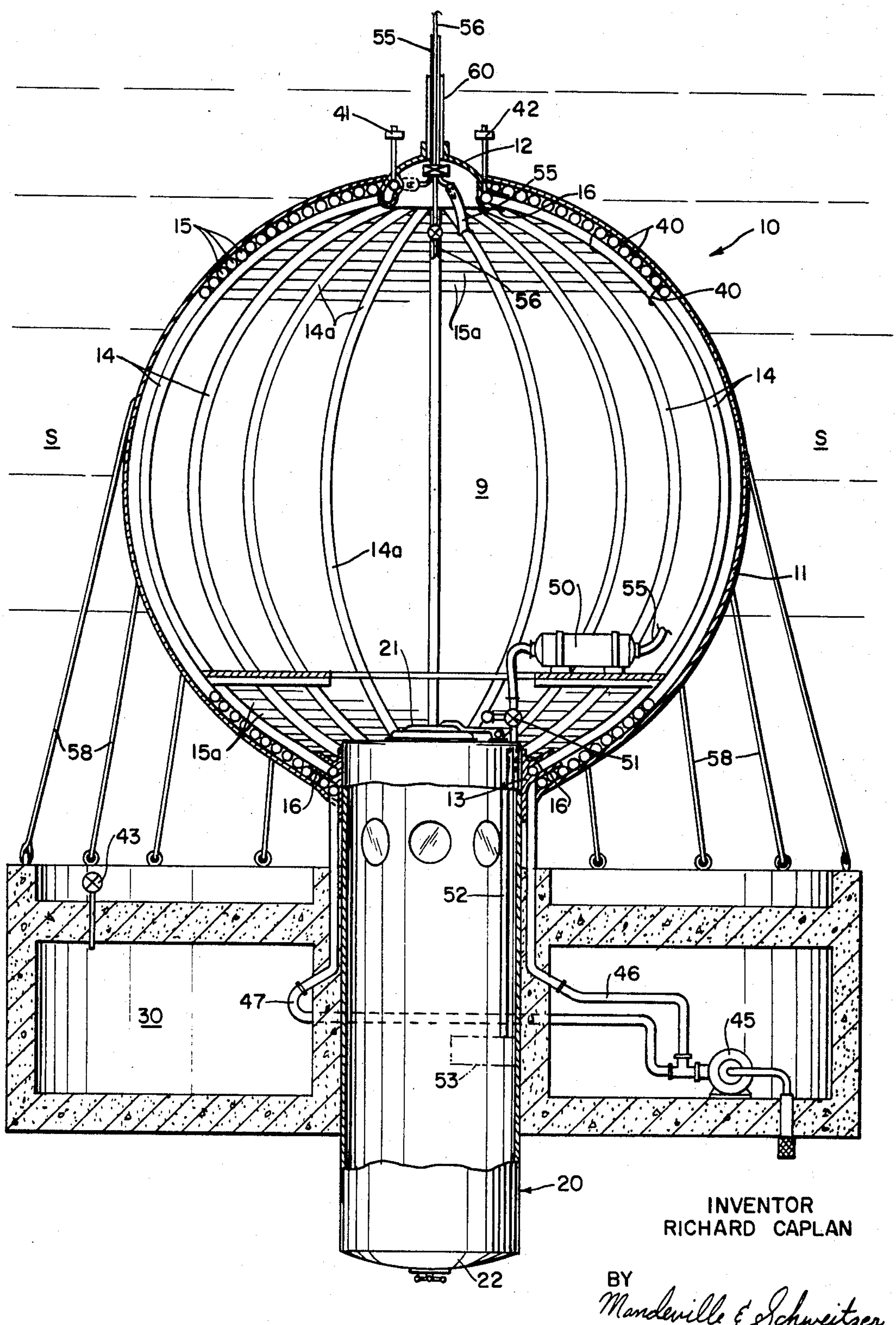
Nov. 4, 1969 R. CAPLAN 3,475,915

UNDERWATER STRUCTURES

Filed April 16, 1968



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United States Patent Office

3,475,915

Patented Nov. 4, 1969

3,475,915

UNDERWATER STRUCTURES

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Filed Apr. 16, 1968, Ser. No. 721,753
Int. Cl. B63c *11/36;* E04b *1/343;* E04g *11/04*
U.S. Cl. 61—69 10 Claims

ABSTRACT OF THE DISCLOSURE

The present invention relates to collapsible submersibles having individual structural elements which are liquid-filled tubes of circular cross section and circular shape. The submersibles themselves are also preferably circular in overall cross-sectional configuration, being spherical, cylindrical, toroidal, or a combination of those shapes. The submersible is normally collapsed when above water and is erected by totally filling its structural elements after submersion.

Background of invention

Heretofore, submerged vessels and habitable structures, i.e., submersibles, have fallen into two general categories. The first class of structures are those constructed from rigid materials, steel, aluminum, etc., having adequate compressive strengths to resist deep water compression forces, in accordance with conventional pressure-vessel design practice. The bathyscaphe "Trieste," the "Sealab" vessels, and the oceanographic research submarine "Aluminaut" are representative of these structures which have descended to enormous depths, the record descent being deeper than 35,000 feet. The design requirements for these or any other underwater structures are severe, since the pressures of the sea approximate one atmosphere (14.7 p.s.i.) for every 28 feet of descent. Thus, for example, the crushing forces on a seven foot sphere at depths beyond 32,000 feet are in excess of 100,000 tons.

The other class of structures are air inflatable, collapsible underwater tents of the so-called SPID-type (submersible portable inflatable dwelling). These structures are essentially reinforced, impermeable fabric balloons which are inflated beneath the water at comparatively shallow depths, by air (a compressible fluid) which is maintained at a pressure equal to the external pressure. However, these underwater tents or balloons are absent structural members and are not adapted for depths much in excess of 400 feet.

Summary of the invention

The present invention provides a new and improved collapsible structure which may be employed in a family of habitable underwater structures or shelters especially well adapted for use at the depths of the continental shelf, approximately 600 feet. The basic elements of the new structures are collapsible, substantially circular tubes of circular cross section which may be filled with an incompressible hydraulic fluid to give the submersible its final closed shape. As a most important aspect of the invention, when totally filled and underwater, the geometry of the tubes maintains the liquid cores in compression at all times. Accordingly, the water filled tubes are highly efficient pressure resisting members in which there are substantially no bending forces. In other words, the pressure resisting members of the invention are not subject to buckling as is the case with conventional solid compression members. Nevertheless, the new submersibles will provide its occupants with protection comparable to that of conventional rigid pressure vessels. Moreover, in accordance with the principles of the invention, the internal atmosphere of the new shelters need only be maintained at or slightly above atmospheric pressure, regardless of the external pressures of the deep sea.

More specifically, a preferred embodiment of the new structure is spherical in shape and comprises a membraneous skin, advantageously a reinforced, synthetic fabric material, which cooperates with a network of fluid-filled, collapsible, generally circular tubular load bearing rib elements. The pressure-resisting ribs are, in effect, composite structural members having tubular casings of solid material (plastic) definitive of the boundaries of the elements and incompressible liquid cores which completely fill the casings. Thus, the arcuate ribs are partially solid and partially liquid, with the liquid cores working in compression and the solid casings working in tension. Accordingly, material for the casings need not be especially thick, since the compression forces of the ambient sea will be translated into tension forces by the liquid cores which are in compression at all times. Thus, the critical design parameter of the new structures will be the ability of the chosen materials to resist deformation induced by tension (tensile strengths). With an "ideal skin," i.e., one which is not permanently deformable regardless of the tensile stretching forces applied thereto, the new structure theoretically could withstand the compression forces of infinite depths. It is, of course, well established that solids resist tension forces much more readily than compresion forces.

In accordance with the principles of the invention and as will be understood, the entire structure, which is primarily a network of thin-walled plastic tubes enveloped by or otherwise cooperating with a continuous skin, may be collapsed to a comparatively small volume having little if any buoyancy. The collapsed structure may be readily submerged and then anchored at a predetermined underwater site. Thereafter, it may be erected by completely filling its structural elements with liquid (an incompressible fluid) while introducing pressurized air into the inner space of the structure.

As will be appreciated, submersibles embodying the inventive concepts have widespread utility and immediately suggest themselves to a plethora of oceanographic applications.

Drawing

For a more complete understanding of the present invention, reference should be made to the following detailed description taken in conjunction with the accompanying drawing, in which:

FIG. 1 is a cross-sectional view of an erected underwater structure embodying the inventive principles.

Detailed description of invention

Referring to FIG. 1, the new underwater structure **10** of the invention is shown as the spherical crew compartment of a mesoscaphe (a submersible for medium depths). The illustrated mesoscaphe also includes a selectively pressurizable entry and exit lock **20** and a selectively fillable ballast hold **30**. As will be understood, entry and egress to the crew compartment is had through the lock **20**, which is of conventional pressure vessel construction and which is suitably affixed in a watertight manner to the compartment **10** by means of a collar manifold **13** which will be described in greater detail hereinafter. As shown, the lock **20** has an upper hatch **21** leading directly into the compartment **10** and a lower hatch **22** leading into the sea. Thus, the spherical crew compartment is, in effect, "anchored' to the annular ballast hold **30**, which may be of cast concrete or other suitable construction. In accordance with well-established principles, the hold **30** can be selectively ballasted with sea water to sink the mesoscaphe.

Specifically, the new structure **10** comprises a substantially spherical, continuous external skin **11** which is supported by an internal system of the new pressure-resisting members, liquid-filled ribs **14, 15**. The ribs are arcuate and terminate at opposite poles of the spherical compartment **10** defined by a rigid crown manifold **12** at the top and a collar manifold **13** at the bottom. The skin **11** may be fabricated from any tough, impermeable, sheet material, such as impregnated reinforced nylon fabric, which possesses flexibility and sub stantial non-deformability when subjected to tension (i.e., tensile strength).

More specifically and as shown, the longitudinal or vertical members **14** are permanently connected to radially extending nipples **16** in the crown manifold **12** and collar manifold **13** and are disposed in a skeletal array interiorly of the latitudinal members **15** which are arrayed to define a spherical shell. In accordance with the invention, the tubular casings or boundaries **14***a*, **15***a* of the circular rib members **14** and **15** are defined by collapsible, seamless, substantially non-deformable plastic tubes, although in some applications it may be desirable to fabricate the rib casings and the external spherical skin from the same or similar reinforced fabric material. Advantageously, the skeletal system of ribs **14** and the shell system of ribs **15** are independent of one another, as shown.

As shown, the latitudinal, liquid-filled ribs **15** may be arrayed as a continuous helix extending from the crown **12** to the collar **13**. The turns of the helix gradually increase in diameter to an equatorial turn and then decrease in diameter as shown. Alternatively, the ribs **15** may be in the form of discrete, abutting toroids of graduated diameter which are stacked between the crown and collar to define a generally spherical shell.

In accordance with the inventive principles, the ribs **14, 15** and the external skin **11** are linked to each other in a predetermined configuration definitive of the final spherical shape, by slip connections or loose ties **40** of nylon cord or the like which accommodate predetermined limited, mutual displacement and yielding of the elements of the structure during erection and while in service. In other words, this loose tying together of the network of ribs **14, 15**, and the external skin **11** of the new structure provides the structure as a whole with limited built-in resiliency, which enables the structure to adjust dynamically to any stresses and to assume its final shape without any self-induced stresses.

As an important and, indeed critical, aspect of the invention, the external water pressure is resisted by the network or hydraulic system of pressure-resisting members or liquid-filled ribs **14, 15**. Specifically, the geometry of the pressure-resisting members **14, 15** is such that the cores or liquid portions of all of the ribs will be maintained constantly under compression. The compressive external forces of the ambient sea will be resisted by the water within the tubes which work in compression and will be translated by the hydraulic system into tangential and longitudinal tensile forces in the rib casings **14***a*, **15***a* which work in tension. In accordance with a further important aspect of the invention, heavy solid structural members are not required to resist the compression of the ambient sea, since the liquid pressure within the ribs will always be equal to the pressure of the sea outside of the ribs regardless of the depth. Therefore, the rib system will not be collapsed by the pressures of the deep sea and the ribs will, in fact, maintain the shape and integrity of the structure **10** as long as the rib casings do not stretch or otherwise fail. Theoretically, the casing material defining the boundaries of the ribs may be extremely thin, since its function is to envelop discrete columns of liquid in the predetermined rib configurations, and it need not resist compression. However, the casing material must possess sufficient strength to withstand the tensile forces induced therein. Tensile forces are, of course, more easily resisted than compression forces. Hence, the new "composite" pressure-resisting members are more efficient than conventional solid compression members for use in the new underwater structures.

While in underwater service, it is most important that the ribs **14, 15** be absolutely and entirely filled with liquid, so that they are, indeed, totally incompressible. To that end and as a further important aspect of the invention, the series of ribs **14, 15** are connected to special selective check valves **41, 42** which communicate between the liquid cores of the ribs and the ambient sea. The valves **41** permit only the outward flow of gases trapped from the ribs and prohibit all other flow of liquid or gas therethrough. Accordingly, during filling of the ribs only air trapped therein will be vented through the valves **41, 42**.

In accordance with the principles of the invention, the new structures are collapsed when out of the water and are erected underwater by filling the structural elements with liquid while contemporaneously pressurizing the developing interior space **9** of the structure with gas at a pressure equal to or greater than that of the ambient sea. More specifically, the collapsible crew compartment **10** of the illustrated mesoscaphe is placed in service as follows.

The collapsed compartment is initially lowered to a selected site in the sea S by appropriately admitting ballasting sea water to the ballast chamber **30** through a valve **43**. Thereafter, the hollow, collapsed ribs **14, 15** are filled with sea water S by the submersible pump **45** through appropriate feed pipes **46, 47**, respectively. As shown, the valve **41** is the upper terminal of the closed latitudinal rib system (one continuous spiral tube **15** definitive of a hydraulic mono-coque), and the lower terminal of the system is the junction of rib **15** with the feed pipe **47**. Similarly, the closed longitudinal rib system, comprising discrete vertical tubes **14** which extend between manifolds **12, 13**, is bounded by the valve **42** and the junction of the feed pipe **46** with the manifold **13**.

While the ribs **14, 15** are filling with liquid, the shaping of the compartment **10** is assisted by inflating the inner space **9** with gas at a pressure greater than that of the surrounding sea. This, of course, also prevents the structure **10** from being caved in during erection. The pressurized gas is admitted to the inner space **9** by a suitable compressor **50** which is connected through a three-way valve **51** and air line **52** to an appropriate pressurization system **53** (indicated in phantom). A gas supply line **55** from the surface, e.g., "mother ship," will connect the compressor to a gas source. When the compartment **10** is inhabited, a gas return line **56** will allow the gas within the spherical compartment to be continuously recirculated and reoxygenated for adequate sustenance of the crew. Advantageously, the air lines **55, 56** and any power lines, telephone lines, or the like are sheathed in a suitable "umbilical cord" **60**, which is connected to the structure **10** through the crown **12**. As shown in the drawing, stabilization of the erected structure **10** in relation to the ballast hold **30** may be had by suitably connecting nylon ropes or cables **58** between the external skin **11** and the ballast hold.

From the foregoing, it will be appreciated that the collapsibility of the new and improved submersibles enable them to be readily submerged in a compact and substantially non-buoyant state and to be erected beneath the water either while in transit (sinking) to a selected underwater site or after reaching the site itself. It should be further appreciated that the new and improved "composite pressure-resisting members " of the invention comprising thin-walled tubes filled with incompressible liquid are able to withstand, in a highly efficient manner, the compressive forces of the sea regardless of the depth at which the submersible is erected and used. Accordingly, the gas pressure in the submersible may be maintained at or near atmospheric for the comfort of its inhabitants after the tubes have been filled.

It should be further understood that the foregoing description of one embodiment of the invention is intended to be representative only, as certain changes may be made therein without departing from the clear teachings of the disclosure. For example, while the new circularly shaped, collapsible water-filled elements have been shown as structural members of an underwater spherical shell in a compressive environment, they may be employed with like efficacy in compressive underwater environments in cylindrical structures, toroidal structures or any structure which is a combination of spherical, cylindrical and toroid shapes. The new structures of the invention may be used for underwater shelters or habitats, submersible vessels, or underwater hydrospace suits to protect divers from the pressures encountered at great depths or other oceanographic applications. Therefore, reference should be made to the following appended claims in determining the full scope of the invention.

I claim:

1. A pressure-resisting submersible comprising
(a) a collapsible closed structure including a series of collapsible, liquid holding ribs all of which have a circular cross section when filled with liquid;
(b) valve means associated with said ribs and accommodating the total filling of said ribs with an incompressible fluid.

2. The submersible of claim **1**, in which
(a) each of said liquid filled ribs is generally circular; and
(b) said series of ribs is substantially definitive of a sphere, torus, or a cylinder.

3. The submersible of claim **2**, which includes
(a) a continuous skin means cooperating with said ribs to define its final geometrical shape.

4. The submersible of claim **3**, which includes
(a) flexible slip connection means loosely fastening said skin means and said ribs.

5. The submersible of claim **4**, which includes
(a) entry and exit lock means communicating between the inner portions of said submersible and the ambient atmosphere.

6. The submersible of claim **3**, in which

(a) said skin means comprises an impermeable, substantially unstretchable sheetlike material;
(b) said ribs are defined by substantially unstretchable plastic tubing.

7. In a pressure-resisting submersible, a composite underwater compression-resisting structural member, comprising
(a) a collapsible tubular casing of substantially nonstretchable material having a circular cross section;
(b) said casing being substantially circular in overall configuration;
(c) a liquid core completely filling said casing;
(d) whereby said liquid core is maintained in compression by the configuration of said casing when totally filled;
(e) the casing of said structural member when subjected to forces encountered underwater thereby being substantially totally free of compressive forces and being subject substantially only to tensile forces.

8. The composite structural member of claim **7**, which includes
(a) valve means associated with said casing and accommodating the complete filling thereof with liquid.

9. A plurality of the composite members of claim **7**, in which
(a) said members are closely arrayed and cooperate to define a closed structure.

10. The structure of claim **9**, which further includes
(a) skin means cooperating with said pressure-resisting members to define the shape of said structure.

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U.S. Cl. X.R.

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