioned at a greater horizontal distance from said marine structure than is the corresponding said each float means and disposed in a plane passing through the vertical axis of said marine structure and said corresponding float means, a respective second anchor line connecting said each of said float means and said marine structure, and means for adjusting the tension in each of said respective second anchor lines to apply a predetermined restraining force to said marine structure when said marine structure is in an equilibrium position while said float means is in said substantially stationary submerged position.

5. A means in accordance with claim 4 wherein said second anchor lines are placed under equal initial predetermined tension to hold said marine structure relatively stationary when said structure has imposed on it transverse wave forces below a predetermined minimum amount, and the buoyant force of said float means is selected to permit each said float means to be moved downwardly in the water when the tension in the corresponding said second anchor line exceeds a predetermined amount.

6. Means for anchoring at a fixed location in the water a column structure extending vertically from a footing at the bottom of the water to the surface thereof comprising a plurality of bottom anchor means disposed circumferentially around said column structure in equiangular relationship and spaced radially from said column structure, a corresponding plurality of float means

submerged in the water and disposed circumferentially around said column structure in equiangular relationship and spaced radially from said column a distance less than said bottom anchor means, a first anchor line of substantially neutral buoyancy connecting each of said bottom anchor means with a corresponding one of said float means, a corresponding second anchor line connecting each of said float means with the said column structure adjacent its bottom, said first and said second anchor lines cooperating to restrict the upward movement of said float means to a predetermined minimum depth of submersion, a corresponding third anchor line of substantially neutral buoyancy adjustably connecting each of said float means with said column structure adjacent the top portion thereof, adjusting means in each of said float means to adjust the position of each of said float means on the corresponding said first anchor line while said float is submerged.

7. Means for anchoring a column structure in accordance with claim 6 wherein the means to adjust the position of a float means on its corresponding said first anchor line is remotely controlled from the surface of the water.

8. Means for anchoring a structure in the water comprising a plurality of buoyant elements submerged in the water and spaced around said structure, a pair of anchor lines for each of said buoyant elements, means connecting one end of each of the anchor lines of said pair to the corresponding buoyant element, means anchoring the other end of each of said anchor lines of said pair at the bottom of the water in spaced relationship and in mutual alignment with said structure to anchor said buoyant elements in normally staitonary submerged positions, a corresponding anchor line connecting each of said buoyant elements with said structure, and means to dispose said anchor lines as substantially straight lines when said anchor lines are placed in tension.

9. Means for anchoring a marine structure against substantial lateral displacement comprising a marine structure positioned in a body of water, a plurality of float means placed circumferentially around said structure, a respective plurality of bottom anchor lines for each float means of said plurality of float means, a respective bottom anchor means for each anchor line of said respective plurality of bottom anchor lines and placed in spaced apart relationship to each other, means connecting each said anchor line of said respective plurality of bottom anchor lines to the corresponding said each float means and to the corresponding said respective bottom anchor means with said respective plurality of bottom anchor lines proportioned in length to hold the corresponding said each float means submerged below the surface of said body of water in a substantially stationary normal operating position, a respective lateral anchor line means connecting said each float means with said marine structure and extending as a substantially straight line between the corresponding said each float means and said marine structure, and means to adjust the tension in each said lateral anchor line means to apply a predetermined anchoring force to said marine structure while maintaining said each float means in its substantially stationary normal operating position.

10. A method for anchoring a marine structure in a manner to remain substantially stationary against the action on it of transverse normal water forces comprising placing a structure at a predetermined location in a body of water, placing a plurality of float means in submerged positions circumferentially around said structure, restraining the respective float means of said plurality to operate normally in a substantially stationary submerged position by restraining means which permit said respective float means to be individually submerged deeper in the water under abnormal operating conditions and prevent said respective float means from decreasing the submerged depth of said substantially stationary submerged position under abnormal operating conditions, connecting said respective float means to said structure by respective flexible connecting means, and placing substantially equal tension in each of said respective flexible connecting means to anchor said structure at said location.

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