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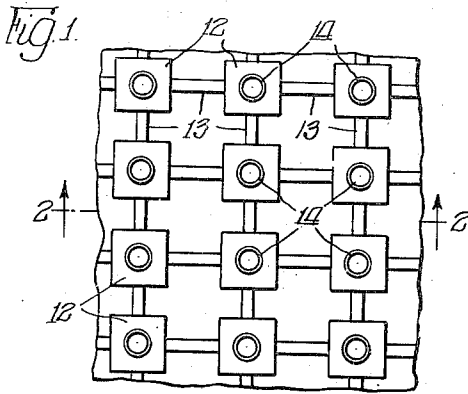
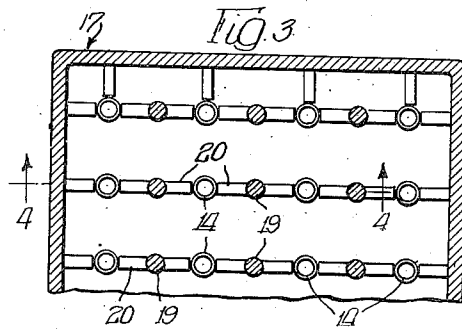
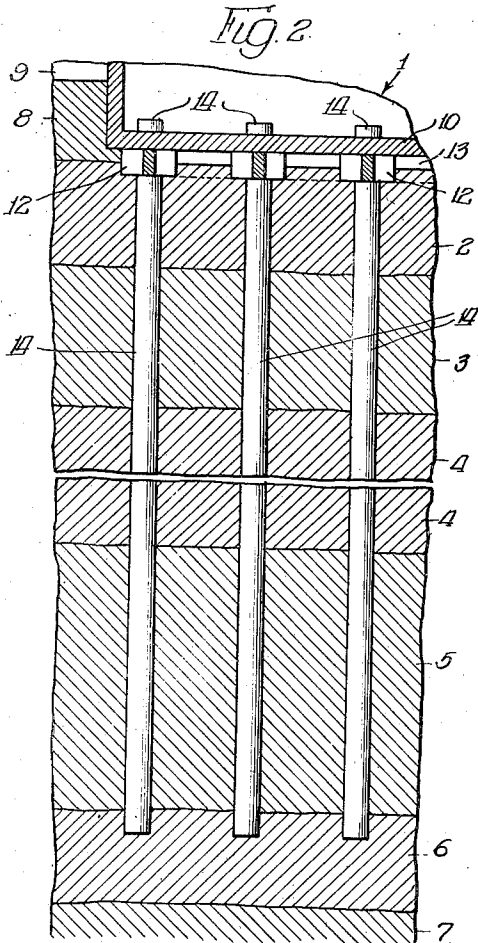
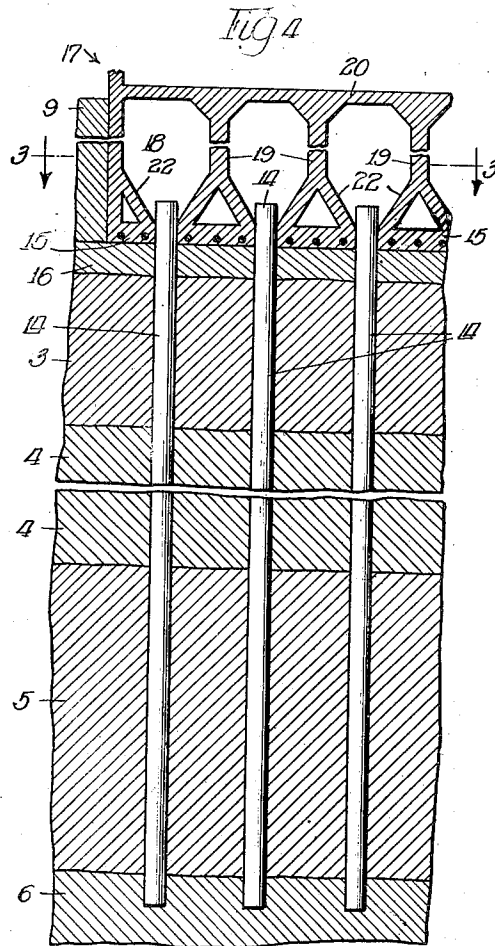
J. H. THORNLEY

2,381,014

FOUNDATION AND METHOD OF FORMING SAME

Filed May 6, 1944

2 Sheets-Sheet 1



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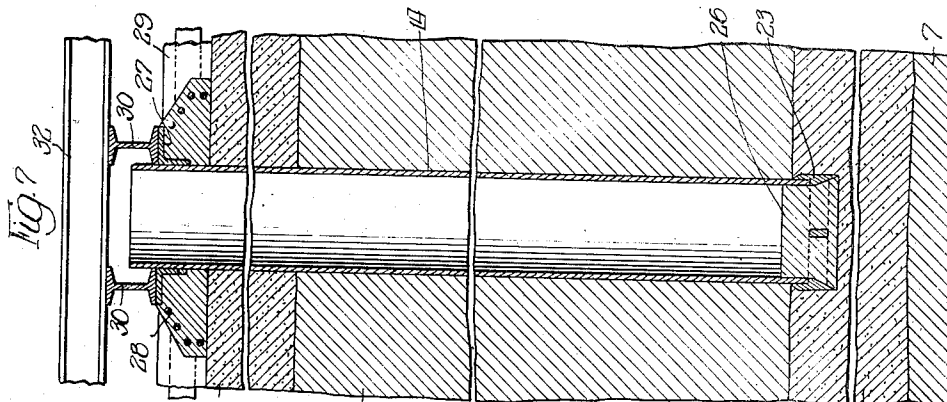
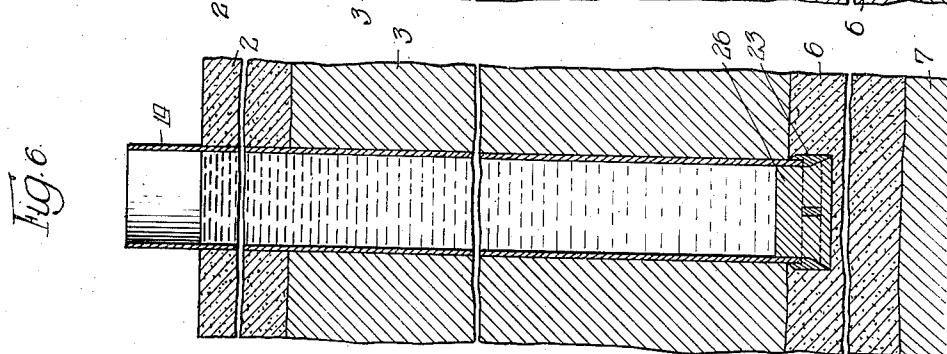
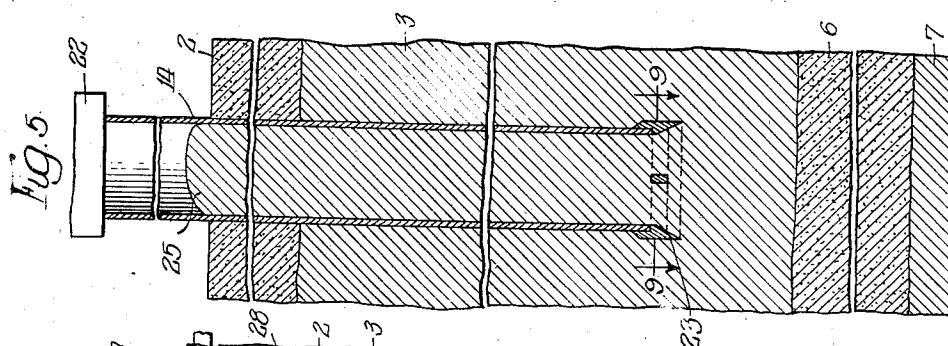
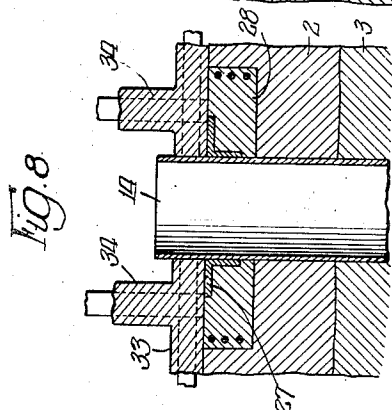
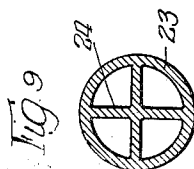
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2,381,014

FOUNDATION AND METHOD OF FORMING SAME

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2 Sheets-Sheet 2



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FOUNDATION AND METHOD OF FORMING
THE SAME

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Application May 6, 1944, Serial No. 534,408

20 Claims. (Cl. 61—50)

The present invention relates to foundations and the method of forming the same. The invention is particularly concerned with gaining support by flotation, preferably with some positive bearing, from soil strata which are unable to support the desired loading entirely by positive bearing reaction.

On the basis of the method or theory on which they carry their loads foundations may be broadly divided into three types.

1. Spread footings—including mat foundations.
2. Piles. (a) Direct bearing.
(b) Friction bearing.
(c) Compaction.
- 2x. Caissons: As used under buildings caissons are really oversized piles delivering load usually by direct bearing or spread foot action.
3. Float foundations: Based on the principle of displacement.

In practice many foundations partake of two or more of the above basic types. For example, a true float foundation could only occur in a soil fully fluid under atmospheric pressure, from the surface to the necessary depth of displacement. This would occur but rarely on any site where a building would be erected. The float would almost certainly partake of the action of a mat. Contrary-wise a mat often develops some float action.

For all practical purposes calculable, positive, foundation reactions can be obtained only under the two extreme conditions, i. e. direct bearing on sound rock or hardpan OR bearing calculated on the basis of displacement of fluid of known specific gravity.

Foundations of any type must be designed from two separate and distinct points of view.

- (a) The compression and frictional value of the immediately loaded soil.
- (b) The ultimate disposition of the load.

Most instances of foundation settlement arise from the failure of engineers to obtain the necessary data and to carry their calculations through to the ultimate disposition of the load.

My attention has been called to the Palace of Fine Arts of Mexico City (see plate X of the "National Geographic Magazine" of February 1944). The structure is a massive building. It is located on a site which was produced by filling in a lake, part of which lake is still unfilled. This lake it appears was located in the crater of an extinct volcano. I am informed that solid or bedrock is

to be found at a depth no less than one thousand feet below the surface of the site. Much of the material, including part of the fill, is light volcanic ash, the water content of which is in many strata in excess of 50% by weight, and some is said to be very much higher. At all events, it acts like silt or quicksand. There appears to be a fairly firm and compact top layer, the shear strength of which is enough to support six story buildings, but will not support any such load as is imposed by the said Palace of Fine Arts. There are no firm strata below this top layer at less than 100 feet. At about that depth, a stratum of fairly firm sand is encountered.

The said palace is carried on a large mat foundation disposed at no great distance below the surface of the site. It appears to be inadequately supported and is sinking through the supporting strata, and to date has sunk about seven feet. When its subsidence first became noticeable, numerous engineers were consulted and invited to submit proposals. Numerous proposals, most of them obviously unworkable and some wholly fantastic, were submitted. One proposal was to inject masses of concrete into the soil strata immediately under the present foundation. This was in fact done. It checked the rate of subsidence for a short period, and then appeared to have accelerated it. The obvious fact is that adding weight to the building which is already too heavy for the underlying strata can only intensify the difficulty.

The foundation condition in Mexico City cannot be met by carrying the loads directly to rock or hardpan because of the extreme depth to such material.

Naturally attempts have been made to turn to the other calculable and positive type—float foundations. The Government lottery building, which has been under construction for some years, is perhaps the best example.

Theoretically, this is the right solution, but practically the difficulties are enormous.

The float as generally used is designed as a barge or scow. The barge could rarely be launched and it must therefore be built in place. This has been attempted by many methods, but all have serious drawbacks.

1. An excavation is made within a cofferdam. The cofferdammed area pumped or excavated and the float built. Such a scheme is based on an erroneous assumption. If the coffer can be unwatered, then its side wall sheeting must reach a nonfluid stratum. Such a stratum would usually offer the required bearing for the building.

Further, even if the soil is only semi-fluid, this construction fails because exposure of the bottom relieves the pressure and permits the soil to "fluff." Settlement will then occur when fresh load is applied.

2. The float is partially or completely built at or near the original ground surface. Theoretically, in a true fluid, as the construction of the building proceeds, the float will settle uniformly to its correct position. The joker arises, of course, from the fact that rarely, if ever, will a building be constructed where the soil will act as a true fluid and consequently the uniformity of the settlement cannot be depended upon and because of the introduction of a mat reaction, the extent of the settlement cannot be calculated.

There is also the danger that a mud wave will be set up causing disturbance to adjacent structures.

3. An excavation sufficient for the float is dredged out, the sides being maintained at their natural subaqueous slope by means of the hydraulic head, possibly with the assistance of driven sheet piling. The float is then formed, largely under water by means largely dependent upon divers. This "barge structure" is anchored down by piles or other means attaching it to the subsoil. When the float is completed the water is pumped out and the building started.

While not installed primarily for their float value, the many million dollar dry docks built on Admiral Harris' design are of this type of structure.

For building foundation purposes this method of constructing floats, while entirely feasible, is useless because of the prohibitive cost, also the disturbance to adjacent structures would generally preclude its use in cities.

All types of float foundations, if not in truly fluid soil, must develop some small friction value on the side walls, but the area in contact is so small in proportion to the load carried that this feature is almost negligible.

If placed by method No. 2 or No. 3 the foundation float when finally under load usually develops a considerable mat value. However, the depth of the foundation below the water line, sets a fairly arbitrary level for the point at which the mat action must be developed and unless this happens to coincide with a soil stratum of some density this load bearing feature may be rather small.

Float foundations as now built suffer from another disadvantage. To keep the cost of the float at anything like a reasonable figure, the load of the superstructure must be uniformly distributed. This imposes certain limitations on the superstructure design.

I have conceived a method and structure which includes the possibility of saving the said Palace of Fine Arts, and in the solution of the problem involving this specific building lies the solution of the general problem of providing a foundation for a heavy structure in such a situation as is presented in Mexico City, in New Orleans, or any river delta, or where there is a great depth of fill with silt and/or quicksand constituting a large part of the fill. Similarly, in any case where the site is underlaid to great depth by light water-logged soil of insubstantial bearing value and bedrock is at too great a depth for economical reach, my present invention is an economical and practical solution of the problem.

The solution lies in sinking a series of caissons which have a buoyant upthrust, and also have, either by themselves or in some part attached to

them, as, for example, the existing foundation mat in the case of said palace, a necessary amount of positive bearing reaction.

I have analyzed the situation, and have conceived that a perfect foundation for heavy, major structures, founded in Mexico City conditions, or similar conditions, would be required to embrace the following characteristics, or as many of them as possible:

1. Since rock bearing is out of the question, it should depend on calculable float action to carry at least a major part of the dead load.

2. It should avoid adding to the superstructure load the enormous weight of a thick mat or massive barge float.

3. The cost should be far below that of the dredged type (No. 3) which is the only dependable type developed to date.

4. It should lend itself to the simultaneous development of the bearing values of compacted strata which can be reached within reasonable depth, where such exist. Note that flotation upthrust does not transmit load to such lower strata. Therefore the values obtained from such strata are a true extra bearing value. It should also take advantage of soil friction values where such exist.

5. It should be proof against the possibility of uneven settlement or canting.

6. It should have the flexibility necessary to take superstructure load no matter how unevenly distributed without adding to the cost per unit of bearing value.

7. It should avoid settlement during the erection of the superstructure.

8. The natural pressures on the fluid or semi-fluid soils must at no time be released so allowing soil "fluff" or expansion.

9. It should give positive assurance against the creation of a mud wave.

10. It should have a deadening effect against earthquake shock.

For saving the Mexican Palace of Fine Arts, I propose to thrust down, one or more at a time, open ended tubes of, for example, 36" to 48" inside diameter $\frac{1}{4}$ " to $\frac{5}{16}$ " wall steel pipe (building up the length as necessary by welding or otherwise) into the soil (through suitable holes in the mat foundation), until they strike the stratum of sand. These tubes may be pressed down as by weight or jacks, or driven down. At all events, when they are down with the lower ends resting in the aforesaid fairly firm stratum of sand, the contents of soil are removed as by churning and bailing out and are replaced by water. The concept is to retain or impose a water head in the tube approximately equal to the natural hydrostatic head at the site throughout the operation of setting the caisson. Then a body of cement grout or concrete is lowered through the water by means of tremie or bottom dump bucket and deposited at the end of the tube. This plug of concrete, after it sets, renders the lower end of the tube liquid tight. The upper end of the tube is suitably anchored to the building to receive the upthrust of the tube. This upthrust or bearing value is due both to the bearing upon said fairly firm stratum and to the buoyancy which is thereafter produced in it by pumping out the liquid and the replacement of the same by air. The bearing which the tubes have in the lower stratum, plus, the bearing which the building has on the upper stratum, i. e., on the mat, plus the buoyancy of the caissons, will then fixedly support the building.

Where the soil is only semi-fluid and has some friction value, it may be feasible to carry all of the load on float caissons.

The general problem is solved substantially in the same way except that for any new construction the building will not be in the way. If a stratum firm enough to develop a part of the load requirement can be reached within reasonable depth—say, within 150 feet—then the length of the float caisson will be such as to reach and slightly penetrate this stratum. The length of caisson can be varied almost indefinitely by varying the number of caissons to be used; e. g., if a useful stratum exists at 60' then twice as many caissons to that depth will be required to develop the desired flotation as would be needed if the stratum were reached at 120 feet. The caisson tubes will be sunk, and thereafter joined together at their upper ends by ties or bracing which may form part of the foundation as such, or may form part of the building frame. Buoyancy should be produced no more rapidly than is necessary to take on the load of the building without displacing the caissons. This will be accomplished by progressive pumping out of the water contained in the caissons. The diameter of the caissons may obviously be more or less than 36" to 48", and would in many cases be 4' or 5' or even more, depending upon design and the character of the particular building to be erected and the soil conditions encountered. Also the diameter would be governed to some extent by the facilities available for transporting and handling the tubes and for sinking the same. The internal resistance to flow of the semi-fluid soil will generally permit of a substantial loading positive or negative without causing displacement of the caisson. The shape of the caisson presents a large area for frictional engagement which is a favorable factor.

Within the principle of utilizing a buoyant caisson having also positive bearing value either in conjunction with an upper mat or by a series of pads or collars or the likes resting upon a suitable stratum, and/or upon a lower stratum, for carrying a building upon strata of otherwise inadequate bearing value, the specific structure may be widely varied, and the method of making and installing may also be widely varied, as circumstances dictate.

While the preferred structure and method of installation is as above indicated, variants will at once occur to those skilled in the art. For example, instead of closing the lower end only, the upper end only may be closed, and the air or a neutral gas retained under pressure. Alternatively, both ends may be closed, and if desired, pressure of air or a neutral gas maintained. The tubes may, if desired, be made of corrosion resisting metal or may be coated inside with the same or may be enameled, painted, or surface treated inside or otherwise protected to avoid corrosion or oxidation. Where the tubes are closed at the bottom they may be periodically inspected, and if necessary seepage and/or condensation pumped out.

There may be situations where a suitably firm stratum for producing the end bearing of the caisson may not be available. In the event that the lower end of the tube cannot be satisfactorily closed by a soil stratum, I may introduce a slug of cement or concrete above a septum or between two septums, and force the slug down to the desired level hydraulically or otherwise, as is done in oil well cementing practice, using a line to determine the exact depth.

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

In the drawings:

Figure 1 is a fragmentary top plan view of a section of foundation constructed in accordance with my invention;

Figure 2 is a section taken on the line 2, 2 of Figure 1, showing a part of the building structure superposed upon the foundation;

Figure 3 is a horizontal section taken on the line 3, 3 of Figure 4;

Figure 4 is a vertical section taken on the line 4, 4 of Figure 3;

Figure 5 is a vertical sectional view, in more or less diagrammatic form, illustrating the initial step of sinking a tube;

Figure 6 is a similar view, showing the tube sunk to seat in a relatively firm stratum, and filled with water;

Figure 7 shows the tube anchored to a pad and frame member of the building and filled with air;

Figure 8 is a fragmentary view of the upper end of the tube, showing a reinforced concrete frame bearing upon the tube or caisson; and

Figure 9 is a cross sectional view taken on the line 9, 9 of Figure 5.

Now referring first to Figures 1 and 2, assume that it is desired to support a building indicated generally at 1 in Figure 2 on a site in which none of the conventional methods above discussed is available. That is to say, the strata of soil 2, 3, 4, 5, 6 and 7 represents strata of sufficient bearing value so that even a mat laid upon the upper fairly firm stratum 2 would not support the desired weight of the building. Assume that no stratum of rock is within feasible depth under the site and that most of the strata, namely, 3, 4 and 5, are of insubstantial bearing value, as for example, quicksand, silt, volcanic ash or the like, with a high water content, such as would occur in a natural basis silted or filled up with water borne solids but nevertheless trapping and retaining a high water content. Assume that the stratum 2 near the surface of the site is a fairly firm stratum, and that the stratum 6 is a fairly firm stratum located at a depth of not to exceed approximately 150 feet, but neither one or both of sufficient positive bearing value to sustain the load of the proposed structure. The strata 8 and 9 may be merely fill or surface strata below the level of which the sub-structure such as the basement wall 10 is located. Pads or piers 12 rest upon the stratum 2 and are joined together by ties 13, 13 to brace the piers relatively to each other. The basement wall 10, or other part of the building structure, may serve to brace these piers and their connected caissons 14, 14 together at the top. The hollow air-filled vertically extending caissons 14, 14 which may be steel tubes made up, for example, out of spiral welded strips or in any other preferred form, extend down to the layer 6, which may be of sand, clay, or other suitable strata having more or less bearing value, and having at least sufficient firmness to constitute a closure for the lower end of the tubes (obstructed by additional vertical steel fins if necessary) when the tubes are set in place, as will be described later. Obviously, if the stratum 6 could support the load by direct positive bearing, then the present foundation would not be required.

The tubes 14, 14 when finished are closed at their lower ends, and open at the upper, and are filled with air. They constitute buoyant bodies which according to Archimedes, principle lose weight in amount equal to the difference between their own weight and the weight of the fluid medium which they displace. The tubes 14, 14 may, for example, be 36" to 48" inside diameter tubes of wall thickness $\frac{1}{4}$ " to $\frac{3}{8}$ " more or less in this specific illustration, although it is to be understood that the diameter of the tubes will vary, and their length may be varied within the needs of the specific design conditions, as above explained.

In the example which I have above referred to, namely, the Palace of Fine Arts in Mexico City, Mexico, there is no firm stratum at less than about 100 feet from the mat on which the building rests. By selection of the diameter and length and number of buoyant caissons 14, 14, the buoyant upthrust of the caissons may be determined. The positive bearing value of the bottom end of the caissons depends in each case upon the firmness of the layer 6, it being assumed that the layers 3 to 5, inclusive, and any lower layers which are within reach, are of no more bearing value than silt, quicksand or like volcanic ash with a high water content.

While the sand stratum 6 is sufficient to act as a plug for the cement closure which is put in the lower end of the caisson 14, as will be later described, it is to be observed that the hydrostatic pressure of the liquid head standing above the lower end of the tubes is fully effective across the bottom cross sectional area of the same, and thereby the caissons exert the upward buoyant thrust which is desired.

It is desirable that some part of the weight of the building rest at a definite level upon supporting stratum or strata furnishing some positive bearing reaction, but the loading must not be so great as would produce any sinking of the building. In other words, since the edifice is to retain a definite datum level, the buoyant caissons must exert a force upwardly of less value than the minimum weight of the building; otherwise the building would tend to come to equilibrium by rising due to the flotation power of the caissons. While separate piers or pads 12 are shown, a slab may be employed if it receives sufficient bearing support by the shear strength or displacement strength of the stratum 2 and the underlying strata.

Situations may conceivably be encountered where it is necessary to project the buoyant caissons into and terminate them at a point in a semi-fluid water-logged stratum which has no substantial bearing value, and in fact no great tendency to plug the lower end of the tube. In that event the fixed position of the building may be maintained by taking advantage of the upper layer 2 to carry such part of the weight as is needed to get positive foundation reaction to keep the level of the building at a fixed datum level. Such means may be a slab or mat or other appropriate engaging means.

Figures 3 and 4 illustrate an installation of my invention employing a mat 15 in the form of a reinforced concrete slab resting positively upon stratum 16 which, however, is of insufficient value to carry the entire load of the building. The foundation reaction value of the slab or mat 15 is supplemented by the flotation reaction of the caissons 14—14 and their positive bearing reaction upon the stratum 6. Thereby the building 17 is adequately supported in fixed position.

The upper ends of the tubes 14, 14 forming the buoyant caissons are anchored to the mat 15 or to some other part of the structure. The walls 18 and posts 19, 19, may transmit the reaction for the upward support of the remainder of the building, as, for example, to the slab 20 from which posts or framing (not shown) may carry the weight of the higher parts of the building. Suitable means for this purpose is well known to those skilled in the art.

As an optional variant the caisson may be left open at their lower ends and capped at their upper ends and supplied with air under definitely known pressure to secure the buoyant effect desired. Such buoyancy might then be controlled by regulating the air pressure to allow water to enter the lower end of the caissons. I prefer the construction wherein the lower ends of the caissons are plugged tight with cement or otherwise closed tight, and are normally filled only with atmospheric air. The buoyant effect of the caissons, the bearing value of the mat 15, and the weight of the building may be sufficiently closely figured that even with the variable loading of the building no detectable change in level of the building will occur. The buoyant effect of the caissons 14 can if need should ever arise be regulated by raising or lowering the level of liquid filling in them, or any part of them.

The manner in which these caissons may be formed and installed is illustrated diagrammatically in Figures 5 to 9.

Assume the site affords the strata 2, 3 and 6 of which the upper stratum 2 is fairly firm, and the lower stratum 6 is likewise fairly firm, but the interposed stratum 3 and the lower stratum 7 are of light and insubstantial bearing value such as would be the case with silt, water logged volcanic ash, quicksand or the like. The tube 14 which may be constructed of spirally welded steel strip is forced down vertically in the earth through the stratum 2 as by driving or by applying the weight 22. The tube may be jacked down. The tube 14 may be, for example, of 36"—48" in inside diameter with a wall thickness of $\frac{1}{4}$ " to $\frac{3}{8}$ ", although it is to be understood that tubes of larger or smaller diameter and wall thickness may be employed, as desired. The tube may be in sections which may be connected together by external sleeve fully welded joints, or by any other preferred method of making a joint which is adequately strong mechanically and permanently fluid tight. The inside of the tube, and such part of the outside as may be desired, may be enamelled or otherwise surface treated to avoid corrosion or rusting later. A bituminous compound may be employed for coating the surface. The market affords a material designated as "Lyne Kote," and described as "bitumastic enamel," which may be applied cold. It is suitable for the purpose.

A circular cutting shoe illustrated in Figures 5 and 9 may be welded upon the lower end of the tube 14, this shoe having the bracing cross bars 24 shown in Figure 9, or otherwise disposed vertical cutting fins of about 12" height may be used. These fins or bars tend to prevent inflow of material during cleaning, and before placing of the concrete bottom plug, and serve to reinforce the plug 26 when provided, but form no usual or essential part of the structure.

As the tube 14 is forced down, earth tends to fill the bore as indicated at 25, and this may be removed from time to time as the tube is forced down, or it may be allowed to remain until a

suitable part or the entire length of the caisson 14 is set to the proper depth.

The contents of the tube 14 may be washed out by a water jet from time to time if desired. Also the tube may be sunk by means of a water jet where conditions for that operation are favorable. The tube is forced down until it is firmly seated in the stratum 6, as indicated in Figure 6. The soil contents of the pipe 14 are at this stage extracted or washed out, so that the tube then contains only water down to the shoe 23. Then a mass of concrete is introduced through the water to the lower end of the tube 14, and is allowed to set as a complete plug 26 making a fluid-tight closure at the lower end of the tube 14. The concrete may be deposited either by tremie pressure grouting or by bottom dump bucket.

If the caisson 14 has been bottomed on a bearing stratum 6 of some value the caisson 14 will be redriven or rejaacked after the concrete plug has set, but without dewatering. The resistance to driving or jacking will represent the local value of the bearing stratum plus the difference in flotation arrived at by subtracting the weight of the water in the caisson from the weight of the displaced fluid soil.

The water will be allowed to remain in the caisson till the building load carried is sufficient to assure against their rising due to float action. The caisson will then be pumped dry. An opening will be left in each caisson so that a small portable electric well pump may be inserted and condensation water pumped out once a year or so, if necessary. There should be no difficulty in making the pipes absolutely fluid tight.

If the situation should be encountered that a fairly firm stratum such as stratum 6 on which the tube 14 desirably rests and provides a plugging of the lower end thereof, is not available, as determined by test drilling, the slug of cement may be lowered between two septums or below one septum, as is done in the oil well cementing procedure. The concrete and the superposed septum and where present, the underlying septum, constitute a piston which may be driven down by hydraulic pressure, the exact depth of the same being determined by a measuring line carried down with the piston. At all events, suitable methods of plugging the lower end of the tube 14 are available, and may appropriately be employed by those skilled in the art.

If with the tube and its plug 26 in the position illustrated in Figure 6, water should now be pumped out, the tube 14 would begin to exhibit buoyancy, the amount depending upon the size of the tube and the extent to which the water in the tube is lowered. In the final condition, the tube 14, when it forms a fully buoyant caisson, is completely emptied of water as indicated in Figure 7. However, the load which the hollow caisson 14 is to carry must be sufficiently imposed upon the caisson as it is emptied of water to avoid upward displacement.

Hence I prefer to impose the load upon the caisson 14 as its buoyancy is developed. This may be done by simultaneously imposing the load of the superstructure and correspondingly lowering the water level in the caissons. The procedure may be varied. It is to be understood that the full load of the building is not to be imposed upon the foundation until buoyancy is developed therein; and vice versa, full buoyancy is not to be developed until sufficient load is im-

posed thereupon to hold everything in fixed position.

In Figure 7 I have shown a flange 27 as welded to the upper end of the tube 14, the flange resting downwardly upon a reenforced concrete cap or pier 28 which may be joined by ties 29 to adjacent caps or piers for rigidly bracing the upper ends of the tubes, so that there is no tendency for them to move sidewise or get out of vertical alignment. Whatever be the nature of the attachment of the tubes 14 to the superstructure the tops of the caissons are gripped and braced by suitable connecting means between them. The load of the superstructure may be imposed by pairs of transverse beams 30, 30 and longitudinal beams 32, of which only one is shown, or in any other preferred manner depending upon the design of the building.

Alternatively, the cap or pier 28 may be joined by reenforced concrete framing, including horizontal members 33 and vertical members 34 (see Fig. 8). The members 33 form bracing between the upper ends of the buoyant caissons and they may form a part of the framing of the foundation or of the building. The vertical members 34 carry the vertical load of the building above them and impose the same upon the pads 28 and upon the tubes 14, which tubes embody the upward buoyant thrust and also such bearing reaction as the lower end of the tube has upon any firm stratum in which its lower end is placed.

I believe it is broadly new to support a building structure upon buoyant caissons and depend upon the positive bearing value of some stratum to which the buoyant caisson is anchored, or upon which it rests either at its upper end or at its lower end, or at some intermediate point, in order to retain the building in a definite position. The structure will neither float nor sink, but will rest with sufficient weight upon earth strata to assure static equilibrium, and will be sustained as to the remainder of its weight by the buoyant effect of the hollow float type caissons.

The interior of the caisson may be coated with enamel or otherwise surface treated initially, and they may be inspected periodically.

The present foundation tends to deaden the effect of ground disturbances, particularly earthquake shocks.

I claim:

1. Load supporting construction comprising a buoyant shaft extending down into and displacing water saturated strata of insubstantial load supporting value, and resting upon a stratum having some load supporting value and a superimposed structure supported on said shaft at its upper end constituting loading great enough to overcome the buoyancy of said shaft and to hold said shaft in engagement with said stratum.

2. Load supporting construction comprising in combination a buoyant hollow shaft closed at its lower end and extending vertically down in and displacing water saturated uncompacted strata of insubstantial load supporting value, and engaging at its lower end a stratum having some load bearing value and a structure superposed on said buoyant shaft at its upper end and constituting a loading great enough to overcome the buoyancy of said shaft and to hold said shaft in fixed position in engagement with said stratum.

3. Load supporting construction comprising in combination a plurality of buoyant hollow shafts extending down into and buoyed up by an uncompacted water saturated stratum, said shafts

being tied together at their upper ends, said shafts having vertical engagement with a compacted stratum of some load bearing value, and a structure superposed on said shafts at their upper ends and constituting loading great enough to overcome the buoyancy of said shafts and to hold said shafts in fixed vertical position in engagement with said load bearing stratum.

4. Foundation means comprising a plurality of hollow vertical shafts coupled at their upper ends and closed at their lower ends, said shafts being projected into soil of uncompacted and water saturated character of no substantial load bearing value, said shafts engaging endwise at some part of their length against a stratum having some load bearing value, and being adapted to have a useful load imposed vertically upon the upper ends thereof.

5. Foundation means comprising a plurality of vertical buoyant tubes projected into a relatively dense sub-surface stratum, and having plugs of concrete resting upon said stratum and plugging the lower ends of said tubes and coupling means at the upper ends of said tubes coupling the tubes, the walls of the tubes being adapted to sustain useful load.

6. Foundation means of claim 5 further characterized by pads secured to the upper ends of said tubes and resting upon a stratum substantially at the surface of the site.

7. Method of providing support for a structure the foundation of which depends for support at least in part upon uncompacted water saturated soil of inadequate bearing value, which comprises disposing hollow air filled caissons vertically in the water saturated soil below said part of the structure to be supported and anchoring the upper ends of said tubes to the said part of the structure to be supported.

8. Method of providing support for existing building structure having a foundation depending for support in part at least upon uncompacted water saturated soil into which said foundation is sinking, which comprises projecting a cylindrical caisson vertically down into said water saturated soil through the existing foundation of said part of the building, anchoring upper part of the caisson to the part of the structure to be supported and rendering the caisson buoyant.

9. Method of claim 8 wherein the caisson is initially in the form of an open ended tube projected into the soil, and wherein the caisson is rendered buoyant by removing the soil in the tube, plugging the lower end of the tube with a filling of cement and pumping out the caisson.

10. Method of providing support for an existing building having inadequate support by virtue of resting upon uncompacted water saturated soil which comprises projecting down vertically into said soil under the building a series of caissons, anchoring the caissons to the building and rendering the caissons buoyant.

11. Method of producing a buoyant caisson for use in water saturated soil which comprises projecting a tube lengthwise down into said soil,

closing an end of the tube and replacing the contents of the tube with air rigidly engaging the tube at its upper portion with the load to be supported.

12. Method of claim 11 wherein the lower end of the tube is sealed off and the contents of the tube are removed through its upper end.

13. Method of claim 11 wherein the upper end of the tube is closed and air is forced into the caisson to displace at least a part of the contents downwardly.

14. Method of claim 11 wherein the soil is washed out of the tube, the lower end of the tube sealed with cement, and the contents above the seal pumped out to render the caisson buoyant.

15. Method of erecting a structure upon a site where the soil within feasible depth is inadequate to give permanent direct bearing support by reason of semi-fluid underlying soil strata, which comprises projecting a plurality of tubes vertically down into underlying semi-fluid strata which have internal friction against displacement, joining the tops of said tubes to brace the same against each other and to a load to support the same vertically, removing the enclosed soil and replacing the same with air, said internal soil friction presenting substantial resistance to any displacement of the tubes in said strata.

16. The method of claim 15 wherein the soil is removed from each of the tubes and replaced by water, an end of each tube is closed off and air is substituted for water to render the tubes buoyant.

17. The method of claim 15 wherein the soil is removed from each of the tubes and replaced by water, the lower end of the tube is sealed off with cement and the water is pumped out of the tube, with imposition of some of the weight of the structure.

18. In a foundation structure comprising a series of connected vertically disposed buoyant caissons, the method of control of buoyancy which comprises partially filling the caissons with air and partly with water and changing the relative proportions of air and of water contained therein.

19. Method of forming a foundation having both bearing value and buoyancy which comprises sinking a tube through uncompacted water logged strata into a stratum having bearing value, plugging the lower end of the tube with a plug of cement which engages said stratum engaging the upper end of the tube with the load to be supported and substituting air for contents of the tube above said plug to the extent of rendering said tube buoyant.

20. Foundation having both buoyancy and bearing value whereby it retains under load a fixed position comprising a plurality of connected tubular caissons closed at one end and resting at some part of their lengths upon a soil stratum having bearing value, said caissons having a filling of air to render them buoyant and being usefully loaded by load superposed upon the upper ends of the caisson.

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