

[54] FOUNDATION METHOD FOR CAISSONS

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[52] U.S. Cl. 61/46.5; 61/50

[51] Int. Cl.² E02D 17/00; E02D 23/02

[58] Field of Search 61/46.5, 46, 50, 53.74

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[57]

ABSTRACT

A support structure for providing a support for a marine structure to be submerged onto a submarine bed. The support structure includes a base which is intended to rest on the sea bed. The base includes three or more cells, and three or more hollow downwardly open skirts which project downwardly from the lower portion of the base. The skirts are each formed as a static and continual unit with the portion and have a length which enables each to be pressed far down into the sea bed, whereby the deeper layers of the sea bed soil cooperate directly with the skirts to support the marine structure in position on the sea bed. The skirts, which have a substantially cylindrical cross-section, being located at least along the periphery of the base in such a way that a continuous barrier wall is formed along the periphery of the base.

15 Claims, 15 Drawing Figures

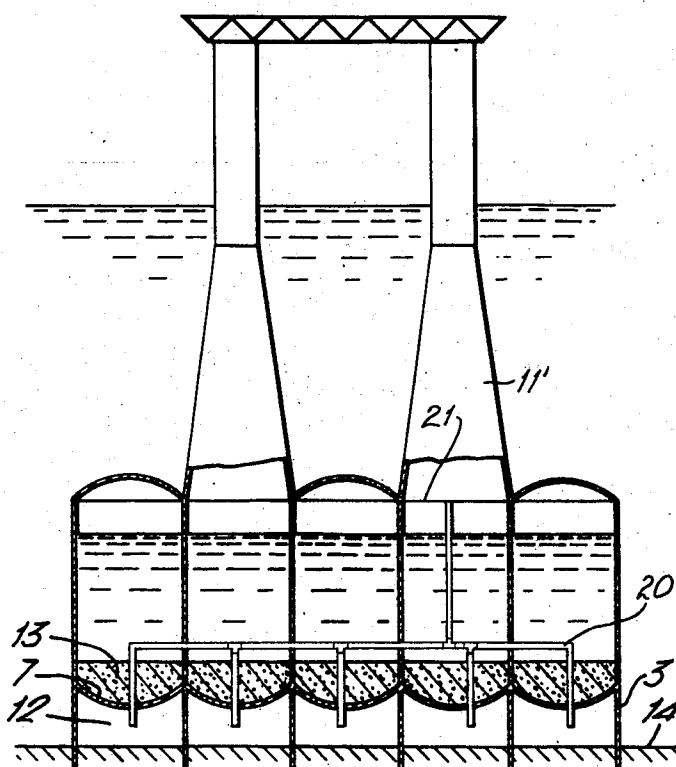


FIG. 1.

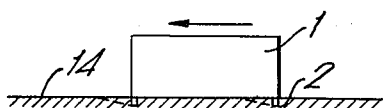


FIG. 2.

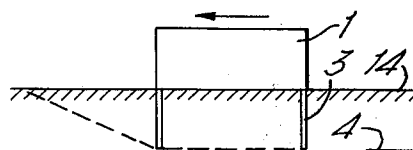


FIG. 3.

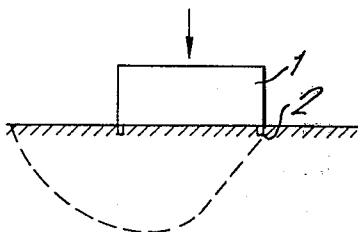


FIG. 4.

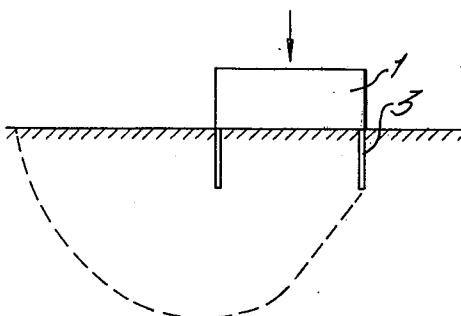


FIG. 5.

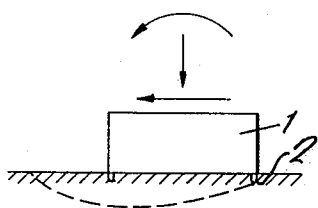


FIG. 6.

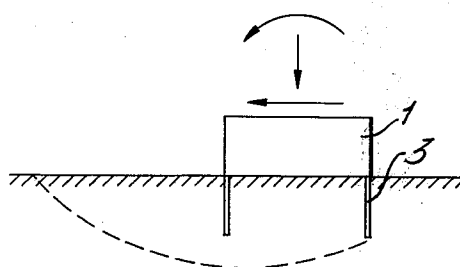


FIG. 7.

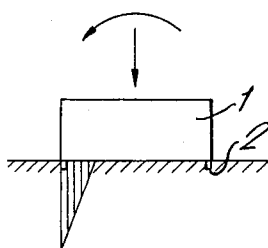


FIG. 8.

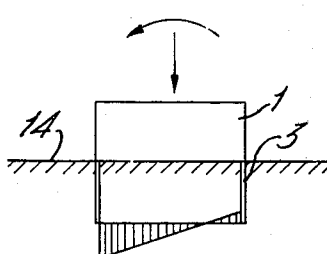


FIG. 9A.

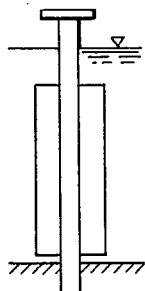


FIG. 9B.

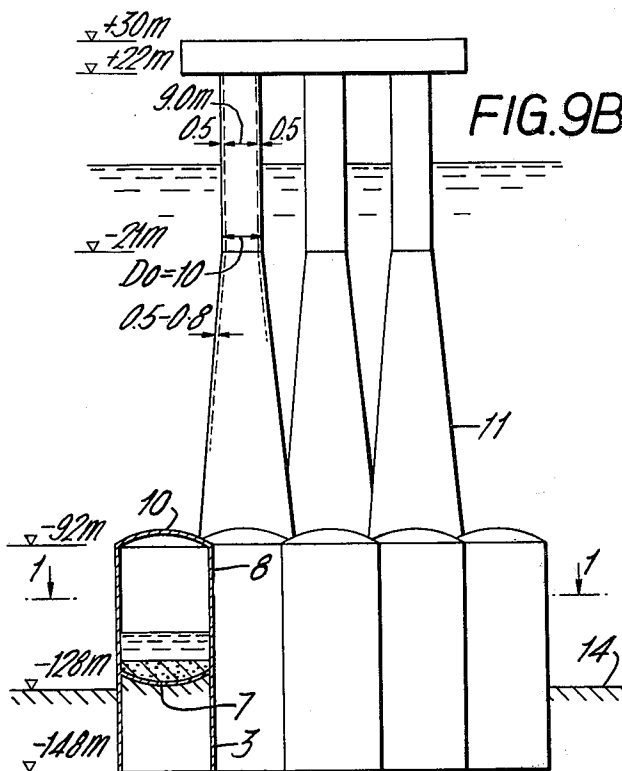


FIG. 10.

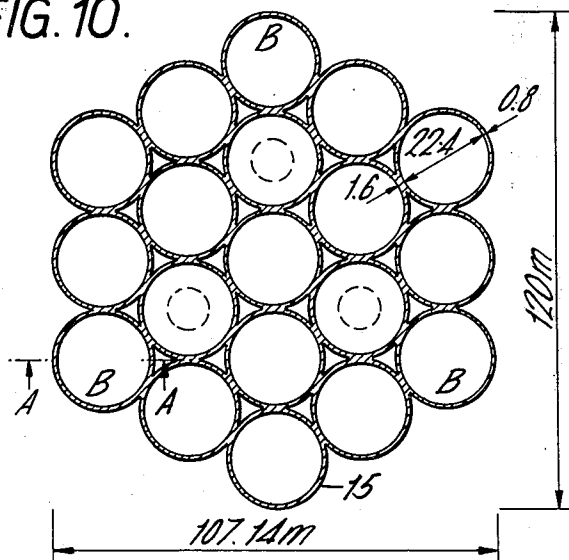


FIG. 11.

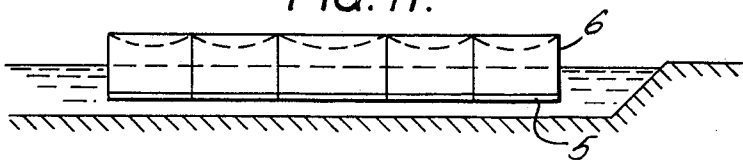


FIG. 12.

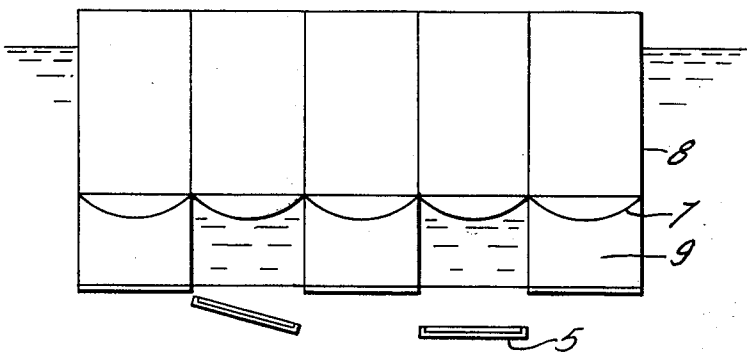


FIG. 13.

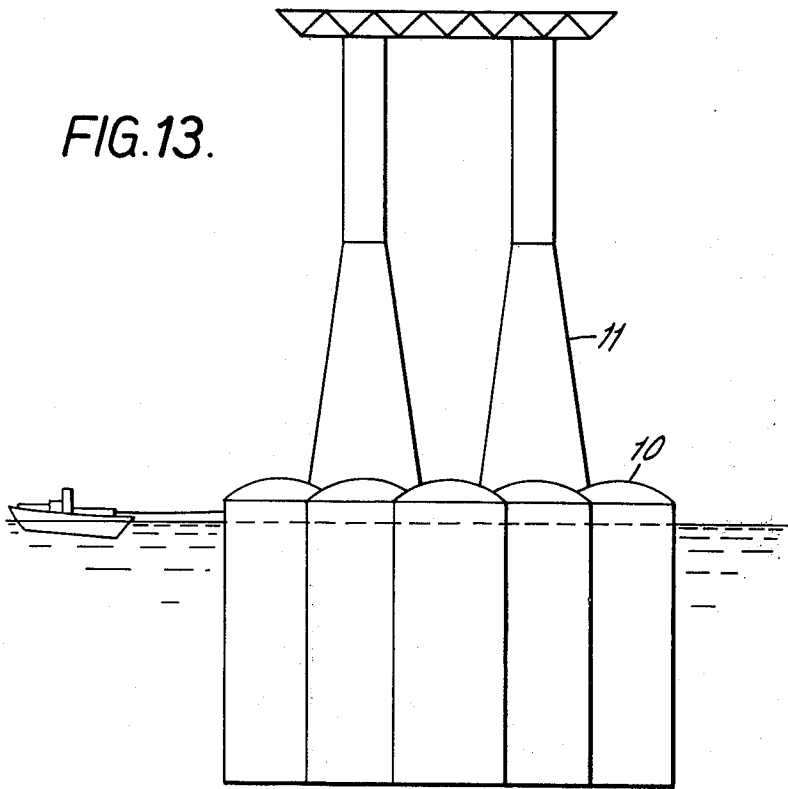
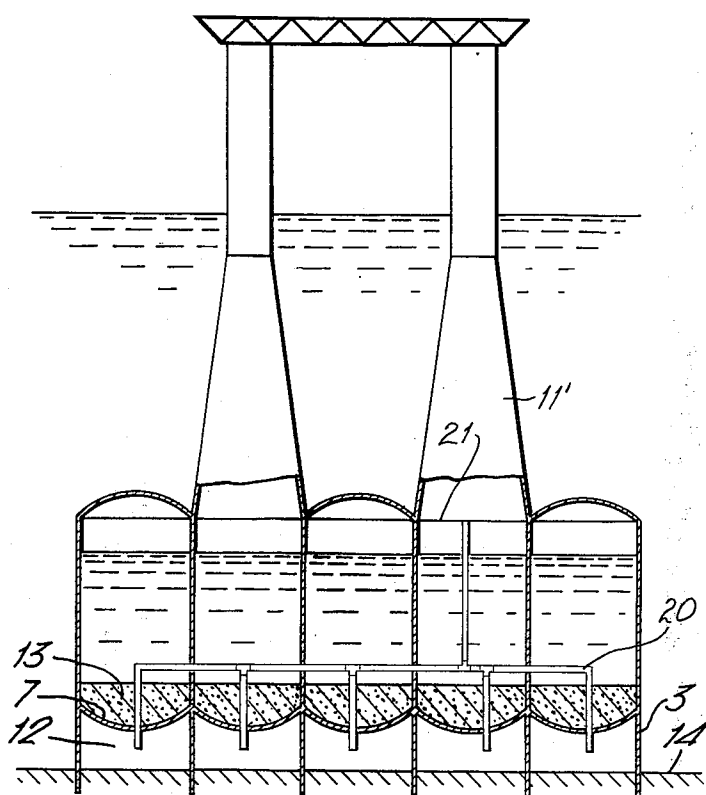


FIG. 14.



FOUNDATION METHOD FOR CAISSONS

The invention relates to a foundation method for caissons, in particular in connection with offshore petroleum production.

To place a caisson on the bottom of the sea and use it as a foundation for platforms, possibly as an oil storage, is known *inter alia* from the Norwegian patent application Nos. 3325/71 and 3326/71. The application No. 4282/71 also indicates a method for depth foundation, i.e. by using piles which are pressed down. It is also known to use a caisson on the bottom of the sea as oil storage and provided with a small cutting edge.

In many cases it will however not be possible to perform a positioning of a caisson on the bottom of the sea. The most frequent reason will be that the state of the bottom is poor, but also with good sea bed conditions foundation may be impossible if the applied moments and forces are large. Another case where conventional surface foundation is not possible is where the foundation results in large longtime settlements, for example where the sea bed consists of soft clay.

The object of the present invention is to find a way for founding a caisson in deeper earth strata which are good enough to absorb the applied forces and preferably so that the foundation can be combined with a pile effect, i.e. that stresses may be taken up by friction/adhesion or passive earth pressure.

The invention involves the extension of the walls of the caisson a significant distance below the bottom slab and to press/jet the walls down into the ground until the bottom slab reaches the sea bed. In reality, the caisson is in this case founded at a depth corresponding to the lower edge of the extended wall (the skirt) and will in addition be stabilized by friction/adhesion along the outside of the outside walls as well as by passive earth pressure against the front wall.

The skirt according to the invention must not be mistaken for the previously mentioned conventional cutting edge, since the effect in practice is completely different. Such a small cutting edge may have a certain value against erosive undermining and may likewise prevent sliding in the joint between the caisson and the ground, but is without any effect in confrontation with geotechnical conditions at greater depths, and these are as a rule decisive.

FIGS. 1-8 are diagrammatic side elevation views illustrating forces resulting from the use of several different types of marine support structures;

FIG. 9 is a diagrammatic side elevation view, partly in section, of a device according to the present invention;

FIG. 10 is a diagrammatic top sectional view taken along the line 1-1 of FIG. 9;

FIGS. 11-14 are diagrammatic side elevation views showing the assembly and submersion of a support structure according to the present invention.

FIGS. 1-6 show schematically how a construction according to the invention may appear in contrast to conventional structures. The dotted lines indicate the sliding surfaces. FIG. 1-2 show the conditions with a pure horizontal force. The caisson is denoted by 1, the conventional cutting edge by 2, a skirt according to the invention by 3 and the sea bed by 14. FIG. 1 shows that a cutting edge can prevent sliding in the joint between the caisson and ground, but that the sliding joint only moves downwards to the edge point and the conditions do not particularly improve. FIG. 2 shows the condi-

tions according to the invention. The sliding surface has now moved down to the level 4, where the mobilized shear forces normally will be far larger than in the surface layer. In addition there is achieved a passive earth pressure at the front edge and an active one at the rear edge which together provide a substantial resistive force, and frictional forces are also obtained along the outer walls lying parallel to the direction of force.

FIGS. 3-4 show the conditions for pure vertical load. It is immediately seen from FIG. 3 that it is without significance whether a small cutting edge is present or not.

FIGS. 5-6 show an example of the conditions for combined horizontal-, vertical and movement load, i.e. the normal case. Also in this case the skirt will act in a stabilizing way similar to the case of a pure vertical load.

Another advantage of the caisson according to the invention and in comparison with ordinary caissons is that friction/adhesion along the skirt wall leads to the tensile forces being absorbed by the foundation. In dense soil tension may also be absorbed in the level 4 (FIG. 2) of the horizontal joint, since an upward movement will lead to an under-pressure in this joint. The fact that tensile forces can be absorbed means great advantages, *inter alia* in that the resultant will have less eccentricity for large overturning moments. It will also prevent lifting of the caisson at the rear edge, and thereby scour at this point. The FIGS. 6-7 show the difference in ground stress (hatched area). The skirt provides less absolute ground pressure and maximum ground pressure occurs in addition at larger depths, which normally is an advantage.

A usual surface foundation which is subject to horizontal forces and movements is dependent on simultaneously having a large dead weight to prevent sliding or capsizing. Sufficient dead weight may be difficult to achieve, *inter alia* because a submerged caisson subject to wave loads simultaneously with the other loads also obtains substantial upward forces, which will act against the dead weight. There is also a limit for the vertical forces which a building a site can absorb. Lastly, there is a limit for the dead weight if a caisson is going to be floated. To fill ballast after the caisson has been positioned means extra costs. A large dead weight has besides the disadvantage that the settlements become large, which may be particularly troublesome on soft ground.

With a construction according to the invention these problems will be substantially reduced. One becomes far less dependant on large vertical forces because passive earth pressure, frictional/adhesion forces as well as forces due to underpressure are mobilized. If the skirt is made sufficient long the forces due to the skirt can alone absorb all external forces and the dead weight may be zero. This may be achieved by pumping water out of the caisson. In such a case the construction will "float" and the soil is only stressed by shear forces due to external forces. The settlement will thus be minimal, since these will only be a result of short external loads, while the settlements due to dead weight becomes zero.

FIGS. 9-10 show a proposal for an actual and present case somewhere in the North Sea. A platform was to be placed at a site where the ground consisted of soft clay with a shear strength of approximately 1 t/m² for the upper 4 m and thereafter increasing to approximately 5 t/m² at a depth of 20 m. It was tried to solve

this problem with a usual surface foundation, but this had to be abandoned since it showed impossible to construct a foundation which resulted in sufficient low shear forces in the clay. Even if this had been possible to solve, longtime settlements of several meters would have prevented the project in any case.

By introducing a skirt 3 according to the invention the conditions were radically changed. The platform was now in reality founded on a clay with a shear strength increased by 5— in relation to the surface clay since that clay which lies inside the skirt in practice acts as a part of the caisson.

In addition one achieved a certain force absorbance due to a friction against the outer walls. By pumping most of the water out of the caisson the buoyance became equal to the dead weight and the vertical load thereby became zero, except for variations in the payload and uplift due to waves which both were small in this case. The result was that the clay without difficulty could absorb the applied forces and moments and at the same time the settlements became minimal.

The production of a skirt according to the invention offers special problems. Normally a larger caisson for positioning on the bottom of the sea will be made as follows: The bottom section is cast in a dock, is thereafter towed out on deeper water and the walls are cast using a slipform in the floating state. The top cover and superstructure is thereafter cast, and finally the construction is towed out on deep water and lowered by letting water into it.

The same method may be used in order to produce a structure according to this invention, but the depth of the dock becomes so large due to the skirt that this may make the project uneconomical. Another method is to cast the caisson in similar way as described but turned upside down. The skirt may thus be cast above water in the floating state, and the caisson is turned by pumping water into the cells on one side. The caisson may consequently be put into a right position by trimming and the work is terminated as described above.

A third possible production and positioning method will now be explained step by step. (FIGS. 11 – 14).

1. Loose, temporary bottoms 5 are made in a dry dock.

2. The lowermost part of the skirt 6 is cast on the bottoms 5.

3. Water is let into the dock and the structure is floated out on deep water (FIG. 11). The water pressure will press the bottoms against the walls and hold the bottoms in position.

4. The rest of the skirts are cast.

5. New bottoms, the permanent ones 7, are cast.

6. The caisson walls 8 are cast.

7. Water is let into the interspace 9 between the temporary and the permanent bottoms. When the water pressure becomes large enough the temporary bottoms 5 will sink to the bottom by their own weight and the structure floats on the permanent bottoms (FIG. 12)

8. The top cover 10 and superstructure 11 are completed.

9. The platform is towed to its position (FIG. 13).

10. The platform is lowered by letting in water. When the caisson is filled it will rest on the bottom of the sea with its complete dead weight and the skirts will have penetrated some distance down into the ground, possibly completely down such that the caisson bottom rests on the sea bed.

11. If the caisson has not come completely down by its own weight and the ground consists of a "dense" kind of soil, water is pumped out from the interspace 12 below the caisson bottom 7 and the caisson is pressed further down. (FIG. 14).

12. If the caisson cannot be pressed to the bottom by the method as stated under point 10 and 11 the cells are filled with sand till it is pressed completely down such that the bottom plate is contacting the bottom of the sea.

13. Excess sand according to point 12 is removed.

14. Water and/or ballast sand is pumped out of the caisson until the platform's dead weight is equalized.

15. When the platform is to be removed, water is pumped in under the bottom plate 7 until it lifts due to overpressure.

16. If the measures according to point 15 are insufficient, the part of the ballast 13 which is present in the caisson is removed until it lifts.

17. The caisson is lifted fully up to the floating state by pumping out water and may be towed to a new site.

A fourth possible solution to reduce the dock depth, is to cast the lower bottoms 7 in the dock and have an air cushion in the interspace 9.

25 A skirt can be given series of different shapes. Normally it will extend around the outer edge of the caisson. It is however, advantageous in addition to divide the underside of the caisson into several cells, and in practice the skirt walls should flush with the walls of the caisson. It will thus be a close connection between the construction of the caisson and the skirt.

A particularly preferred embodiment is to let both the caisson and the skirt consist of a series of vertical cylindrical cells 15 which are held together monolithically in the points of contact, as e.g. shown of FIGS. 9 – 10. The advantages of this embodiment is that the walls will obtain a nearly constant load in the ring direction and substantially pure pressure and tensile forces, and no moments. The cells will also act independent of each other, a fact which is of large importance if a wall is breaking down due to some accident. If the number of cells is large enough this means that the construction is fully functionable even with local breakdowns. If one examines the separate operations one arrives at the following result: During production a break down of a cell will only lead to the construction obtaining a certain tilt. The same is the case during towage provided one have a relatively large freeboard. Any tilt during lowering will become larger, but provided one or several towers are present as shown in the figures, the structure will not tilt over. Even if the conditions are such that the caisson goes to the bottom each intact cell will anyway resist the full water pressure such that the structure later may be lifted up and repaired.

Division into many small cells have further the advantage that the ballast cannot move as well as the reduction in metacenter height due to inner free water surface becomes insignificant.

A division of cells has also advantages in the ground. A break down of a cell will also there have small consequences due to the fact that each cell only represents a fraction of the carrying capacity and that intact cells have full strength independant of the damaged one. In practice it has proved that it is difficult to achieve full carrying capacity in those cells where drilling equipment or the like is going down into the ground. This re-

action will be small by division into small independant units.

A division into small, round cells also offers advantages in that the trimming becomes easy to perform, both in floating state and by the operations as mentioned above in point 10 - 17. A bottom which is not even may to a certain degree be compensated for by overweight on the highest side.

The round shape is also advantageous with regard to cracking of the walls.

The invention may be supplemented with a series of details of which some shall be mentioned:

By pumping in water (point 15) it may be theoretically thought that it will be difficult to get the water to penetrate in between the bottom and the clay. The underside of the bottom 7 may in order to prevent this be provided with a layer which is permeable to water but too dense for the clay to penetrate into it. The layer may e.g. be constituted by extremely lean concrete.

The temporary bottoms 5 may be provided with floating tanks, for example for later lifting and reuse.

The lowermost part of the skirt may be shaved like a knife for easier penetration into the ground.

A small deviation from the uniform circular form which is indicated may be considered e.g. to achieve a form which in a better way can absorb the shear forces.

Equipment for jetting may be arranged on the lower part of the skirt in order to ease penetration.

The temporary bottoms 5 may be constructed as a continuous whole and with an edge around the lot. The bottom will thereby have the character of a floating dock, but deviated from a floating dock in that it is lowered rather than having a dock gate, and also in that the permanent construction will distribute and stiffen "the floating dock", such that it will be made very simple and inexpensive. The permanent construction will in reality be statically co-operating with the dock when the dock is maximally loaded.

A series of other variations of the construction than indicated above may be considered. Just a part of the caisson cells may be extended with a skirt. If one let the skirt consist of only three cells this will result in an approximate statically determined threepoint mounting with the static advantages this offers. Besides the penetration resistance will become less such that the skirts can be made longer and thus reach larger depths. On FIG. 10 one may consider just to extend those cells which are marked B. These cells may be connected by a framework instead of by other cells.

Another variation is shown on FIG. 8. Only one cell is here carried out with a skirt. The moments will in such a case not be absorbable such that the caisson will oscillate according to the waves. Drilling may however be performed through the central cell.

It is not necessary that all the cells in the caisson are provided with a permanent bottom 7. It is possible to omit the bottom in some, e.g. in those cells which are provided with a skirt, such that all forces must be absorbed by shear forces against the skirt walls.

Even if it has in the foregoing been assumed that concrete is the construction material, it is evident that other materials, e.g. steel also may be used. Some of the mentioned advantages will, however, be reduced or disappear. The concrete may be not reinforced, reinforced in the normal way or prestressed.

In the foregoing a particular emphasis has been placed, on the very static foundation on soft ground.

Such a deep skirt which is shown will however also offer other advantages. In particular it should be mentioned that a deep penetration downwards will prevent scour. This is in any case a fact if the skirt penetration scour-proof layers as for example clay. There is also at present a factor of unsafety on sand because the wave will also have an effect on the underside of the caisson. A deep skirt will also reduce this effect.

An important advantage of the skirt is that a better overall control of where the bearing pressure is acting is achieved, such that the caisson can be dimensioned correspondingly. For a normal "surface foundation" one may risk that the bottom is somewhat uneven such that the structure is founded on limited areas resulting in large moments and shear forces.

In the foregoing examples there are always shown very long skirts. It may be mentioned, however, that in some cases a foundation according to the invention may be carried out with substantially shorter skirts. If for example a stiff clay has an overburden of loose sand, any skirt that penetrates the sand layer in fact will foundate the caisson on the stiff clay.

By means of skirts according to the invention it will always be possible to "suck" or to "jack" a tilting structure into vertical position if the number of skirt cells are at least 3. Grouting between lower bottom 7 and sea bed is not necessary if the dead weight is compensated as described above, as the wave forces can be carried by the trapped water cushion. The skirts will however always offer the advantage that grouting can be carried out if necessary.

If the sea bed is uneven, pipes for grouting can be placed in advance. The platform can then, when it is placed, be jacked to the correct position by the ballast system, and finally the space below the bottoms are grouted. The structure can be designed to resist full water pressure and then it is possible to empty one of the towers during the grouting. This grouting can therefore be done from a deck inside a tower in a suitable height. This is very important because if the grouting is carried out from above sea level, the difference in specific weight between the grouting material and the sea water may cause that the pressure is too high and the platform is lifted.

Pumping machinery for sea water should preferably be placed below water surface. Pumps placed above water surface will have a very poor suction effect.

It will easily be seen that the main difference between a usual gravity caisson and a caisson according to the invention is that the latter is more or less cantilevered from the sea bottom and not solely dependent on gravity forces.

It is also possible to let the underpressure mentioned in fabrication step 11 stay permanent. This will preconsolidate the soil and thereby reduce later settlements. It will also create a permanent load on the structure and thereby stabilize it against wave action.

The suction procedure described may be limited by the possibility of a bottom heave. This will happen if the underpressure is too large compared with the shear strength of the clay, and may also happen if for example sand layers occurs in a clay. Bottom heave can be avoided by creating the underpressure not in the space 12, but somewhere on the already downpressed wall, for example on the tip. This can be done by suction pipes following the skirt and ended with a filter to avoid earth flowing into the pipe.

It will immediately be understood that the embodiments of the invention as shown on the drawings and described above only are meant to illustrate the inventive thought, and that this inventive thought may be varied in a series of ways within the scope of the invention.

The trapped water cushion (pore water) in the inter-space 12 will during lifetime carry compressive and tensile forces by overpressure respectively underpressure in the water. This gives the advantage that all short time forces (wave forces) are evenly distributed on the bottoms 7.

I claim:

1. A support structure for providing a support for a marine structure to be submerged onto a submarine bed, the support structure comprising: a base which is intended to rest on the sea bed and intended to project upwards from the sea bed; the base comprising a plurality of cells, and including a plurality of hollow downwardly open skirts substantially cylindrical in cross section which project downwardly from the underneath side of said base; said skirts each being formed as an integral unit with the base and having a length which enables each to be pressed down into the sea bed, whereby the deeper layers of the sea bed soil cooperate directly with the skirts to support the marine structure in position on the sea bed; a continuous wall formed underneath said base and along the periphery of the base, said wall comprising a plurality of said skirts.

2. A support structure according to claim 1, wherein the skirts along the periphery of the base are formed by tubes being joined together along the contacting lines of adjacent tubes.

3. A support structure according to claim 1, wherein the skirts are formed by lengthening the walls of the cells in the base.

4. A support structure according to claim 1, including means for removing water from a part of the structure.

5. A support structure according to claim 1, wherein said cells include ballast and wherein the structure includes means for changing the amount of ballast in each cell.

6. A support structure according to claim 1 including means for introducing grouting into the space enclosed by each of said cylindrical wall members to compensate for unevenness of said sea bed.

7. A support according to claim 1, wherein the skirts and at least the lower section of the marine structure are made of concrete.

8. A support according to claim 1, wherein the skirts are made of metal, such as for example steel, and at least the lower section of the marine structure is made of concrete.

9. A support according to claim 1, wherein the lower part of the skirts are made of metal, such as for instance steel, while the part of the skirts being built-in to the lower section of the marine structure are made of concrete.

10. A support according to claim 1, wherein the underside of the marine structure is provided with a water-permeable layer.

11. A support according to claim 1, wherein the skirts have a circular cross-section area.

12. A support structure according to claim 1, further including means for reducing the pressure in the space enclosed by said skirts to facilitate the pressing downward of said wall member into said sea bed.

13. A support structure according to claim 1, further including means for increasing the pressure in the space enclosed by said skirts to facilitate the raising upward of said wall member out of said sea bed.

14. A support structure according to claim 1, including ballast chamber means and means for changing the ballast in said chamber to change the buoyancy of said structure.

15. A support structure for providing a support for a marine structure to be submerged onto the submarine bed, the marine structure consisting of a lower section which is intended to rest on the sea bed and intended to project upwards from the sea bed, the lower section consisting of three or more discrete vertical cylindrical cells joined together in a monolithic structure at least three of said cells being provided with a cylindrical downwardly open skirt which projects downwardly from the lower section, these skirts being formed as a static and continual unit with the lower section and having a length which enables them to be pressed far down into the sea bed, whereby the deeper layers of the sea bed soil adjacent the wall member cooperate directly with the wall member to support the marine structure in position on the sea bed, the skirts having a cylindrical or nearly cylindrical cross-section, said structure further including chamber means for retaining ballast in each of said cells, means for changing the amount of ballast in each cell, and means for introducing grouting into the space enclosed by each of said cylindrical wall members to compensate for unevenness of said sea bed.

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