March 7, 1967 A. LUBINSKI 3,307,624

LOAD-SUPPORTING STRUCTURE, PARTICULARLY FOR MARINE WELLS

Filed May 22, 1963 7 Sheets-Sheet 1

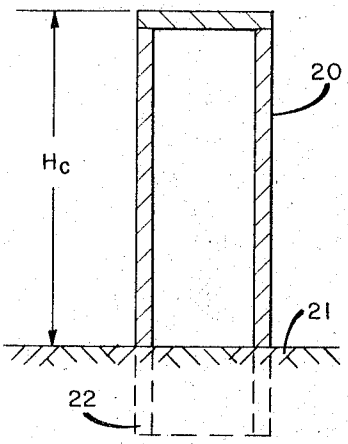


FIG.-1

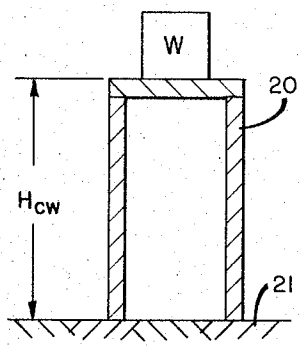


FIG.-2

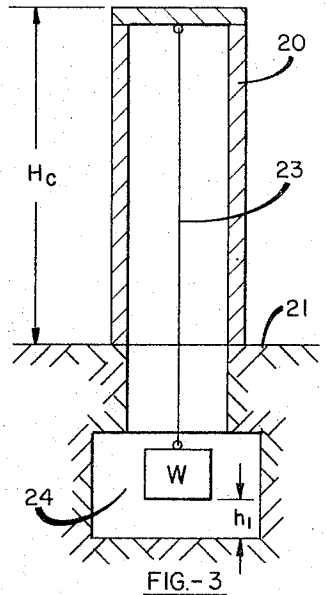


FIG.-3

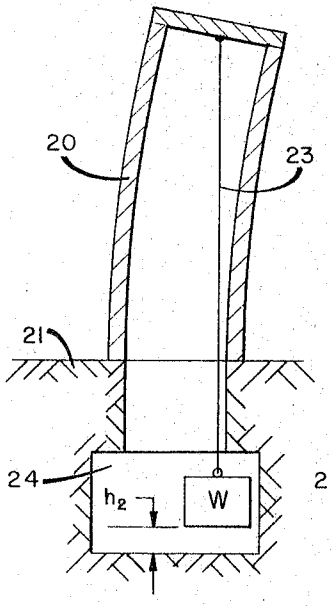


FIG.-4

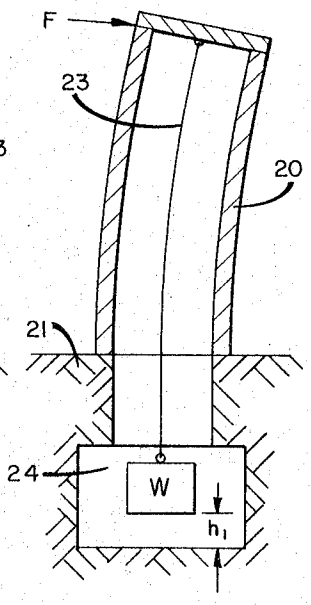


FIG.-5

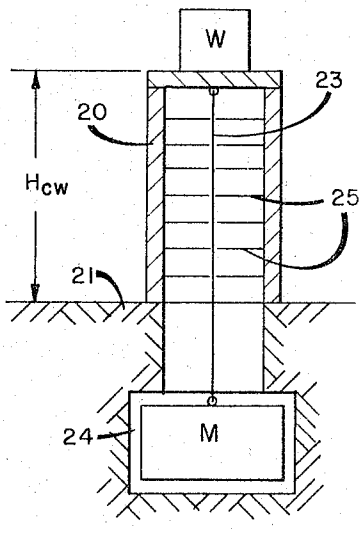


FIG.-6

ARTHUR LUBINSKI
INVENTOR.

BY Newell Pottorf

ATTORNEY.

LOAD-SUPPORTING STRUCTURE, PARTICULARLY FOR MARINE WELLS

Filed May 22, 1963 7 Sheets-Sheet 2

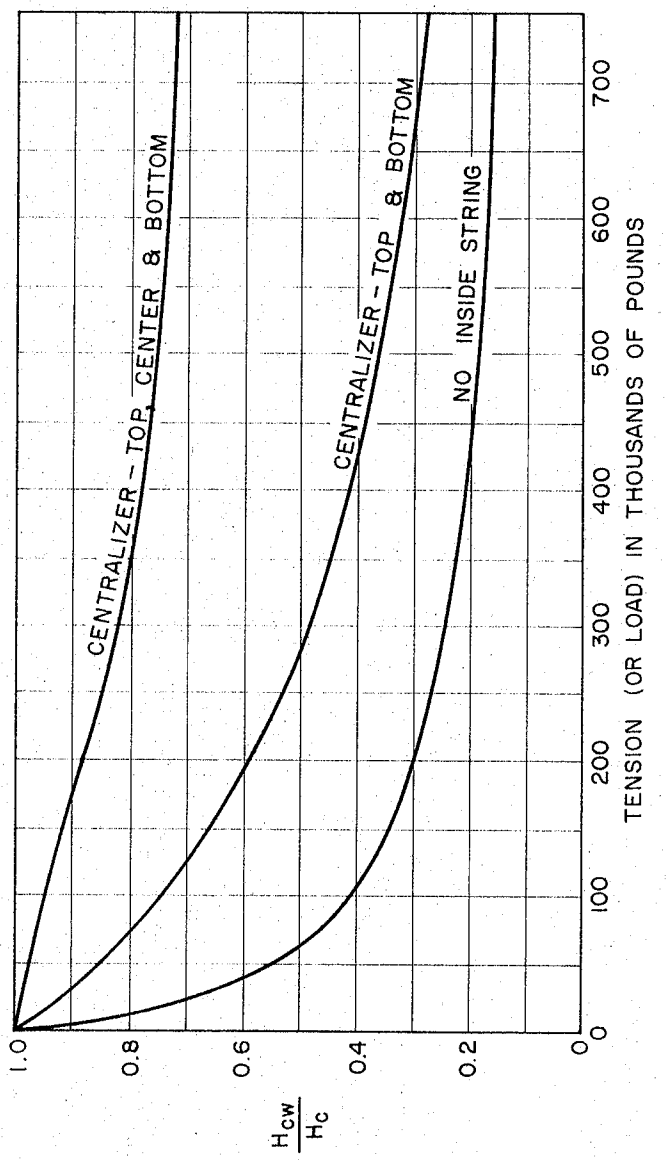


FIG.-8

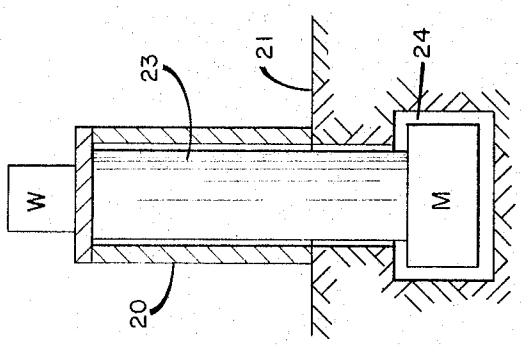


FIG.-7

ARTHUR LUBINSKI
INVENTOR.
BY Howell Portor
ATTORNEY.

March 7, 1967 A. LUBINSKI 3,307,624

LOAD-SUPPORTING STRUCTURE, PARTICULARLY FOR MARINE WELLS

Filed May 22, 1963 7 Sheets-Sheet 3

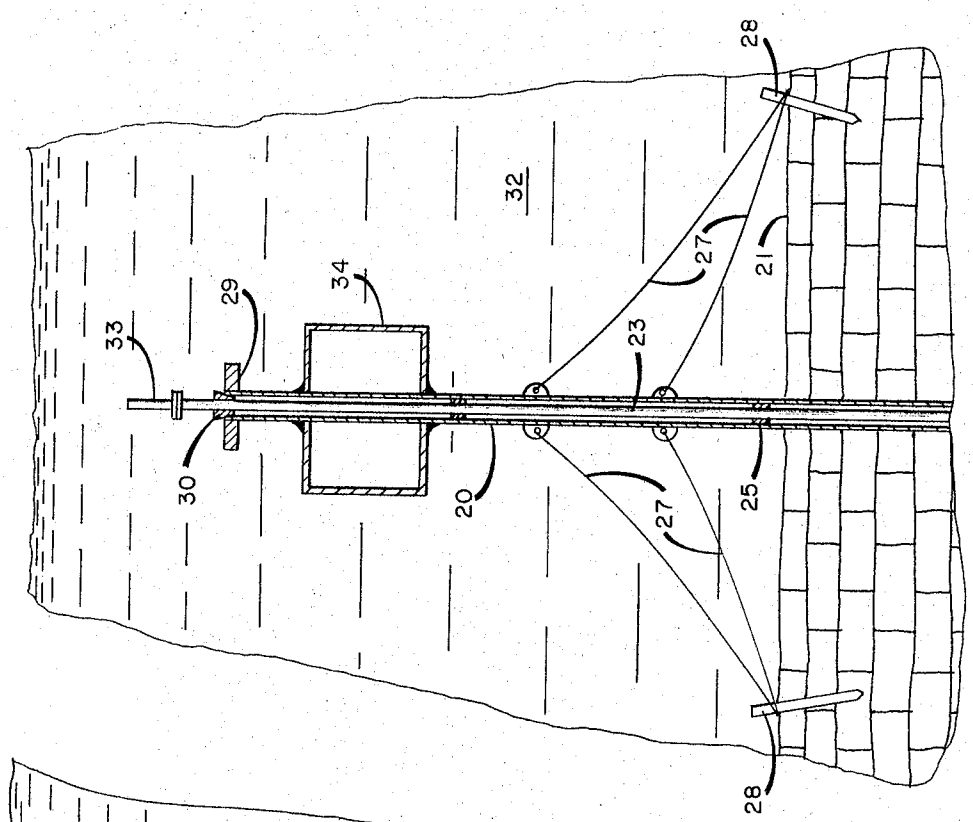


FIG. -10

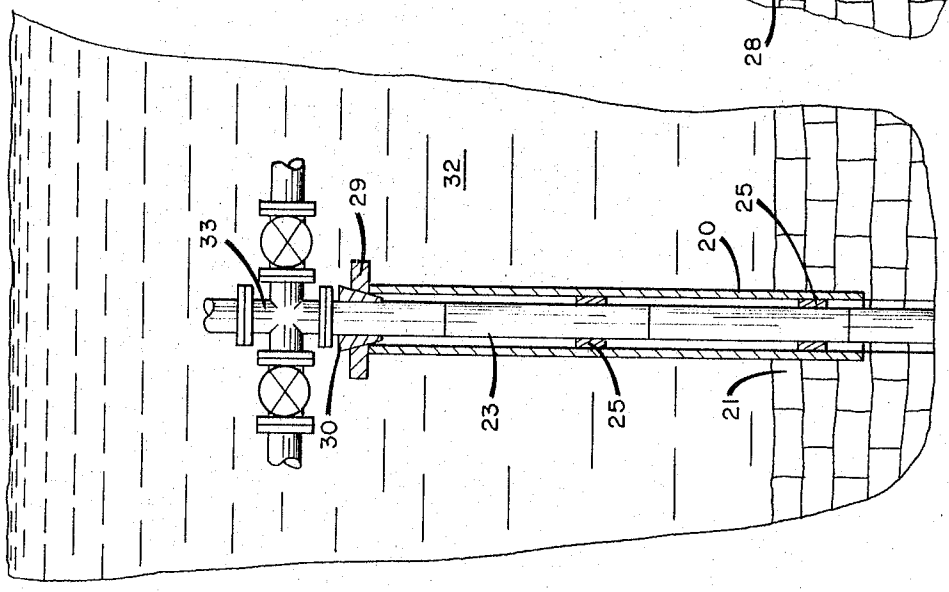


FIG. - 9

ARTHUR LUBINSKI
INVENTOR.

BY Newell Polley

ATTORNEY.

March 7, 1967 A. LUBINSKI 3,307,624

LOAD-SUPPORTING STRUCTURE, PARTICULARLY FOR MARINE WELLS

Filed May 22, 1963 7 Sheets-Sheet 4

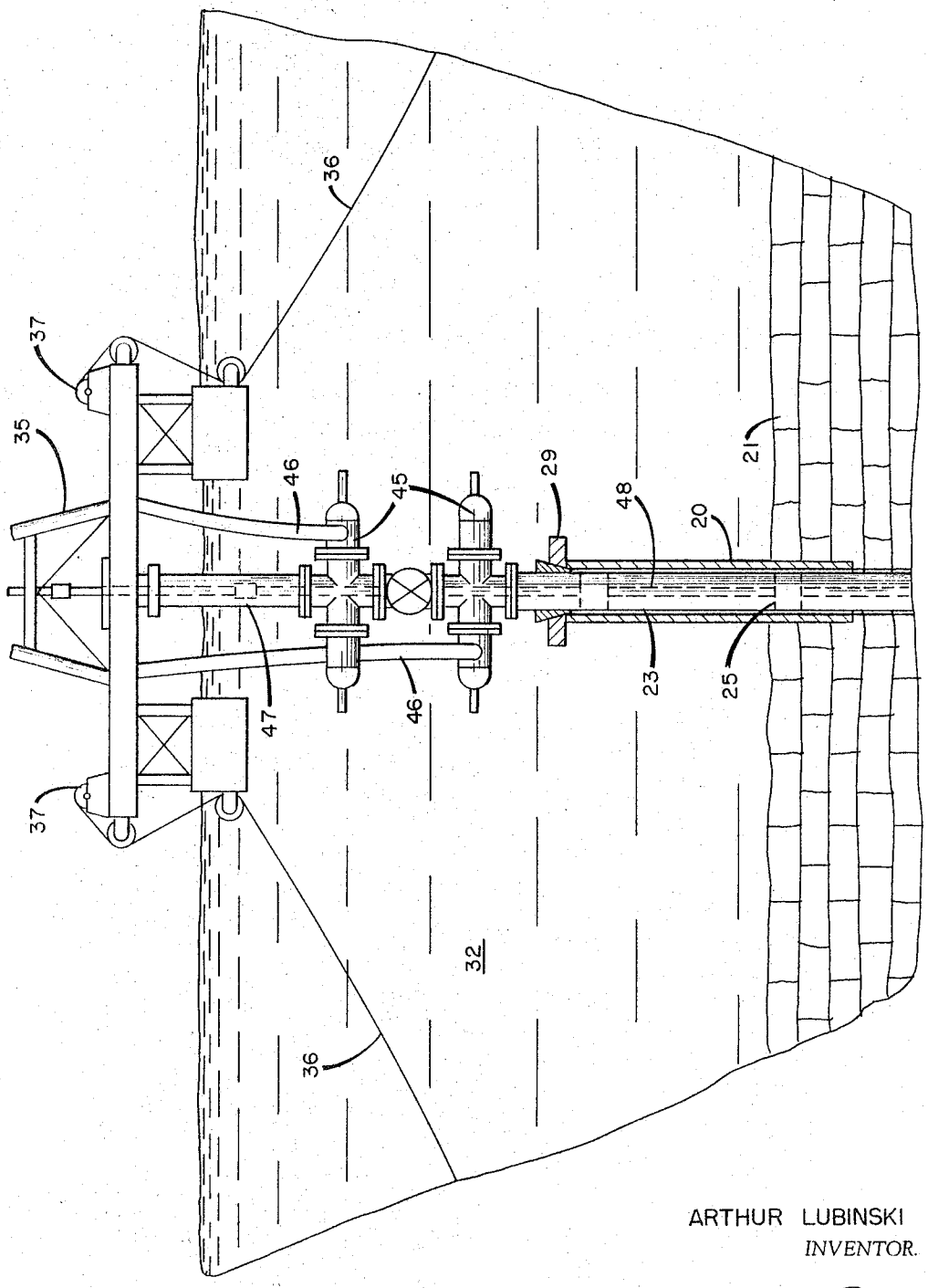


FIG. - 11

ARTHUR LUBINSKI
INVENTOR.

BY Newell Potter

ATTORNEY.

March 7, 1967 A. LUBINSKI 3,307,624

LOAD-SUPPORTING STRUCTURE, PARTICULARLY FOR MARINE WELLS

Filed May 22, 1963 7 Sheets-Sheet 5

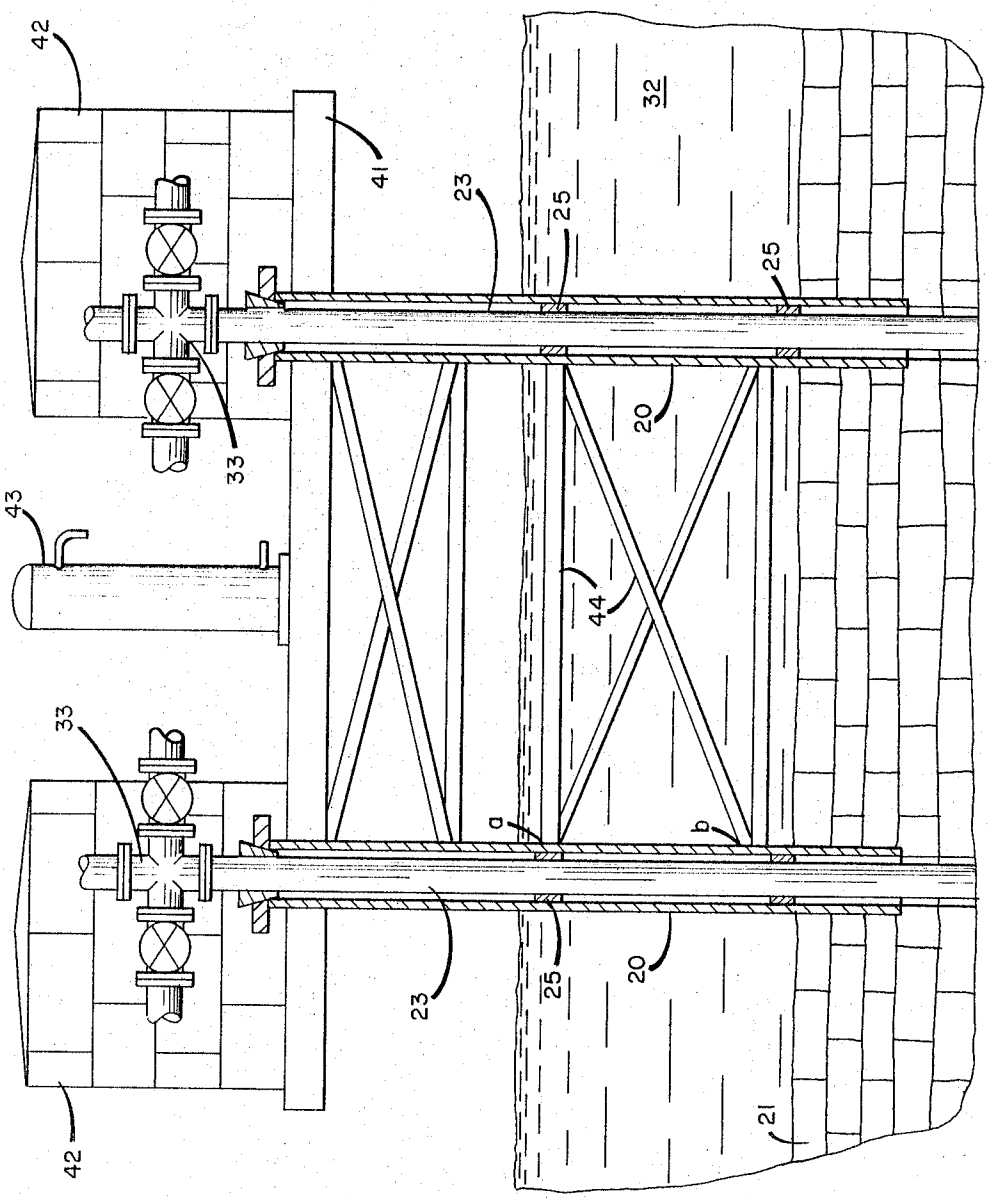


FIG. - 12

ARTHUR LUBINSKI
INVENTOR.

BY Newell Potter

ATTORNEY.

March 7, 1967 A. LUBINSKI 3,307,624

LOAD-SUPPORTING STRUCTURE, PARTICULARLY FOR MARINE WELLS

Filed May 22, 1963 7 Sheets-Sheet 6

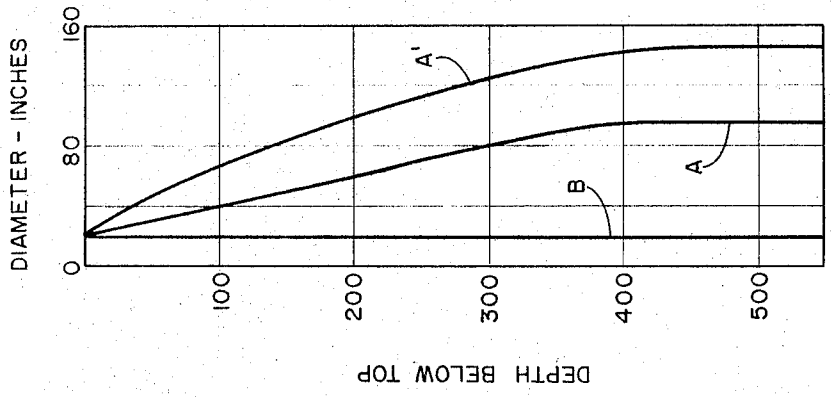


FIG. - 14

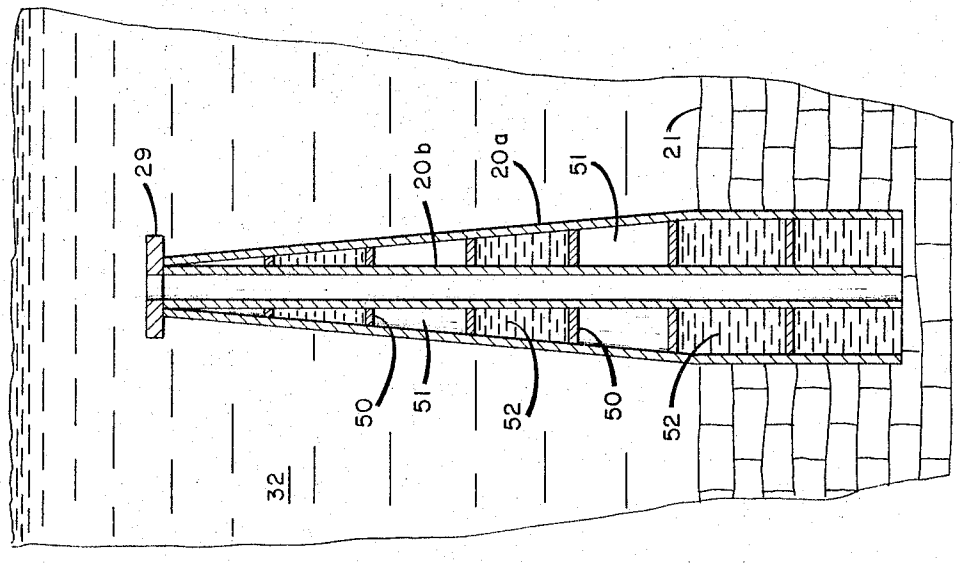


FIG. - 13

ARTHUR LUBINSKI
INVENTOR.

BY Newell Potting

ATTORNEY.

March 7, 1967 A. LUBINSKI 3,307,624

LOAD-SUPPORTING STRUCTURE, PARTICULARLY FOR MARINE WELLS

Filed May 22, 1963 7 Sheets-Sheet 7

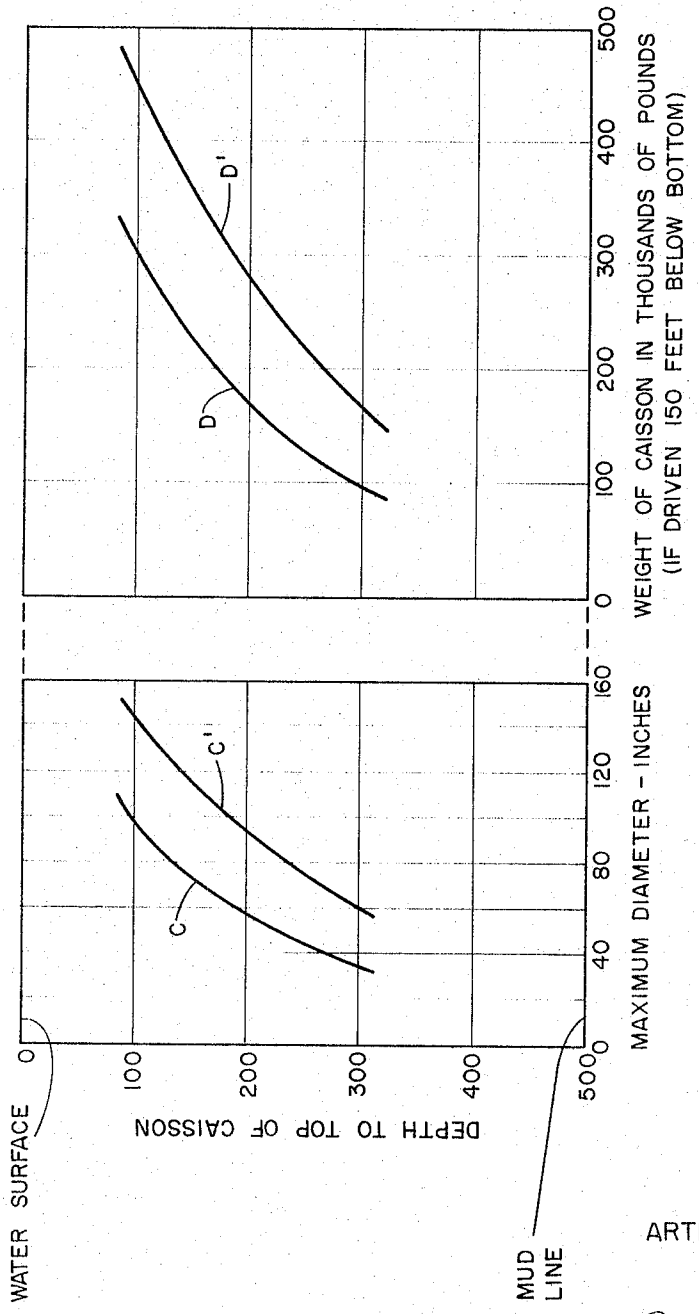


FIG. - 16

FIG. - 15

ARTHUR LUBINSKI
INVENTOR.

BY Newell Potter

ATTORNEY.

United States Patent Office 3,307,624 Patented Mar. 7, 1967

3,307,624

LOAD-SUPPORTING STRUCTURE, PARTICULARLY FOR MARINE WELLS

Arthur Lubinski, Tulsa, Okla., assignor to Pan American Petroleum Corporation, Tulsa, Okla., a corporation of Delaware

Filed May 22, 1963, Ser. No. 282,462
14 Claims. (Cl. 166—.5)

This invention relates to load-supporting structures and is directed particularly to a structure adapted for drilling and producing operations in connection with marine oil and gas wells.

Off-shore wells which are completed for the production of oil or gas, or both, may generally be considered to fall in one of three categories, as regards the location of the wellhead or "Christmas tree" which carries the control valves and which supports the well casing string or strings. The wellhead may be located above the water surface, below the water surface but within diving range, or beyond diving range on the marine floor. With present diving techniques and equipment, work at a depth of 100 feet is routine. At 200 feet depth, working time is short. A descent to 300 feet of depth would only be tried in case of serious emergency. Thus, "diving range" is now considered to be from zero depth to depths of between 100 and 200 feet. For marine floor wellheads beyond diving range, complex and expensive remote control apparatus, which is not always completely reliable, must be provided for both installation and operation of the well equipment.

When the wellhead is above the water surface, or below it at such a depth as to be accessible to a diver but still a substantial distance above the marine floor, it has heretofore been considered necessary to use a caisson surrounding the well casing. The caisson is essentially a large, hollow column driven into the marine floor for a sufficient depth to provide stable support for the weight of the column itself, for the wellhead equipment, and for the very large weight of the casing strings which it is required to support. Heretofore, the fact that the very large weight of the casing strings is applied at its top has been considered to require that the caisson be extremely heavy and bulky to support the heavy loads and withstand the very high resulting compression without buckling. In view of the experience heretofore gained in drilling with caissons in water depths generally accessible to divers, it has been generally considered that caissons will not be practical for much greater depths because of their large size which makes them both difficult to handle and high in cost.

In view of the foregoing, it is a primary object of my invention to provide a novel structure of the caisson-type which substantially avoids the relative disadvantages of cost, size, and weight noted above, particularly for drilling and production in water depths some hundreds of feet greater than diving range. A more specific object is to provide a caisson-type of supporting structure for use in marine drilling and producing operations where the wellhead is either above or below the water surface, but especially where it is below the surface in a range of water depths, both within and somewhat greater than diving range, which structure saves much of the weight, expense, bulk, and difficulty of manufacture and installation of the heavy caissons heretofore utilized. A still further object is to provide a caisson construction which utilizes the structural materials with increased efficiency, by taking advantage of existing forces to provide stability instead of merely increasing the bulk or the thickness of the caisson walls. A still further object is to provide a caisson-type supporting structure of reduced size over those heretofore employed for supporting given loads,

so as to be less subject to the external forces of wind and waves and, therefore, to minimize resulting problems. Still another object is to provide a caisson-type structure substantially free of limitation as to the depth of water in which it can be economically utilized for drilling and production operations, or as to the depth of wells which may be drilled utilizing it, except insofar as the weight and bulk of the caisson itself required for it to be substantially self-supporting, become too large for handling. Other and further objects, uses, and advantages of the invention will become apparent as the description proceeds.

Briefly stated, my invention is based on the discovery that, by insuring that the various members of the structure and of the load it supports remain in a proper geometric relationship, the very large force of the tension in an inner member suspended within an outer caisson member can be converted into very effective stabilizing forces substantially decreasing bending of the caisson member due to the high compression to which it is subjected by the very weight which is responsible for the tension. That is, the caisson structure of my invention is in a large degree a self-stabilizing system, in that the greater the load carried by an inner member in tension which tends to cause bending or buckling of the caisson, the greater is the force available to oppose the bending.

In its simplest terms, this means essentially that the inner tension member (casing) must be centralized within the outer tubular caisson member to a sufficient extent, or the clearance between the tension member and the compression caisson member must otherwise be maintained small enough, so that the bending of the caisson due to the compression imparted to it by the weight of the casing encounters an opposing force from the tension in the casing.

The meaning of the foregoing and the manner in which it is employed in the design and construction of various types of marine drilling and producing structures will be better understood by reference to the accompanying drawings forming a part of this application. In these drawings,

FIGURES 1 through 7 are diagrammatic cross sections of various elementary column structures showing the principles upon which the invention is based;

FIGURE 8 is a graph showing the relationship between column height and load-supporting capacity of a representative caisson material under various conditions;

FIGURES 9 through 12 are schematic cross-section views of various embodiments of a caisson structure showing its adaptation to various marine drilling and producing operations;

FIGURE 13 is a cross-section view, similar to FIGURES 9–12, of a preferred caisson structure utilizing the invention; and

FIGURES 14 through 16 are graphs showing certain properties of the caisson of FIGURE 13.

In order to understand the invention, it is important first to understand the concept of critical column length or height. Consider FIGURE 1. A vertical column **20** is rigidly attached at its base to a horizontal surface **21**, which is typically the surface of the solid earth. In practice, the column **20** generally extends some distance into the earth as indicated by the dotted outline **22**, in order to find load-bearing support by contact with the bedrock or frictional engagement with the surrounding earth medium. For the purposes of this simplified explanation, however, the portion **22** can be neglected simply by assuming that the base of column **20** is rigidly fastened to surface **21**.

While the column **20** is illustrated as a single hollow tubular member having a finite wall thickness, it may consist of two or more concentric tubular members with cross bracing between them to maintain concentricity;

or it can assume a variety of still different forms. That is, other than being tubular, the column might be in the form of a solid member of circular or other cross-section, or it might consist of a plurality of such members spaced apart and interconnected by bracing and the like. Regardless of its particular form, the column **20** has a certain effective cross section and weight per unit length. It also is formed of a material having known mechanical properties of strength and rigidity. Keeping these factors in mind, as the height or length of column **20** increases, its weight similarly increases. Obviously, for a very great height critical conditions of stability will be reached, and the column will buckle and collapse under its own weight. For small heights the column is more than sufficiently strong to support itself. Accordingly, for any given material and cross-sectional configuration of the column, there is a definite height where the column just loses its ability to be self-supporting. This is termed the critical length or critical height and is designated in FIGURE 1 as H_c.

If the column is required to support an additional load, such as the weight W in FIGURE 2, this load will reduce the height of the column that is just able to support both its own weight and the weight W. This length or height of the column **20** may be termed a critical loading height, analogous to H_c and designated H_{cw}. H_{cw} is thus the critical column height where the load W is just stably supported, with the meaning that if the weight W is increased by even the smallest amount, or the height of the column **20** is increased by the smallest amount, the column **20** buckles and falls.

Now consider FIGURE 3. With the column **20** at its critical height H_c where it is just able to support its own weight, the additional weight W is now applied to the top of the column by hanging it on a tension member **23** attached at the center of the top of the column and extending into a cavity **24** below the bottom of column **20** through an opening in the earth's surface **21** assumed to be made without disturbing the attachment of the base of column **20** to this surface. Based upon the concept of critical height as stated above, this places column **20** in an unstable condition where it must buckle.

What actually happens is illustrated in a general way by FIGURE 4. The top of column **20** deflects laterally as the column bends under the applied total load, which is greater than its ability to support, and the tension member **23** and weight W similarly move in the direction of the deflection of the top end of column **20**. This movement continues until the column buckles and falls. The force responsible for this collapse can be understood by noting that, with weight W centered in the cavity **24**, it is at a height h_1 above the floor of the cavity. In FIGURE 4, however, as weight W swings to the side of the cavity, it drops to a lesser height h_2. This means that the potential energy of the weight W at its position in FIGURE 3 is greater than at its position in FIGURE 4; and the difference in the potential energy is converted into the strain energy of bending of the column **20** at its point of attachment to base **21** during the process of buckling.

Now suppose that by some means the tension member **23** is constrained from being decentralized in column **20** as in FIGURE 4, but remains centered within the column as it bends. Then, if a force F acting laterally at the top of the column in FIGURE 5 moves it to the position shown in FIGURE 4, while the tension member **23** remains centralized in the column **20** as in FIGURE 5, the weight W in the cavity **24** does not move and, therefore, no bending strain contributing to the buckling of column **20** is produced by it. In other words, this means that if the tension member **23** is maintained in the center of the column, the weight W is without effect on the column stability, and the column **20** is able to support both its own weight and the weight W, even though its height H_c is such that even the smallest fraction of weight W applied to the top of the column rather than through the tension member **23**, would cause it to buckle.

In a practical sense, this means that a load-bearing column **20** carrying a weight W at its top as shown in FIGURE 6, as long as it does not exceed the length or height H_{cw}, can additionally support through a tension member **23** attached to the midpoint of the top of the column, a weight M attached to the tension member **23**, provided there are a sufficient number of stabilizing members **25** between the tension member **23** and the compression column member **20** to keep the tension member **23** centralized in the center of the column. The weight M can even be much greater than the weight of the column **20** and external weight W combined. Qualitatively, the functioning of the centralizers **25** can be visualized as simply utilizing the tension of the member **23** which tends to keep it straight, to provide a lateral force that effectively opposes the tendency of the column to bend or buckle, just as soon as bending establishes a force-transmitting contact between the member **23**, the centralizer **25**, and the inner wall of column **20**.

FIGURE 7 shows diagrammatically an equivalent and generally preferred form of supporting structure utilizing the invention in which the tension member **23** has an outside diameter only slightly smaller than the inside diameter of column **20**, by an amount required for minimum operating clearance. A very small bending of outer column **20** under load then brings it and member **23** into contact over most of their lengths; and the weight M remains substantially motionless, thus creating no further bending stress.

FIGURE 8 shows graphs of the column stability of a typical material from which a column might be made for use in some of the applications to be described below. Specifically, the graphs of FIGURE 8 apply to a column made out of a standard 20-inch outside diameter, 94 pounds per foot, API steel casing. These dimensions, material, and weight establish a certain critical height H_c.

The lower curve of FIGURE 8 labeled "No Inside String," however, shows how this critical height must be reduced in order to support various external loads without buckling. In other words, this curve corresponds to the conditions illustrated in FIGURE 2, with abscissas of the curve corresponding to various values of the weight W. It may be observed that it is largely immaterial to the column stability whether the weight W is imposed at the top end of the column directly as in FIGURE 2, or as tension through an uncentralized tension member **23** attached in the center of the column cap as in FIGURE 3, with the height of the column in FIGURE 3 reduced to its value H_{cw} as in FIGURE 2. For example, if the column of 20-inch casing is required as a caisson to support a load W of 200,000 pounds at its top as in FIGURE 2, FIGURE 8 shows that its load-bearing height H_{cw} can be only about 30 percent of its critical height H_c when unloaded. If, however, this same column is provided with a centralizer only at its bottom, and the load is supported from the center of the top of the column by the tension member **23**, the presence of the bottom centralizer allows supporting almost an additional 500,000 pounds of load, for a total of nearly 700,000 pounds of stably supported weight. Alternatively, with a bottom-end centralizer and with the weight supported from the center of the top, the 200,000-pound load can be supported as tension on the inner member by a column which is almost 60 percent of the critical unloaded column height. This is nearly twice the height of the stable column capable of supporting this load without centralization.

If in addition, a centralizer is placed also at the center of the column, so that the tension member is centered at the top, center, and bottom of the column, the reduction in height of the stable column otherwise capable of supporting only its own weight is only about 13 percent, for the purpose of supporting an additional load of 200,000 pounds through the tension member **23**. More importantly, to support very large loads much lighter-weight

and therefore much less expensive and more easily handled columns can be employed than have been heretofore used, when such loads can be applied through a tension member passing through and maintained in the center of the column.

FIGURE 9 shows how the invention may be applied to the subsurface completion of an oil or gas well in a marine location. Thus, the caisson **20** is driven to a load-supporting depth below the marine bottom **21**. The top of caisson **20** carrying the slip bowl **29** and slips **30** is located at a suitable depth below the surface of the water **32** so as to be accessible for work by divers sent down from the water surface, but sufficiently below the surface to offer no hazard to navigation. That is, the wellhead control mechanism **33** can be reached from the water surface for installation, adjustment, maintenance and the like. In this case, the caisson member **20** need be only of sufficient strength with respect to bending to support its own weight plus that of the slip bowl and slips **29** and **30** and the wellhead equipment **33**. For support of the very large weight carried by the casing **23**, it is necessary only to provide a sufficient number of centralizing devices **25** between the caisson **20** and the casing **23**, within the depth range from the casing bowl **29** to the mud line **21**. Obviously, the centralizers **25** are not necessary if the outer diameter of casing **23** and inner diameter of caisson **20** are very nearly the same, so that the clearance between them is small. By "small clearance" is meant clearance such that only a small amount of bending (much less than it is capable of withstanding) of caisson **20** brings it and casing **23** into contact over most of their length, as in FIGURE 7. With this arrangement of elements, the conditions in effect are those illustrated by FIGURES 6 and 7, so that substantially any desired load may be supported by the casing **23** below the level of mud line **21**, without the structure becoming unstable.

The showing of wellhead **33** within diving range below the water surface in FIGURE 9 should not be interpreted to mean that the advantages of the invention are limited to subsurface well completions. On the contrary, for well completions where the wellhead is at a safe height above the water surface, utilization of the invention can make an important saving. That is, the caisson structure of FIGURE 9 might be extended above the water surface. Centralizing the casing strings, either by small clearance or annular spacers in accordance with the invention, allows bending stresses due to the casing weight to be neglected in the caisson design.

In FIGURE 10 is an embodiment of a supporting structure illustrating the use of auxiliary stabilizing means in conjunction with the invention. Thus, in water depths where the length of the caisson **20** is too great to be self-supporting, so that it would buckle or even prior thereto would bend excessively due to its own weight, this tendency may be counteracted in either or both of two ways. The column may be stabilized by one or more sets of guy cables **27** extending from appropriate points along the length of the column to anchors or anchoring piles **28** set at some distance away in the marine bottom **21**, in three or more equiangular directions from the base of the column. Alternatively or in addition, a substantial portion of the weight of the column may be supported by a buoyancy chamber **34** concentrically surrounding the column **20** near its upper end. By either or both of these means, column **20** may be stabilized substantially without regard to its total length, while by providing a small clearance or a sufficient number of centralizers **25** between the column **20** and suspended tension member **23**, any additional weight which appears as tension in the member **23** is substantially without effect on the bending and stability of the column structure.

In FIGURE 11 is shown one manner of utilizing the invention in the course of a marine drilling operation. The caisson **20** for a marine well location is ordinarily set in place as one of the first steps in the drilling operation. Next is installed the surface casing **23**, here shown as of a diameter to have only small clearance with the inside of caisson **20**. A floating drilling vessel **35** is held centered over the caisson **20** by anchor cables **36** extending to remote anchors (not shown), with winches **37** adjusting the tension in the respective anchor cables to maintain the vessel **35** correctly positioned. The blowout preventer and drilling head **45** is attached to the top of surface casing **23** and remotely controlled by hydraulic lines **46** extending upward to vessel **35**. For circulation of drilling fluid, a riser pipe **47** extends between drilling head **45** and the deck of the vessel **35**.

Upon completion of drilling, the head **45** is merely exchanged for the control head **33** with any additional strings of casing being centralized within and suspended from the slip bowl **29** concentrically within the surface casing **23**.

A particular benefit of the invention, however, is that if an emergency arises during the progress of drilling that requires quick removal of vessel **35** from the location, it is not necessary to pull the drill pipe **48** out of the hole. It may simply be suspended by slips in drilling head **45** with the blowout preventers closed around it, provided it is centralized in casing **23** by centralizers **25** or by small clearance, without danger of causing excessive bending of caisson **20** due to the drill pipe weight. Then, upon disconnecting control lines **46** and riser pipe **47** and stowing them aboard the vessel, it is ready for removal except for casting off anchor lines **36** or other appropriate measures.

FIGURE 12 shows how the principles of the invention can advantageously be applied in a production platform. In the development of offshore leases producing oil and gas, it is conventional to drill directionally a number of field development wells from a single platform or location. The production from several wells is frequently treated and stored on a platform supported at a safe height above the water surface.

An embodiment of such a platform taking advantage of the principles on which the present invention is based comprises the platform **41** supported by a plurality of columns **20** of tubular form driven into the marine bottom **21** and extending to a safe height above the surface of water **32**. The platform **41** carries all of the necessary producing equipment, such as storage **42**, separator vessels **43**, and the like. Instead of drilling the field wells through separate casings, each is drilled through one of the supporting-column caissons **20**. Upon then hanging each casing string within the corresponding column **20** and providing each caisson or casing string with small clearance or a sufficient number of centralizers **25** to maintain the casing **23** centered therein, the platform **41** can then safely support both the producing equipment and the large weight of the well casings. Although the vertical member *ab* of each caisson **20** between the successive points *a* and *b* of attachment of the structural cross bracing **44** (i.e., the joints of the structure) is subjected to very high compression due to the casing weight, this compression does not contribute to bending of the member *ab*. By thus being able to neglect bending stresses due to the weight of the casing strings in the design of the platform and its supporting caissons, substantial savings in weight, bulk, and expense of construction of the platform can be made.

In FIGURE 13 is shown a preferred form of the invention which minimizes both weight and expense by most efficient utilization of the structural materials. In this embodiment, the caisson structure comprises two concentric tubular members, an outer member **20***a* and an inner member **20***b*. Preferably the inside diameter of member **20***b* is just slightly larger than the well casing subsequently to be installed therein, so that a minimum but adequate clearance exists between the outside of a well casing and the inside of inner member **20***b*. Unlike the constant diameter of inner member **20***b*, the diameter of outer member **20***a* varies from top to bottom, being

narrowest at the top where it just encircles and is attached to the inner member **20***b*, and widest at the level of mud line **21**, below which it may have a constant diameter to whatever depth is required to find stable support. Spaced along the length of the column in the annular space between members **20***a* and **20***b* are a plurality of braces **50** which rigidly interconnect members **20***a* and **20***b*.

For use as an example only, FIGURE 14 shows computed optimum design curves for a column of the type shown in FIGURE 13 wherein allowances have been made for a certain external or static load and for maximum storm-wave forces, and the combined stresses of compression and bending are everywhere uniform throughout the structure. That is, the sum of the compression and bending stresses is a constant, the effect of the casing weight being included in the compressive, but not the bending stress in accordance with the invention.

As is suggested by its correlated position with FIGURE 13, FIGURE 14 refers to a column of total length 550 feet, of which 150 feet are below mud line **21**, installed in water 500 feet deep, so that the top of the column is 100 feet below the water surface. Curve B represents the diameter of inner member **20***b* chosen to fit with small clearance around the outside of a well casing later to be suspended in the structure, and is shown as of constant diameter throughout its entire length. Curve A shows the necessary variation in diameter of the outer member **20***a* to provide the uniform stress condition, with allowance for storm waves and a certain static load. Thus, the outer member **20***a* is of the same diameter as inner member **20***b* at the top of the structure and increases in diameter more or less uniformly to a value of about 96 inches at a 400-foot depth below the column top, the column thereafter retaining the same diameter for the 150-foot length below mud line **21**.

Curve A′ shows how the diameter of outer member **20***a* would have to be increased if a load of 460,000 pounds, representing the weight of the typical well casing string or strings were to be stably supported by the column structure at its top. This requires that column **20***a* increases in diameter quite rapidly near its top and then somewhat more slowly in a manner generally parallel to curve A, until a final diameter of somewhat more than 140 inches is reached. If however, in accordance with the invention the 460,000 pounds of casing are attached at bowl **29** and so supported as to have small clearance inside inner member **20***b*, then the diameter of outer member **20***a* need be only that shown by curve A, as the entire weight of the casing strings increases only the compressional stresses in the structure and adds substantially nothing to the bending stresses. That is, the difference in diameter values at any depth between curves A and A′ represents the saving in weight, size, and expense of the outer structural member **20***a* due to the utilization of the present invention.

This is shown even more clearly in FIGURE 15. In this figure, curve C shows the maximum diameter of outer member **20***a* for various depths of the top end of the caisson **20** below the water surface, where the total water depth is 500 feet as was assumed in FIGURES 13 and 14. In other words, this curve shows that if the wellhead is at somewhat greater depths than 100 feet, i.e. if the caisson height is somewhat less than 400 feet, the maximum-diameter requirement of outer caisson member **20***a* at the mud line decreases markedly. For example, it is only about 54 inches instead of 96, if the top of caisson **20** is placed 200 feet below the water surface.

Curve C′ shows the variation in maximum diameter of outer caisson member **20***a* if it is assumed that the weight of the casing strings is applied to the top end of the column rather than as tension in a casing with small clearance or centralization. As is apparent, this maximum diameter decreases also as the top of the caisson is placed at greater depths below the water surface with a resulting decreased height of the caisson. The space between these two curves represents the difference in maximum diameter and corresponding saving made by use of the present invention. Consideration of actual magnitudes of diameter involved shows that the diameter reduction is from about 33 to over 50 percent, based on the values of curve C′.

A similar difference is shown by Curves D and D′ of FIGURE 16, which respectively show the total weight of the caisson in pounds, assuming penetration of the maximum-diameter portion to a depth of 150 feet below mud line **21**. Due to the weight of this portion of the caisson structure, the difference between curves D and D′ is not so great on a percentage basis as between curves C and C′, the saving in weight ranging from about 32 to about 41 percent. Obviously, however, due to the greater ease of manufacturing and handling the smaller and lighter structure, as compared with the more bulky and heavier structure required in the absence of this invention, the real saving in cost of the structure is a larger percentage than either the saving in diameter or weight.

While the water depth of 500 feet and the position of the caisson top at 100 feet of depth below the water surface have been thus shown and described as a typical embodiment of the invention, it will be undersood that its advantages are not limited to a narrow depth range of this magnitude. In general, utilization of the invention in the design of marine supporting structures affords some saving in substantially all cases, though for shallower water depth the advantage may be less pronounced, while for greater water depths it is even more outstanding than in the example given.

As an alternative and also preferred embodiment of my invention, the members **50** of FIGURE 13 act not only as rigid internal bracing within the annulus between members **20***a* and **20***b* but also form bulkheads dividing this space into water- and air-tight compartments, by which the buoyancy of the structure may be adjusted or varied at the respective locations along its length. Then, by providing appropriate valves and piping in a manner well known in the art, water may be admitted into or exhausted from any of the various compartments to aid in handling and transportation of the caisson structure. For example, the buoyancy of air-filled compartments **51** may either in part or entirely offset the weight of the structure, while the flooded compartments **52** insure that the structure will remain in place below mud line **21** and not rise to the water surface due to excess buoyancy.

By thus offsetting the weight of the caisson through buoyancy the tendency of the column to bend and buckle under its own weight is eliminated. Then, as the bending effect due to the weight of the casings is substantially cancelled by proper centralization or use of small clearances in accordance with the present invention, the only bending tendency comes from the weight of the wellhead equipment. This, however, is usually not very large compared to the weight of the caisson itself and of the well casings, so that by a proper distribution and amount of buoyancy, the caisson structure of FIGURE 13 can be adapted for use in almost any depth of water.

While my invention has been described by reference to the foregoing specific details and examples, its scope should not be considered as limited thereto, but is properly to be ascertained from the scope of the appended claims.

I claim:

1. A stable load-supporting marine structure comprising an elongated vertical hollow compression member having its bottom end fixed solidly in the earth below the marine bottom and its upper portion extending for a substantial distance through the water to a point in the vicinity of the water surface, the strength and stability of said hollow member being sufficient to support substantially only its own weight and any external loads or forces imposed on it, and a tension member for carrying additional weight extending below said bottom end of said hollow member, the combined loads carried by said hollow and said tension members substantially exceeding

that which said hollow member alone may support as an external load without buckling, said tension member being attached to the center of the upper end of said hollow member and having a small clearance within said hollow member at at least one point intermediate its ends, so that the tendency of said hollow member to bend due to said additional weight brings said members into contact at least at said one point to substantially prevent increased bending of said hollow member by said additional weight.

2. A stable load-supporting marine structure as in claim 1 in which said tension member has a small clearance with said hollow member at a plurality of spaced points intermediate the ends of said hollow member, so that the tendency of said hollow member to bend due to said additional weight brings said members into contact at at least some of said points to substantially prevent increased bending of said hollow member by said additional weight.

3. A stable load-supporting marine structure as in claim 1 in which said tension member has a small clearance with said hollow member substantially throughout the length of said hollow member, so that the tendency of said hollow member to bend due to said additional weight brings said members into contact over a substantial portion of the length of said hollow member to substantially prevent increased bending of said hollow member by said additional weight.

4. A stable load-supporting marine structure as in claim 1 comprising also centralizing means between said members at least at said one point for providing said small clearance at said point.

5. A stable load-supporting marine structure as in claim 2 comprising also a plurality of vertically spaced centralizing means between said members at said plurality of spaced points for providing said small clearance at said points.

6. A combination column for marine wells comprising an outer vertical hollow compression member stable under its own weight and any additional external loads and forces to which it may be subjected, said member extending for a substantial distance through the water above a marine bottom, and an inner tension member attached to said outer member at the center of its upper end, said tension member extending below the lower end of said outer member and supporting, as a substantial additional load different from and in addition to said weight and external loads and forces, the well equipment below said marine bottom, the clearance between said outer and inner members being small enough so that a small amount of bending of said outer member under said additional load brings said members into contact at at least one point substantially below the top of said outer member to substantially prevent further bending of said outer member by said additional load.

7. A marine well structure comprising a well casing, a caisson in compression surrounding said casing and extending from a load-supporting depth below the marine bottom upward for a substantial distance above said bottom to a point in the vicinity of the water surface, auxiliary stabilizing means acting on said caisson to prevent it from buckling under the weight of itself and of external loads and forces which may act on it, means suspending said casing from the center of the top of said caisson, and at least one point of small clearance between said casing and said caisson in the vicinity of the marine floor to substantially prevent bending of said caisson by the additional load represented by the tension in said casing.

8. A marine well structure as in claim 7 in which said auxiliary stabilizing means comprise a plurality of equiangularly spaced guy cables extending from said caisson at a depth substantially above the marine floor to anchor points horizontally spaced from said caisson on the marine floor.

9. A marine well structure as in claim 7 in which said auxiliary stabilizing means comprise at least one buoyancy chamber attached to said caisson in the vicinity of its upper end and buoyantly supporting a substantial part of the caisson weight and external load.

10. A stable load-supporting structure for marine wells comprising a well casing, a caisson surrounding said casing and extending upwardly from a load-supporting depth below the marine floor, said casing being supported from the center of the upper end of said caisson, said caisson having two concentric hollow members, means in the annular space between said members for maintaining them concentric, the inner of said members having a constant internal diameter slightly larger than the outer diameter of said well casing suspended therein, the outer of said members having a diameter increasing generally with depth below the water surface such that the sum of the compressive and bending stresses in the caisson due to the caisson weight and to the maximum known and anticipated external loads and forces, plus the compressive but not the bending stress imparted to the caisson by the casing weight, is substantially constant throughout said caisson, the small clearance between said casing and said inner hollow member being such that a small amount of bending of said caisson due to the casing weight brings said casing and said inner member into contact throughout a substantial portion of the length of said inner member to substantially prevent increased bending of said caisson by the weight of said casing.

11. A structure as in claim 10 wherein said maintaining means comprise spaced fluid-tight bulkheads subdividing the annular space between said inner and outer members into buoyancy compartments.

12. A structure as in claim 11 wherein said caisson extends from a load-supporting depth below the marine floor to within diving range from the water surface.

13. A structure as in claim 11 including also auxiliary stabilizing means acting on said caisson to prevent it from buckling under the weight of itself and of said external loads and forces which may act on it.

14. A structure as in claim 11 wherein said well casing is substantially smaller in diameter than the internal diameter of said inner member, and including also a plurality of vertically spaced centralizing means between said casing and said inner member to substantially prevent increased bending of said caisson by the weight of said casing.

References Cited by the Examiner

UNITED STATES PATENTS

157,908	12/1874	Cornell	138—115
2,236,682	4/1941	Gross	61—46.5
2,512,783	6/1950	Tucker	175—6
2,598,329	6/1952	Wilson	61—46.5
3,017,934	1/1962	Rhodes et al.	175—7 X
3,166,125	1/1965	Hubby	166—75 X

ERNEST R. PURSER, *Primary Examiner.*