Nov. 23, 1971 L. A. STARR ET AL 3,621,662

UNDERWATER STORAGE STRUCTURE AND METHOD OF INSTALLATION

Filed Sept. 29, 1969 5 Sheets-Sheet 1

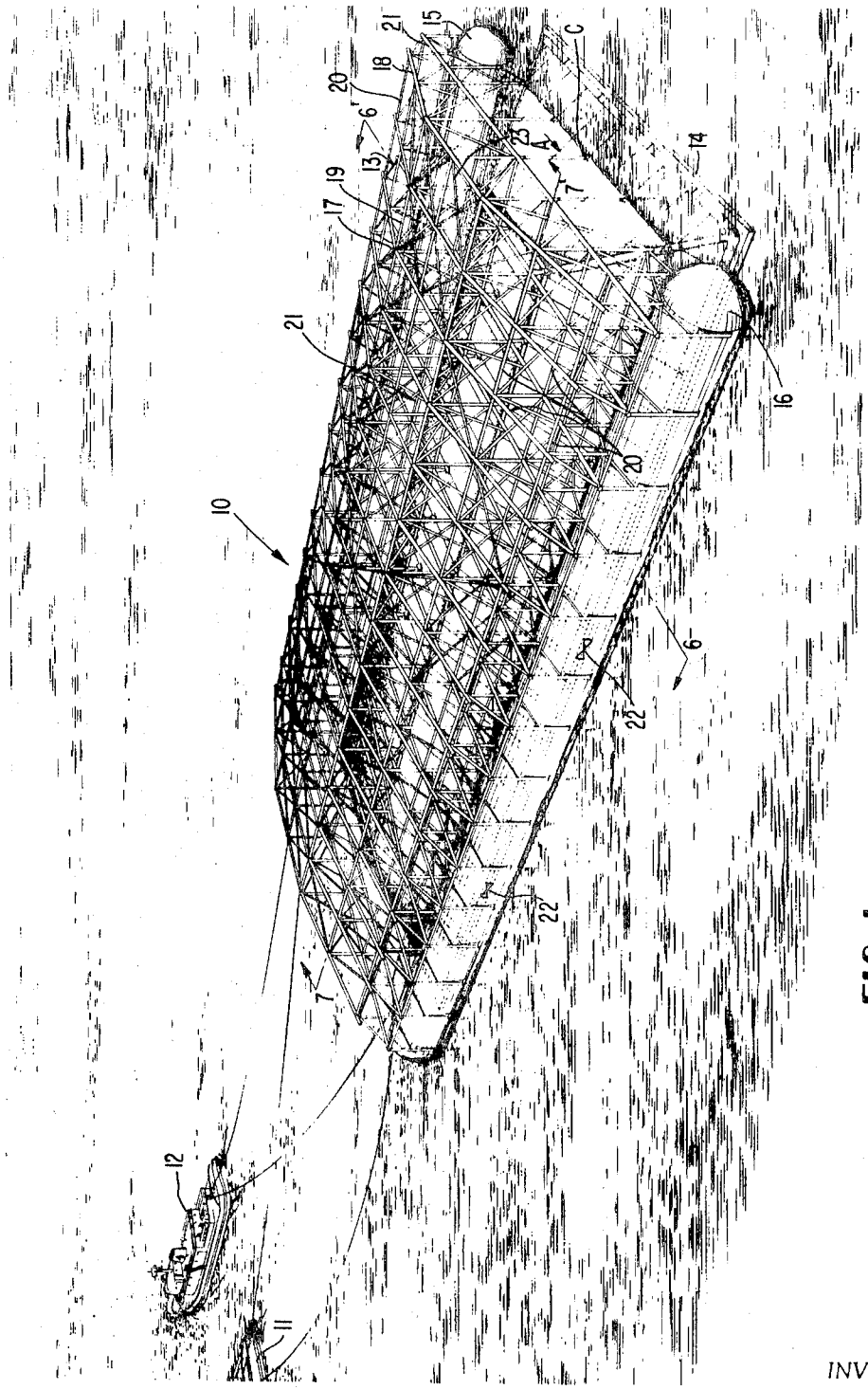


FIG. 1

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UNDERWATER STORAGE STRUCTURE AND METHOD OF INSTALLATION

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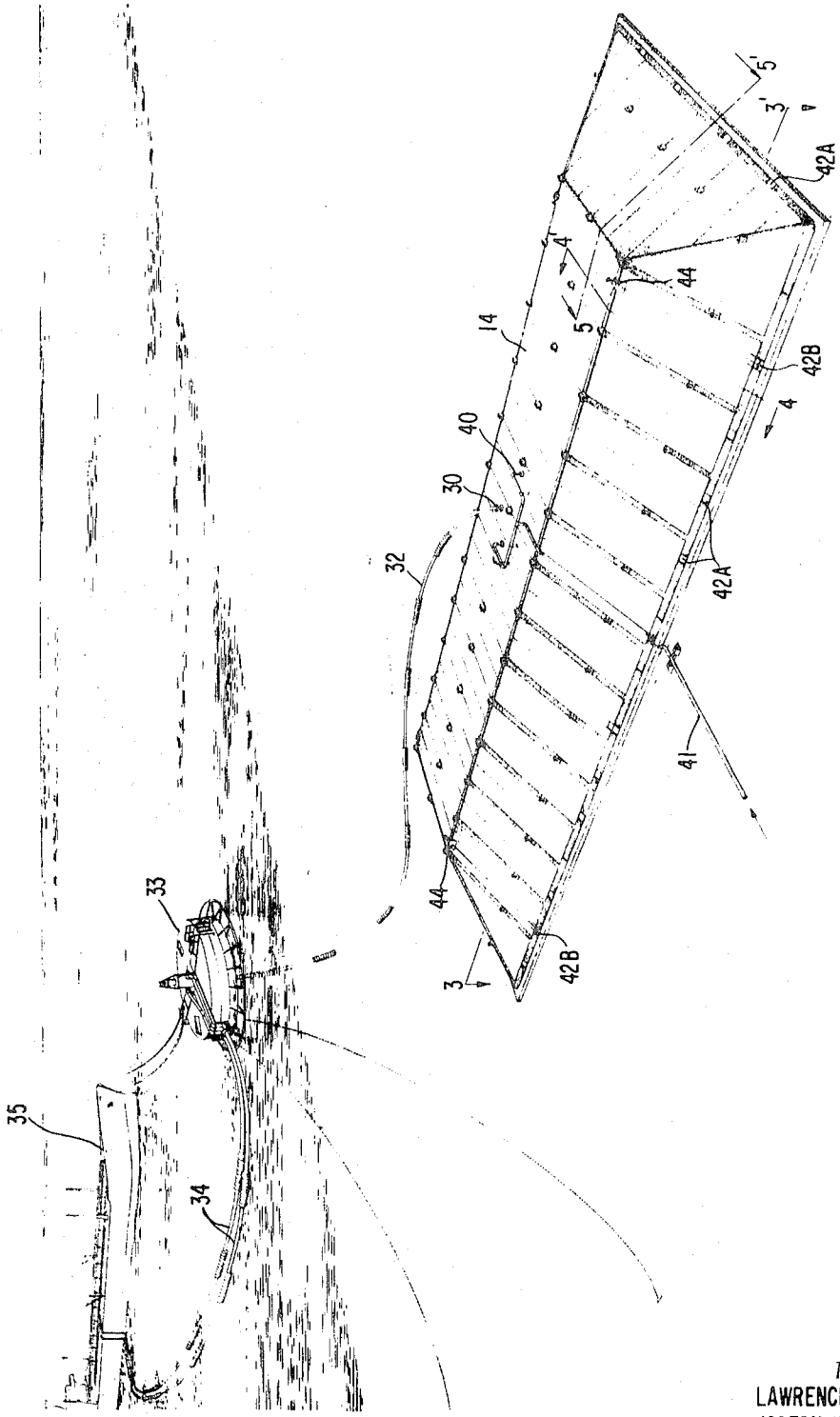


FIG. 2

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UNDERWATER STORAGE STRUCTURE AND METHOD OF INSTALLATION

Filed Sept. 29, 1969 5 Sheets-Sheet 3

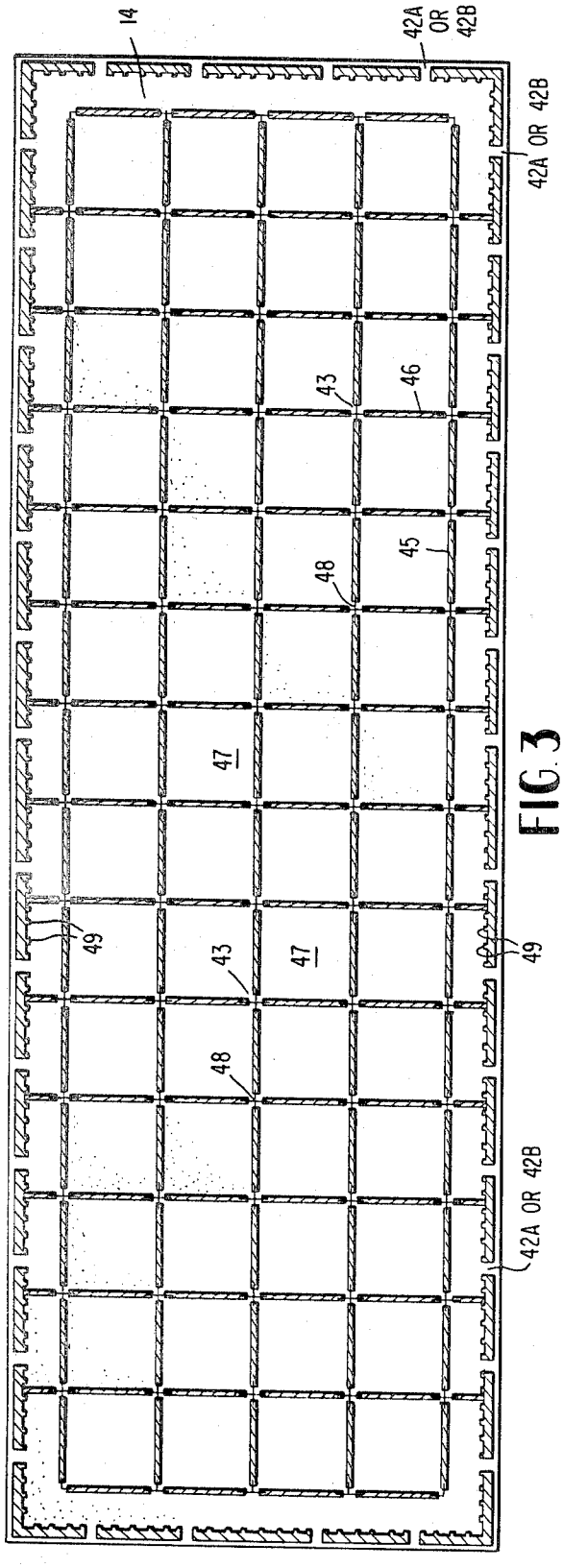


FIG 3

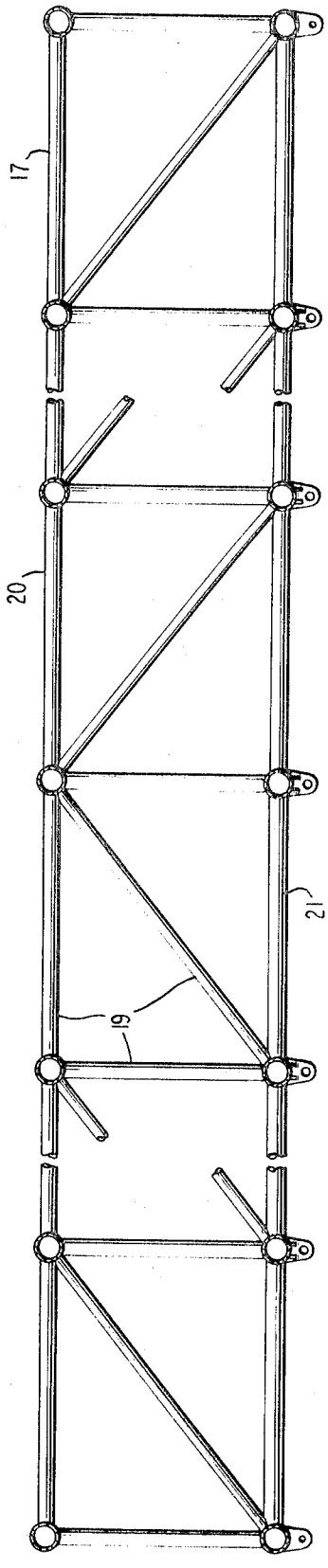


FIG 7

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UNDERWATER STORAGE STRUCTURE AND METHOD OF INSTALLATION

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FIG.4

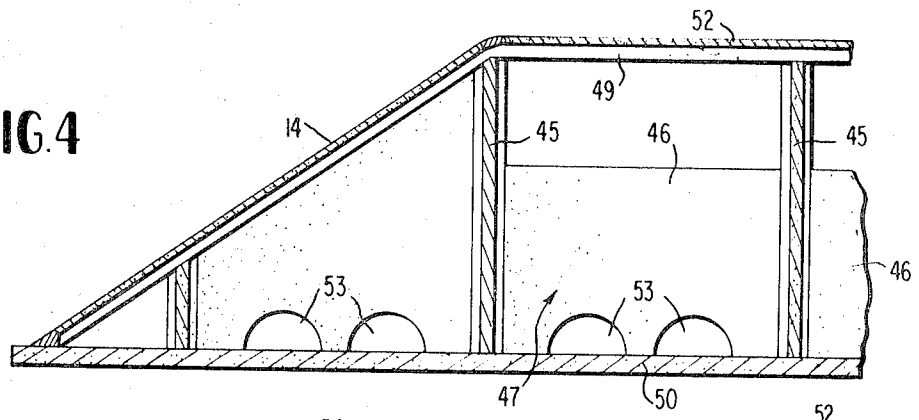


FIG.5

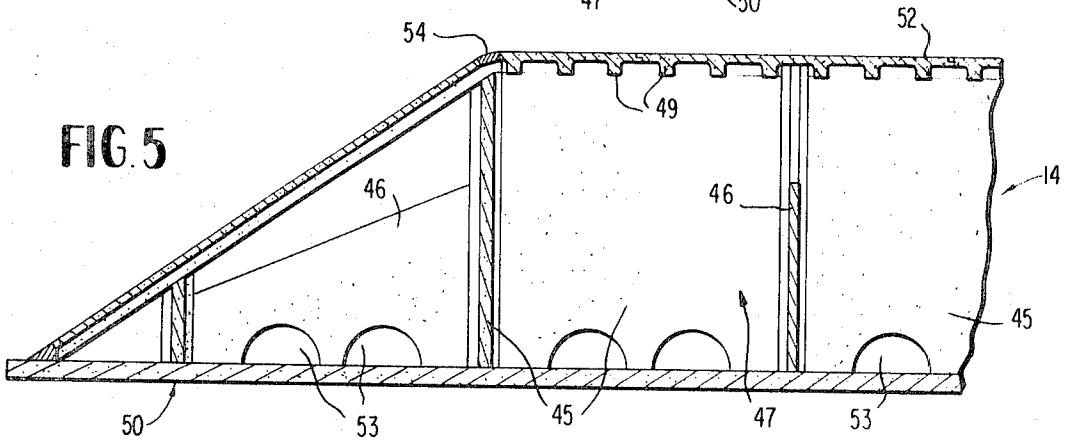


FIG.11

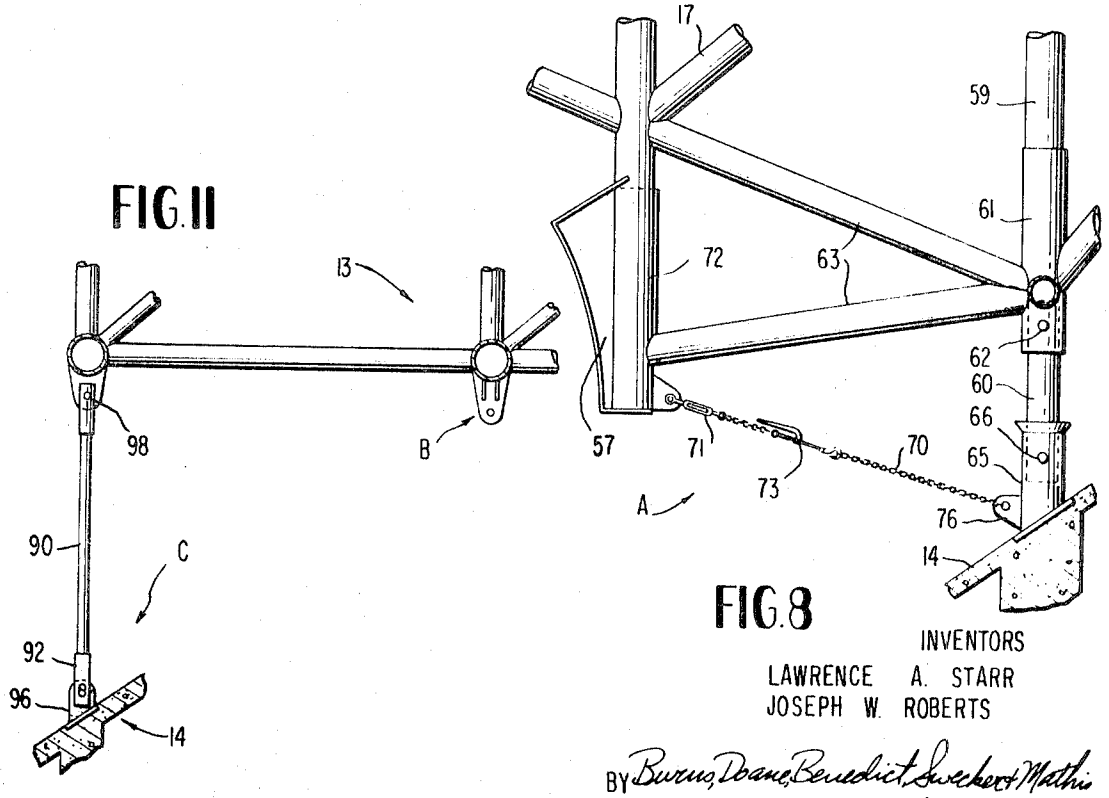


FIG.8

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UNDERWATER STORAGE STRUCTURE AND METHOD OF INSTALLATION

Filed Sept. 29, 1969 5 Sheets-Sheet 5

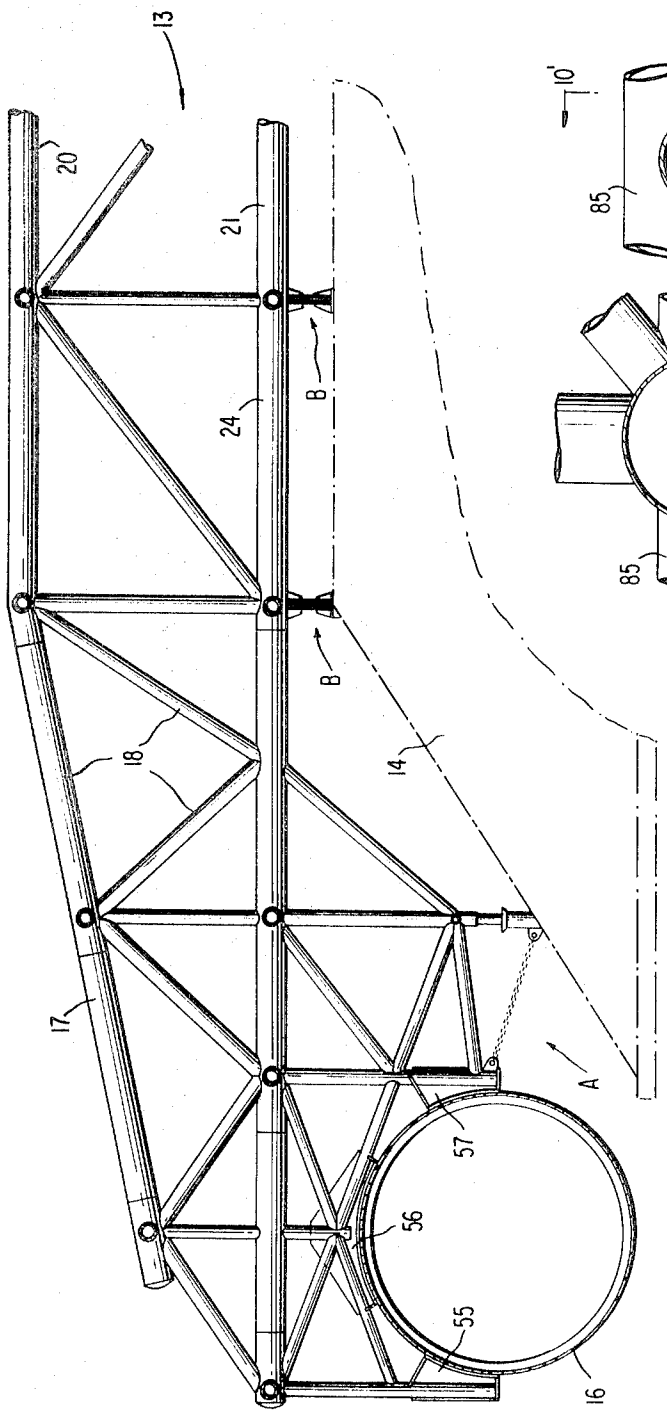


FIG 6

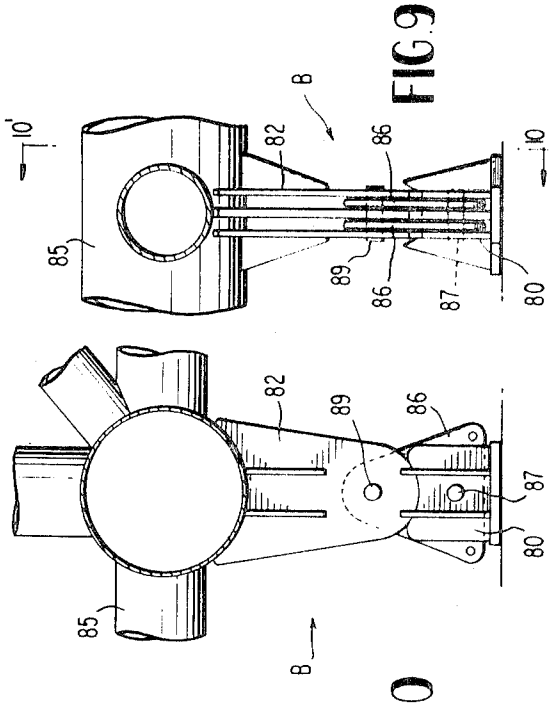


FIG 9

FIG 10

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3,621,662

UNDERWATER STORAGE STRUCTURE AND METHOD OF INSTALLATION

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Filed Sept. 29, 1969, Ser. No. 861,560
Int. Cl. B63b 35/44; E02b 17/00
U.S. Cl. 61—46.5 16 Claims

ABSTRACT OF THE DISCLOSURE

An underwater storage structure, for fluids such as oil which are immiscible with and of lesser specific gravity than water, is capable of being towed to a site and submersed to the floor of the body of water. The storage structure is made of concrete and has a truncated pyramidal shape with the interior of its lower portion in communication with the body of water. A tender frame having tanks for buoyancy and ballasting may be used to install the storage structure on the floor of the body of water. The installation procedure includes positioning the tender frame over the storage structure, tying the tender frame to the storage structure, flooding the storage structure, and ballasting the tender frame to achieve negative buoyancy and to position the storage structure on the floor of the body of water.

FIELD OF THE INVENTION

The present invention relates to an underwater storage structure and to methods and apparatus for installing the structure on the floor of a body of water.

BACKGROUND OF THE INVENTION

In recent years, the continued exploitation of offshore petroleum oil resources has presented the problem of storing the oil produced. That is, in many instances the location of offshore wells makes it impractical to pipe the oil directly to storage tanks on shore. The effects of wind, waves, tide and currents acting on pipelaying vessels and pipelines laid, as well as underwater topography, tend to make it difficult to lay a pipeline such distances under water. Although the oil can be piped directly from the well to a waiting tanker vessel, this approach is not generally economical because of the scheduling and time involved in pumping the products from the well to the tanker. Another approach to handling the products is to store them in one or more tanks in the vicinity of the offshore wells and to transfer them to a tanker when the supply is large enough.

Again, because of the wind, waves, tide and currents, as well as the water depths encountered in offshore oil production, the provision of storage tanks or structures at the site has presented many engineering problems. To be economically useful, such tanks must be of large volume, such as of 100,000 barrel capacity and upwards. The large size of the tanks, and the unwieldy construction problems which would be involved in building them offshore, has effectively made it essential that they be built completely, or in major components, on land and transported to the offshore site for positioning on the floor of the body of water. Thus, such storage structures must also be adapted to float on the surface of the body of water prior to installation so as to be manageable by tugs when being towed long distances. Towing the tanks to the site involves all the problems of buoyancy and stability plus maintenance of structural integrity.

Upon arriving at the offshore site, the tanks are lowered or submerged until they are supported by or rest upon the floor or bed of the body of water. Problems involved

during submerging operations include dangerous listing or tilting of the tank and control of its rate of descent.

Another of the problems which has been associated with a submerged storage tank structure is that of providing for the rigid and positive anchoring necessary due to the tremendous buoyancy effect of the contained products which are lighter than water. Additionally, the underwater storage structure must be able to withstand the lateral drag forces produced by strong underwater currents and even surface waves.

A corollary problem to be met during installation of the storage tank structure at a remote offshore site is that of the expense and/or scarcity of handling equipment which may be necessary for installing very large storage tank structures. It would certainly be advantageous if the storage tank structure could be lowered to the floor of the body of water with as little aid as possible from derrick barges or the like which could be in short supply and expensive to rent in remote areas.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide an underwater storage structure which substantially alleviates or prevents the problems discussed above.

Another object of the present invention is to provide a tender frame attachable to an underwater storage structure, the frame capable of being towed to a site and submerged to the floor of a body of water.

Another object of the present invention is to provide a method for installing a submersible underwater storage structure on the floor of a body of water.

Other objects and advantages of the present invention will become apparent from the disclosure herein.

In accordance with the present invention, an underwater storage structure is provided for fluids immiscible with and of lesser specific gravity than water, which structure is capable of being towed to a site and submersed to the floor of the body of water. The underwater storage structure comprises a storage container fabricated primarily from or being of concrete to provide a net negative buoyancy when positioned on the floor of the body of water and filled with the buoyant immiscible fluid. Moreover, the container has a truncated pyramidal shape which tends to increase the frictional sliding resistance to lateral forces due to storm waves and currents, and a relatively low profile to decrease the effects of these lateral forces. Means are also provided for removing air from the interior of the container, for communicating the interior of the lower portion of the container with the body of water, and communicating the interior of the upper portion of the container with the supply of the immiscible fluid.

In another aspect of the invention, an underwater storage structure as described above is provided which further has a plurality of interior baffles comprising walls extending between the floor and the roof, the baffles positioned to form cells within the container, and the cells being in communication with each other. These baffles provide increased stability during submerging operations, maintain overall structural integrity, and serve as aids against mixing losses during filling and emptying operations.

In another aspect of the invention, a tender frame is provided for an underwater storage structure, the frame also capable of being towed to a site and submersed to the floor of the body of water. The tender frame comprises first and second parallel horizontal elongated hollow tanks for buoyancy and ballasting, the tanks being spaced apart to allow the container portion of the storage structure therebetween. Reticulated or trusswork structure

means are provided for rigidly connecting the tanks, the reticulated means comprising primary transverse vertical truses spanning between the tanks for transferring loading of the container to the tanks, secondary longitudinal vertical trusses parallel to the tanks and interconnecting the primary transverse trusses for balancing and distributing loading on the primary trusses, the primary and secondary trusses forming spaced-apart upper and lower interconnected horizontal reticulated layers, and secondary horizontal bracing members in the planes of the layers for rigidifying the overall reticulated structure. In a preferred embodiment, the trusses and bracing members comprise rigid tubular members sealed against the intrusion of water to add buoyancy and stability of the tender frame. Means are also provided for admitting water and air to the tanks, and for connecting the tender frame to the storage structure.

In another aspect of the present invention, a method is provided for installing a submersible underwater storage structure on the floor of a body of water, which method includes positioning a tender frame over the storage structure, tying or attaching the tender frame to the storage structure, flooding the storage structure, and ballasting the tender frame to a net negative buoyancy to achieve submergence and to position the storage structure on the floor of the body of water.

Other aspects of the present invention will become apparent from the following description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

In describing the present invention, reference will be made to preferred embodiments shown in the appended drawings.

FIG. 1 provides a perspective view of an underwater storage system in its towing phase.

FIG. 2 provides a perspective view of an underwater storage container in its operational phase.

FIG. 3 provides a top plan sectional view of the underwater storage container shown in FIG. 2, looking downwardly at a horizontal cross section taken along section line 3–3′ of FIG. 2.

FIG. 4 provides a side elevation sectional view of the storage container as viewed along section line 4–4′ of FIG. 2.

FIG. 5 provides a side elevation sectional view of the storage container as viewed along section line 5–5′ of FIG. 2.

FIG. 6 provides a partial front elevation sectional view of the underwater storage system as viewed along line 6–6′ of FIG. 1.

FIG. 7 provides a partial side elevation section view of the underwater storage system as viewed along line 7–7′ of FIG. 1.

FIG. 8 provides a fragmentary view on a larger scale of connection A in FIG. 6.

FIG. 9 provides a fragmentary view on a larger scale of connection B in FIG. 6.

FIG. 10 is a side elevational view of the connection shown in FIG. 9 taken along section line 10–10′.

FIG. 11 is a fragmentary view on a large scale of connection C in FIG. 1 as viewed in the direction indicated by the arrow A.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates in a perspective view an underwater storage system **10** being towed to an offshore site by tug boats **11** and **12**.

The underwater storage system **10** includes a strong back or tender frame **13** and a storage tank or container **14**.

The tender frame **13** has parallel, horizontal, elongated, hollow pontoon-like structures or tanks **15** and **16** which are spaced apart to allow the container **14** therebetween. Reticulated or trusswork means **17** rigidly connect tanks **15** and **16**, and provide the means for transferring the loading from the container **14** to the tanks **15** and **16**.

Valves **22** located on each of the tanks **15** and **16** may be used to supply water and pressurized air to the tanks during ballasting operations to alter buoyancy of the tender frame **13** and, when the tender frame **13** is attached to the storage container **14**, of the overall storage system.

Connecting means C on the frame for connecting the frame **13** to the storage structure or container **14** are discussed in more detail hereinafter.

The storage container **14** is shown more clearly in FIG. 2 which is a perspective view of the underwater storage container in its operational phase.

The container **14** is fabricated primarily from concrete or the like and has a net negative buoyancy when positioned on the floor of the body of water and filled with immiscible fluid such as crude hydrocarbon oil. For example, if the container **14** has a storage capacity of approximately 100,000 barrels, contained crude oil having a specific gravity of 0.87 would produce a buoyant force of about 5.5 million pounds. However, the container **14** when fabricated primarily from concrete and filled with the crude oil would have a net negative buoyancy of over 6 million pounds and, thus, an inherent safety factor against floating of about 2.1. Moreover, such a significant net negative buoyancy, i.e., a safety factor against floating of greater than about 2.0, is also beneficial in activating the frictional forces required to resist lateral movement or sliding of the container **14** when acted upon by wave and current forces.

Further, the container **14** has a truncated pyrimidal shape which tends to increase the frictional sliding resistance to lateral forces due to storm waves and currents, by a resulting pressing down effect which increases the existing normal force.

Another advantage of the shape of container **14** lies in the increased structural integrity of the container as a result of the triangular effects produced by the sloping sides, the container bottom, and the connecting interior vertical walls discussed below.

Fitting **30** on the container **14** may be used to remove air from the interior of the container during submerging operations, and, as shown in FIG. 2, may also be used as exiting means for the fluids stored within the container.

Flexible conduit **32** connects fitting **30** with a terminal or monomooring unit **33**, with flexible conduits **34** connecting the monomooring unit with a tanker **35**.

A fitting **40** atop the storage container **14** connected to conduit means **41** may be used to connect the container **14** with a supply of the immiscible liquid to be stored, which, for example, may be a producing offshore well or the like (not shown).

A plurality of open ports **42A** and **42B** communicate the interior of the lower portion of the container **14** with the surrounding body of water. If desired, the ports may be valved or gated so as to control flow therethrough. For example, ports **42B** spaced uniformly around the container **14** are provided with valves **44** to control flow therethrough. Other ports **42A** may have removable covers or the like bolted on to prevent flow therethrough during installation operations.

Ports **42A** and **42B** will prevent or alleviate the crushing effect of large hydrosatic pressure differentials to which underwater storage containers may be subjected. That is, pipeline pressures will force the water out of the container during loading or filling operations, with the water forcing the stored fluid out during unloading or emptying operations due to the buoyancy of the immiscible fluid.

FIG. 3 illustrates interior structural details of the storage container **14**.

The container **14** has a plurality of interior walls **45** and **46** which extend between the floor and the roof of the container **14**. Wall **45** and most of those parallel to

it serve as bearing walls, while wall 46 and most of those parallel to it serve as stiffener walls. The walls 45 and 46 are connected at their intersections 43 by poured-in-place concrete in conjunction with tied or welded spaced steel rods 48 inserted therein. The plurality of wall intersections 43 serve to contain the anchorage systems for supporting the immersed weight of the container 14 from the ender frame 13 during towing and installation.

FIG. 4 provides a side elevational view of a partial section of the interior of the container 14 as viewed upon section line 4–4′ in FIG. 2. As can be seen from FIG. 4, bearing walls 45 extend from the floor or mat 50 of the container 14 to the bottoms of web portions 49 of the structural components 52 comprising the roof or ceiling of the container 14. Communication between cells 47 over the tops of bearing walls 45 is provided by the spaces between web portions 49 of the roof components 52. Ports 53 at the bases of walls 45 and 46 are provided to allow further communication between the cells 47.

FIG. 5 provides a side elevational view of a partial section of the interior taken along section line 5–5′ of FIG. 2. Stiffener walls 46 are shown which extend part way from the floor or mat 50 but do not touch the roof components 52 of the container 14 to allow communication thereover between cells 47.

Joints such as is indicated at 54 may be sealed by use of various combinations of synthetic resin waterstops or seals, and small quantities of poured-in-place concrete. In addition, the inner surfaces of the container 14 may be sprayed with a filler or sealer material for the purpose of surface densification.

FIG. 6 is a partial front elevation sectional view of the underwater storage system shown in FIG. 1 as viewed along line 6–6′ of FIG. 1. As can be seen from FIG. 6, tank 16 may be attached to the reticulated connecting structure 17 by means of welds at saddle points 55, 56 and 57. Preferably, the tanks 15 and 16 and the connecting structure 17 are designed such that the natural displacement level of the tender frame 13 is such that the frame may be floated over the container 14 when the container is at its natural displacement level to facilitate installation procedures as described below.

FIG. 7 is a partial side elevation sectional view of the underwater storage system as shown in FIG. 1 as viewed along line 7–7′ of FIG. 1. FIG. 7, in conjunction with FIG. 1 and FIG. 6, illustrate the reticulated connecting structure 17. The reticulated structure 17 comprises primary transverse vertical trusses 18 spanning between the tanks 15 and 16 for transferring loading of the container 14 to the tanks 15 and 16. Secondary longitudinal trusses 19 are parallel to the tanks 15 and 16 and interconnect the primary transverse trusses 18 for balancing and distributing of the loading on the primary trusses 18. The primary trusses 18 and the secondary trusses 19 form spaced apart upper and lower interconnected horizontal reticulated layers 20 and 21, respectively. In the planes of the layers 20 and 21, secondary horizontal bracing members 23 are provided to rigidify the overall reticulated structure 17. Preferably, the individual rigid members 24 making up the reticulated structure 17 are tubular, i.e., hollow, and are sealed against the intrusion of water. Thus, added buoyancy and stability are provided for the tender frame 13.

The means connecting the tender frame 13 with the container structure 14 are more clearly shown in FIGS. 8 through 11.

FIG. 8 is a fragmentary view on a larger scale of connection unit A of FIG. 6.

A vertical tubular truss member 59 with socket end member 61 is part of transverse frame structure 63. Tubular member 60 connects socket end member 61 and receiving pipe member 65 which is mounted on the storage container 14. Tubular member 60 is free to nest or telescope into socket end 61 prior to connection of the container 14 and the trusswork 17. After connection, pin 62 holds tubular member 60 fast in socket end 61, and pin 66 holds the tubular member 60 fast in pipe member 65. A chain 70, load binder 73, and turnbuckle 71 provide connecting means between vertical tubular member 72 and a flange member 76 on pipe member 65 for lateral stability.

FIG. 9 is a fragmentary view on a larger scale of connection B of FIG. 6. FIG. 10 is a side elevational view taken along line 10–10′ of FIG. 9. As can be seen from FIGS. 6, 9 and 10, a flange member 80 on container 14 is connected to flange member 82 of tubular trusswork 85 by means of connector plates 86 which are pinned to the flange 80 and the flange 82 at points 87 and 89 respectively. Prior to connection, connector plates 86 may nest in flange 82 by swinging or folding up around point 89.

FIG. 11 is a fragmentary view on a larger scale of connection C in FIG. 1 as viewed in the direction indicated by arrow A. As can be seen from FIG. 11, vertical tubular frame member 90 has a slotted member 92 for receiving an upstanding lug 96 which is mounted on the container 14. The upstanding lug 96 and the member 92 are held fast by a pin fastener (not shown). Prior to connection, frame member 90 may be swung up about point 98 as desired for ease of handling tender frame 13.

In operation, the tender frame 13 may be designed to be moved or floated into position over the floating storage container 14 while they are both floating freely at their natural displacement level at a site near shore. The container 14 may have its ports 42A and 42B closed at this point to prevent flooding and sinking. The tender frame 13 is then ballasted down by supplying water to tanks 15 and 16 through valves 22 to allow attachment of the container 14 at the various connecting points. After effecting these connections, the buoyancy tanks 15 and 16 may then be deballasted by pumping or otherwise forcing the water out, thus elevating the container 14 to a position slightly higher than its natural displacement level. Any hydrostatic pressures on the container 14 are thereby reduced somewhat. The complete system is then ready for tow.

For towing, two or more tugs 11 and 12 may be supplied to push or pull in tandem, or pull and push by placing one tug in front of the system and one behind.

Although the buoyancy tanks 15 and 16 provide an appreciable degree of protection for the container sides, it may be desirable to build additional forward shielding on the tender frame 13 if necessary, e.g., where open water is extremely rough, but this may create additional drag.

Once deep water has been reached, the container 14 may be flooded by selectively opening ports 42B so that the overall system attains a stable attitude whereby it floats at some plane in the tender frame 13. In this manner, it may be possible to eliminate any shell stresses due to hydrostatic pressure differential for the remainder of the tow.

With the container and tender frame systems at the offshore site on the surface of the body of water, the following procedural sequence is applicable to its installation.

Depending upon the existing conditions at the sea or ocean bed or floor of the body of water, particularly as related to topography, some degree of sweeping and leveling may be required. It may be assumed that this type of work will be minimal, however, or else an alternate site could be selected. A relatively smooth site is desirable, for a level or horizontal plane maximizes effective storage capacity.

During submerging operations, work or derrick barges may be used, if desired, in such a manner as to provide lateral stability for the container and tender frame system. To initiate sinking or submergence operations, the storage container ports 42B may be opened to flood the container 14 if it was towed in an unflooded condition.

Flooding control may be provided by proper selection of port opening sizes and their locations.

The interior walls **45** and **46** provide a baffling system to control excessive compartment interflow and thus contribute significantly to the stability of the system during this phase of the installation.

After the flooding procedure has been initiated, the interior air pressure of the container **14** may build up to a level which requires venting. At this stage, additional flooding control is available through proper setting and subsequent resetting of suitable pressure relief valves of such size and location as is necessary.

The buoyancy tanks **15** and **16** are sized on the basis of providing enough displacement to offset the immersed weight of the storage container **14**, plus the tender frame **13** weight in air, including the buoyancy tanks. With the tender frame **13** secured to the container, the relative positions of the buoyancy tanks **15** and **16** may place their bottoms at the same elevation as the top of the container mat **50**. The tops of the buoyancy tanks **15** and **16** may also be below the container top or roof components **52**. Therefore, a point may be reached near the end of the flooding cycle whereby inflow will cease because the exterior and interior pressure heads are balanced. Even when the container air bubble is exhausted to atmospheric and the interior and exterior water surfaces attain a common level, the container **14** may not be completely flooded. To finish the flooding operations, it may be necessary to introduce water into the buoyancy tanks **15** and **16** equally for balance.

Upon completion of container flooding the system reaches a stable position floating on the tender frame **13**. Additional ballasting of the buoyancy tanks **15** and **16** is then required to offset the natural buoyancy of the tender frame and bring about a state of overall negative buoyancy to the system.

Once the container **14** is completely flooded and sunk below the effects of any wave action, shell stresses are reduced. Although the container walls may be providing some stiffening assistance at this state, because of truss deflection, the tender frame **13** is carrying its maximum load.

By interconnecting tanks **15** and **16** with reticulated means **17** which span across and provide support for the storage container **14**, transverse wall and anchorage stresses are less than those that would be created by the use of buoyancy tanks individually attached to the container **14**.

Pressurization of the buoyancy tanks **15** and **16** may be necessary at various stages during the installation procedure to resist the effects of uniformly varying (with depth) external hydrostatic pressure in combination with the otherwise constant internal air pressure.

With the system ballasted to a negative buoyancy and the tanks pressurized to an appropriate level to resist crushing, lowering operations are continued.

Lowering of the system can be accomplished in fairly rapid order so long as adequate control is maintained to insure safety, and may be controlled by the amount of ballast added to tanks **15** and **16**, and cable payout from derrick barges, if any.

Should the water depth at the installation site be great enough to require it, one or more delays in the lowering operation may be required for addition of pressure to the buoyancy tanks **15** and **16**. As stated previously, the additional internal pressure is required to resist the crushing effect from increasing external hydrostatic pressure.

A slowdown in the rate of descent will be necessary as the system approaches the seabed or marine floor where some visual control by divers may be required for orientation purposes. In general, however, it is thought that placement tolerances relating to angular orientation and coordinate location of the container are not critical. With the container tender frame system in place on the seabed, the next portion of the installation phase can be accomplished.

In order to detach the tender frame **13**, additional flooding of the buoyancy tanks **15** and **16** is required for relieving tension in the elements connecting the frame **13** to the container **14**.

With the tender frame **13** negatively buoyant and the connections relieved of tension, the uncoupling may be accomplished by divers. An automatic uncoupling system based on the use of small, hydraulically operated jacks mounted within the reticulated trusswork **17** may also be used. Another detachment method which may be used involves the use of shaped charges on the connecting elements.

After detachment of the tender frame **13** has been accomplished, it may then be deballasted for raising to the surface, and re-use. Again, work or derrick barges may be used to assist in the raising of the tender frame **13**. Depending on the installation water depth, it may be necessary to bleed off internal air pressure in the tanks during the ascent. Alternatively, the tender frame **13** may be left on the marine floor, still attached to the container **14**, if the container **14** is to be left at the site for only a short time.

Connection of the incoming pipeline **41** from the product source and discharge hose **32** from the monomooring **33** essentially completes the installation.

If the ports **42A** and **42B** around the base periphery of the container **14** have not been completely opened or removed during previous stages of the installation phase, this task may be accomplished by divers prior to the operating phase.

The container **14** may also be moved to a new location on the floor of the body of water by the tender frame **13**. This involves a general reversal of the sinking or lowering operations described above. For example, the tender frame **13** may be floated over the container **14** installed at the old location on the ocean floor, ballasted to a negative buoyancy, lowered with the use of guidelines or the like into contact with the container **14**, and tied to the container **14**. The tender frame may then be deballasted and the tied structure raised to the surface, and towed to another location after deballasting of the storage container. The installation procedure at that point is as described hereinabove.

With the storage container installed as described above, it is ready for operation.

Immiscible fluid products such as crude hydrocarbon oil may be introduced under pressure into the top of the container **14** through the manifold system **40**. The manifolding need only be sophisticated enough to minimize mixture of the oil and seawater. The necessary pipeline pressure may be supplied by pumps located on an adjacent platform.

The incoming oil will maintain its relative location in the upper portions of the container **14** because of its lighter specific gravity and will force water such as seawater out of the lower flooding hatches or ports **42A** and **42B**. Intercompartmental flow of the oil will occur over the tops of the interior wall or baffle system and between the webs **49** of the roof components **52**, but mixing is minimized by the baffle system. Openings **53** at the wall bases will allow for seawater interflow. The wall openings **53** and ports **42A** and **42B** near the container mat **50** are intended to allow a maximum of self-cleaning action primarily during the loading stage and also due to any stray currents existing at the site.

During unloading operations, the pressure head differential due to the difference in specific gravities of the oil and seawater will act to help boost the product upward. Pumping will still be required, however, in order to transfer product from the container **14**, up the flexible hose **32** to the monomooring **33** or other intermediate station and thence through conduits **34** into the tanker or barge **35**.

The same container manifolding system 40 may be used for both loading and unloading.

As a general order of magnitude range, water depths between 150 and 600 feet are contemplated. Greater depths are very possible with limiting factors relating to pumping of product into and out of the container, compressive capacity for pressurizing the buoyancy tanks during descent, hoist drum capacity for any lowering cables and the crushing stresses applicable to unpressurized tubular truss members of the tender frame. Shallower installation depths are also possible and are primarily dependent on predicted sea and weather conditions.

Other aspects of the overall problem of underwater storage parallel those of storage on land and are known to those skilled in the art. Thus, subproblems such as pipelining from the wellheads or a production platform, manifolding, hose connections, and valving are described herein only insofar as to complete the overall picture.

SUMMARY OF ADVANTAGES AND OVERALL SCOPE OF INVENTION

A primary advantage of the invention resides in a storage system which can efficiently resist the loads and forces imposed during all phases of its existence. In order to resist the significantly higher loadings which occur during the towing phase and particularly the installation phase, heavier construction and greater attention to more highly load resistant shell configurations have heretofore been necessary. These additional strength characteristics are wasted for the most part during the operating phase which constitutes almost the total lifetime of an underwater storage container. It is true that in some instances and for some container elements this added strength provides greater operating safety factors, but not in every case. The present invention, on the other hand, not only creates a storage system with adequate operating safety factors, but also with maximum efficiency and flexibility of materials. For example, the tender frame could be tied to the storage container with cables or the like in lieu of the illustrated connecting elements.

Further, an underwater storage structure fabricated primarily from concrete and having a truncated pyrimidal shape provides a particular unique combination leading to advantages such as inherent negative buoyancy, even when filled with buoyant fluids, and increased resistance to lateral forces due to storm waves and currents. Thus, any need for an elaborate anchoring system is lessened or eliminated entirely. Further, the concrete components may be pre or post stressed and reinforced as needed to provide as strong and safe a system as could be envisioned.

A particular advantage of the invention is attributed to the interior baffling system which is tri-functional, i.e., provides increased stability during submerging operations, maintains overall structural integrity, and serves to prevent mixing losses during filling and emptying operations by decreasing sloshing or turbulence.

In connection with the tender frame, it is significant to note that the trusswork connecting the buoyancy tanks serves to alleviate or prevent many of the stresses heretofore incurred by underwater storage structures during their towing and installation phases. Further, the tender frame is reusable and thus significantly contributes to the efficiency and economy of the overall system. Moreover, the tender frame could assist in unrelated operations such as salvage.

The principles, preferred embodiments, and modes of operation of the present invention have been described in the foregoing specification. The invention which is intended to be protected herein, however, is not to be construed as limited to the particular forms disclosed, since these are to be regarded as illustrative rather than restrictive. Variations and changes may be made by those skilled in the art without departing from the spirit of the present invention.

We claim:

1. An underwater storage system for fluids immiscible with and of lesser specific gravity than water, the system capable of being towed to a site and submersed to the floor of a body of water, which system comprises:
- a storage container including upper and lower portions;
- the container being of concrete and having a negative buoyancy when positioned on the floor of the body of water and filled with the immiscible fluid;
- means for removing air from the interior of the container;
- means for communicating the interior of the lower portion of the container with the body of water; and
- means for communicating the interior of the upper portion of the container with a supply of the immiscible fluid;
- a tender frame attached to the storage container, the tender frame and storage container attached thereto adapted for towing to the site and submergence to the floor of the body of water;
- the tender frame including first and second hollow tanks on the frame and adapted to provide for buoyancy and ballasting of the frame and the container attached thereto, the tanks being spaced apart to allow the storage container therebetween;
- reticulated means extending over the storage container and rigidly connecting the tanks;
- connecting means for connecting the reticulated means to the storage container, the connected reticulated means adapted to provide support for the storage container from the tender frame during towing and submergence;
- means for admitting air to the tanks for buoyancy; and
- means for admitting water to the tanks for ballast.

2. An underwater storage system for fluids immiscible with and of lesser specific gravity than water, the system capable of being towed to a site and submersed to the floor of a body of water, which system comprises:
- a storage container having a greater length than width and including upper and lower portions;
- the container being of concrete and adapted to float at a natural displacement level when unflooded, the container also adapted to have a net negative buoyancy when positioned on the floor of the body of water and filled with the immiscible fluid;
- means for removing air from the interior of the container;
- means for communicating the interior of the lower portion of the container with the body of water; and
- means for communicating the interior of the upper portion of the container with a supply of the immiscible fluid;
- a tender frame attached to the storage container, the tender frame and storage container attached thereto adapted for towing to the site and submergence to the floor of the body of water;
- the tender frame including first and second elongated parallel hollow tanks attached to the frame and adapted for buoyancy and ballasting of the frame and the container attached thereto, the tanks being spaced apart to allow the storage container therebetween and elongated in the lengthwise direction of the container;
- the tender frame further including reticulated structure rigidly connecting the tanks, the reticulated structure comprising a plurality of parallel first vertical trusses perpendicular to the tanks and spanning over the storage container and between the tanks for transferring loading of the container to the tanks, a plurality of parallel second vertical trusses spanning over the storage container and parallel to the tanks and at right angles interconnecting the first trusses for balancing and distributing loading on the first trusses, the first and second trusses forming spaced apart upper and lower interconnected hori-

zontal reticulated layers, and secondary horizontal bracing members in the planes of the layers for rigidifying the overall reticulated structure;

means on the tanks for admitting air to the tanks for buoyancy;

means on the frame for admitting water to the tanks for ballast; and

connecting means on the frame and on the container for connecting the reticulated structure to the storage container, the reticulated structure adapted to provide structural support for the storage container from the tender frame during towing and submergence.

3. The storage system of claim 2, including baffle walls within the storage container, the baffle walls intersecting with one another, and the intersections defining anchorage points for the tender frame, and wherein the reticulated truss structure is connected to the storage container at these anchorage points.

4. The storage system of claim 3, wherein the trusses and bracing members comprise rigid tubular members sealed against the intrusion of water to add buoyancy and stability to the tender frame.

5. An underwater storage system for fluids immiscible with and of lesser specific gravity than water, the system capable of being towed to a site and submersed to the floor of a body of water, which system comprises:

a storage container having a greater length than width and including upper and lower portions;

the container being of concrete and adapted to float at a natural displacement level when unflooded on the surface of the body of water, the container also adapted to have a net negative buoyancy when positioned on the floor of the body of water and filled with the immiscible fluid;

the container having a truncated pyrimidal exterior shape including a horizontally extending flat roof and a floor parallel to the roof, and integral fixed sloping side walls vertically extending between the floor and the roof, to increase frictional sliding resistance to lateral forces due to storm waves and currents when positioned on the floor of the body of water; the container having a plurality of interior baffles comprising

a plurality of upstanding parallel bearing walls extending horizontally between opposite side walls and extending vertically between the floor and the roof,

a plurality of upstanding parallel stiffener walls perpendicular to and intersecting with the bearing walls to form cells within the container, the stiffener walls extending partially upward from the floor toward the roof to allow fluid passage between the roof and the stiffener wall, the cells also being in fluid communication with each other through fluid passages disposed in lower portions of the bearing and stiffener walls, and the intersections of the bearing and stiffener walls adapted to define anchorage points for a tender frame;

the floor, the sloping sidewalls, and outermost bearing and stiffener walls adapted to form a structural integrity-giving outer perimeter for the storage container;

means for removing air from the interior of the container;

means for communicating the interior of the upper portion of the container with a supply of the immiscible fluid;

means for communicating the interior of the lower portion of the container with the body of water;

a tender frame attached to the storage container, the tender frame and storage container attached thereto adapted for towing to the site and submergence to the floor of the body of water;

the tender frame including first and second elongated parallel hollow tanks on the frame and adapted to provide buoyancy and ballasting for the frame and the container attached thereto, the tanks being spaced apart to allow the storage container therebetween and elongated in the lengthwise direction of the container;

the tender frame further including reticulated truss structure rigidly connecting the tanks, the reticulated structure comprising a plurality of parallel first vertical trusses perpendicular to the tanks and spanning over the storage container and between the tanks for transferring loading of the container to the tanks, a plurality of parallel second vertical trusses spanning over the storage container and parallel to the tanks and interconnecting the first trusses for balancing and distributing the loading on the first trusses, the first and second trusses forming spaced apart upper and lower interconnected horizontal reticulated layers, and secondary horizontal bracing members in the planes of the layers for rigidifying the overall reticulated structure;

means on the tanks for admitting air to the tanks for buoyancy;

means on the tanks for admitting water to the tanks for ballast; and

connecting means for connecting the reticulated truss structure to the storage container at the anchorage points, the truss structure adapted to provide support for the storage container from the tender frame during towing and submergence.

6. An underwater storage system for fluids immiscible with and of lesser specific gravity than water, the system capable of being towed to a site and submersed to the flood of a body of water, which system comprises:

a storage container including upper and lower portions;

the container being of concrete and adapted to float at a natural displacement level when on the surface of the body of water, the container also adapted to have a net negative buoyancy when positioned on the floor of the body of water and filled with the immiscible fluid;

the container having a truncated pyrimidal exterior shape including a horizontally extending flat roof and a floor parallel to the roof, and integral fixed sloping side walls vertically extending between the floor and the roof to increase frictional sliding resistance to lateral forces due to storm waves and currents when positioned on the floor of the body of water;

the container having a plurality of interior baffles comprising

a plurality of upstanding parallel bearing walls extending horizontally between opposite side walls and extending vertically between the floor and the roof,

a plurality of upstanding parallel stiffener walls perpendicular to and intersecting with the bearing walls to form cells within the container, the stiffener wall extending partially upward from the floor toward the roof to allow fluid passage betwen the roof and the stiffener wall, the cells also being in fluid communication with each other through fluid passages, in lower portions of the bearing and stiffener walls, and the intersections between the bearing and stiffener walls adapted to define anchorage points for a tender frame,

the roof having a plurality of downwardly depending spaced rib portions parallel to the stiffener walls, the rib portions having lowermost face portions, the bearing walls abutting the face portions to allow fluid passage over the bearing wall and between the rib portions;

means for removing air from the interior of the container;

means for communicating the interior of the upper portion of the container with a supply of the immiscible fluid;

means for communicating the interior of the lower portion of the container with the body of water;

a tender frame attached to the storage container, the tender frame and storage container attached thereto adapted for towing to the site and submergence to the floor of the body of water;

the tender frame including hollow tanks adapted to provide buoyancy and ballasting for the frame and the container attached thereto, the tanks being spaced apart to allow the storage container therebetween;

reticulated means for rigidly connecting the tanks;

means for connecting the reticulated means to the storage container at the anchorage points to provide support for the container from the tender frame during towing and submergence;

means for admitting air to the tanks for buoyancy; and

means for admitting water to the tanks for ballast.

7. The storage system of claim **6**,

wherein the storage container has a greater length than width, and wherein the hollow tanks comprise first and second elongated parallel hollow tanks on the frame for buoyancy and ballasting of the frame and the container attached thereto, the tanks being spaced apart to allow the storage container therebetween and elongated in the lengthwise direction of the container;

and wherein the reticulated structure comprises a plurality of parallel first vertical trusses perpendicular to the tanks and spanning over the storage container and between the tanks for transferring loading of the container to the tanks, a plurality of parallel second vertical trusses spanning over the storage container and parallel to the tanks and interconnecting the first trusses for balancing and distributing the loading on the first trusses, the first and second trusses forming spaced apart upper and lower interconnected horizontal reticulated layers, and secondary horizontal bracing members in the planes of the layers for rigidifying the overall reticulated structure.

8. A method for installing a submersible underwater storage structure on the floor of a body of water, which method comprises:

positioning a tender frame over the storage structure,

connecting the tender frame to the storage structure,

flooding the storage structure while the connected frame and storage structure are afloat and while maintaining buoyancy of the connected frame and storage structure,

ballasting the tender frame, whereby a net negative buoyancy is produced to achieve submergence and to position the storage structure on the floor of the body of water,

disconnecting the tender frame from the storage structure, and

raising the tender frame to the surface of the body of water.

9. A method for installing a submersible underwater storage structure on the floor of a body of water, which method comprises:

floating a tender frame over the storage structure while the storage structure is afloat;

ballasting the tender frame to lower it into contact with the storage structure;

connecting the tender frame to the storage structure;

flooding the storage structure with water to achieve partial submergence, and then further ballasting the tender frame to achieve full submergence and to position the storage structure on the floor of the body of water;

disconnecting the tender frame from the storage structure; and

raising the tender frame to the surface of the body of water.

10. The method of claim **26** wherein the tender frame is ballasted by admitting water to hollow tanks attached thereto.

11. The method of claim **9** further comprising

after positioning the storage structure on the floor of the body of water and prior to disconnecting the tender frame from the storage structure, further ballasting the tender frame to relieve tension in the connection between the tender frame and the storage structure; and

after disconnecting the tender frame from the storage structure and before raising the tender frame to the surface of the body of water, deballasting the tender frame.

12. A method for installing a submersible underwater storage structure on the floor of a body of water at an offshore site, which method comprises:

floating a tender frame over the storage structure at a site near to shore while the storage structure is afloat;

ballasting the tender frame to lower it into contact with the storage structure;

connecting the tender frame to the storage structure;

towing the connected tender frame and storage structure to the offshore site;

flooding the storage structure with water to achieve partial submergence;

further ballasting the tender frame to achieve full submergence and to position the storage structure on the floor of the body of water;

further ballasting the tender frame to relieve tension in the connection between the tender frame and the storage structure;

disconnecting the tender frame from the storage structure;

deballasting the tender frame; and

raising the tender frame to the surface of the water.

13. The method of claim **12** further comprising

after connecting the tender frame to the storage structure, deballasting the tender frame to elevate the storage structure to a position higher than its natural displacement.

14. The method of claim **12** further comprising

prior to further ballasting the tender frame to achieve full submergence, venting the interior of the storage structure to relieve air pressure therein.

15. A method for installing an underwater storage structure at a new location on the floor of a body of water, which method comprises:

positioning a tender frame floating on the surface of the water over a storage structure installed at a first location on the floor of the body of water,

ballasting the tender frame to a negative buoyancy to lower it into contact with the storage structure,

connecting the tender frame to the storage structure,

deballasting the tender frame to provide buoyancy for the connected tender frame and storage structure,

raising the connected tender frame and storage structure to the surface of the body of water,

deballasting the storage structure,

towing the connected tender frame and storage structure to another site on the surface of the water, and

ballasting the connected tender frame and storage structure whereby a net negative buoyancy is provided to achieve submergence and to position the connected tender frame and storage structure at a second location on the floor of the body of water.

16. The method of claim **15**, further comprising

ballasting the tender frame to relieve tension in the

connection between the tender frame and the storage structure;

disconnecting the tender frame from the storage structure;

deballasting the tender frame to a slight negative buoyancy; and

raising the tender frame to the surface of the body of water.

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