March 7, 1967 W. D. WATERMAN 3,307,361

METHOD OF CONSTRUCTING AN UNDERGROUND STRUCTURE

Original Filed Oct. 21, 1964 5 Sheets-Sheet 1

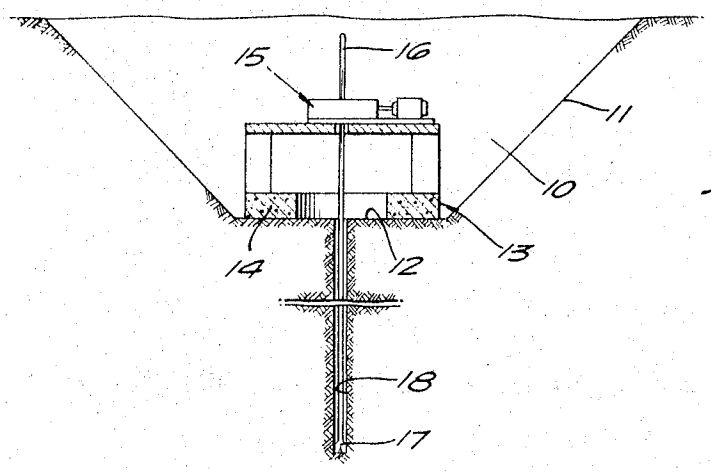


FIG. 1.

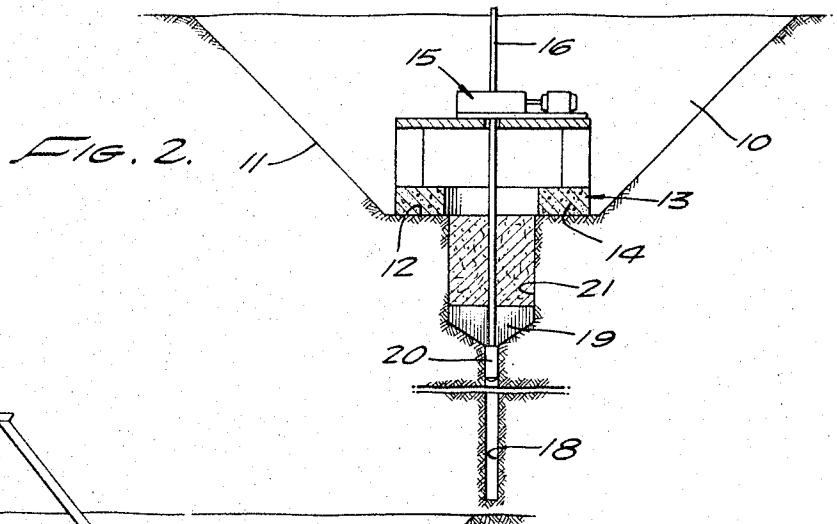


FIG. 2.

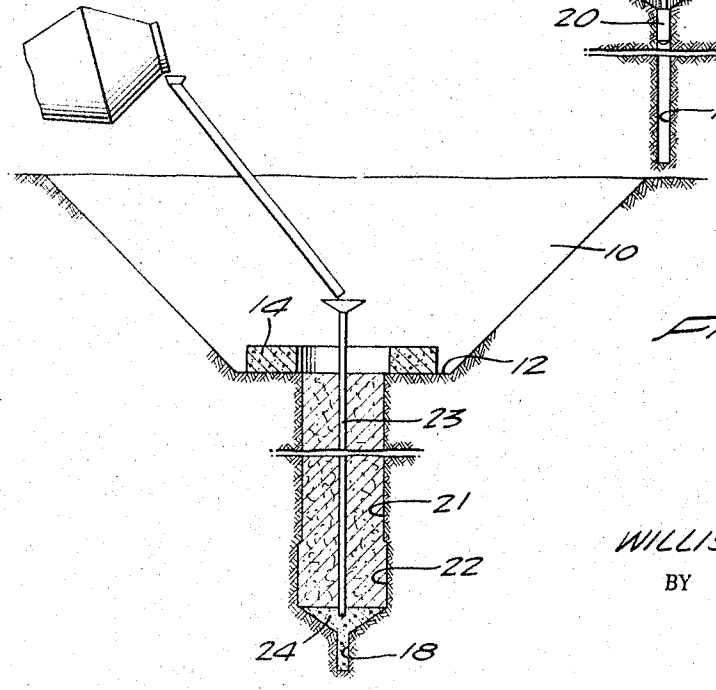


FIG. 3.

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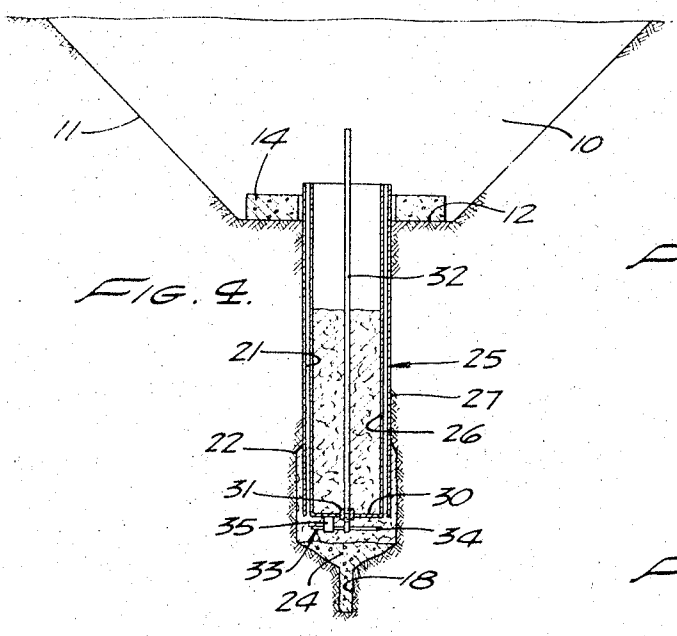


FIG. 4.

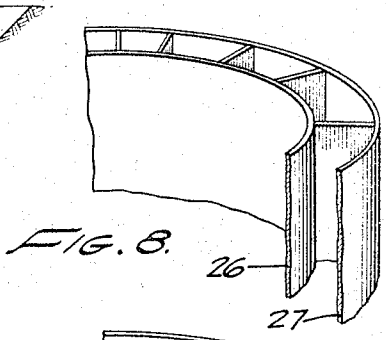


FIG. 8.

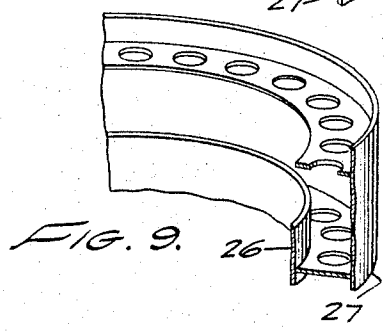


FIG. 9.

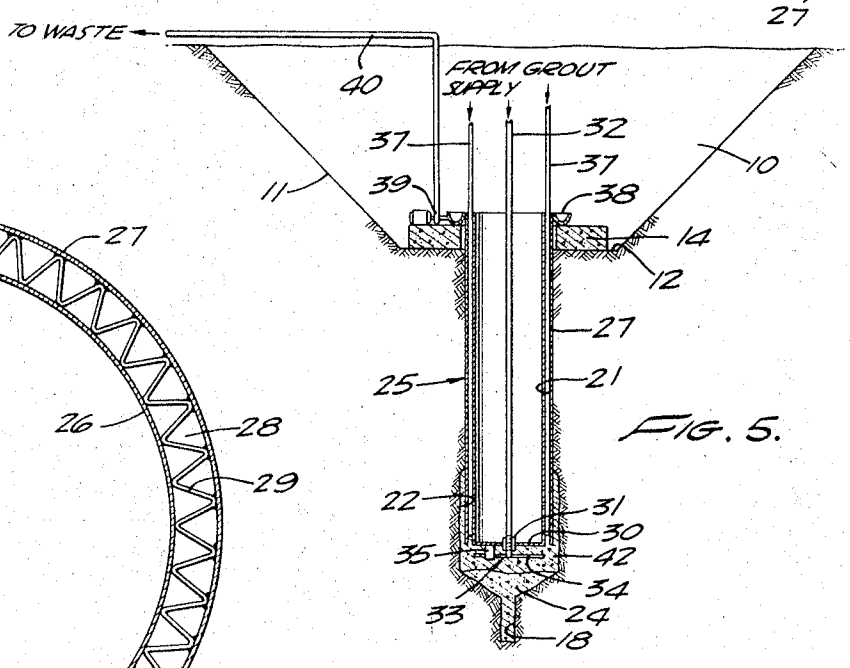


FIG. 5.

FIG. 7.

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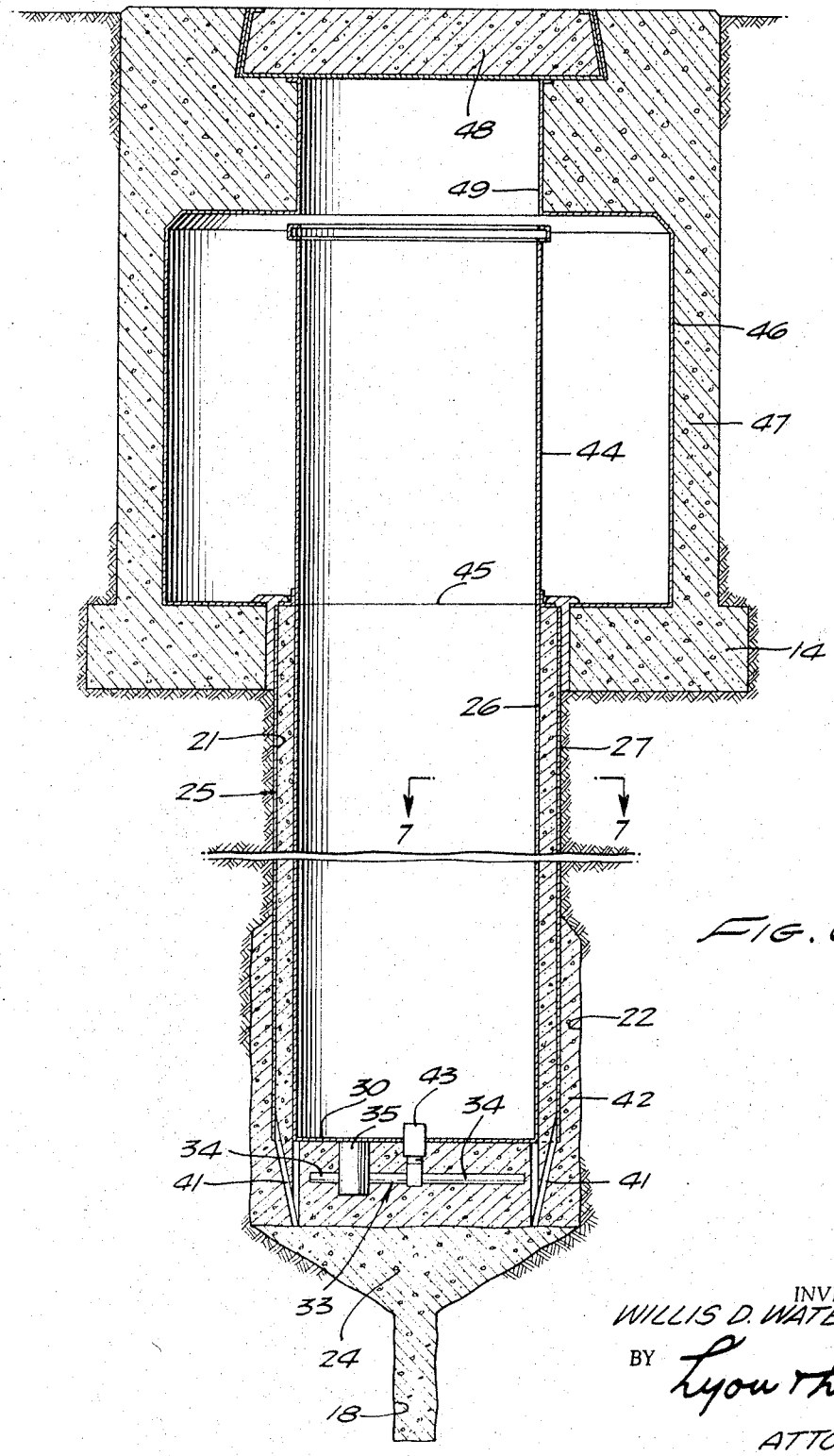


FIG. 6.

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METHOD OF CONSTRUCTING AN UNDERGROUND STRUCTURE

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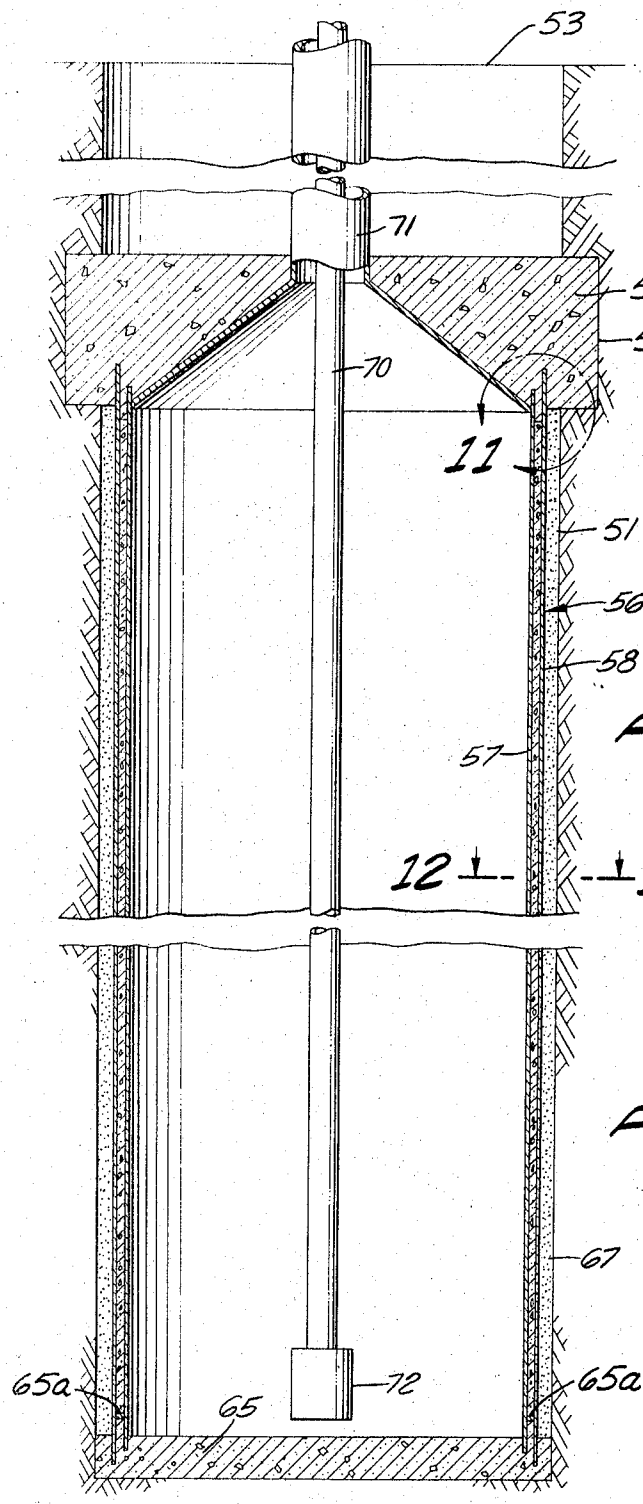


FIG. 10.

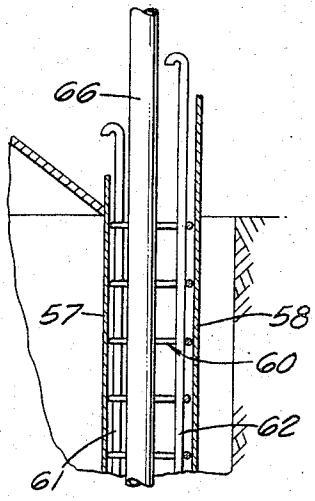


FIG. 11.

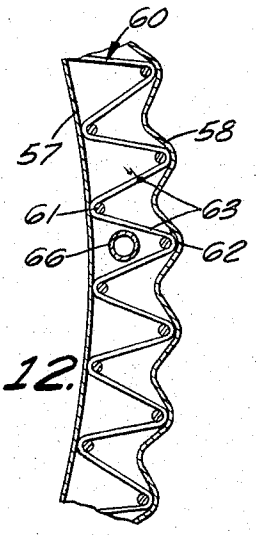


FIG. 12.

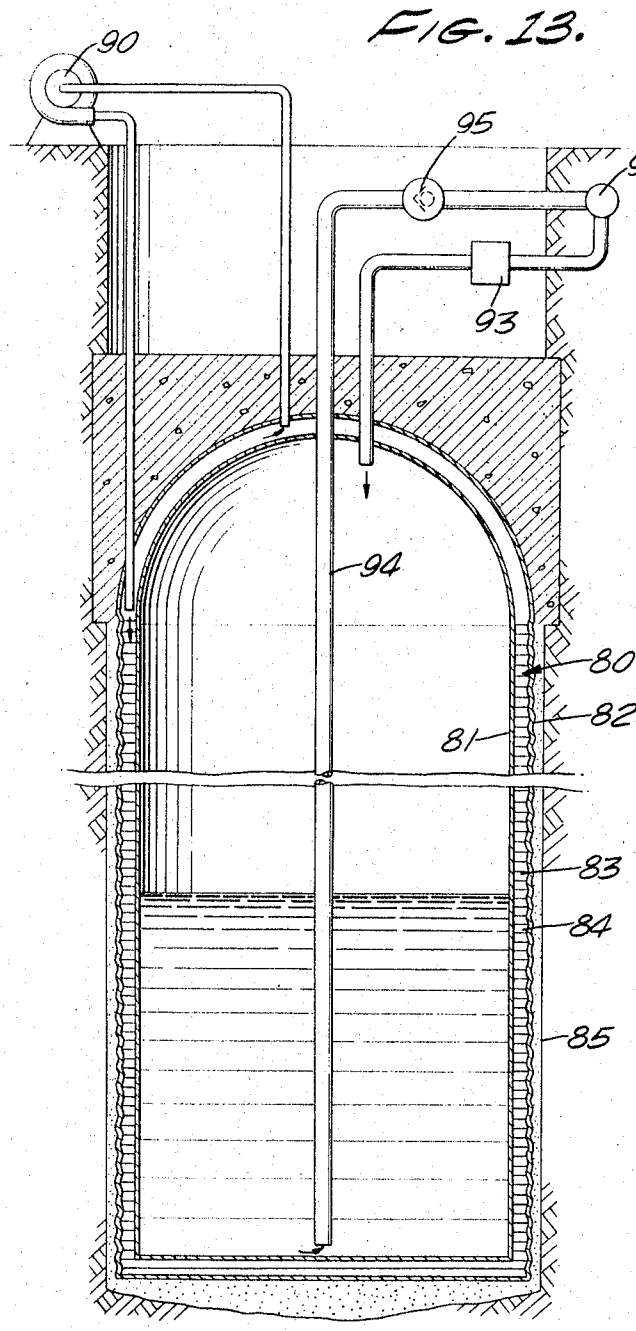
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METHOD OF CONSTRUCTING AN UNDERGROUND STRUCTURE

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FIG. 13.



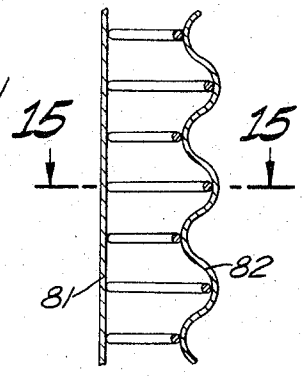


FIG. 14.

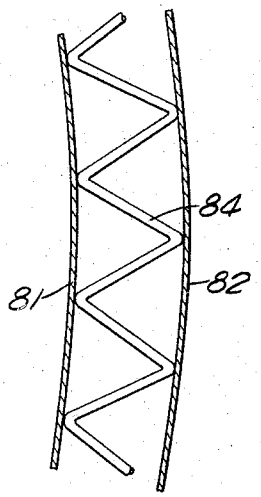


FIG. 15.

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3,307,361

METHOD OF CONSTRUCTING AN UNDERGROUND STRUCTURE

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Original application Oct. 21, 1964, Ser. No. 405,432. Divided and this application Sept. 1, 1965, Ser. No. 495,372

9 Claims. (Cl. 61—41)

This application is a division of my copending application Serial No. 405,432 filed October 21 1964, which application was a continuation-in-part of my earlier application Serial No. 207,658, filed July 5, 1962, now abandoned.

This invention relates to method of constructing an underground structure and is particularly directed to construction of such a structure having double walls, the space between the walls containing reinforcing elements and being filled with cementitious materials to form an integral trussed beam.

Briefly stated, the method comprises lowering a double wall member axially into a shaft in the earth containing liquid, the walls being closed at the lower end to form a buoyancy chamber, and introducing cementitious material between the bottom end of the shaft and the lower end of the closed wall and into the space between the walls to form a continuous reinforced concrete beam.

An important object of the present invention is to provide a novel form of double-wall housing member as well as a novel method for installing it underground in an upright position.

Another object is to provide a structure of this type, having a metal liner encircled by a metal shell with reinforcing elements positioned in the space between the liner and shell, the remainder of the space being filled with cementitious material.

Another object is to provide such a structure in which the liner and shell are circular in cross-section and wherein the reinforcing elements are located in the annulus between them to form a trussed circular beam, the remainder of the annular space being filled with cement grout.

Another object is to provide a novel method of installing such a structure upright in an underground location.

Other and more detailed objects and advantages will appear hereinafter.

In the drawings:

FIGURES 1, 2, and 3 are side elevations in diagrammatic form, showing steps in forming the shaft in the earth for subsequent reception of the double-walled reinforced structure.

FIGURES 4 and 5 are side elevation views in diagrammatic form, showing steps in the method of placing the double-wall reinforced structure in position.

FIGURE 6 is a side elevation of the completed structure installed in an underground location.

FIGURE 7 is a sectional view, partly broken away, taken substantially on the lines 7—7 as shown in FIGURE 6.

FIGURE 8 is a perspective view, partly broken away, illustrating a modified form of the double-wall reinforced structure.

FIGURE 9 is a view similar to FIGURE 8, showing a second modification.

FIGURE 10 is a view similar to FIGURE 6, showing a third modification.

FIGURE 11 is an enlarged sectional detail taken in the location shown by the arrows 11 on FIGURE 10.

FIGURE 12 is a transverse sectional detail taken substantially on the lines 12—12 as shown in FIGURE 11.

FIGURE 13 is a view similar to FIGURE 10, showing a further modification.

FIGURE 14 is an enlarged sectional detail of a portion of FIGURE 13.

FIGURE 15 is a sectional view taken substantially on lines 15—15 as shown on FIGURE 14.

Referring to the drawings, an excavation is first made in the earth to form a shallow hole 10 having sloping sides 11 and a horizontal floor 12. A support structure 13, including a base ring 14, is then installed on the floor 12. A conventional drilling machine 15 turns a sectional pipe 16 having a bit 17 at the lower end in a conventional manner. A small diameter hole is thus drilled to the desired depth.

As shown in FIGURE 2, the small hole 18 is enlarged by means of a wing bit 19, having a pilot 20 and carried on the lower end of the sectional drill pipe 16. A relatively large diameter shaft 21 is formed by the bit 19 as the drilling machine 15 turns the drill pipe 16. An under-reamer, not shown, is then used to form an enlarged cavity 22 at the lower end of the shaft 21. Cementitious material, such as, for example, concrete, is then introduced into the lower end of the hole by means of a tremie pipe 23. The concrete displaces the drilling fluid in the hole and forms a plug 24, filling the lower end of the shaft 21. The tremie pipe 23 is then withdrawn.

A double-wall housing member, generally designated 25, is constructed in the shop and transported to the jobsite. As shown in the drawings, this member 25 comprises a cylindrical steel liner 26 encircled by a cylindrical steel shell 27. The liner and shell are concentric, and the annular space 28 between them contains steel reinforcing members 29 integrally joined to the shell and liner by welding. Member 25 thus comprises a trussed circular beam.

A circular bottom wall 30, formed of steel plate, closes the lower end of the liner 26. A pipe coupling 31 is mounted centrally of this bottom wall 30 and projects therethrough. A grout delivery pipe 32 extends centrally through the member 25 and is connected to the coupling 31 at its lower end. A grout distributor assembly 33 is connected to the coupling 31 below the bottom wall 30. This assembly 33 includes a central hollow member, having a plurality of tubular spokes 34 radiating therefrom.

A short hollow tubular member 35 is closed at its lower end and also projects below the bottom wall 30 and communicates with the interior of the liner 26, to form a sump.

The diameter of the shaft 21 is only slightly larger than the outer diameter of the cylindrical shell 27, while the cavity 22 is considerably larger. The member 25, which may be constructed in the shop under ideal conditions, is transported to the jobsite and then placed in upright position over the shaft 21. Conventional means are employed for lowering the double-wall member 25 into the shaft which is initially filled with drilling fluid. Since the lower end 30 of the member 25 is closed, the member may be "floated" into position, displacing the

mud fluid 22 from the hole 21 and enlarged cavity 22. Control of the member 25 during the lowering operation is facilitated by controlling the buoyancy thereof, and this is effected by admitting drilling fluid into the interior of the liner 26. As the member 25 moves downward into the shaft, drilling fluid is displaced upward through the clearance space between the shell 25 and the hole 21 and also through the annular space 28 between the shell 27 and the liner 26.

FIGURE 4 shows the position of the parts at the end of the lowering operation. In this position, the lower end of the member 25 projects into the enlarged cavity 22, and the grout distributor device 33 lies immediately above the cementitious plug 24. Drilling fluid remains in the enlarged cavity 22 and in the shaft 21 outside the member 25 and also remains inside the annular space 28. Excess drilling fluid displaced from the cavity 22 and shaft 21, and not transferred into the interior of the liner 26, is pumped from the hole 10 by conventional means, not shown.

Grout delivery pipes 37 are then installed in the annular space 28 so that their lower ends terminate near the lower end of said space 28, and grout is then forced downward through the pipes 32 and 37 into the lower end of the enlarged cavity 22. This action displaces the remaining drilling fluid and causes it to escape upward through the annulus 28 and through the clearance space between the shaft 21 and the shell 27. A trough 38 may be provided at the surface, if desired, to facilitate in removing the drilling fluid thus displaced by means of pump 39 and discharge pipe 40. Efficient displacement of drilling fluid by means of grout is assured by the action of the radiating hollow spokes 34 on the grout distributor 33. After the drilling fluid has been completely displaced by grout from the large cavity 22 and shaft 21, additional grout material is introduced through the pipes 37 while the pipes are withdrawn in an upward direction, thereby assuring complete filling of the annular space 28 with cementitious material.

In FIGURE 6 there is shown a cross-section of the completed installation. Metal landing shoes 41 fixed to the lower end of the double-wall member 25 are shown in position and embedded within the cementitious sheath 42. These landing shoes 41 are omitted in FIGURES 4 and 5 for clarity of illustration. The interior of the liner 26 is pumped free of drilling fluid, and the group pipes 32 and 37 are withdrawn. A metal plug 43 replaces the coupling 31. A tubular extension 44 projects upward from the liner 26 and is connected thereto by means of a welded joint 45. An enclosure 46 formed by reinforced concrete walls 47 surrounds the upward extension 44, and the member 14 may be joined integrally to form a part of the walls 47. A reinforced concrete cover 48 may be provided and mounted to slide horizontally to expose the central opening 49, when desired.

From the above description, it will be understood that the double-wall member 25, with its reinforcing elements forming a trussed circular beam, forms an exceptionally strong underground housing or silo for a missile. Moreover, the relatively light weight of the double-wall structure permits its fabrication under factory conditions rather than field conditions, and subsequent installations without danger of collapse.

The modified form of my invention, shown in FIGURES 10, 11, and 12, relates to a storage vessel 56 for liquid petroleum gas. The vessel comprises a steel and prestressed concrete structure that is capable of storing vapor-phase products under high pressures. A hole 51 is drilled in the earth having a diameter and depth to accommodate the size of the storage vessel. As an example, the diameter may be about 20 feet and the depth about 250 feet, for a vessel of 10,000-barrel volume. A portion 52 of the hole 51 is reamed to a larger diameter near the upper end of the vessel 50, for example, about 25 to 32 feet below the ground surface 53. This reamed section 52 of the hole 51 provides space for the later construction of a concrete disk or cap 54 that is thus effectively keyed to undisturbed earth materials.

The double-wall casing member 56 is preferably prefabricated in sections and comprises a cylindrical metal liner 57 encircled by a cylindrical metal shell 58. The metal shell 58 is longitudinally corrugated as shown in FIGURE 12. A cage 60 of metal-reinforcing bars is positioned in the annular space between the liner 57 and the corrugated shell 58. The cage 60 includes vertical bars 61 welded to the liner 57, vertical bars 62 spaced therefrom in a circumferential series, and horizontal crimped reinforcing bars 63 welded to the vertical bars 61 and 62 and welded to the liner 57. The vertical bars 62 are spaced so that they extend into the outer portions of the longitudinal corrugations in the shell 58. Vertical grout pipes 66 are loosely positioned within the reinforcing cage 56.

The double-wall casing member 56 is "floated" into the hole 51, additional sections being connected end-to-end as the lowering operation progresses. The rate of lowering the casing member 66 is controlled by pumping water into the annular space between the liner 57 and shell 58. This annular space is closed at the bottom by means of the annular steel ring 65*a*. When the entire member 56 has been placed in position adjacent the bottom of the hole 51, a sand layer 67 is placed in the annular space between the corrugated shell 58 and the hole 51.

After placement of the sand layer 67, the annular space between the liner 57 and shell 58 and the interior of the vessel are both filled with water. Cement is then poured through the pipe 71 to form the concrete floor 65 and is allowed to set. Grout is then pumped under pressure through the grout pipes 66 to fill the annular space between the liner 57 and the corrugated shell 58 with cementitious material. The grout pipes 66 are withdrawn upwardly while the pumps continue to force grout through the pipes 66 to fill the annular space containing the reinforcing cage 60. The pumping pressure is controlled by limiting the flow of water displaced from the annular space. The pressure grouting expands the outer shell 58 against the sand layer 67, but the liner 57 is substantially unaffected, because the pump pressure of the grout acts upon the water confined within the vessel. After the grouting operation is complete and the grout pipes 66 are completely withdrawn from the annular space, the curing of the grout takes place while the interior of the vessel is still full of water. The earth exerts a ring-compression force against the vessel for effectively closing any longitudinal cracks that may develop in the concrete grout. Circumferential cracks are closed by the weight of the vessel and to some degree by elastic rebound of the steel liner and shell and of the reinforcing cage 60. After the water has been removed from the interior of the vessel, the reinforced concrete cap 54 is poured in position within the portion 52 of the hole 51.

It will be observed that after construction of the vessel has been completed by the steps described above, that the corrugated steel shell 58 exerts compressive stresses on the concrete in the annular space between the liner and the shell. No unbalanced forces are exerted on the shell 57 of the vessel during the cementing operation because the closed interior of the vessel is filled with water at that time. The water may be removed from the storage area within the vessel by pumping through a product pipe 70, which projects through the pipe 71 connected to the interior of the vessel at its upper end. The liquid petroleum gas may be pumped into the vessel through the annular space between the pipes 70 and 71, thereby forcing the water in the vessel to be discharged through the pipe 70. A submersible pump 72 is attached to the lower end of the pipe 70 for the purpose of discharging liquid petroleum gas through the interior of the pipe 70. Suitable valve connections, not shown, are provided at the ground surface.

The modified form of the invention shown in FIGURE 13 relates to storage of liquid natural gas in a refrigerated underground pressure vessel. The pressure vessel **80** is of the double-wall construction previously described and includes a metal cylindrical liner **81** enclosed by a metal corrugated shell **82**. The corrugations of the shell **82** extend circumferentially rather than longitudinally. The annular space **83** between the liner **81** and the shell **82** contains metal reinforcing bars welded to both the liner **81** and the shell **82**. These bars **84** may take any suitable or desirable form, and they serve as reinforcing spacers between the liner **81** and the shell **82**. The shell **80** is floated into position within the hole **85** in the manner described above, and an insulating type of concrete, preferably containing vermiculite, is placed in position within the hole **85** and outside the corrugated shell **82**.

A thermostatically controlled compressor **90** at the surface together with associated refrigerating means, not shown, cools the annular space between the liner **81** and shell **80** to form a condensing tank of the interior of the vessel. This "cold tank" draws natural gas from the main **91** through reducer **93** due to lowering of the temperature in the inside of the tank. In effect, a "rain" of methane occurs in the tank. The pressure reducer **93** is needed to avoid exceeding the design stress of the tank.

When pressures in the main **91** are lowered by excessive demand, the pressure in the vessel forces liquid gas back into the main through pipe **94** and check valve **95**, where it is regasified either artificially or by the ambient temperature of the ground. Alternatively, pressures in the vessel may be somewhat lower, and a pump may be used to return gas to the main **91**.

The following are among the advantages of the apparatus shown in FIGURE 14: Natural gas can be placed in storage during low-use months with relatively small compressing equipment. The operation of the storage is automatic. The vessel is cooled uniformly, thus reducing differential stresses occasioned by the low temperatures. The refrigerant (methane) also acts as an insulator. Relatively small storage facilities can be located along distribution systems to maintain minimal line pressures, much like stand-pipes on water-supply systems. Natural gas, rather than relatively pure methane, can be stored because the liquid mixture of hydrocarbons is returned to the main. The heat transfer through the reinforcing bars is insignificant because of their small cross-sectional area. No corrosion of the steel liner or shell occurs, because of the low operating temperatures.

Having fully described my invention, it is to be understood that I am not to be limited to the details herein set forth but that my invention is of the full scope of the appended claims.

I claim:

1. The method of constructing an underground structure of the type described, comprising the steps of: forming an upright shaft in the earth, maintaining liquid in said shaft, floating a double-wall member axially of the shaft, the lower end of the inner wall being closed to permit floating of the member downward in the liquid until the lower portion of the member is positioned near the bottom of the shaft, and introducing cementitious material to fill the space between the lower end of the member and the shaft, and to fill the space between the inner wall and the outer wall.

2. The method of constructing an underground structure of the type described, comprising the steps of: forming an upright shaft in the earth, lowering a double-wall member axially of the shaft to bring the lower portion of the member adjacent the bottom of the shaft, providing a bottom for the lower end of the member following the lowering operation, placing a layer of sand between the outer wall of the member and the shaft, filling the interior of the member with a liquid, and introducing cementitious material under pressure into the space between the walls of the member.

3. The method of constructing an underground structure of the type described, comprising the steps of: forming an upright shaft in the earth, maintaining liquid in said shaft, lowering a double-wall member axially into the shaft, the lower end of the inner wall being closed, floating the double-wall member downward in the liquid while displacing liquid upward between the walls of the double-wall member until the lower portion of the member is positioned near the bottom of the shaft, and introducing cementitious material to fill the space between the lower end of the member and the shaft and to fill the space between the walls.

4. The method of constructing an underground structure of the type described, comprising the steps of: forming an upright shaft in the earth, maintaining liquid in said shaft, lowering a member having inner and outer concentric walls axially into the shaft, the lower end of the inner wall being closed by a bottom wall, floating the member downward in the liquid while displacing liquid upward between the concentric walls until the bottom wall of the member is positioned near the bottom of the shaft, and introducing cementitious material to fill the space between the bottom wall of the member and the shaft and to fill the space between the walls.

5. The method of constructing an underground structure of the type described, comprising the steps of: forming an upright shaft in the earth with a lateral enlargement spaced above its lower end, maintaining liquid in said shaft, lowering a vessel having inner and outer concentric walls axially into the shaft, the lower end of the inner wall being closed by a bottom wall, floating the vessel downward in the liquid while displacing liquid upward between the concentric walls until the bottom wall of the vessel is positioned near the bottom of the shaft, and introducing cementitious material to fill the space between the bottom wall of the vessel and the shaft, and introducing cementitious material into the space between the walls and into the shaft above the vessel to fill the lateral enlargement and provide a cap for the vessel.

6. The method of constructing an underground structure of the type described, comprising the steps of: forming an upright shaft in the earth with a lateral enlargement spaced above its lower end, lowering a member having inner and outer concentric walls axially into the shaft to bring the lower portion of the member adjacent the bottom of the shaft, providing a bottom for the lower end of the member following the lowering operation, placing a layer of sand between the outer wall of the member and the shaft, filling the interior of the member within the inner wall with a liquid, introducing cementitious material under pressure into the space between the walls of the member, and introducing cementitious material into the shaft above the member to fill the lateral enlargement and provide a cap over the member.

7. The method of constructing an underground structure of the type described, comprising the steps of: forming an upright shaft in the earth, maintaining liquid in said shaft, floating a double wall member axially into the liquid to a position adjacent the bottom of the shaft, the member comprising a metal liner part encircled by a metal shell part, one of said parts being closed at the lower end to form a buoyancy chamber to increase the buoyancy of the double wall member in the liquid, the space between said parts containing metal reinforcing elements, and introducing cementitious material between the bottom of the shaft and the lower end of said closed part and into said space to form a continuous reinforced concrete beam.

8. The method of claim **7** in which the lower end of the liner is closed to provide buoyancy during the floating operation.

9. The method of claim 7 in which the lower end of the member is closed between the liner and shell to provide buoyancy during the floating operation.

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