

June 14, 1966

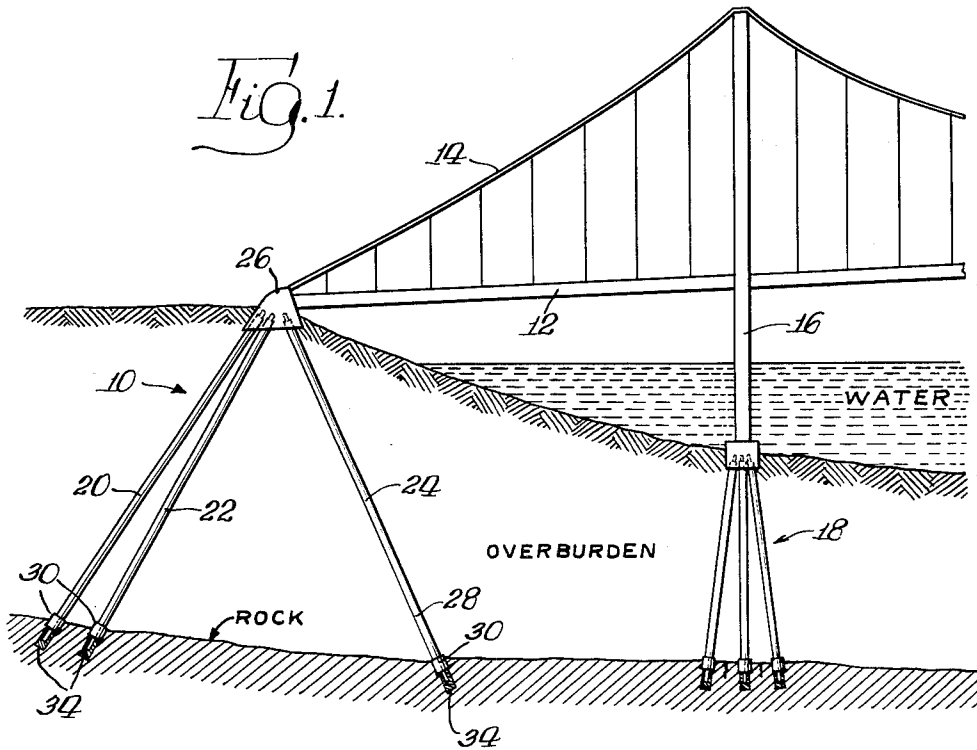
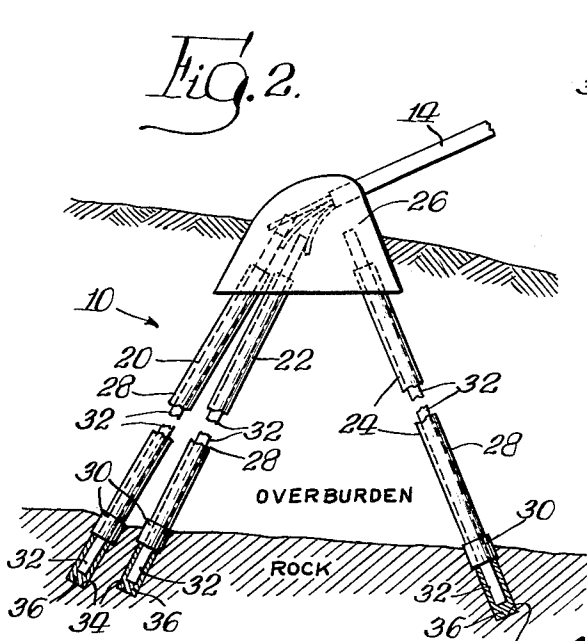
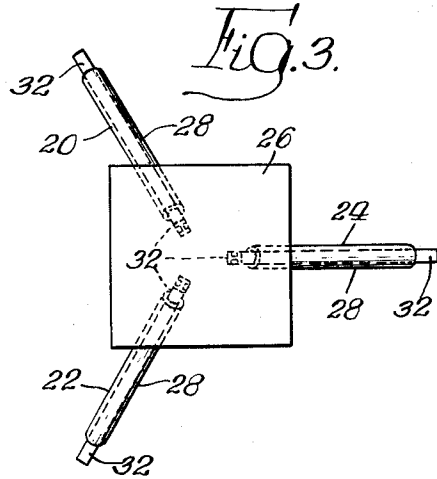
J. H. THORNLEY

3,255,591

HORIZONTALLY STABILIZED FOUNDATION

Filed Aug. 23, 1961

8 Sheets-Sheet 1



INVENTOR,
Joseph H. Thornley,
BY
Brown Jackson Bottel & Dineen
Attys.

June 14, 1966

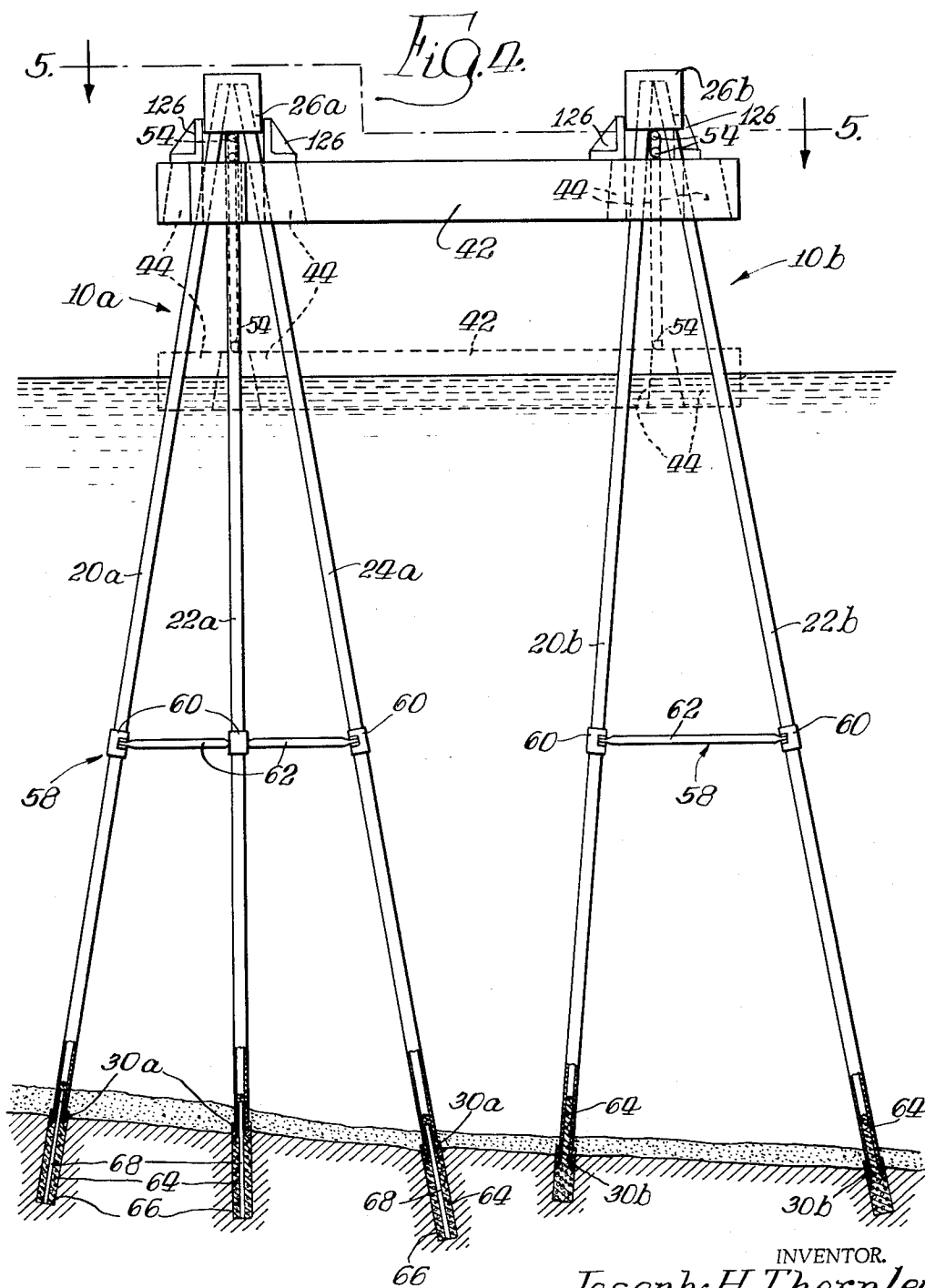
J. H. THORNLEY

3,255,591

HORIZONTALLY STABILIZED FOUNDATION

Filed Aug. 23, 1961

8 Sheets-Sheet 2



INVENTOR.

Joseph H. Thornley,

BY

Proctor Jackson & Bortolucci, Inc.
Attys.

June 14, 1966

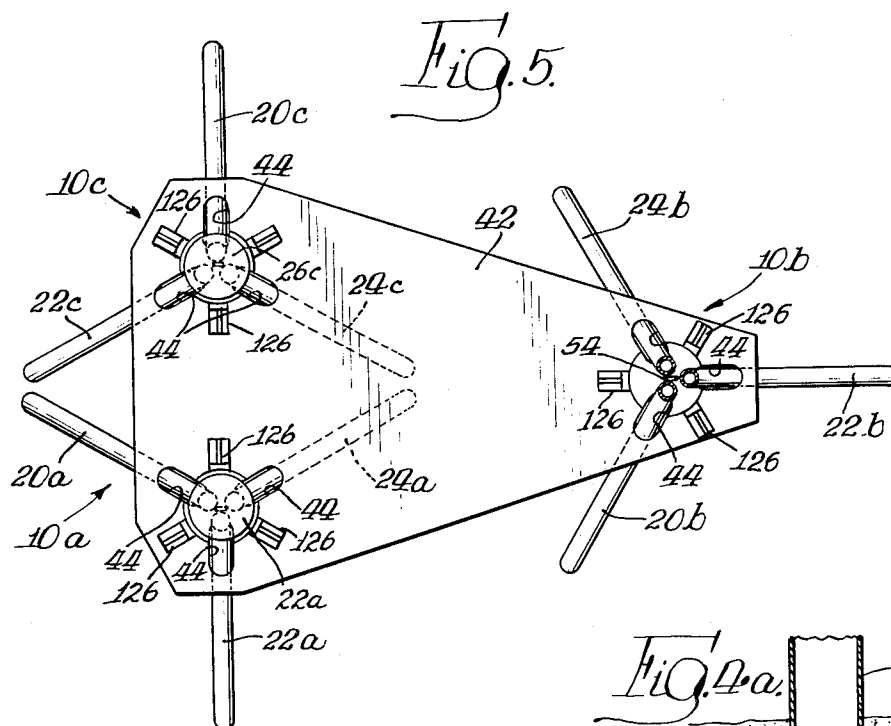
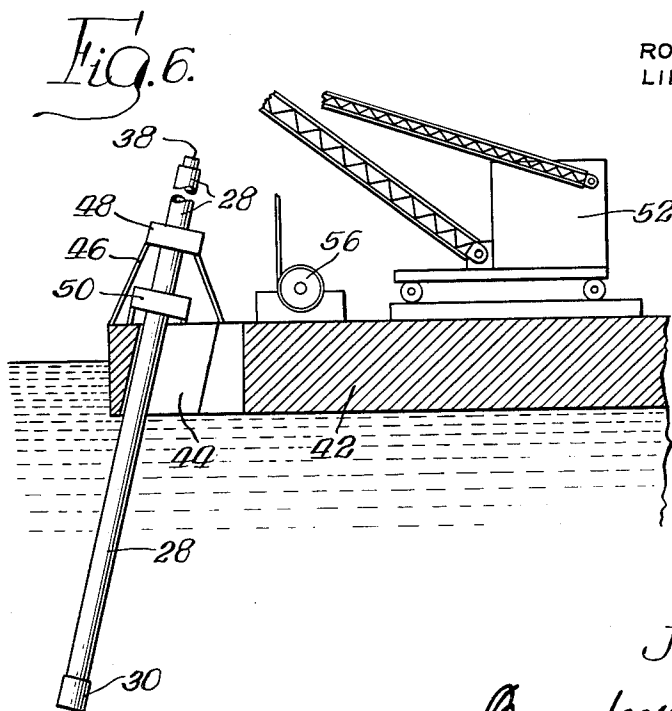
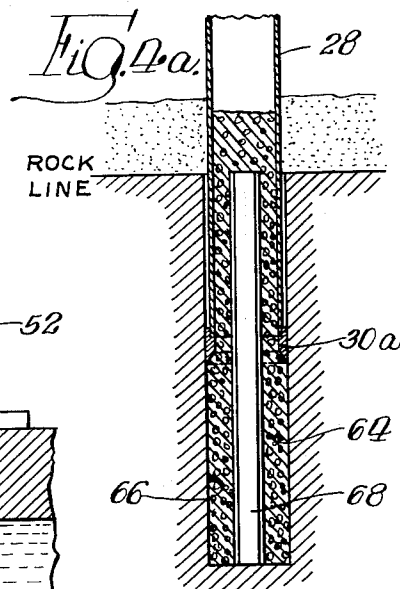
J. H. THORNLEY

3,255,591

HORIZONTALLY STABILIZED FOUNDATION

Filed Aug. 23, 1961

8 Sheets-Sheet 3



INVENTOR.
Joseph H. Thornley,
BY
Morton Jackson Bottcher, Diener
Catty's

June 14, 1966

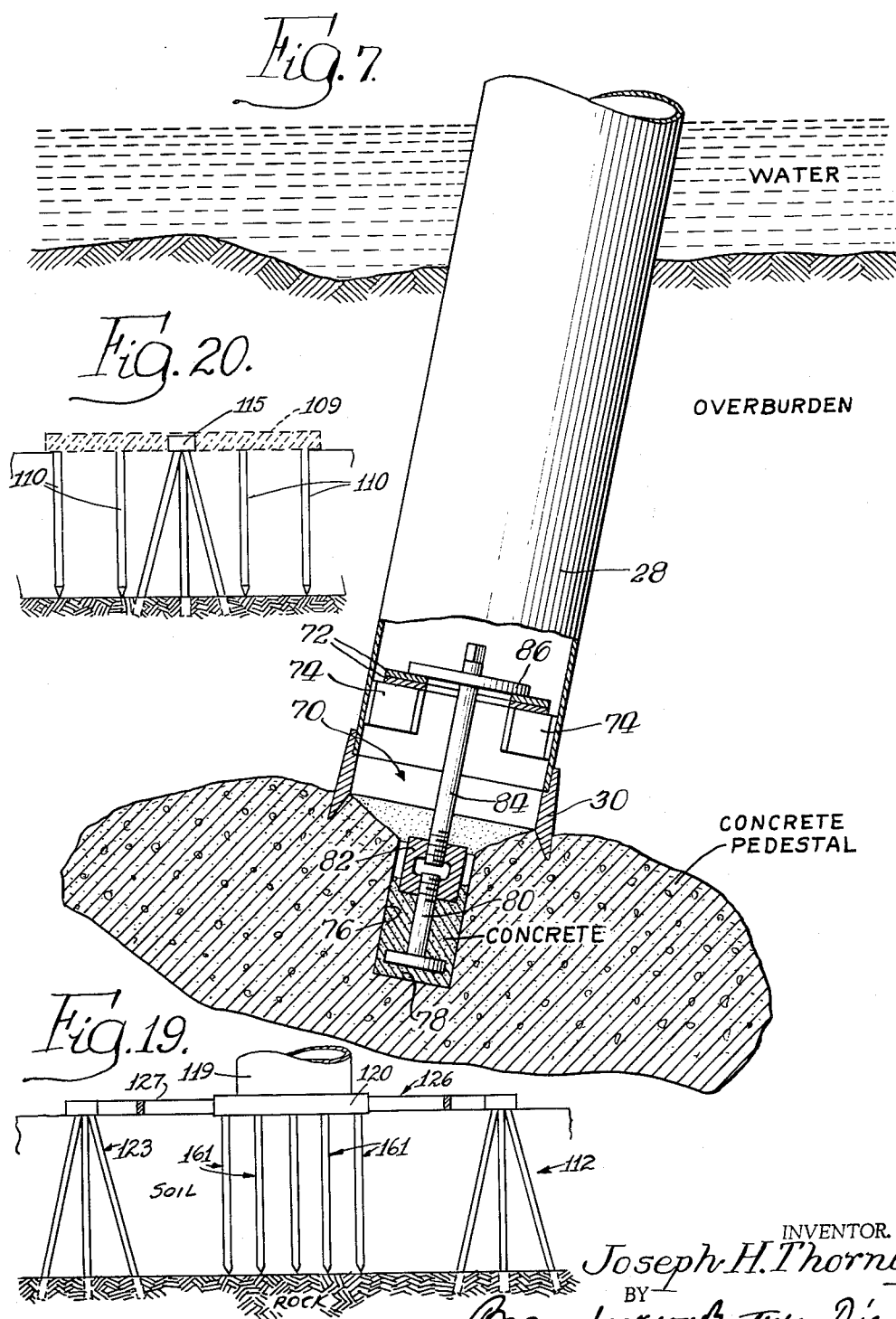
J. H. THORNLEY

3,255,591

HORIZONTALLY STABILIZED FOUNDATION

Filed Aug. 23, 1961

8 Sheets-Sheet 4



INVENTOR.
Joseph H. Thornley,
BY
Brown, Jackson, Fortner & Dierker
Attys.
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June 14, 1966

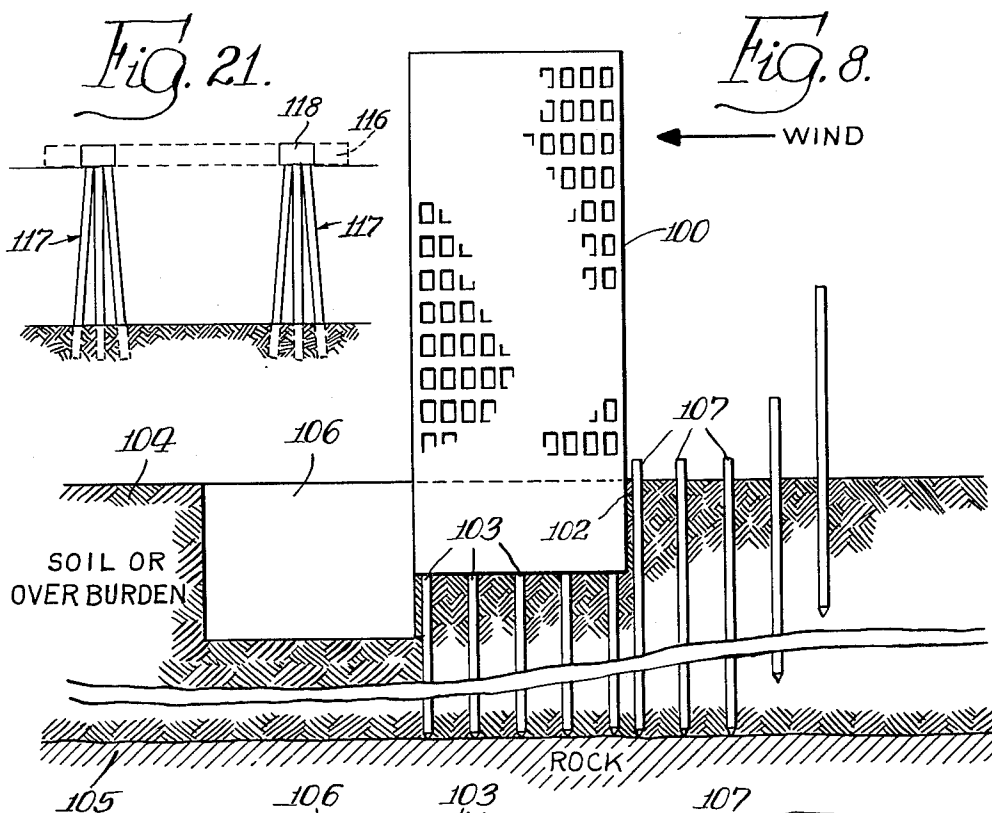
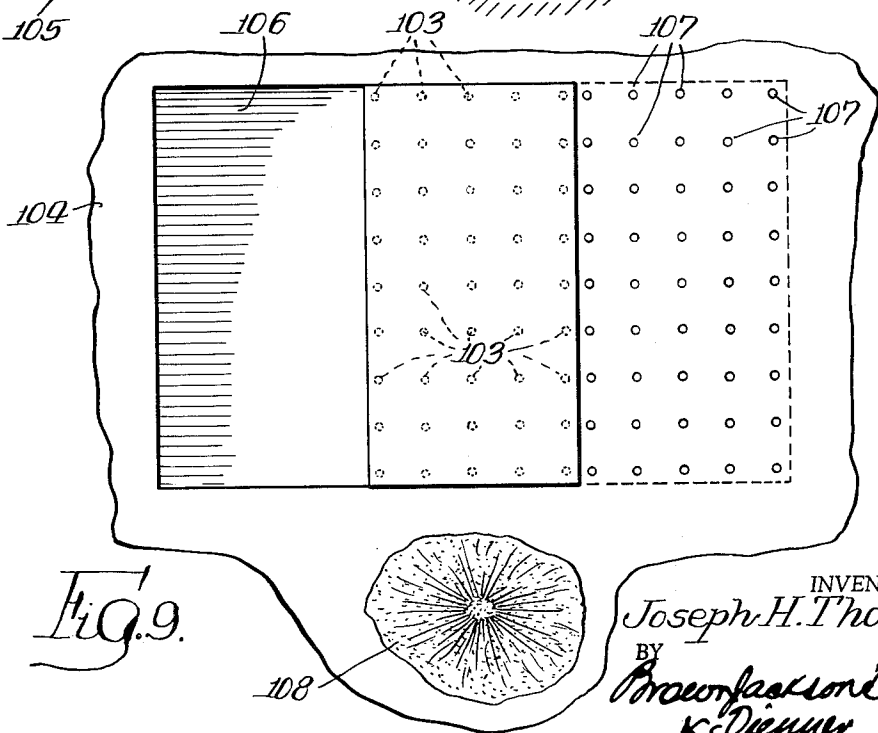
J. H. THORNLEY

3,255,591

HORIZONTALLY STABILIZED FOUNDATION

Filed Aug. 23, 1961

8 Sheets-Sheet 5



INVENTOR.
Joseph H. Thornley
BY
Proffessionally
& Diener
Attys.

June 14, 1966

J. H. THORNLEY

3,255,591

HORIZONTALLY STABILIZED FOUNDATION

Filed Aug. 23, 1961

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Fig. 16.

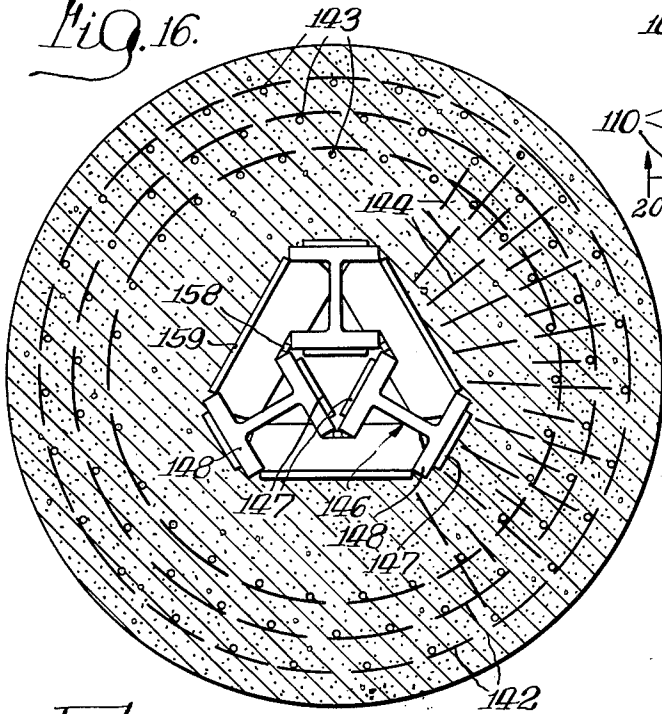


Fig. 10.

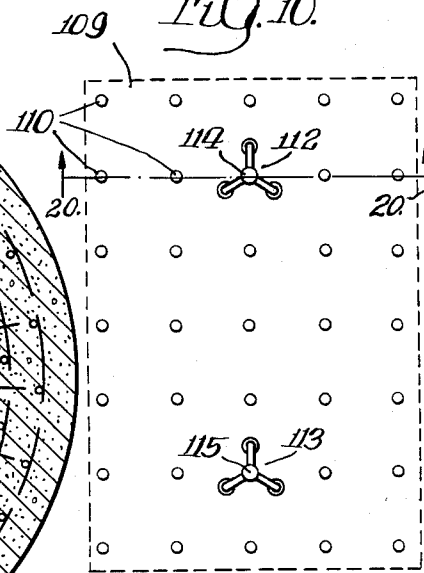


Fig. 17.

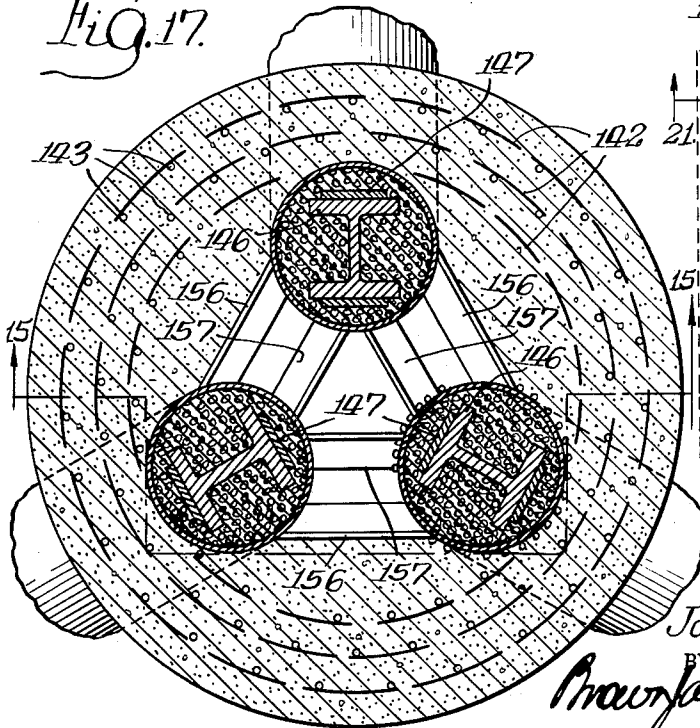
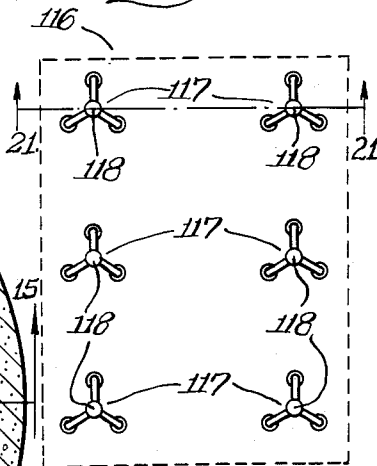


Fig. 11.



INVENTOR.
Joseph H. Thornley,
BY
Maurice M. Batten &
Dinner Attys.
34

June 14, 1966

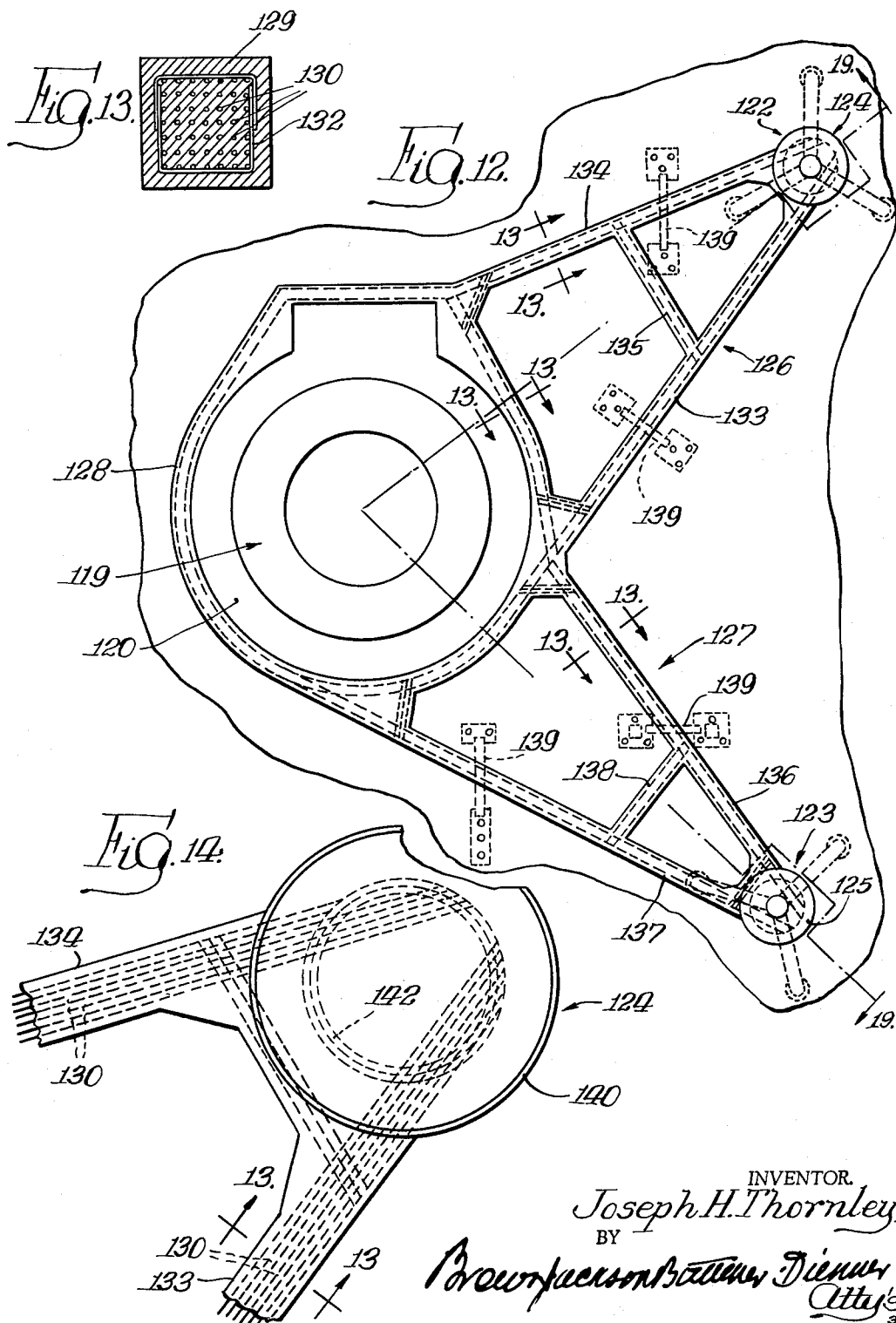
J. H. THORNLEY

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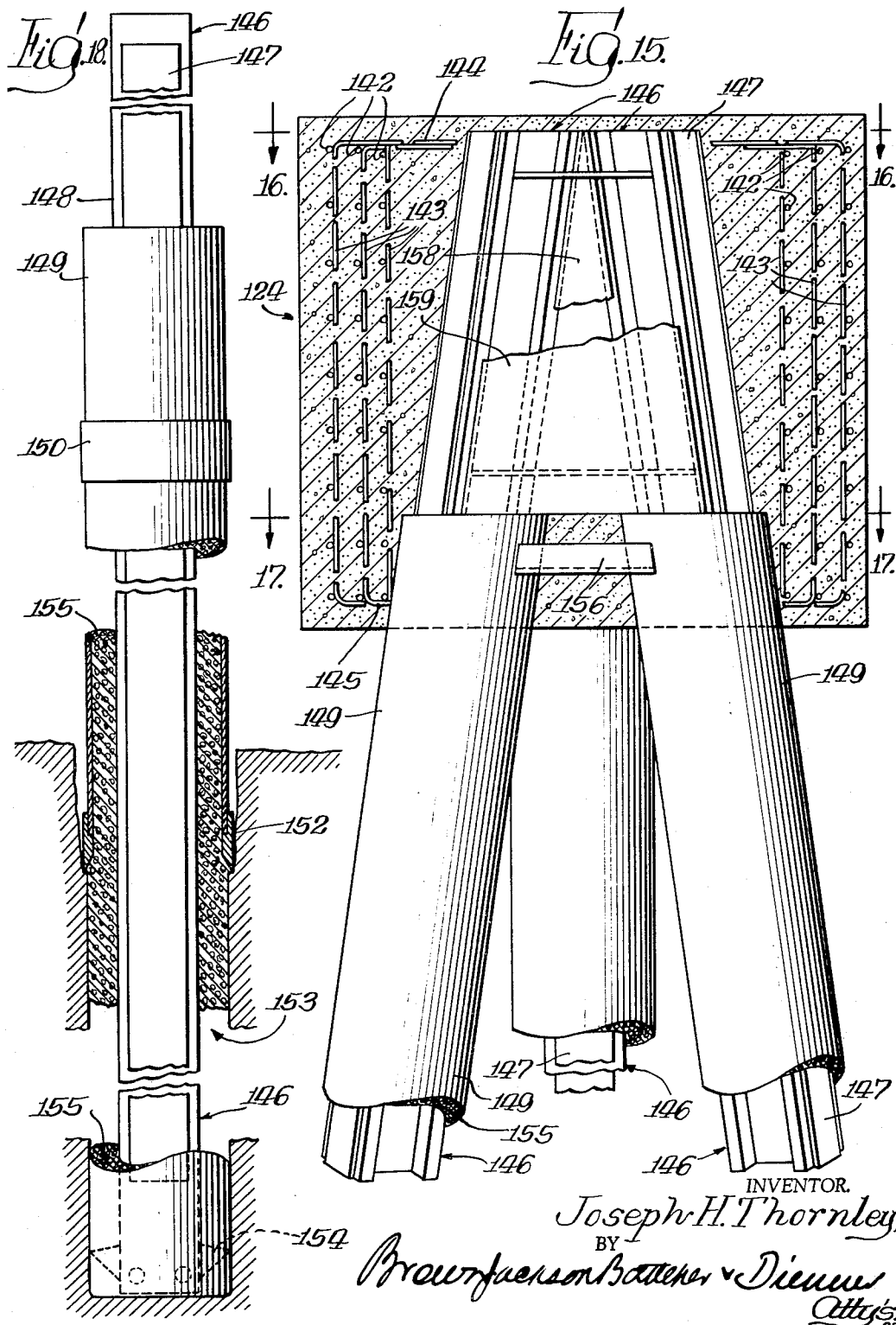
J. H. THORNLEY

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HORIZONTALLY STABILIZED FOUNDATION

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HORIZONTALLY STABILIZED FOUNDATION
Joseph H. Thornley, Douglaston, N.Y.; Beatrice Thornley,
executrix of the estate of Joseph H. Thornley, deceased
Filed Aug. 23, 1961, Ser. No. 133,440
7 Claims. (Cl. 61-46)

This application is a continuation-in-part of application Serial No. 608,079, filed September 5, 1956, now abandoned. Application Serial No. 608,079 in turn is a continuation-in-part of application, Serial No. 311,995, filed September 29, 1952, now abandoned, which is a division of application, Serial No. 40,323, filed July 23, 1948, now abandoned.

This invention relates to foundations and more particularly to stabilization of foundations against force components acting in a horizontal plane in compass directions which may be not definitely predetermined or may be subject to change, and to a bottom anchored tripod unit which is an essential element of such a stabilized foundation. The stabilizing ability of the means of the present invention is not confined to force components operating in horizontal planes, but it is in the field of horizontal stabilization that this invention shows a unique utility.

The construction of foundations providing stable support in a vertical direction has reached a high state of development. But it is a surprising fact that in the field of supports for structures subject to horizontal forces which are of substantial magnitude, and which are unpredictable as to direction of application and may be variable as to degree of applied force, there has heretofore been no solution of the problem of how to construct a foundation having horizontal stability.

In this connection, it is to be understood that my invention is concerned, as one example, with the stability of structures presenting very great vertical loads, as, for example, a tall office building or a heavily loaded warehouse, a blast furnace, etc., and subject also to substantial horizontally acting forces tending to displace such structures horizontally, and as another example with the support of structures which, while they present no massive vertical load, are subject to the application thereto of great horizontal force components or overturning forces due to movement of earth, air or water in relation to them, and applied from various and/or unknown compass directions. An example of this latter type is to be found in building foundations, bridge piers, docks, ship anchorages, "Texas Towers," artificial islands for offshore drilling, heavy industrial structures, etc. In other words, structures needing the benefit of horizontal stability range from those which present chiefly an enormous vertical load insecurely supported laterally and which, if not stabilized horizontally, may develop lateral instability and be destroyed, to those which present no great vertical load, but are subject to great and unpredictable horizontal forces, as by wind, wave, land or snow slides, floods, etc., which forces must be resisted in such a manner and to such an extent as to give horizontal stability, and preserve the structure against destruction.

The problem of horizontal stabilization of a vertically acting supporting element capable of sustaining vertical load ranging from the relatively inconsequential to the massive may be greatly complicated by pre-existing limitations, as by the nature of the terrain at the location where such supporting element is required to be located. To illustrate, the vertically acting supporting element may be required to be located at or above the surface of a body of water having a bottom which is bare sloping rock, such as a location along the eastern Atlantic coast of the United States. Or the desired location of the supporting ele-

ment may be a swamp or fill which in effect is neither solid nor liquid and wherein an underlying firm stratum, such as a suitable layer of rock, is located below the surface at a distance so great as to make an open coffer dam impracticable.

As another example of an exceptionally difficult location is a site for a tall or heavy building between existing tall or heavy buildings, and where a firm stratum, such as a suitable layer of rock, is at a considerable distance below the surface. Other situations may require stabilization of a supporting element subject to uncontrolled movement of wind, waves, water flow, ice, snow or adjacent artificial structures which are not amenable to alteration.

The problem as exemplified in the above illustrative difficult locations and conditions generally can be solved or the solution aided by the anchored tripod unit which consists principally of three bottom anchored axially loaded, battered, drilled-in caissons with their upper ends brought together and bonded to each other in a cap which forms a common apex and so anchored in or to a suitable firm earth stratum at the corners of a triangle as to develop load resistance either in compression or in tension as required.

The concept of stability, as herein referred to, means the ability when subjected to its design load, to retain a fixed position, subject, of course, to such deviation as is involved in elastic deformation of the structure under stress, but without reaching the yield point. It is not enough for the requirements of stability that a foundation structure will afford resistance to movement of displacement while allowing such movement to occur. It must resist permanent displacement. For adequate stabilizing of a structure against horizontal forces, it is essential to have a tight connection of the structure with the stabilizing means, so that the least tendency to displacement of the structure will instantly call into play a stabilizing force from a direction such as to oppose the force tending to cause displacement, both in direction and amount within the design strength of the structure. The present stabilizing means in turn must have and does have a tight and unmovable bottom connection at the corners of a triangle with a firm stratum of earth crust, such as underlying bed rock or other immovable layer. This firm and unmovable bottom socket connection must be such that it will resist to the full strength of the connection means longitudinally in either tension or compression, and be capable of going from tension to compression without any perceptible displacement. The entire tripod has the same property, namely, that the parts are all subject to reversal of stress therein, and this occurs without lost motion or any substantial displacement.

Now the variety of circumstances presenting the problem of horizontal stabilization is much greater than is generally realized in the art. That is due, in my opinion, to the fact that the art has found no way to provide adequate stabilization of a structure against horizontal forces, and has accepted the destruction of structures which actually were inadequately supported in a horizontal plane, as an act of God. Witness the recent destruction, by ocean storms, of Texas Tower No. 4 in the Atlantic Ocean, occupied by a radar station. Here was need for horizontal stabilization, but the prior art had not developed the means to provide the necessary stability. The result was the destruction of the structure, the loss of equipment and needless sacrifice of lives.

In accordance with the present invention, I provide as the preferred form of the basic unit for solving the problem of stabilizing an earth supported structure, the so called "rock socketed caisson tripod," also sometimes designated as the "stable tripod" or "bottom anchored tripod." Such a unit comprises three downwardly divergent caissons each of the type known in the art as "rock

socketed" or "drilled-in" caissons, and described and claimed in my prior Patent No. 1,822,550, to which reference is here made for a more complete explanation of the structure and its advantages and of its mode of installation. The longitudinal axis of each caisson of the tripod unit diverges downwardly from each of the longitudinal axes of the other two caissons of the tripod unit, said axes defining three edges of a tetrahedron whose base is the top surface of said bed rock or rigid earth stratum.

The preferred form of the unit employs only three such caissons, but the addition of other connections between the apex and the firm earth stratum does not involve departure from my invention, so long as the main load carrying members are stressed longitudinally in tension or compression and are not substantially subject to bending.

In general, such a "drilled-in" caisson is preferably constructed by projecting a steel casing down into sealing engagement with a firm stratum, such as bed rock. The casing is emptied. A socket is cut or drilled into the firm stratum as a prolongation of the bore of the casing. The socket is cleaned out. A filling of grout extending up into the casing is deposited in the socket and casing. An H-beam or some built up steel section of the desired size is extended down through the casing into the socket to the bottom thereof. The grout is allowed to set, and the remainder of the space in the casing is filled with concrete. The core is bonded to the side walls of the socket and to the inside wall of the casing. Bonding of the core to the socket provides the necessary strength in tension. Other forms of steel reinforcement may be employed. The essential feature is the lateral bonding of the lower uncased end of the caisson to the side of the socket in the rock, which enables the rock to accept load in a direction longitudinally of the shaft or body of the caisson to the extent of the full design strength of the said shaft or body of the caisson in either compression or tension without yield beyond the elastic deformation of the parts involved in opposing the applied load.

A short core or metallic reinforcement extending into the socket and terminating a short distance above the bottom of the casing may be employed. In this case, the load is transferred from the walls of the socket to the core by the bond of the cement in the socket and from the core to the lower end of the casing by the bond of the cement filling in the casing. To insure adequate hold in tension, the socket or a part thereof may be tapered, i.e., on a diameter which increases downwardly. The taper need be only slight, i.e., an inch or a few inches in a 10 to 20-foot socket for a 30-inch to 48-inch or larger caisson shell.

Three "rock socketed" or "drilled-in" caissons, as above described, and also disclosed in my aforesaid patent, are installed in convergent relation relative to each other, and are so disposed that their upper ends are brought to substantially a common point of intersection. Their lower ends diverge relative to each other and are suitably bonded in rock sockets at points spaced from each other at the corners of a triangle and a sufficient distance from each other to provide a stable tripod. For the general case, these three caissons will be disposed on a batter of from about 1 horizontal to 6 vertical to about 1 horizontal to 8 vertical, and will be symmetrical about a vertical line or axis through the apex or common intersection. In hard granite the batter may be less than 1 horizontal to 8 vertical, for example, 1 to 12 or less. In some cases, particularly installations of low to medium height, the batter may be as great as 1 horizontal to 5 vertical or even more. Symmetry about a vertical axis through the apex is not essential to secure certain important benefits of my invention; and for some purposes, such as a ship anchorage or installation on a sloping rock base, as later explained, an asymmetrical arrangement has certain advantages. Likewise, the batter may be greater or less without losing the benefit of the invention. As will be explained later, the caissons should preferably be disposed in a symmetrical arrangement about a common axis passing through

the apex, but this axis need not be strictly vertical. This may be of advantage, particularly where the pattern of resistance in a horizontal plane is not required to be uniform.

For all cases, the upper convergent ends of the tripod-forming caissons are brought together to a rigid junction herein sometimes termed "an apex," with their longitudinal axes if extended intersecting or substantially so, and these upper ends are rigidly connected or bonded to each other, preferably with great strength against longitudinal displacement relative to each other.

As a preferred means for effecting this connecting together of the converging upper ends to form an apex, I employ a welding together, by trapezium-shaped gusset plates, of the upper ends of the reinforcing H-beams where such are embodied in the caissons, the lower ends of which H-beams are bonded in the sockets drilled into the rock. The upper ends of the shells of the caissons and the welded-together ends of the intersecting H-beams are embedded in and bonded to a cap of reinforced concrete. It is to this cap or apex which lies substantially at the intersection of the extended longitudinal axes of the caissons that the load to be resisted is applied. Theoretically and ideally, the convergent upper ends of the caissons should intersect at a point at which level the load should be applied. But point intersection is not essential, and application of the load in the region of the junction will serve without imposing significant bending stresses. The practical consideration is to bring the convergent ends together so closely that they may be bonded together into a rigid apex and the extent of departure from point intersection being small enough that load applied from any direction to the cap at the apex will stress the caissons relative to each other mainly in shear, and will stress the caissons relative to the cap to so low a value of bending as not to affect substantially their load carrying ability in the tripod unit.

While the unit thus far described is capable of resisting forces applied to the apex from any direction whatever, the chief function of the bottom anchored or stable tripod of my invention is not to sustain vertical loads (although it will readily do so), but to provide stabilizing resistance to loads in a horizontal plane from any direction, or the horizontal component of any load applied to the cap.

Where the stress applied to the cap or apex of the stable tripod acts in a horizontal direction, it will be resisted by tension longitudinally of one (or two) of the three caissons and by compression longitudinally of the other two (or one) caissons, but at the same time, all three caissons are subject to shear to resist horizontal movement of the tripod. The strength of the three caissons in shear easily exceeds any load which the unit can resist by longitudinal compression and tension above referred to.

The bottom anchored tripod unit as a horizontal stabilizing unit will, in the embodiment where the three caissons of equal size are equally and symmetrically disposed about a vertical line passing through the top connection or apex, presents a stable resistance, the maximum of which is substantially uniform to forces from any compass direction in a horizontal plane. This stable resistance rests upon the strength of the caissons in tension and compression, and not in bending. Hence, the unit is capable of presenting its maximum resistance to such horizontal forces substantially independent of the distance between the apex and the stratum containing the anchoring rock sockets. Obviously, the caissons may be laterally braced intermediate their length to overcome the tendency of slender columns to bow as their length is extended. Such bracing, termed sway bracing, is not a substantial load carrying part. As a consequence, the stable rock socketed tripod unit may extend to great height or depth, such as 200 to 300 feet and more; and the caissons being disposed

upon the selected batter, the spread of the lower ends, i.e., of the rock sockets, will be proportionately increased; and within economically feasible limits, the resistance of the tripod remains substantially the same for any height. This is a remarkable property of great value.

The stable or rock socketed tripod unit does not require the presence of overburden to permit it to be installed or to perform its function. It may be installed from the surface of supporting soil, or it may be installed from a platform or from a floating barge. It may be installed on bare rock, flat or sloping or irregular, or extending through any intervening strata whether the same provide lateral support or not.

Lateral support from overburden is important to a pile, caisson or column which is loaded by a horizontal force component as a cantilever, i.e., loaded under bending stress by a horizontal force. But the present invention differs from all prior art structures which involve loading of the piles or caissons in bending since the present invention for the first time provides a structure in which lateral (i.e., horizontal) load from all directions is taken up by tension or compression longitudinally of the caissons without any bending. This is basically new and provides highly important results.

I am aware of Patent No. 2,608,830, which provides a foundation structure shown as comprising a vertical rock socketed caisson, the upper end of which is bonded into a cap which receives the vertical load of one end of a bridge span. A second rock socketed caisson disposed on a batter and lying in the plane of the bridge span has its upper end brought into substantial intersection with the first caisson and bonded into the aforesaid cap. This structure is capable of providing a resistance to a force applied to the cap at the upper ends of the caissons, but only in case said force lies in the plane of the two caissons. A horizontal force applied to said cap, provided it acts in the plane of the two caissons, is resisted by tension in one of the two caissons and compression in the other.

But for a horizontal force applied to the cap from any compass direction other than those of the plane of the two caissons, the caissons must develop such resistance as they can offer by their strength in bending plus whatever lateral support they may gain from overburden. Consequently, the theory and mode of operation of the device of said patent requires that the structure if unsupported laterally be not substantially loaded in a horizontal direction, except only in the plane of the members. The application of a heavy horizontal load at right angles to the plane of the two caissons will subject the caissons to bending stresses which are a maximum at the point of maximum leverage, i.e., just above the rock sockets. The greater the length of the caissons, the less horizontal force at right angles to the plane of the caissons can the structure withstand in the absence of lateral support by external means.

As shown in said patent, overburden of soil above the anchoring stratum of rock is relied upon for lateral support against the bending stresses which will be imposed by wind or water flow or the like transverse to the plane of the two caissons. Hence, a foundation unit such as is shown in said patent, is not suitable for erection upon bare rock or in the absence of an amount and character of overburden which will supply the necessary resistance to lateral forces.

The bottom anchored tripod of the present invention is in the preferred form completely free of the weakness of being subject to bending stresses upon its members by a horizontal force component applied to its apex from any direction. It is further free of the limitations of reduction of resistance as the height is increased as is the case in the foundation structure of said patent. A striking advantage of the bottom anchored tripod of the present invention is the ability to afford substantially uniform resistance to horizontal forces from any compass direction without involving bending stresses and substantially in-

dependently of the height of the cap or apex above the rock sockets. The ability to perform the above is not dependent upon the presence of overburden, since the tripod can be installed on uneven or sloping bare rock even though the same be at the bottom of a body of water, such as a river, lake, reservoir, or the ocean, through fluid or semi-fluid soil.

Neither is such ability dependent upon the presence of an artificial vertical load to prevent overturning. Overturning of the rock socketed caisson tripod is resisted by the inherent strength of the caissons in longitudinal tension and compression, and is not dependent solely upon vertical load which must be raised to allow overturning as is the case with all foundation structures which are not anchored for tension by connection with a firm underlying stratum.

As a horizontal stabilizer for structures designed to carry vertical loads or embodying such loads, the rock socketed caisson tripod unit has a unique mode of operation. Although as a unit it is loaded as a cantilever, its members are not subjected to bending. Attachment of the top of the tripod directly to the structure or frame to be stabilized supplies a horizontal resistance to motion of the connected structure in any horizontal direction.

The rock socketed tripod of my invention has peculiar and unique utility for horizontal stabilization of heavy structures which have vertical support but which are subject to disturbing forces which may make them unstable. The provision of one or more rock socketed caisson tripods with the apex or cap of the tripod connected at substantially the level of the connection between the superposed structure and the underlying vertical support provides a stabilizing resistance to movement of the building in any direction. This resistance to such displacing movement in any horizontal direction is evolved by the interrelation of the parts of the tripod. The most economical and effective arrangement is to extend the tripod to the level of the frame where it obtains its horizontal support from the foundation proper and to make the connection with the structure to be stabilized at that level. The structure of the tripod provides great rigidity, that is, great resistance is developed upon very small lateral displacement of the cap of the tripod. This arises from the fact that any horizontal pressure on the cap tends to swing the top of the adjacent caisson or caissons downwardly. Since the top of the adjacent caisson is attached to the top of the remote caisson or caissons (in the direction of the applied force) the top of the said remote caisson or caissons will tend to rise. These two forces are balanced, namely, the tension in the near or adjacent caisson is exactly balanced by the compression in the remote caisson. The result is that the full strength of the caissons in tension and compression resists any horizontal displacement of the cap which bonds their tops together. The consequence is a maximum horizontal resistance within the strength of the caisson in longitudinal tension and compression for a very small displacement of the cap in a horizontal direction. This is of great practical value, since it affords the necessary resistance to displacement of the critical vertical alignment of the vertical supporting means with the superposed structure.

In stabilizing a structure against movement in a horizontal plane, it is necessary to oppose motion of translation as by a linear force or force component, and it is also necessary to oppose angular motion of the same. The tripod of the present invention will to great advantage oppose a motion of translation of its apex or cap by stressing the caissons longitudinally on the near side in tension and on the far side in compression. Angular motion can be opposed by the tripod of the present invention through its ability to resist not only linear forces, but also a force couple applied to the cap. The stresses imposed by a force couple are different from those imposed by a linear force or force component.

Whereas a horizontal force component stresses the caissons longitudinally only, and does not stress them in bending, a force couple applied to the cap subjects the individual caissons each to a twisting stress and to a bending stress. If the torque to be opposed in stabilizing a structure presents a design load in excess of the ability of the single tripod to sustain it, recourse should be had to two (or more) tripods which can sustain a torque load by resolving the same into two linear forces in opposite directions. A minimum of two tripods suitably connected to a structure to be stabilized against forces and force components and force couples acting in a horizontal plane can produce the desired stabilization entirely by stressing the individually rock socketed caissons of each tripod longitudinally only in tension and compression.

A minimum of two tripods is thus required for complete horizontal stabilization, and where they lie outside the horizontal extent of the rigid frame of the structure, they must be connected to the structure by stiff frames or by torque arms each in effect forming with the frame of the structure to be stabilized, a triangle, one corner of which triangular arm is connected to the cap of one tripod and the other two corners of the triangular arm being rigidly connected at spaced points to the frame of the structure to be stabilized. With two tripods spaced apart and connected by two such triangular arm connections to the frame of the structure, they can hold the structure in a predetermined stable position for horizontal forces and force couples within the design strength of the tripod and the triangular arms. Where the stable tripods can be connected at their apices directly to the frame of the structure to be stabilized, and where the apices of the tripods fall within the confines of the frame, such triangular connection arms may not be required, and where the angular stresses to be encountered fall within the ability of a single tripod to resist, a single tripod may serve to stabilize the structure against both types of forces, i.e., linear or translation or angular as by a force couple.

The convergent upper ends of the three caissons of the tripods of this invention are rigidly unified preferably by bonding the same to each other as closely as is feasible. In the preferred form, the convergent caissons lie in planes intersecting a common vertical line, so that the longitudinal axes of the caissons would, if extended, intersect at substantially a common point. The caissons may be brought into tangency with each other in substantially a horizontal plane and bonded together in that position. This junction involves a problem of suitable physical means, one form of which is a feature of the present invention.

It is of course not practicable to cause the material of the three caissons with their caisson shells concrete filling and contained steel reinforcing columns to fuse together while retaining their structural and functional identities, but that broadly speaking is the desired effect. In the preferred method of joining said upper ends to produce an interconnection at the apex, the reinforcing steel H-beams are disposed in the desired positions and joined together through the intermediary of gusset plates which are welded to adjacent parts of said H-beams. The junction of the said joined H-beams and the tops of the caisson shells are embedded in a filling of concrete in a cap structure to provide the preferred type of interconnection. It will provide the desired strength and will permit the external horizontal load applied to the cap to be distributed among the caissons substantially as longitudinal tension or compression. The junction resists in shear relative endwise movement of one caisson relative to another with a strength great enough to develop substantially the design capacity of the rock socketed caissons in tension and compression. The junction is close enough to avoid the development of significant bending stresses upon the caissons.

The connection of the upper ends of the caissons should, for best results, come as close as practicable to a point

intersection. But since that is not physically feasible, the practicable standard for the connection of the caissons at the cap or apex is that it be sufficiently close to an intersection that whatever bending stress is involved in the connection will not seriously weaken the structure or cause it to fail to function substantially as a point of intersection or spot junction of said caissons.

The connection of the caissons in a cap or apex should be close enough that the stress produced between them by application of a horizontal load is mainly in shear.

Distances of 200 to 400 feet and more are entirely feasible in presently constructed sizes of caissons. For caissons of greater diameter than present dimensions of from 36 inches to 40 inches, greater depths are entirely feasible in presently constructed sizes of caissons. For caissons of greater diameter than present dimensions of from 36 inches to 40 inches, greater depths are entirely feasible.

It is sometimes necessary, as later discussed herein, to erect stabilizing means for a structure while it is under stress and suffering displacement. In such case, it is necessary to pour concrete into a form or container, the shape of which is changing under load. It has been proved that if such displacement is not too rapid, the setting concrete will stiffen and deform at the same time up to reaching a high degree of stability, i.e., resistance to further displacement, whereupon it will retain its design strength with only such elastic deformation as that of which it is easily capable.

This means that the stabilizing means which I have used in extreme cases may be installed in situations where the structure to which stabilizing means are to be applied has begun to suffer displacement, and that such displacement can be stopped by the increasing strength of concrete setting while it is being deformed. This method when correctly and properly constituted and used allows the stabilizing means of the present invention to be successfully applied to a structure which has begun to move toward what would result in certain failure if not checked.

Heretofore, many proposals have been made for foundation structures, including the solid masonry, pile and drilled-in caisson types. For bridges and like foundations to be constructed in a water course, the solid masonry foundation has been widely adopted despite its expense and the limitations of the general design. In particular, in the masonry foundation, the resultant of applied vertical and horizontal forces are generally assigned to fall within the middle one-third of the base or other bearing of the foundation to avoid overturning. Where vertical loading is substantial, the masonry foundation has been acceptable, despite its cost of construction and uneconomical use of large volumes of material. However, where vertical load is small and horizontal forces are large, the resultant of the force components cannot reasonably be made to fall within the defined base area in a feasible foundation design even with a massive construction delivering substantial dead load. The masonry construction therefore is not economically applicable to the specific loading problem.

An alternative is to deliver the loads through piles having their lower ends bedded in a resisting stratum to such extent as to develop resistance to horizontal movement. In such structure, horizontal load is delivered by cantilever beam reaction set up when any force tends to cause lateral movement of the upper end of the pile. Therefore, the optimum load sustaining characteristic of the pile, i.e., in compression, is not utilized in cases of dominant horizontal load. Moreover, the pile foundation suffers the disadvantage of requiring firm overburden, even at a limited depth, since resistance of the pile to horizontal loads is in inverse proportion to depth above a given depth of seating in overburden, i.e., stability is lost in direct proportion to increase in depth above the overburden. Thus, the foundation is also in-

adequate in most instances wherein horizontal load is large.

The chief object of the present invention is to provide means for providing an automatic stabilizing force varying in amount and direction for stabilizing structures subjected to horizontal forces and force components, by a series of rock socketed caissons converging to and connected together against relative longitudinal motion in a rigid body or cap to which the force or force component to be stabilized is applied. In employing the term "tripod" or "tripod unit," I do not intend to exclude similar structures employing more than three rock socketed top connected caissons. Also the employment of one or more vertical legs in or in connection with a tripod or tripod unit is not excluded from the scope of the invention defined by the appended claims, so long as the horizontal forces are transmitted from the cap to the rock by the caissons stressed in tension and compression longitudinally substantially without bending.

Another object of the invention is the provision of an improved foundation unit of maximum stability, comprising one or more rock socketed caisson tripods.

It is also an object of the invention to provide an improved foundation construction of complete stability in a horizontal plane against forces and force couples acting in said plane embodying a plurality of said rock socketed caisson tripod units.

According to the basic concept of the present invention, I provide a foundation unit comprising a skeletal construction of three or more mutually downwardly divergent, bottom anchored caissons, with cap means rigidly connecting the upper ends of the caissons. The downwardly divergent arrangement of three or more caissons diverging in different directions relative to each other and firmly anchored in firm load supporting earth strata at their lower end to support all vertical and horizontal loads that can be applied to the top of the unit by resolving the applied loads into forces in tension and compression longitudinally of the columns, substantially free of bending stresses. The foundation unit thus has maximum stability and is highly economical. Three caissons provide a complete unit, but the new principle embraces more than three.

A further object is to provide means, including a rock socketed caisson tripod, for stabilizing against horizontal displacement due to variable horizontal force components, a structure which is vertically supported.

A further object is to provide means, including a plurality of rock socketed caisson tripods for stabilizing against rotary movement due to force couples, a structure which is vertically supported.

The rock socketed caisson tripod of the present invention develops horizontal resistance at the apex or cap of the structure by its own inherent structure without extraneous attachments. It assures that each caisson will automatically be axially loaded substantially free of bending stresses under all combinations and magnitudes of vertical and horizontal loadings within its capacity applied to the cap or top of the tripod. The reason for this resides in the fact that any tendency towards movement of the apex of the caissons will tend to cause rotation of the whole tripod around a horizontal axis passing through one or two legs of the tripod substantially at the rock line. Tendency towards such rotation, however, will cause tension in one or two legs, as the case may be, and corresponding compression in the other leg or two legs, as the case may be. The apex thus tends to move (according to Hooke's law) only to the extent that said one or two legs, as the case may be, under tension can tend to elongate and the remaining leg or legs under compression can tend to shorten under stress. In brief, a horizontal force applied to the cap produces a swinging down tendency in one or more legs, and at the same time a swinging up tendency in the other connected leg or legs in opposition. Since the upper ends are firmly tied

together in the cap, the top of each caisson cannot tend to rise or fall without creating a tendency to fall or rise in the remaining caissons. This is true regardless of the compass direction of the horizontal force applied to the tripod cap.

A surprising property of the rock socketed caisson tripod of the present invention in its symmetrical form, i.e., when each of the legs is substantially equal in size and symmetrical with respect to a vertical axis passing through the cap, resides in that this structure presents resistance to horizontal forces applied to its cap substantially equally in every direction of the compass. Thereby, for any desired load, such a three-legged rock socketed caisson tripod employs the material of its construction to maximum advantage, and no other foundation structure approaches it in efficiency.

Another surprising property of the preferred form of this structure of the present invention is that the tripod unit constructed of caissons disposed on a predetermined batter joined or united by a cap at a common apex and bottom anchored by being socketed and bonded in rock or other firm earth strata, presents substantially the same strength or resistance to horizontal loads from any direction within practicable limits independently of the height to which the loading apex is carried above the base. Where the slenderness ratio of the caisson exceeds a certain value, bracing between caissons, as hereinafter explained, is resorted to. Such bracing has no load-carrying function.

This resistance to horizontal forces is developed without any requirement for external vertical loading or external lateral support. Because of these properties, the structure is peculiarly valuable for so called "off-shore island" construction, where the foundation must be set from a floating base, such as a barge or ship, and the depth at which units must be set is not uniform. Lack of overburden, irregularity of the rock or sloping rock surface is not a bar to the use of the bottom anchored caisson tripod unit.

In producing a platform structure, mounted on three or more such top jointed, bottom anchored caisson units, the vertical distance between water level and firm earth strata may vary considerably, or the depth of water may vary from location to location, yet the installation of the caisson of given cross section at a predetermined batter in the aforesaid tripod arrangement will automatically produce foundation units having substantially the same resistance to horizontal load applied at the apex independently of the vertical height between the apex and the bottom anchorages. This is of great advantage. It opens up a field of construction previously untouched because it was too costly to be economically feasible. The engineering design is simple and positive.

A further object of the invention is the provision of an improved foundation construction comprising at least three of the said tripod units disposed preferably at the corners of a closed figure of three or more sides, as the foundation is viewed in plan, and a pier or the like frame structure is supported on the caps of the tripod units. Since each tripod unit itself is stable, the resultant structure is highly stable, and moreover provides at least three spaced points of stable load support to resist not only straight line horizontal forces applied thereto, but horizontal and vertical turning couples, as well, by resolution of stresses substantially longitudinally only of the caissons, that is, without bending. The foundation is thus completely stable under all design load conditions.

The latter advantage of the foundation construction of my invention renders the same ideally suited for installation in which vertical loading is relatively slight, and the live horizontal loads are large and are applied in various directions. In particular, recent developments in the oil industry and in national defense have given rise to demands for artificial islands along the coastal areas of the country for radar installations and off-shore drilling rigs. In both

cases, the islands may be only temporary, and therefore must be economical and relatively easy to erect and capable of being readily dismantled so as to cause no permanent obstruction to navigation. Yet in use, the islands must be completely stable. The vertical loading will be small, and live horizontal loading will be large and of variable direction and magnitude as caused by shifting winds, currents, tides and waves. The foundation construction of the present invention is suited for such installations, being completely stable, economical and easy to erect and may be constructed to be readily dismantled.

Now in order to acquaint those skilled in the art with my invention, I shall describe, in connection with the accompanying drawings, a preferred embodiment of my invention, and the manner of constructing and using the same.

In the drawings, wherein like reference numerals indicate like parts:

FIGURE 1 is a partial side elevation of a bridge having a suspension span, the lower part of the figure being in section to show the relative location of the bridge piers and bed rock;

FIGURE 2 is a detail on an enlarged scale, showing the manner of constructing the tripod foundation unit of the present invention, and utilizing the same as an end anchorage for the cable of a suspension span;

FIGURE 3 is a plan view of the tripod foundation unit of FIGURE 2;

FIGURE 4 is a side view of a foundation construction of my invention embodying a plurality of the said foundation tripod units. This view shows a construction which constitutes an off-shore island with the caissons of the tripod unit to the left of the view fixedly set, and the caissons of the tripod unit to the right of the view releasably set, the barg, platform, or island being shown in dotted lines in its initial position, and in solid lines in its final position;

FIGURE 4a is a fragmentary vertical section showing the lower end of a caisson employing a stub core installed far enough below the rock line to bring the upper end of the reinforcing core down to approximately the rock line so that the caisson can be cut at the rock line by explosives, burning or other means for severing the same at substantially the rock line.

FIGURE 5 is a top view of the foundation construction of FIGURE 4, the view being taken substantially on the line 5—5 of FIGURE 4;

FIGURE 6 is a somewhat schematic, fragmentary representation of the barge and equipment employed in erection of the foundation and island;

FIGURE 7 is a diagrammatic fragmentary vertical section of a caisson and anchoring means therefor, showing, first, an improved manner of anchoring a caisson other than by embedding the same in bed rock, and, second, an improved device for attaching the caisson to its anchor, whether that be bed rock or other means;

FIGURE 8 is a vertical section, partly in elevation, showing a building subject to horizontal force components of various kinds, for some of which it is not stabilized;

FIGURE 9 is a plan view of the structure and location shown in FIGURE 8;

FIGURE 10 is a diagrammatic plan view of a structural frame supported on vertical piles, and stabilized in a horizontal plane by means of two rock socketed caisson tripods of my invention;

FIGURE 11 is a similar diagram of a building or supporting structural frame, which is supported for vertical load upon a series of rock socketed caisson tripods, and is stabilized for horizontal forces or force components by said tripods;

FIGURE 12 is a plan view of stabilizing means for supporting a blast furnace foundation against horizontal displacement;

FIGURE 13 is a cross sectional view taken on the line 13—13 of FIGURE 12;

FIGURE 14 is an enlarged fragmentary plan view of the connection between the cap of a tripod and the frame connected to the blast furnace base shown in FIGURE 12;

FIGURE 15 is a side elevation, partly in section on the line 15—15 of FIGURE 17 of the cap and the upper ends of three rock socketed caissons forming a tripod;

FIGURE 16 is a horizontal sectional view taken on the line 16—16 of FIGURE 15;

FIGURE 17 is a horizontal section taken on the line 17—17 of FIGURE 15;

FIGURE 18 is a side elevation with parts broken away showing the construction of an individual caisson anchored in its rock socket;

FIGURE 19 is a section shown in elevation taken on the line 19—19 of FIGURE 12;

FIGURE 20 is a cross section taken on the line 20—20 of FIGURE 10; and

FIGURE 21 is a cross section taken on line 21—21 of FIGURE 11.

In FIGURES 1 and 2 of the drawings, a rock socketed caisson tripod foundation unit of my present invention is indicated generally at 10. I have shown the same as providing the foundation for one end of a suspension bridge. The bridge includes a deck 12 which may be supported at one end by the unit 10, a plurality of main tension cables 14 which may be anchored at one end in the unit 10, and a vertical load sustaining frame 16 resting upon a pier 18.

The tripod foundation unit 10, as shown in FIGURES 1 to 3, constitutes a permanent installation, and consists of a tripod including in detail, three downwardly divergent bottom anchored or rock socketed columns or caissons 20, 22 and 24, and a rigid structure or cap member 26 within which the converging upper ends of the columns or caissons are fixedly bonded together in or at a common apex. This apex is preferably a cap or connecting structure embedding or rigidly embracing the upper ends of the caissons substantially at the common intersection of the extended longitudinal axes of the caissons. The rigid structure or cap member illustrated at 26 may take various forms, such as a concrete cap formed of either steel reinforced or plain concrete as shown in the drawings, but the term "cap" or "cap member" as here applied is intended to include any rigid structure connecting the upper end of the caissons 20, 22 and 24, and their included steel reinforcements at substantially the point of nearest approach of the axes to each other, theoretically at a common intersection of such axes extended. This uppermost part of the tripod is sometimes referred to as the "apex."

The bottom anchor caissons, herein sometimes referred to as "legs" or "tripod legs," preferably comprise drilled-in caissons of the general type disclosed in my Patent No. 1,822,550, and as illustrated in FIGURE 18 herein. Each caisson, as shown in FIGURE 2, comprises a tubular steel shell 28 having a hardened steel drive shoe or cutting shoe 30 secured to the lower end of the shell 28, as by welding. A core 32, consisting preferably of an H-beam of structural steel lies within the caisson shell, and has its lower end extending beyond the shell and projected into the rock socket 34 a distance adequate to provide a connection between the side walls of the socket and the side walls of the reinforcing member 32, which will sustain in either tension or compression a load which is substantially as great as the capacity of the said caisson to sustain in compression or in tension. This capacity of the socket to sustain load in tension may be improved by tapering the socket outwardly and downwardly for all or a portion of its length. Likewise, the socket may be tapered inwardly and downwardly for all or a portion of its length to improve its compression sustaining ability.

To this end, the socket may be tapered part way to improve ability to sustain tension load on the caisson, and part way to improve ability to sustain compression load on the caisson at the bond which transfers stresses from rock to caisson or vice versa.

The shell 28 is preferably formed of steel usually having a yield point of not less than 40,000 p.s.i., and of a diameter and thickness appropriate to the particular construction contemplated. The shell or casing 28 may, for example, be of 30 inches to 36 or even 40 or more inches in diameter, and the wall thickness may be of $\frac{1}{4}$ to $\frac{5}{8}$ inch or higher, depending upon the load to be carried.

The depth below ground or water level to which the caisson may be projected depends upon the requirements of the situation. In all cases, it is necessary to project the same into contact with a firm load bearing earth stratum, such as a stratum of rock, of natural or artificial character. The caisson shell may be made up of suitable standard lengths welded end to end through suitable external or internal telescopic welding sleeves to provide the overall longitudinal dimension required. The drive shoe 30, which has a cutting edge adapted to engage the rock and to be driven into silt tight engagement therewith, is preferably formed of a high carbon steel properly tempered, a special alloyed steel, or the like. This drive shoe which is welded to the lower end of the shell, as shown in FIGURES 1, 2, 7 and 18, has its lower inner edge bevelled to produce a sharp cutting edge of maximum or outside diameter. The reinforcing core 32, as shown in FIGURES 1, 2 and 3, preferably comprises a steel H-beam, sometimes reinforced cover plated extending throughout the length of the shell 28 and protruding from each end thereof. The space within the shell 28, the rock socket 34 and cap 26 and not occupied by the core 32 is filled with concrete. Instead of a single central steel reinforcement in the shape of an H-beam or like structural bar, the shaft of the caisson may be reinforced with distributed steel reinforcement from within the socket 34 throughout the length of the shell 28 and into the cap 26 which bonds the upper ends of the convergent caissons 20, 22 and 24 together.

The shell 28 of each caisson is driven on a batter, preferably on the order of from 1 horizontal to 6 to 8 vertical, frequently by the drill rigs which include suitable guides or leads. The shell is frequently driven to rock before cleaning. This depends upon the nature of the soil to be penetrated. However, when driving through overburden, as indicated in FIGURES 1 and 2, if resistance becomes too great, due to hard layers or boulders, the shell may be cleaned out prior to reaching bed rock and a churn drill employed to cut into the resisting layer or to break up boulders which may be in the way. As the shell 28 is driven to a suitable firm earth stratum, such as bed rock, indicated in the drawings, the drive shoe 30, by means of its cutting edge, cuts into the rock sufficiently to embed the lower end of the shell 28 into the rock to provide a tight joint between the rock and the shell. This tight engagement between the driving shoe 30 and the rock into which it is driven excludes the inflow of water, silt, and sand from the outside. Thereby, the rock socket may be drilled out and cleaned out to receive its filling of grout for cementing the lower end of the H-beam in the socket and in the lower end of the caisson shell 28. This type of operation is known.

After the shell 28 has been driven into sealing engagement with bed rock, a rock socket 34 is drilled in the firm earth stratum, such as bed rock, axially in line with the shell 28, as by means of a star drill or other known drilling means. The drilling of the rock socket is generally performed with standard tools, that is, a reciprocating cutting bit which may be of the spade type or of the star type or of any desired form. Alternatively, a rotary rock bit may be employed where rock is soft and reasonably uniform. Such rock bits of the rotary type employing rotary cutters are well known, and are

used extensively in oil well drilling operations in the softer rocks.

I have experimented with various forms of cutters, and I find that by providing inclined vanes or ribs, in addition to the four fins of the standard star type bit, I can secure a progressive rotation of the tools, particularly since the bit, in falling down through the chipped rock and sludge in the bottom of the hole, will tend to give a slight rotative movement on each downward stroke. It will thereby cut fairly evenly across the face of the end of the hole to provide a rock socket disposed on the desired batter. The batter may obviously be greater or less than the preferred ratios above given.

After the rock socket 34 has been cut to the desired depth, it is cleared of sand and loose rock, but need not be dewatered. A charge of grout sufficient to fill the socket and to extend a yard or so up inside the casing 28 is deposited in the bottom of the bore, as indicated at 36, and the steel core 32 is then set in place in said grout filling. For the purpose of centering the lower end of the steel core 32 in relation to the shell 28 and socket 34, a suitable plate may be welded to the bottom of the core, or alternatively, projections, such as fins or pivoted fingers 90 (see FIGURE 18) extending from the side of the core and resting against the walls of the rock socket, may be employed.

The object is to space the reinforcing core 32 from the side walls of the shell and of the rock socket a sufficient distance that an effective and substantially symmetrical filling of grout between the two is assured. In some installations, the shell 28 may be bottom anchored by means of a stub core and the grout fill, as thus far described, whereupon the shell per se may serve as the column or support with or without further filling of concrete. However, in the specific installation illustrated in FIGURES 1, 2 and 18, I prefer to use a full length reinforcing core and to fill the shell 28 throughout its full length with concrete, thus to complete the caisson. The cap member 26, if formed of concrete, may be cast when the shells 28 are filled, or separately later, as desired. Both the shell 28 and the core 32, shown in FIGURES 1, 2 and 3 (and also similar parts in FIGURES 15, 16 and 17) are bonded in the cap 26 at the apex of the structure.

The cap 26 joins the upper ends of the columns 20, 22 and 24 rigidly and immovably together. The intended effect is that of unifying the said converging ends, so that a force applied to the cap 26 is in effect applied to the point where the axes of the columns intersect or come closest together, and said applied force is distributed aside from its effect in shear, as tension or compression longitudinally of the columns without subjecting them to substantial bending stresses. In the preferred embodiment, the longitudinal axes of the columns, such as 20, 22, 24, intersect at the common point substantially within or slightly above the cap 26. The bond of the cap 26 to the columns ties them together, so that upon the application of the horizontally acting design load, the columns will develop their design strength in tension or compression, as the case may be, without substantial stresses in bending.

While the rock socket caisson generally is employed in the form illustrated herein, modification thereof is contemplated as above noted. In the structure shown in FIGURES 1, 2 and 3 the core 32 extends the full length of the shell, and extends out of the ends of the same. When the thickness of the shell, with or without the filling of concrete, is ample to carry the load independently of the core 32, the core is employed only to transfer the load of the shaft of the caisson to the walls of the rock socket 34. The core then is not always necessary, and in such case needs only be long enough to extend from the bottom of the rock socket a distance great enough inside the shell to gain a transfer of the load on the shaft of the caisson to this included short length of core, as illustrated at 68 in FIGURE 4. In FIGURE 4a,

the caisson 28 is extended far enough below the rock line that the upper end of the stub core 68 will not project above the rock line if the lower end of the caisson shell is severed. The shaft of the caisson above this short stub core consists of the shell only or the shell and a concrete filling with or without further reinforcement. A similar short stub core may be employed at the upper end of the shaft, but reinforcing bars are usually more convenient for transferring the stress from the cap 26 to the shaft of the caisson, or vice versa, where a full reinforcing H-beam is not employed.

As an alternative to bonding the lower ends of the caissons or supports to bed rock, the caissons may, under certain conditions, be bottom anchored in a somewhat different manner by creating a firm earth stratum artificially. Specifically as shown in FIGURE 7, a substitute for bed rock may be employed in instances wherein the artificial substitute can be provided at greater economy and with greater practicality than driving the caissons on to bed rock. In certain areas it will be found that the strata of the earth are such that bed rock is exceedingly deep. There is a great depth of firm soil overlying said bed rock. Under these conditions, it is practical, both commercially and from the standpoint of structural rigidity, to substitute for natural bed rock, huge artificial pedestals or strata formed by the driving out of large bodies of concrete into the overburden, the depth in the overburden at which the pedestals are formed, together with the volume of concrete used, governing the load capacity of the fabricated anchor, either in tension or compression, to be great enough to sustain the design strength of the tripod itself. After the pedestals have been driven out of the pipe or extruded into the adjacent earth strata, and prior to the setting of the concrete in permanent installations, a caisson shell or one tripod leg may be driven into each such pedestal. Since the lower end of the column or support is driven into the pedestal before setting of the concrete has occurred, the column shell may be directly anchored in the pedestal without employing a core 32, or other anchoring device, unless in view of contemplated load conditions, the core is a structural requirement of the caisson. In such event, the exposed end of the core will be embedded and bonded in the body of concrete forming the pedestal, and the lower end of the caisson shell likewise set in the concrete of the pedestal. The shaft of the caisson on the support end can then be treated for anchoring in the cap as heretofore described. When the caisson is completed in any of the described manners or forms, it provides a bottom anchored support capable of withstanding large forces in the direction of the longitudinal axis, since the caisson is locked in bed rock or equivalent artificial concrete pedestal, and has a side wall bond therewith which is equivalent to a rock socket connection. Accordingly, the construction provides not only greater resistance in compression to loading them than could possibly be accomplished by merely setting a pier or pile on top of bed rock, but also provides the necessary condition for sustaining tension in the caisson longitudinally. Where loads are of a magnitude to warrant their use, rock socketed caissons are considerably more economical than other types of supports, since these supports are of much smaller size for a given load, and need not be located as close together as other types of supports for sustaining a given load in compression.

In the foundation unit shown in FIGURE 3, the supports 20, 22 and 24 are set at a batter to one another, preferably in a regular tripod arrangement, that is, they are symmetrically located about a vertical axis passing through the cap. While such structure is ideal for affording substantially uniform resistance to horizontal forces from any compass direction, the three or more caissons need not be arranged in perfect symmetry about a vertical axis, particularly where circumstances call for a modified arrangement. Thus, one of the caissons may

be on the vertical or nearer vertical than the others to provide clearance at the side of a dock or ship anchorage. The major advantages are obtainable in such structure. This may be particularly the case where the surface of the bed rock is on an incline. Two of such converging caissons may lie in substantially the same vertical plane. I have found that a batter of from 1 to 8 to 1 to 6 to be appropriate for most installations, but do not wish to confine the invention to those limits, since sharper or flatter structures may be employed according to the particular needs of the situation. I have found by experience that the disposal of the caissons on a batter within the range of from about 1 horizontal to 6 vertical to about 1 horizontal to 8 vertical is optimum for most of the installations which I have made. It provides a number of advantages. It is a convenient range of inclinations on which the caisson shells may be set into place and the rock sockets drilled. If the inclination is much greater, inconvenience in handling the caisson shell in the usual contractor's rig, and difficulty in drilling the socket into the rock, may be encountered. If the angularity of the caissons relative to each other is too acute, the caissons may get in the way of each other during installation. Lesser degrees of inclination of the caissons to each other also run into the problem of creating undesirably high shear stresses in the bonded surfaces of the cap and of the rock sockets, as well as requiring higher longitudinal loads in tension and compression in the caissons themselves.

At the upper ends of the caissons, the longitudinal axes thereof extended have substantially a common point of intersection, and the caissons are rigidly connected at their upper ends by the cap 26 such that the point of intersection will lie substantially within said cap 26 or like means.

The cap 26 is preferably constructed in the form of a cylinder or a truncated cone. The point of intersection or the region of closest approach to each other of the longitudinal axes of the caissons theoretically should fall within the cap, but the intersection may be a short distance above the cap, or the cap may extend above said point of intersection or nearest approach so long as the resultant stress in bending produced by application of the force to be resisted a short distance above or below geometrical intersection, is not significant.

Due to the fact that the caissons are each disposed on a batter diverging downwardly, and are bottom anchored and top connected as aforesaid, the tripod foundation unit of the present invention is adapted to resist or support within its design capacity all forces applied to the cap member vertically or horizontally, or combinations of the two. With respect to the application of loads, it will be obvious, considering FIGURE 3, that any horizontal or vertical application of force or load to the cap 26 substantially in line with the point of intersection of the longitudinal axes, can be readily resolved into stresses in compression and tension longitudinally of the bottom anchored tripods without involving bending stresses. Stresses in shear are adequately supported by the cross section of the caisson and present no problem. The ideal situation exists wherein the load is applied in line with the point of intersection of the longitudinal axes of the caissons. In practice, it is generally necessary to join the caissons in the cap below the point of theoretical intersection of the said axes.

In particular, any horizontal force, or any combination of forces having a preponderant horizontal component from any compass direction, would tend to bend either one or two of the caisson supports or tripod legs in the absence of the other or others in such manner as to cause the upper end or ends thereof to rise, and would simultaneously tend to bend either one or two of the remaining supports in such manner as to cause the upper end or ends thereof to fall. Since the supports are each im-

movably anchored at their lower ends, rise or fall of the upper end of one relative to another would have to be the result of bending and elongation or contraction of the respective caissons. By design, each caisson is of a strength in excess of that required to prevent elongation or contraction thereof under maximum calculable load other than for the stress or strain or displacement incidental to an elastic deformation, whereby the possibility of caisson movement due to elongation or contraction is eliminated. This magnitude of the stress, strain or deformation can be controlled by the design of the shafts of the caisson. This design will be in conformity with the requirements of the structure to be supported. Application of a force component to the cap is therefore unable to produce any bending stress upon the caissons. Thus, the analysis is reduced to the possibility of bending, and that possibility is eliminated by the fact that any tendency of one support to rise is directly counteracted by the tendency of at least one support to fall, even if the horizontal load is exerted at right angles to the vertical plane of one caisson, whereby movement of the united upper ends of the support is prevented. Without movement of the top of the supports or caissons, bending cannot occur, and the caissons must be loaded axially thereof in tension or compression. In the case of downwardly exerted vertical load, or in load having a dominant vertically downward component, the tripod unit supports the load primarily by stress in compression in the three legs. In the case of upwardly directed load, as in the installation shown in FIGURES 1 and 2, the net of stresses in the legs of the tripod is essentially in tension to support the load.

From the foregoing, it is apparent that the tripod foundation unit of the present invention will be entirely stable under all loading conditions within its design strength, and constitutes a highly economical and efficient structure. Likewise, it will be appreciated that if one foundation unit is stable for all vertically and horizontally applied forces, and combinations thereof, a plurality of such units will be stable for application of all loads applied to the structure supported thereby, provided in each case that a single tripod unit will sustain a force component from any direction if applied through the cap or point of intersection of the longitudinal axes of the three caissons of the tripod. Any tendency to translate the apex of the tripod laterally must cause shortening in one or two of the caissons and lengthening in the other one or two caissons.

When no dynamic exterior force acts upon the tripod, all three caissons will be occupying a position on the shortest possible line between the apex and its socket. A force applied to the apex from any direction will set up either a compression or a tension in each of the three caissons because the socketed end of the caisson cannot move, and the upper ends of the caissons cannot move relative to each other. A torque applied to the cap or apex of the tripod will tend to produce two stresses in each of the caissons, first, a twisting stress upon each of the caissons because of the tendency to turn the upper end of each caisson relative to the lower fixed end, and, second, a bending stress, due to the tendency of the upper end of each caisson to describe an arc of a circle under the influence of the force couple applied to the cap while the lower end of each caisson remains stationary.

The three static forces delivered by the three caissons are operative only when the dynamic attacking force activates them. If the attacking force ceases to be operative, or lessens from its maximum magnitude an adjustment will take place in the elastic deformation but no other movement will take place in any member of the unit or strong point. If the same attacking force from the original direction again becomes operative, the original stabilizing forces will again come into being automatically.

If an attacking force from a different direction or of a different magnitude to those of the original attacking force, the three stabilizing forces delivered by the three

caissons of the anchored tripod will be automatically re-established but in the correct direction and amounts necessary again to stabilize the supported structure. Three such tripods, when connected to a structure at the corners of a triangle, will support it against forces applied to it in any direction, and in addition, will stabilize the structure against any force couple in a horizontal plane, and against any force couple in a vertical plane.

Referring now to FIGURE 2, I have shown the tripod foundation unit of the invention as utilized for anchoring the end of the main suspension cable 14 of a suspension bridge structure. The end of the cable 14 may be unravelled or have other suitable disposition to facilitate the anchoring of the same by bonding in the concrete of the cap member 26. A short section of cable or an anchor plate with a suitable coupling for connecting to the main length of cable 14 may be utilized instead of carrying the end of the cable directly into the cap 26. The tripod-like arrangement of caissons joined by the cap at the upper end and by the rigid bed rock at the lower end provides a very advantageous arrangement. In effect, it forms an extension of bed rock to a point where the cable may readily be attached. Obviously, the end of the bridge deck 12 may be supported in any desired manner independently of the manner of anchoring the cable 14 on each side of the bridge structure. That is to say, the main vertical load of the bridge frame may be carried by vertical stringers to the cable 14 and the tension in the cable is then carried to bed rock through the foundation of my invention, as illustrated in FIGURES 1, 2 and 3. While only a single tripod unit is shown in FIGURES 1, 2 and 3, it is contemplated that such a tripod unit would be utilized for anchoring each of the main cables 14 at the two sides of the bridge and at both ends of the same. Furthermore, the bridge deck 12 may be supported vertically and stabilized horizontally by one or more tripod units at each end of the bridge. Referring now to FIGURES 4 and 5, I have shown a structure having an improved foundation formed in accordance with the present invention, which structure is stable under all loading conditions within such design strength, and while it is intended to carry vertical load it is particularly adapted to sustain live horizontal loads applied in any compass direction. The foundation construction herein shown consists of three anchored tripod units 10 disposed preferably with the caissons anchored in rock at the corners of equilateral triangles. The three tripod units 10a, 10b and 10c (see FIGURE 5) are disposed at the corners of a triangle, and the caps 26a, 26b and 26c of the tripod units in the finished structure are connected to a common frame or platform 42 which connects them rigidly together. These caps 26a, 26b and 26c are disposed at the corners of a triangle. The platform or frame 42, being connected to the three caps or apices of the three rock socketed caisson tripod units, is stabilized against horizontal forces from any compass direction. Since each tripod unit is capable of resisting horizontal force components substantially equally in all compass directions, the platform 42, which is connected to the caps of each of the supporting tripods is likewise made stable with substantially equal resistance in all compass directions against horizontal force components, by disposing the tripod units 20a, 20b and 20c at the corners of an equilateral triangle. In case of more than three tripod units being employed, they may likewise be disposed in positions which provide equal stabilizing effect for forces from any horizontal direction. Furthermore, the platform frame 42 is stabilized by the connected tripods against force couples applied to said frame 42. Also, since any straight line passing through two of said caps and forming an axis of rotation of the frame 42 must lie outside of at least one of the tripod caps, the said platform is stabilized against a force couple acting on a horizontal axis. Each of the tripod units shown in FIGURES 4 and 5 is similar to the tripod units shown in FIGURES 1 to 3. The three

tripod units 10a, 10b and 10c disposed at the corners of a horizontally disposed triangle stabilize the frame 42 against the force of wind, waves, tides, etc. Obviously, more than three tripod units may be employed to support a frame or series of frames suitably connected to the caps of the tripod units. The structure shown in FIGURES 4 and 5 is intended to provide an offshore island, such as may be employed for drilling an oil well or for supporting radar or other electronic or signalling equipment.

In the structure shown in FIGURES 4, 5 and 6, the preferred arrangement of the caissons 20a, 22a, 24a of tripod 10a, and of the similar caisson members of the units 10b and 10c, is the symmetrical disposition of the individual caissons with respect to a common central vertical axis passing through the cap member 26a, 26b and 26c, as the case may be. They are then arranged on the same predetermined batter, although this feature is optional. That is to say, the arrangement of the individual caissons in a tripod unit may be varied to suit conditions of bottom configuration, depth and clearance for floating vessels which may come alongside. Similarly, the batter of caissons within a tripod may be varied, and different tripods of a group may have variations in symmetry, in batter, and in size and disposition of the individual legs, as may be desired.

The caissons have their lower ends anchored in rock sockets, as above described, and as illustrated additionally in FIGURES 1, 2 and 18. The upper ends of the caissons converge to substantially a common intersection and have said upper ends joined together in a cap with a connection to each other which is able to develop the full strength of the caissons in either tension or compression by stress in shear between them. The caissons are of ample strength to sustain the load in horizontal shear, which results from horizontally acting forces or force components.

This form of structure has remarkable properties, some of which are as follows:

(1) The tripod unit develops resistance to horizontal forces applied to the cap, that is, substantially in line with the point of intersection of the axes of the caissons and tending to overturn the tripod unit, by developing tension and compression in the caissons without bending. The strength of the structure to resist such load in any compass direction is approximately uniform. No vertical extraneous load is required to develop this resistance to overturning.

(2) The height to which the cap is carried above the base anchorage of the lower ends of the caissons does not, within wide limits and theoretically with no limits, affect the strength of the structure for a given batter and a given cross sectional size of axially loaded caisson, to resist such overturning forces.

(3) The height of the unit or the direction of the horizontal force has no effect upon shear stresses, which are the same for all heights and for all compass directions of the design load.

(4) For a given cross sectional size of caisson, the vertical load bearing value and stability of the unit is theoretically independent of the height of the structure, subject only to the slenderness ratio of the columns in compression.

(5) For developing resistance to a horizontal force at any reasonable distance above firm earth strata, and from any compass direction, such, for example, as providing support for an offshore drilling platform for any reasonable depth of water or semi-fluid soil, the aforesaid unit requires a minimum of material and installation cost. No other known structure of equal strength and stability approaches it in economy and ease of construction.

(6) For a given foundation value, after being put into service, it requires a minimum of difficulty for its removal.

The tripod of my invention may be erected on bare rock or through intervening soil overburden or interven-

ing water, and it will nevertheless develop its full load sustaining ability. This is true because the caissons are not subjected to bending but develop the desired load sustaining ability of the tripod as a whole entirely from the longitudinal stressing of the caissons in tension or compression.

The structure shown in FIGURES 4, 5 and 6 is designed particularly for offshore island construction for drilling for oil in locations which are under water or semi-fluid soil, as in the Gulf of Mexico. Similar structures may be employed for supporting light-houses, radomes and the like. By way of example, considerable interest has arisen recently in offshore oil fields in the Gulf of Mexico and in the Pacific Ocean off the California coast. For operating a producing well in these fields, a fixed semi-permanent artificial island is required. The island should, of course, be disposed above peak water level, and must resist all forces applied thereto and support the oil pumping and storing equipment. For such islands, the loading problem is severe, residing primarily in the horizontally applied forces resulting from wind and wave action. The principal load thus is a lateral force exerted at any point 360° around the island, and its intensity may vary from zero during a dead calm to the limits imposed by a hurricane. Foundation designs previously known to the art are not well suited for resistance to such loading. However, my improved foundation structure as shown in FIGURES 4 and 5 is ideally suited for this specific purpose, being stable under all load conditions within its design strength. Thus the invention affords a solution to a specific current problem.

To reach the oil in the off-shore fields, exploratory wells must first be drilled. To carry out the drilling operations, a drilling platform in the nature of a fixed island is required. If the drilling brings in a producing well, a permanent island is necessary, but if a producing well is not brought in, all of the equipment must be removed, at least to the mudline, so as to leave no obstruction to navigation.

With the equipment currently known to the art, feasible drilling platform designs are frequently limited to use in water depth up to about 50 feet and up to about 100 feet as a maximum, and then only in areas where the soil overburden is suitable to carry concentrated loads at a reasonable depth. Many of the rigs available to the art are usable only during periods of relatively calm weather, and are not capable of use as drilling platforms in violent seas, or during the hurricane season in the Gulf of Mexico, or the stormy season in the Pacific. Moreover, in the Pacific, depth will frequently be in excess of that feasible for known designs, and the soil overburden is too shallow, and the rock profile too irregular reasonably to permit of use of conventional apparatus. Currents and wave action also tend to undermine known apparatus, and seriously mitigate against maintaining the drilling platform stationary. If drilling brings in a producing well, then the permanent island for well operation may require to be erected separately of the drilling platform.

To increase appreciably the area of exploration and operation in offshore oil fields, the present invention provides improved foundation means suited for off-shore oil exploration and production. According to the invention, the practical depths of operation are increased to upwards of 300 feet. Soil overburden or lack thereof is not a factor controlling use of the equipment; cost is decreased; stability is increased; and the drilling platform is retained stationary despite the action of the sea. If a well is not brought in, the equipment is readily moved for use at another site, and if a producing well is brought in, part of the equipment used for the exploratory drilling becomes a permanent island foundation structure of FIGURES 4 and 5, and the remainder of the equipment may be removed for use elsewhere.

In bringing the foregoing advantages to a practical fruition, the basic equipment employed by me in its simplest form is the foundation structure shown in FIGURES

4 and 5 embodied in the manner schematically shown in FIGURE 6. As shown in FIGURES 4 to 6, the member 42 comprises a buoyant barge generally of triangular configuration having at each of the three corners thereof three batter slots 44 disposed in star relation. Also, at each corner I provide a slidable tower 46 extending upwardly from the barge deck and carrying guide collar means 48 at the upper end thereof. Each tower structure also includes a locking means 50 adjacent the barge deck for a purpose to be described. Preferably three guide collars and three locking rings are provided at each corner, aligned, respectively, with the outer batter surface of the three slots as shown in FIGURE 6.

As to size, I contemplate that maximum loading conditions and space requirements should result in a design wherein, for purposes of example only, the barge may be approximately 160 feet long, 80 feet wide, and 18 feet deep, having a draft under maximum load of 10 feet. The shells of the caisson may be from about 2½ to about 4 feet or more in diameter, as occasion requires and wall thickness may be of the order of 1 to 1½ inches more or less, depending upon circumstances and the composition of the pipe, the slots 44, guide rings 48 and locking rings 50 being of a size to accommodate and guide the shells. Major deck equipment in addition to the guides 48 and rings 50 may, for example, comprise crane 52 with controlled travel of 80 feet along the major axis of the barge or two derricks, with the necessary boiler, leads, etc., three sets of raising blocks and tackle 54, 1200 tons each, and each operated by a single or double drum hoist 56, the necessary rocker arms and auxiliary gear, and three or more 2,000 or 3,000-pound Danforth anchors with cables to give sufficient rode to hold the barge in approximate position in the maximum wind anticipated during erection.

Prior to the start of the drilling operation, a careful sounding and core boring operation will be carried out to determine rock contours and the nature of the overburden and of bed rock.

To commence operations, the barge 42 is floated on the body of water in which exploratory drilling is to be carried out and the equipment, including the caisson components, is loaded on the barge. The barge is then towed to the drilling site. Upon nearing the well location, one of the caisson shells 28, each perhaps 160 feet long, will have been threaded by means of the crane 52 through the guide collar 48, locking rings 50 and batter slots 44, the shells in their initial position dependent upon the depth of the water, extending 30 or 40 feet below the bottom of the barge, as shown in FIGURE 6, and being guided by the collars 48 above the deck. The degree of batter, about 1 to 8, is calculated for the maximum initial thrust of wind and wave action, and for the maximum final lateral load under the worst possible conditions, the batter, anchorage and thickness being selected accordingly. Each shell passes through a locking ring 50 at deck level so that it may be restrained from descending under its own weight. When the time comes to lower a shell, it will be raised slightly by the derrick or crane to free the locking ring wedges, then lowered to the required position. At its lower end, each of the nine shells carries a tool steel tempered cutting or drive ring 30, and at its upper end an internal or external splice ring 38.

When the barge reaches the drilling site, three or more anchors are placed to retain the barge in position, assuming water depth at the drilling site to be 200 feet at mean high tide and the overburden to comprise 15 feet of silt and sand overlying medium hard bed rock having an irregular surface, the foundation is set as follows: The first section of the shell of each caisson is lowered by the crane 52 after release of the lock 50 in the manner described, and a team of two or three welders to each three caisson group welds the second sections to the lower sections. The locking rings are again released, and all pipes

lowered until they contact the rock. Each of the nine caisson pipes is driven to refusal on or in the rock, using the heavy duty hammer. Thereafter a removable head cap 26 is mounted and firmly clamped on each of the tripod casing groups or foundation units. This cap is designed to be releasable, but it is firmly and fixedly attached to the adjacent convergent ends of the caisson shells to hold them rigidly together to prevent movement of one caisson end relative to that of another under load.

A caisson shell may be set, its socket drilled and its core and filling of cement introduced before the other caissons of a tripod unit are placed. Alternatively, some or all the caisson shells of a tripod unit may be set and the sockets drilled out before they are filled. The cap is affixed to the upper ends of the caissons in a tripod unit after those caissons are individually driven or held in place at their lower ends. This cap serves to unite the upper ends against relative endwise movement by any applied load. That is to say, the individual caissons for a tripod unit are to be individually placed, since they cannot successfully be driven at the same time, and after they are fixed or anchored at their lower ends, the cap is applied to their convergent upper ends.

In the above situation, wherein bed rock is not particularly far below the surface of the water and soil overburden is shallow, the caisson shells are driven to bed rock and socketed as described. However, if bed rock were considerably deeper and firm soil overburden were of substantial depth, concrete pedestals could be driven out in the overburden as previously described to produce an artificial stratum of firm material. In such case, the caissons would be driven to a firm seat in the pedestals, preferably to refusal after the concrete had set, the bottom locking devices installed so that the caisson pipes could be released for the purpose and under the circumstances to be described hereinafter.

After the caisson shells have been driven to refusal, spiders or sway bracings 58 are installed on each tripod unit, the spiders being mounted on and serving to stiffen or hold against lateral deflection the caissons of each unit intermediate bed rock and the platform 42. The purpose of this sway bracing is to avoid, so far as possible, the lateral bowing of the relatively long and slender caisson shells which are required to act as slender columns under compression. The sway bracing 58 is not intended to be and does not serve as a part of the load carrying structure. Each spider 58 may suitably comprise three collars 60 slidably mounted on the caisson shells and three horizontal ties 62, for example, 12-inch diameter pipes, extending between and detachably connected to the collars. Due to the downwardly divergent relationship of the caisson, the spider, by its own weight, will tend to slide down into locking engagement on the caisson shells.

Dependent upon expected weather and/or sea conditions during exploratory drilling, the caisson shells of each of the tripod units may be bonded to their anchoring strata, i.e., bed rock, or a suitable artificial pedestal in any one of several manners. For temporary bonding, each caisson to its anchoring stratum, the simplest procedure is to deposit concrete within the rock socket at the lower end of each caisson shell, said filling extending a short distance into the shell, as indicated by the concrete plug 64 in the caissons of the unit 10b at the right side of FIGURE 4. It is to be understood that a socket 66 is drilled prior to setting the concrete plug 64, and a short axial reinforcing stub 68 of a length to extend upwardly from the socket a short distance into the pipe is employed, as shown at the left side of FIGURE 4.

When the caisson shells of the various foundation units shown in FIGURES 4 and 5 have been engaged on or set in rigid anchorage, that is, bed rock or an artificial pedestal, in any of the manners above described and the sway bracings have been installed, the guard collars 48 and locking rings 50 may be removed from the caisson shells. The caps 26a, 26b and 26c are then fastened onto the ad-

jacent convergent ends of the associated caissons to complete the tripod foundation units. The lifting tackle sets 54 are then attached to the caps 26 and the hoists 56 are operated to raise the barge 42 on the upper ends of the caissons. Lifting is simultaneously carried out at the three locations to insure uniform raising of the barge, and also to accommodate such trimming of the barge as may be necessary. The barge is raised on the tripod units to the required height in relation to peak water level, whereupon it is anchored to the caps 26 for a rigid connection as by the horizontally acting braces 126 shown in FIGURES 4 and 5, whereupon the barge comprises a stationary drilling platform, the slots 44 in the barge being of a length and configuration to accommodate such raising of the barge as is clearly shown in FIGURE 4.

The barge 42 is preferably raised to approximately the plane of the caps 26a, 26b and 26c and firmly braced against them for transferring horizontal forces from the barge 42 to them. At all events, the connection of the barge 42 is to the caps for resisting major horizontal forces, and any connection of the barge to the upper ends of the caissons should be such as to minimize any bending stresses upon the caissons to a point where it does not weaken the load carrying ability of the units. This means that the attachment of the barge to the caps for transferring horizontal load should for maximum effectiveness be as nearly as possible in horizontal alignment with the theoretical point of intersection of the longitudinal axes of the three legs or shafts of the tripod.

With the caisson shells set, the sway bracing spiders in place, the barge elevated and connected to the caps 26, a highly stable stationary drilling platform is afforded, and exploratory drilling for oil or gas may be commenced at once.

If exploratory drilling is non-productive, and the site is to be abandoned, the drilling equipment is retracted to the barge or platform 42; the barge is lowered on the caissons to a floating position on the body of water, and the guides 48 and locking rings 50 are again disposed about the caissons on the towers 46. The caps 26 are removed, as by cutting torches, and the caissons opened at their upper ends. If the caisson shells were anchored by means of concrete plugs 64, the plugs are drilled out. If stub cores were employed, the same are removed if convenient, after drilling out the plugs 64. Alternatively, the lower ends of the caissons may be cut by explosives or burning as by Thermite. In any event, the caissons are released from their bottom anchorage. The spiders 58 are then removed by lifting each spider by means of a crane 52 to slack off the connections of the ties 62, whereupon the ties may each be detached from one collar, and the three collars and ties raised to the barge. The crane 52 and locking ring 50 are thereafter employed to retract the caissons from bed rock to substantially the position shown in FIGURE 6. As the upper shell section of each caisson is raised above the respective tower 46, it may be removed from the lower section, thus to restore the apparatus substantially to its original condition, whereupon the anchors may be weighed and the barge towed to a new drilling location.

As a means for facilitating removal of the stub cores 68, if the structure is to be removed down to a bare rock bottom, the casing or steel tube in each leg may be driven down farther into the socket cut into the rock by a distance substantially equal to the desired length of the cemented bond between the core 68 and the inside wall of the corresponding steel caisson tube. The lower end of the stub core 68 extends to the bottom of the rock socket which is made deep enough below the cutting shoe 30 (FIGURE 4a) to provide the desired length of bond between said lower end of the stub core and the walls of the rock socket. In any case, the top of the stub core may be disposed at the level to which obstruction must be reduced in case of removal of the structure. This may

be the rock line or if permitted, it may be the level of the overburden.

I have found it desirable to make the rock socket, into which the desired length of main reinforcement or the stub core extends, of ample depth, such, for example, as 15 feet to 20 feet or even more on caisson shells of 30 inches to 48 inches or larger diameter, even though the design strength of bond would be developed in less depth of socket. Also, it is desirable for assuring holding ability in tension, to taper all or a part of the socket downwardly and outwardly. Alternatively, where feasible, a circumferentially extending groove may be cut in the sidewall of the socket.

In those instances where contemplated use of the foundation of the invention is as a temporary or semi-permanent island or foundation construction, the caisson shells or pipes are designed to carry the calculated load without necessity for the extra stiffening and bearing value that would be afforded by use of a completely concrete fill and a full length core in a permanent installation. By virtue of this design, the caisson shells, even when rigidly anchored at their bottoms are hollow throughout substantially the full length thereof. This affords the distinct advantage, as will be pointed out hereinafter, of facilitating complete removal of any possible obstructions, and of accommodating recovery to the greatest extent possible of reusable foundation even in those cases where the contemplated temporary nature of the structure proves to be erroneous.

The use of the construction thus far described and its removal or conversion to a permanent installation is the subject of my pending application, Ser. No. 732,609, filed May 2, 1958, now Patent 3,115,013.

For either permanent or temporary anchorage, an anchoring device of the character disclosed in FIGURE 7 may be employed. In the diagrammatic showing of FIGURE 7, the anchoring device indicated at 70 is shown as being bonded in a concrete pedestal or artificial rock. It is to be appreciated, however, that the anchoring device may be installed with equal facility in natural bed rock. As shown, the device comprises one or more annular bearing plates 72 supported on the interior of the caisson shell adjacent the lower end thereof by brackets 74 welded to the wall of the shell. The central opening in the bearing plates may, for example, be about 20 inches in diameter to accommodate passage therethrough of a drill after the shell has been driven to refusal on bed rock or a pedestal, that is, either a natural or an artificial stratum of firm material. The drill is operated in the manner previously described to produce a socket 76 below the cutting shoe 30 of the shell, which socket may, by way of example, extend approximately 6 feet below the shoe. When the socket is completed, the drill is removed, and grout, indicated at 78, is placed in the socket to a depth of 5 feet or more in the example given. Before the grout sets, an anchor member 80 is set axially in the socket 76 and embedded in the grout therein, the members suitably comprising a piece of shafting of the necessary diameter to take the calculated tension load, and a heavy base plate of approximately the maximum diameter that can be accommodated in the socket. At its upper end, the shaft of the member 80 is threaded for the reception of a sleeve coupling 82. The member 80 and coupling 82 are preferably assembled and lowered as a unit into the grout, and are located in the socket with the upper portion of the coupling protruding above the surface of the grout. When the grout is set, the members 80 and 82 are rigidly bonded in bed rock or in a pedestal effectively to constitute a unitary part thereof, and to provide a "handle" on bed rock or the pedestal for attachment thereto of the caisson shell. In the embodiment disclosed, attachment of the caisson shell is effected by means of a second or top anchoring member 84, comprising a piece of shafting of the same diameter as the bottom member 80, and a bearing flange 86 of a diameter greater than

the inner diameter of the bearing plates 72, the flange 86 being welded to the shaft adjacent, but in spaced relation to the upper end thereof. The shaft of the top member 84 is threaded at its lower end for attachment to the couple sleeve 82, and is squared or fashioned into a polygonal form to accommodate a wrench by means of which the top member may be threaded into the sleeve to force the flange 86 into secure engagement with the upper bearing plate 72, whereupon the caisson shell is bottom anchored to accommodate tension loading thereof. Points or areas of moving contact in the anchoring device are preferably graphite packed, and ungrouted section of the socket and the 3 to 4 feet of the shell may be filled with mastic or grease to prevent rusting.

The anchorage shown in FIGURE 7 may be released by a wrench applied to the top shaft section 84 for unthreading its connection with the coupling 82. Thereupon, the tension connection of the caisson shell 28 with the rock socket 76 is released, and the caisson may be removed. Alternatively, the caisson shell 28 may be cut off by burning or blasting as above described.

Such use of the basic bottom anchored caisson tripod unit or units in holding a supporting frame, such as a platform frame 42, against horizontal forces, horizontal force couples, and vertical force couples, illustrates the unique utility of the bottom anchored tripod unit and its application to stabilization of load bearing structures, subject to forces from different directions and of different magnitudes, and specifically large force components in a horizontal plane from various compass directions and of fluctuating magnitude.

Referring now to FIGURES 8 and 9, there is indicated diagrammatically a massive multi-story building 100 having a suitable steel frame. Alternatively, the frame may be of reinforced concrete. This building has a basement or sub-grade space 102. The frame of the building rests upon a suitable multiplicity of driven piles 103 that extend through the soil or overburden 104 to rock 105 against the face of which they are driven. Where such piles are all driven vertically to the face of the rock, they afford surprisingly little lateral stability, the sole resistance to lateral movement being the friction of the piles relative to the soil in which they are disposed. This is quite independent of the weight of the building resting upon them.

Heretofore, it has been not unusual, and particularly in the case of wooden piles, for the piles to be driven not strictly vertical, but to deviate considerably and at random from the vertical, with the consequence that there is an indiscriminate batter effect among them providing a certain degree of resistance to horizontal movement. As the shape of the piles approaches more nearly the perfect cylinder as will be the case with concrete or steel cased piles, and as they are more carefully guided and driven, they tend to be all vertical and parallel, with the result that little lateral stability is provided for a structure resting upon such piles when axially loaded.

The wind pressure indicated by the arrow on FIGURE 8, while it has a displacing or horizontal shear effect, is chiefly to be regarded as an overturning force, tending, in the case illustrated in FIGURE 8, to swing the building 100 counter clockwise around the lower left hand corner of the structure. The weight of the building is designed to be great enough to resist overturning forces from the wind. In addition to wind and water, which may strike the side of a structure or building, and tend to displace the same horizontally, there are other forces which have the effect of pushing the building sidewise. For example, in the case of an open excavation 106, there is a tendency for the soil or overburden under the building 100 to flow laterally towards the excavation, and to carry the piles or caissons 103 with it.

Also, there may be the driving of piles in the space adjacent the building, as indicated by the piles 107, which tend to force the earth sidewise by so called

"heave." This heaving of the soil may have the tendency of displacing the adjacent soil under the building laterally to the left in FIGURES 8 and 9, and thereby produce lateral displacement of the said building.

There are times when the soil adjacent a structure is heavily loaded, as by a heap or pile of coal, sand, ore or other material, such heap being illustrated in FIGURE 9 by the coal pile 108. Or a structure adjacent building 100 may be resting on a mat or shallow foundation.

Furthermore, there may be heaving of the soil due to natural disturbances, such as earthquakes and the like. Soils may become impregnated with water and become more fluid, and be subject to the pressure of land slides and the like. All these indicate phenomena which may impose horizontal force components upon a building or its foundation. Heretofore, there has been no satisfactory method or structure for resisting such forces beyond the most primitive expedients, such as driving piles to support diagonal braces or timbers. Such expedients are unsatisfactory, and the art has long needed means for stabilizing structures against horizontal forces or force components.

FIGURE 10 shows diagrammatically in dotted line outline a rectangular building frame 109 supported vertically on a series of piles or caissons which provide adequate vertical support for the load of a building which may be erected on the frame or platform 109. Such frame 109 and superposed building is stabilized vertically by the piles 110, but it is not stabilized against horizontal movement in any compass direction, as in the plane of the paper of FIGURE 10, or against a force couple in said plane which would tend to swing the building or frame 109 on a vertical axis. To anchor such a building or frame 109 against horizontal movement of translation or of rotation, I provide the two rock socketed caisson tripod units 112 and 113 having their caps 114 and 115 disposed substantially in the plane of the frame 109 and anchored directly or indirectly to the said frame 109 to stabilize the frame 109 and its building against forces or force couples in the horizontal plane of the frame 109. The said rock socketed caisson tripod units 112 and 113 have their caps rigidly connected to the said frame 109 for the horizontal application of load thereto. It is not essential that these tripod units be loaded vertically, since the vertical load may be carried readily by the vertical piles or caissons 110. However, if desired, a part of the load may be carried on said tripod units 112 and 113.

In FIGURE 11, I have shown in dotted line outline, a similar frame or building 116 in which both functions of vertical support and horizontal stabilization are performed by the rock socketed caisson tripod units 117, in this case six in number, disposed symmetrically for substantially even weight distribution with respect to the frame or building 116. The caps 118 of the tripod units 117 lie in substantially the horizontal plane of the frame or lower part of the building 116 and are rigidly connected to the frame or building 116, whereby both vertical load and horizontal forces and force couples, as well as force couples tending to overturn the frame or building 116 in any vertical plane, are adequately met.

It will be observed that in the structures of both FIGURES 10 and 11 one or more of the rock socketed caisson tripod units may serve in tension to overcome overturning forces which may be applied to the supported structure 109 or 116. Said frames or building structures 109 and 116 are typical of any rigid construction, whether it be merely a horizontal supporting frame or a part of a larger construction, such as a building having a horizontal frame connected by columns vertically to an upward extension.

It will be seen from the above that the rock socketed caisson tripod unit having the unique ability to sustain forces applied to its cap from any direction whatsoever is peculiarly adapted to stabilize load carrying frames, buildings and the like against horizontal displacement,

either by forces of translation or force couples in a horizontal plane, or in fact in any plane.

Additionally, the tripod unit is capable of carrying a vertical load, and where the caissons are capable of sustaining greater longitudinally downward force (compression) then upward force (tension), the addition of vertical downward (gravity) load is helpful in meeting the overturning force on a building or like structure supported on one or more of such tripod units.

In FIGURES 12 to 19, there is illustrated the application of my invention to the horizontal stabilization of a blast furnace foundation. A modern blast furnace is a heavy structure, which according to present practice, puts about 10,000 tons weight upon its foundation slab. The foundation slab 119, shown in FIGURE 12, was approximately 60 feet in diameter, and about 11 feet thick. The outer periphery of the foundation slab carries a generally circular rim 120 upon which the supporting columns for the superstructure of the blast furnace are mounted. The foundation slab 119 was supported on vertical piles 161 driven to refusal on top of bed rock or boulders 162, with the tops of the piles about 10 feet below yard level. In the embodiment shown, this furnace foundation slab 119 exhibited lateral instability on its foundation, and it became necessary to apply means for lateral stabilization. The means for lateral stabilization comprises two rock socketed caisson tripod units 122 and 123, spaced about 107 to 109 feet, respectively, away from the center of the foundation slab and about 140 feet apart. The structure of the rock socketed caisson tripod units here employed is shown in detail in FIGURES 15 to 18, inclusive. To the caps 124 and 125 of the two tripod units, skeleton arms 126 and 127 of open triangular shape were connected between the caps 124 and 125 and the encircling reinforced concrete ring 128 embracing the periphery of the foundation slab 119. The embracing ring 128, as well as the arms 126, 127, were formed of heavily reinforced concrete with longitudinally extending bars therein. Due to the somewhat keyhole shaped contour of the foundation slab 119, the embracing ring 128 was securely keyed to the foundation slab, so that the two arms 126 and 127 operate substantially as torque arms in addition to their function of serving also as radius arms. The embracing ring 128 is shown in cross section in FIGURE 13, and is consists of a body of concrete 129 of rectangular cross section in which are longitudinally threaded reinforcing bars 130 embraced circumferentially by further reinforcing bars 132.

The sides of the arms 126 and 127 are formed of reinforced concrete substantially in the same cross sectional pattern as the embracing ring 128. The triangular torque arm 126 has the two side members 133 and 134 at their inner ends merging with the embracing ring 128 and at their outer ends merging into the cap 124, as is more clearly shown in FIGURE 14. The two arms 133 and 134 are connected to each other intermediate the length of the arm by the cross brace 135. This cross brace is similarly formed of reinforced concrete with the reinforcing bars threaded inbetween the longitudinally extending bars in the side members 133 and 134 of the arm 126. The arm 127 is similarly formed of side members 136 and 137, joined by the cross connection 138, similar to the cross connection 135. The arm members and their cross connections were supported by suitable vertical supporting members or bridges 139 under the side bars 134, 133, 136 and 137 of the arms 126 and 127. These side members 133 and 134 of the arm 126 are capable of sustaining tension or compression, depending upon the force acting upon the said furnace foundation slab 119. The construction of the caps and their connection to the side members of the arms 126, 127 is illustrated in detail FIGURES 14 to 17, inclusive. The caps 124 and 125 are alike in structure and function. The arms 126 and 127 are joined to the rock socketed caisson tripod unit tops. As shown in FIGURE 14, the side

member 134 contains longitudinally extending reinforcing bars 130 which extend into the region of the apex of the caissons of each of the tripod units. These longitudinal reinforcing bars 130 extend into the interior of the cylindrical shell 140 which is a steel cylinder about 14 feet in diameter, one-half inch wall thickness, and approximately 9 or 10 feet high. The said bars 130 are interlaced with circumferentially extending reinforcing bars 142, and a series of vertically disposed bars 143 arranged in a concentric circumferential pattern about the upper ends of the converging caisson cores. The cap is filled with concrete, which completely embeds the reinforcing bars, including the circumferential bars 142, the vertical bars 143, and the interthreaded ends of the horizontal reinforcing bars 130, which extend out into the arm portions 134 and 133, as shown in FIGURE 14. The vertically extending bars 143 have their upper and lower ends 144 and 145 turned horizontally and extending towards the center of the cylindrical cap.

The final pouring of concrete to join the various parts of the stabilizing means was performed while the blast furnace foundation slab 119 was moving sidewise at a maximum rate of about $\frac{3}{16}$ inch in 48 hours. The setting of the concrete halted the movement without deterioration of the concrete and stabilized the foundation plate 119 and its connected parts against any movement in the horizontal plane. The two arms 126 and 127 acted both as radius arms and as torque arms, consequently permitting no movement of the foundation member 119 by virtue of the horizontal load supporting ability of the tripods 122 and 123.

The construction of the individual tripod units is illustrated in FIGURES 15 to 18, inclusive. Each individual caisson, as illustrated in FIGURE 18, comprises a central H-beam 146, reinforced with welded plates 147, 147, to both outer flat sides of the head portions 148. These plates 147 were welded along their edges to the heads of the H-beam, and were arranged to overlap the junction between sections of H-beam employed in producing the full length of the caisson reinforcement. The caisson shell consisted of a 30-inch diameter steel tube of a wall thickness of approximately .438 inch, and sections of such shell were joined endwise by external joining sleeves 150 about 12 inches long and about one-half inch thick. The lower end of the shell 149 had the driving shoe 152 welded thereto, this driving shoe having a cutting edge which had a bevel on the inside edge, and for the purpose of the installation shown in FIGURE 12, was driven into sealing engagement with the rock, and the rock socket was cut down into the solid rock for a distance of approximately 19 feet deep from the surface of the rock, and about 15 feet below the cutting edge of the shoe of the caisson shell. The caisson was disposed on a batter of approximately 1 horizontal to 6 vertical, and the three caissons of each tripod unit were disposed in symmetrical relation around a vertical axis passing through the meeting point of the longitudinal axes extended. The rock socket 153 was approximately 33 inches in diameter and was filled with grout 155 to fill the space between the core 146 and the walls of the rock socket 153, as well as to fill the space between the said core and the inside of the shell 149.

The lower end of the core rested upon the bottom of the rock socket, and it was spaced by means of pivoted spacers 154 secured to the flanges of the H-beam.

The length of the core was of the order of 90 feet. The shell terminated short of the top of the core. The upper ends of the caisson shells 149 are tied together by angle bars welded at their ends to the adjacent shells. The cores 146 are joined by groups of gusset plates 158, 159. The gusset plates 158 are welded to the edges of the flanges nearest to each other, as illustrated in FIGURE 16, while the gusset plates 159 are welded to the adjacent edges of the outer flanges of the H-beams 148.

Thus the upper ends of the cores 146 are rigidly and

permanently joined together immediately below the intersection of the extended longitudinal axes of the caissons. However, the location of the cap and the connection of the radius arms 126 and 127 is as close as is feasible for the application of the load to the theoretical point of intersection. In other words, the point of intersection in this case does not lie within the cap, but slightly above the same. Substantially the full strength of the caissons is available for useful load, since the bending stress imposed upon the upper ends of the caissons is readily sustained by the cap and the other connections between the upper ends of said caissons and the caissons themselves.

It is not essential within this embodiment of my invention that the connections, such as the arms 126 and 127 between the foundation and the stabilizing tripod units be integral with the tripod unit caps 124 and 125 and with the band or ring 128. It is essential that the arms 126 and 127 be so attached to the band or ring 128 that torque may be applied by a force component acting at right angles to the longitudinal axes of each of said arms 126 and 127, and that a pull or a thrust may be exerted longitudinally of the same. The arms 126 and 127 may, instead of open frames, be of suitable I or channel shape or other suitable section. The arms 126 and 127 may be pinned or otherwise connected at their inner ends to the ring or band 128 or to any similar frame. The outer ends of the arms 126 and 127 may be pinned or pivoted, or otherwise suitably connected to the caps 124 of the tripods 122, 123. The requirements are that the stabilized frame or base, such as 119, be held against any angular or rotary motion which would involve a swinging, a pulling, or a pushing force, or a combination of the same, upon the arms 126 and 127, and against any motion of translation which would likewise involve a swinging, a pulling, or a pushing force, or a combination of the same, upon the said arms 126 and 127. This means that the caps 124 and 125 may be stressed by forces acting in a horizontal plane from any compass direction, and the tripod units will hold the frame or base 119, or any like structure requiring lateral stabilization, against movement in said plane.

As a consequence, the tripod units 122 and 123 which are constructed of rock socketed caissons, as illustrated in FIGURES 15, 16, 17 and 18, sustain all force components in the horizontal plane, that is, either forces of displacement or force couples acting upon the stabilized structure, namely, the foundation member 119 of the blast furnace.

The rock socketed tripod of the present invention has a unique value for lateral stabilization of structures. When a building or other heavy structure is supported upon a foundation which provides vertical support, an even distribution of the load among a series of supporting piles would appear to assure permanence and stability, but as shown in the instance of the blast furnace base described in connection with FIGURES 12 to 18, and see also the explanation in connection with the building structure of FIGURES 8 and 9 that consequence does not necessarily follow. So long as the piles are vertical, and take the entire load of the structure axially in a vertical direction with no side thrust or disturbing lateral forces acting, the structure retains its fixed position. However, upon a deviation from the vertical of the axial vertical loading of the supporting means, such as supporting piles, the structure starts to become unstable, and this instability increases with deviation of the piles from the vertical. This increase in instability through increase in lateral deflection of the top of the supporting piles of the structure comes about through the changing angle of the supporting piles with respect to the vertically acting load. The downward pressure of the load no longer falls in the axial line of the supporting pile or piles, and it produces a torque couple which tends to shift the top of the pile and the supporting struc-

ture sidewise and downward. If not checked or prevented, such lateral displacement of the top of the piles will result in collapse of the structure. The rigidity and high stability force evoked upon small horizontal displacement of the cap does not allow the protected structure to shift sidewise, and hence, instability is prevented or held to a minimum.

The rock socketed caisson tripod is not stressed in bending by horizontal forces applied to the cap. It reacts against a lateral, that is, horizontal load upon its cap by transforming the horizontal stress into axial tension upon the near caisson or caissons of the tripod and axial compression upon the remote caisson or caissons. Since the caissons are thus stressed in the direction in which they are of maximum strength, and since the stress is distributed uniformly throughout the cross section, the resulting lateral displacement or deflection of the cap by a horizontal force applied thereto will be very small as compared to what would be the deflection of the same three caissons if they should be connected together in parallel and stressed in bending by horizontal force applied to their tops.

In brief, the rock socketed tripod, since it depends for its anchorage solely upon the bonding of the caisson cores in rigid rock sockets, is able to provide the necessary large horizontal resistance in any compass direction, and at any height (within reasonable limits as herein explained) with surprisingly small lateral deflection. The prior art has failed to provide such a structure, or to realize that such a structure and mode of operation is possible.

In the description and claims the earth stratum in which the so-called rock sockets are formed may be either natural rock or artificial rock such as may be produced by the deposit of a large volume of cement or concrete set in rigid condition. The concept is to perform two functions, namely, to connect the lower ends of the caissons strongly and rigidly together and also to support them fixedly in position so that within the strength of the caissons, the caissons are fixed and cannot be moved.

I do not intend to be limited to the precise details shown and described, but intend to cover such modifications and equivalents as fall within the appended claims.

I claim:

1. In combination a horizontally extending rigid frame adapted to be disposed over a layer of rock, means providing vertical support to said frame and means providing horizontal stabilization for said frame, said last named means comprising a tripod unit having a cap disposed substantially in the plane of said frame, a rigid horizontal connection between said cap and said frame for the transmission of stresses from said frame to said cap, said tripod unit comprising three downwardly divergent metal shell caissons, the longitudinal axis of each caisson diverging downwardly from each of the longitudinal axes of the other two caissons of the tripod unit, said caissons of each unit extending between said cap and said layer of rock and having steel cores the lower ends of which extend into sockets cut into said rock in axial line with the caissons, said lower ends of the cores being bonded to the side walls of said rock sockets to sustain tension or compression developed in the caissons in the direction of their longitudinal axes respectively by a horizontally acting force applied to the cap, the upper ends of said caissons being rigidly bonded together in and by said cap whereby said tripod unit resists lateral displacement of said frame in said horizontal plane by tension and compression forces acting longitudinally of the caissons without bending stresses being imposed upon said caissons, the longitudinal axes of said caissons defining three edges of a tetrahedron whose base is the top surface of said layer of rock.

2. In combination a rigid frame extending in substan-

tially a horizontal plane, means for supporting said frame vertically, and horizontally acting stabilizing means for resisting motion of said frame in said horizontal plane comprising a minimum of two tripod units having caps disposed substantially in the plane of said frame, a rigid horizontal connection between said cap and said frame for the transmission of stresses from said frame to said cap, each tripod unit comprising three downwardly divergent rock socketed metal shell caissons the longitudinal axis of each caisson diverging downwardly from each of the longitudinal axes of the other two caissons of the tripod unit, said caissons of each unit having steel cores projecting into sockets cut into rock and bonded to the side walls of said rock sockets to sustain tension or compression developed in the caissons in the direction of their longitudinal axes by lateral forces applied to the caps of said tripods, the upper ends of the caissons of each tripod being bonded together in and to the corresponding cap whereby said tripod units resist motion of said frame in said plane by tension and compression forces longitudinally of the caissons and without bending stresses being imposed upon said caissons, said caisson units being spaced apart horizontally to provide effective resistance to angular motion of said frame in its horizontal plane, the longitudinal axes of said caissons defining three adjacent edges of a tetrahedron whose base is the surface of the rock into which said sockets are cut.

3. In combination, a substantially rigid frame member extending in substantially a horizontal plane, vertically extending supporting means for supporting said frame member vertically, and horizontally acting stabilizing means for resisting motion of said frame member in said horizontal plane comprising two rock socketed tripod units spaced laterally from said frame member and having caps disposed substantially in the plane of said frame member, horizontally extending torque arms connecting said caps with said frame member, each tripod unit comprising three downwardly divergent rock socketed metal shell caissons the longitudinal axis of each caisson diverging downwardly from each of the longitudinal axes of the other two caissons of the tripod unit, said caissons of each unit having steel cores projecting into sockets cut into rock and bonded to the side walls of said rock sockets to sustain tension or compression developed in the caissons in the direction of their longitudinal axes by lateral forces acting upon the caps of said tripods, the upper convergent ends of said caissons of each tripod being bonded together in and to the corresponding cap whereby said tripod units resist motion of said frame laterally and angularly in said plane by tension and compression forces acting longitudinally of said caissons, said caissons being unstressed in bending, the longitudinal axes of said caissons defining three adjacent edges of a tetrahedron whose base is the surface of the rock into which said sockets are cut.

4. In combination with a load supporting frame, foundation members disposed under said frame to support said frame vertically, and horizontally stabilizing means for said frame comprising a rock socketed caisson tripod unit, said unit consisting of three straight cylindrical metal shell caissons with the longitudinal axes of each caisson diverging downwardly from each of the longitudinal axes of the other two caissons of the tripod unit, said longitudinal axes converging at the upper ends of the caissons to substantially a common intersection, a cap uniting the upper ends of the caissons at the region of substantial intersection of the axes and bonding them rigidly together, the lower ends of each of said metal shell caissons initially positioned free of the other caissons and extending endwise into engagement with a rigid earth stratum, there being cylindrical sockets formed in said stratum below and axially in line with the cylindrical shell caissons, metal cores anchored to and extending from inside the shell caissons into the sockets and

being bonded by cement to the walls of the sockets to anchor the shell caissons rigidly to said rigid earth stratum for both tension and compression stresses in the shell caissons longitudinally thereof, a rigid horizontal connection between said cap of the tripod unit and said load supporting frame for transmitting horizontally acting forces from said frame to said cap, said horizontal forces being transformed into longitudinally acting forces of tension and compression in said caissons without subjecting the caissons to bending stresses, said caissons being rigidly joined together at their upper convergent ends in said cap subsequent to being rigidly joined together at their lower divergent ends through said rigid earth stratum, the longitudinal axes of said caissons defining three edges of a tetrahedron whose base is the top surface of said rigid earth stratum.

5. As a foundation unit having a high degree of stability against horizontal forces applied to its upper end, a rock socketed caisson tripod unit, said unit consisting of three straight cylindrical metal shell caissons, with the longitudinal axis of each caisson diverging downwardly from each of the longitudinal axes of the other two caissons of the tripod unit, said longitudinal axes at the upper ends of the caissons converging to substantially a common intersection, a cap member joined to and rigidly uniting the upper ends of the caissons at the region of said substantially common intersection of the axes, the lower end of each of said cylindrical metal caissons initially positioned free of the other caissons and extending endwise into engagement with a rigid earth stratum, there being cylindrical sockets formed in said rigid stratum below and axially in line with the shell caissons, metal cores extending from inside the lower ends of the shell caissons into the sockets and being connected to the inside walls of the shell caissons and the walls of the sockets to anchor the shell caissons rigidly to said rigid earth stratum for both tension and compression stresses longitudinally of the shell caissons, said caissons being rigidly joined together at their upper convergent ends in said cap subsequent being rigidly joined together and held immovable at their lower divergent ends through said rigid earth stratum, said tripod unit resisting horizontal forces applied to its cap from any compass direction by developing stresses of tension and compression longitudinally of said caissons independently of any lateral support by overburden at the sides of said caissons and free of any bending stresses upon said caissons, the longitudinal axes of said caissons defining three edges of a tetrahedron whose base is the top surface of said rigid earth stratum.

6. The foundation unit of claim 5 wherein the three cylindrical caissons of the tripod unit are disposed symmetrically about a vertical axis with their axes at a batter of from 1 horizontal to 6 vertical to 1 horizontal to 8 vertical, whereby horizontal force applied to said cap from any compass direction stresses the caissons longitudinally in tension and compression and subjects the junction between the upper ends of the caissons to shear stresses substantially without bending stresses upon the caissons.

7. As a marine stabilizing unit extending from the bottom of a body of water to a point above the surface of the same for resisting horizontal forces caused by wind and wave action from various compass directions, a rock socketed caisson tripod unit, said unit consisting of three straight cylindrical metal shell caissons with the longitudinal axis of each caisson diverging downwardly from each of the longitudinal axes of the other two caissons of the tripod unit, said longitudinal axes at the upper ends of the caissons converging to substantially a common intersection, a cap member bonded to and rigidly uniting the upper ends of said caissons at the region of said substantially common intersection of the axes, the lower end of each of said cylindrical metal

caissons initially positioned free of the other caissons and extending endwise into engagement with a rigid earth stratum below said body of water, there being cylindrical sockets formed in said rigid earth stratum axially in alignment with said lower ends of the caissons, cores disposed partly inside the lower ends of the caissons and partly in said sockets, means connecting the cores to the inside walls of the sockets and of the caissons for rigidly connecting the lower ends of the caissons to the rigid earth stratum for tension forces and for compression forces longitudinally of the caissons, said tripod unit resisting horizontal forces applied to the cap from any compass direction, by developing stresses of tension and compression longitudinally of said caissons independently of any lateral support by overburden at the sides of said caissons and free of any bending stresses upon said caissons, the longitudinal axes of said caissons defining three edges of a tetrahedron whose base is the top surface of said rigid earth stratum.

References Cited by the Examiner

UNITED STATES PATENTS

908,783	1/1909	Lawrence et al.	61—49
981,822	1/1911	Upson	61—49

5

10

15

20

1,365,197	1/1921	Scott	61—46
1,410,217	3/1922	Noetzli	61—52.1
1,445,938	2/1923	Farrington	50—465
1,609,260	11/1926	Malone	61—53.6 X
1,822,550	9/1931	Thornley	61—50
2,009,461	7/1935	Wichert	61—52
2,168,459	8/1939	Upson	61—53
2,317,017	4/1943	Allen	61—52
2,377,055	5/1945	Thornley	61—50 X
2,597,110	8/1949	Lacy	61—46.5
2,608,830	9/1952	Burrell	61—52
2,653,451	9/1953	McCullough	61—46
2,775,095	12/1956	Harris	61—46

FOREIGN PATENTS

285,484	6/1915	Germany.
2,929	1855	Great Britain.
606,033	8/1948	Great Britain.

OTHER REFERENCES

Civil Engineering, p. 104, September 1950.

EARL J. WITMER, *Primary Examiner*.

WILLIAM I. MUSHAKE, *Examiner*.