March 22, 1966 R. C. PROCTOR ETAL 3,241,274

ROOF STRUCTURE FOR GROUND RESERVOIR

Filed May 24, 1963 2 Sheets-Sheet 1

FIG. 1

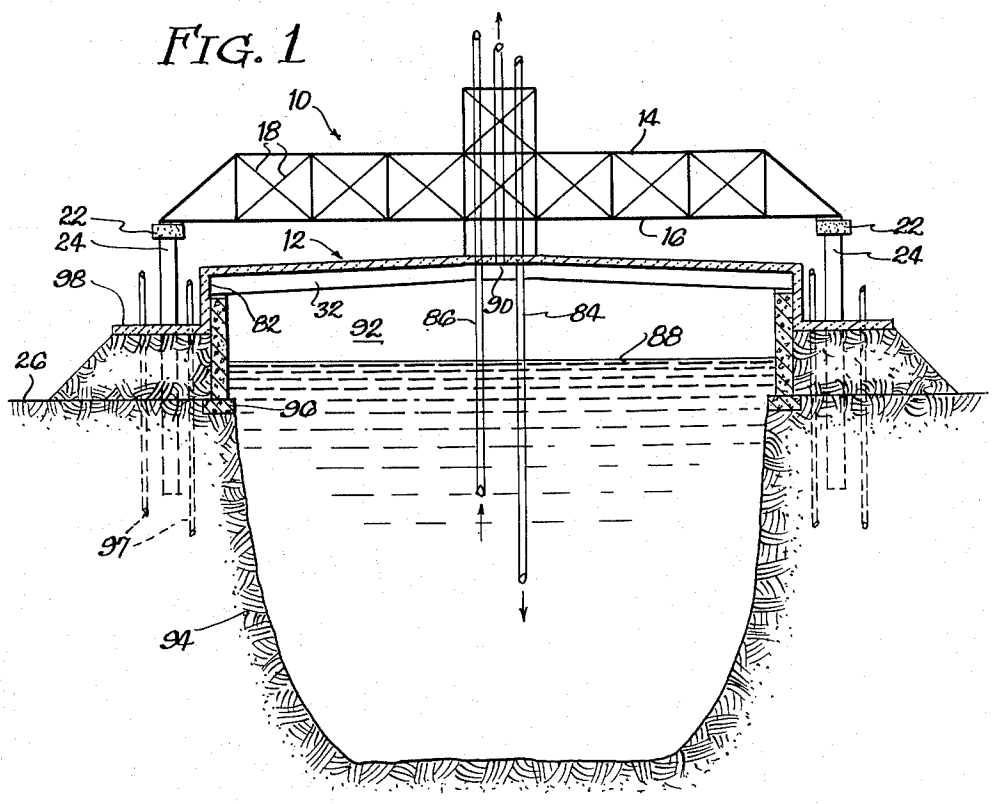
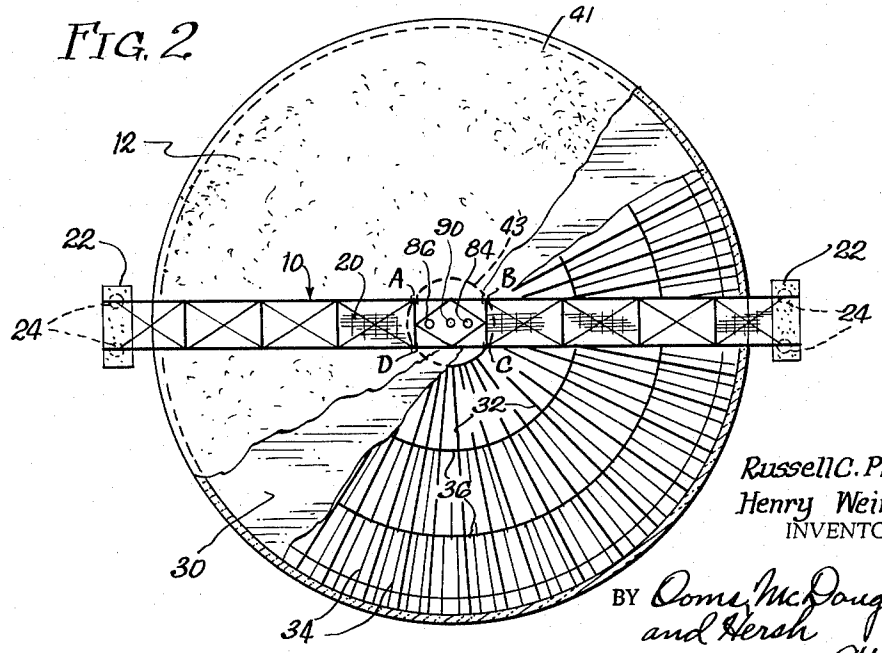


FIG. 2



Russell C. Proctor
Henry Weinstein
INVENTORS

BY Dorn, McDougall and Hersh
Attys

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FIG. 3

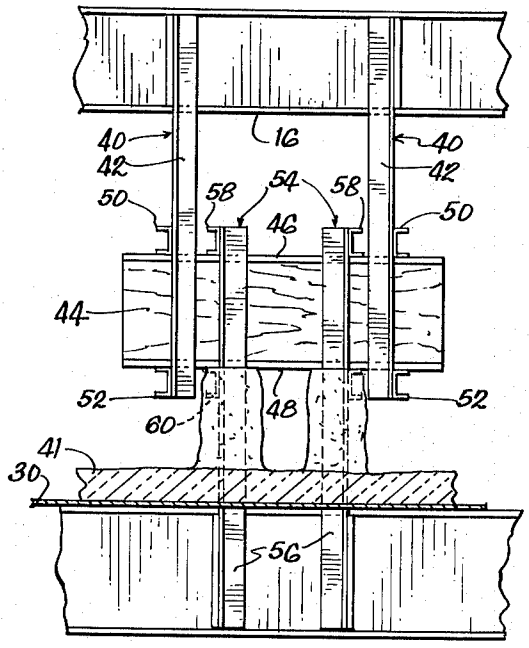


FIG. 4

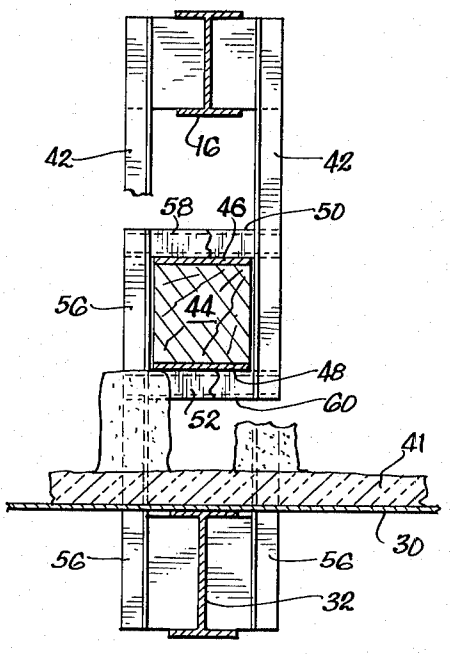
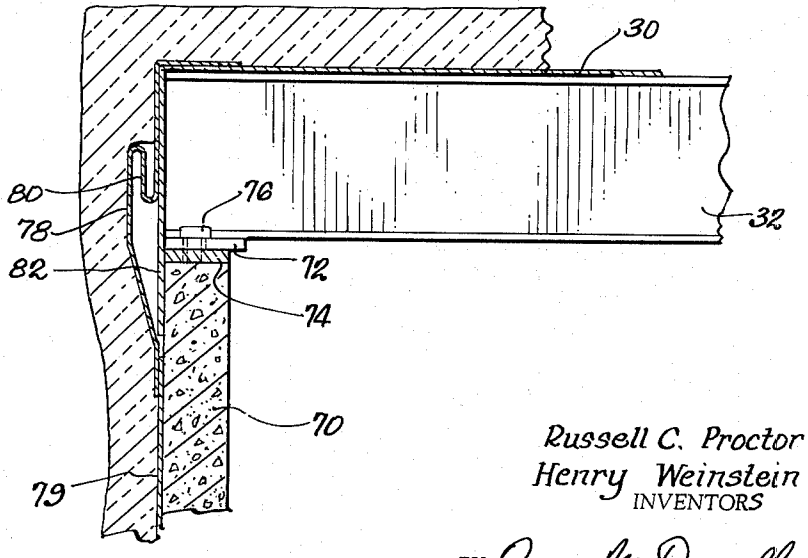


FIG. 5



Russell C. Proctor
Henry Weinstein
INVENTORS

BY Toms, McDougall and Hersh
Att'ys

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ROOF STRUCTURE FOR GROUND RESERVOIR

Russell C. Proctor, Tulsa, Okla., and Henry Weinstein, Prairie Village, Kans., assignors to Conch International Methane Limited, Nassau, Bahamas, a Bahama corporation

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This invention relates to a ground reservoir suitable for the storage of a liquefied gas, as represented by a liquid which boils, at atmospheric pressure, at a temperature below ambient temperature, and it relates more particularly to a roof construction for the coverage of a storage facility of the type described.

Examples of liquefied gases having characteristics of the type adapted to be housed in the ground storage of this invention are liquefied nitrogen, liquefied air, liquefied methane, liquefied natural gas, liquefied oxygen, liquefied propane, anhydrous ammonia, and anhydrous hydrochloric acid.

To the present, large ground reservoirs for the storage of such cold liquefied gases have made use of roof structures fabricated of costly metals which do not become embrittled at the low temperatures of the liquefied gas. Such disadvantages and others of the undesirable features of constructions heretofore employed are obviated by the use of a roof structure, in accordance with the practice of this invention, which comprises the combination of a super-structure, a substantially flat sheet of a fluid and vapor impervious material, a thermal insulating layer lining at least one surface of the sheet, means for firmly fixing the position of the sheet, means for interconnecting the periphery of the sheet in sealing relation with the side walls of the storage facility, and supporting means fixed to the super-structure for supporting the sheet beneath the super-structure as a roof over the ground reservoir.

The preferred forms of super-structure comprise girders or trusses of any suitable structural material (e.g. metal, wood, precast or prestressed concrete). These may be arranged in spaced parallel rows, or to intersect one another, or may be arranged radially. In the preferred form of this invention, the super-structure comprises trusses extending crosswise of the ground reservoir and interconnected by beams and bracing members to provide a support of grating, walkways, piping and pumping assemblies, and wherein the trusses are supported at their ends on piers, in the form of columns of steel or reinforced concrete which extends downwardly into the ground for support.

Alternatively, the super-structure may comprise steel ribs. Such ribs may be spaced at intervals across the roof and may intersect each other (e.g. at right angles) to form a grid. In the case of a circular roof, they may all meet one another in the center thereby acting as radial ribs. The ribs would preferably be straight so that an essentially flat roof that could be sheeted economically with flat plates might be produced.

The sheet which is attached to the super-structure is preferably in the form of a thin metal (e.g. a metal membrane). When the roof is used for a ground reservoir for the storage of liquefied gases, use should be made of

metals which do not become embrittled at low temperatures, such for example as high nickel steels, stainless steels, copper, aluminum, or alloys of aluminum. Usually the metal membrane is stiffened by small ribs extending in two or more directions. Instead of metal sheets, sheets of other fluid and vapor impervious materials, such as plywood, may be employed. The sheet is preferably flat but it may be curved.

The thermal insulation can be of fiber glass, foamed plastic (e.g. polyurethane foam or polystyrene foam), balsa wood, paper honeycomb, kapok, mineral wool or rock wool. Preferably the insulation lines the upper surface of the sheet where it is laid on or supported by the sheet. If desired, however, it may line the underside of the sheet whereby it becomes necessary to provide support for the thermal insulation lining. In many cases, the means for supporting the sheet beneath the super-structure can also be employed to support the insulation. If necessary, further support may be employed and such suitable insulation support may comprise a wire mesh grid or a metal grid.

It is preferred to have part of the super-structure extend outwardly beyond the sheet so that it becomes easier to support the sheet beneath the super-structure.

It is preferred also to anchor the periphery of the roof to the side walls of the container in a manner to prevent relative movement in the vertical direction, while permitting relative movement in the horizontal direction. In this way, shifting movement is prevented. Where the container terminates in a wall, and especially when it terminates as a concrete wall, the wall may be lined with steel or other metal on the outside or inside and the sheet welded to the metal liner to effect a sealing relationship therebetween. Alternatively, anchoring bolts secured to the roof structure may be embedded in the wall. Other means for fixing firmly the position of the sheet will include welding the sheet to the supporting structure at all or some of the points of contact between the sheet and the supporting structure.

The supporting structure for the sheet would preferably be fixed to the region of the super-structure which is vertically above the central portion of the sheet, which would be the apex of the sheet when the sheet is cambered. With this arrangement, coupled with the fixing of the position of the sheet, any upward thrust on the sheet is counteracted and the position of the sheet resists being shifted. The supporting structure preferably comprises girders extending from the periphery of the sheet towards the center of the sheet. If the sheet is substantially circular in shape, these girders would be radially disposed. If the sheet is square or rectangular in shape, the girders would preferably intersect each other (e.g. at right angles) to form a grid. In any event, the ends of the girders near the periphery of the sheet are preferably secured in position (e.g. to the top of the container). In a circular roof, reppresenting the preferred practice of this invention, the radially disposed girders may be reinforced by purlins as well as by rafters located in spaced relationship between the girders, and especially the outer portions of the supporting structure. When girders, purlins and rafters are used as the supporting means, in order that the means may be attached to the super-structure, preferably at the region where the girders converge (if

they are radially disposed) or at the intersections (if they intersect), they are attached to a member which is secured to the super-structure. This member may conveniently be a ring through which conduits, pumping means, vapor outlets, etc. may pass. However, there may be other hatches, outlets and connections to the storage means. This member should be firmly interconnected with the super-structure and with the girders to resist vertical displacement of the girders in response to any upthrust. When the roof is used for a ground reservoir for liquefied gases, it is desirable to protect the super-structure against excessive chilling and therefore there should be an insulation block between the supporting means and the super-structure. When the supporting means comprises girders attached to a central member, such as a ring, there may be thermal insulation between said member and the super-structure. Alternatively, there may be a layer of thermal insulation between said member and each of the girders.

When the roof is used for a ground reservoir for liquefied gases, the material of the supporting means, including girders, rafters and purlins, should be of a material which does not become embrittled at low temperatures, such for example as aluminum, nickel steels, or other materials mentioned as being suitable for the sheet itself.

If the insulation is above the sheet and the sheet is likely to be at the freezing point of water or at a lower temperature, it is preferred to make use of a vapor barrier placed above the insulation and arranged in sealing relationship with the supporting means. Suitable vapor barriers comprise plastic sheets, such as sheets of polyethylene, polyesters and the like, although sheets impregnated or coated with bituminous materials may be employed.

The roof is particularly suitable for a ground reservoir. According to the invention, a ground reservoir suitable for storage of a liquefied gas is one which makes use of a hole in the surface of the earth, which hole has walls which are impervious to the substance to be stored, a gas vent, conduit and pumping means for filling and emptying the reservoir and a roof comprising a super-structure, a substantially flat sheet, thermal insulating material lining at least one surface of the sheet, means for firmly fixing the position of the sheet, and supporting means fixed to the super-structure for supporting the sheet beneath the super-structure. Preferably the gas vent, the conduit or the pumping means or all three will pass through the roof of the reservoir for communication with the interior thereof. The hole in the surface of the earth is preferably a hollow space in the surface of the earth which has substantial area in the plane of the surface in relation to its capacity. The hole in the surface of the earth is also preferably one wherein at least the upper region of the side walls is lined, as with concrete. According to the invention, a capping for a ground reservoir suitable for the storage of a liquefied gas comprises a super-structure supported above the ground, a substantially flat sheet, thermal insulation material lining at least one surface of the sheet, a lining for the upper region of the side walls of the reservoir, means for fixing the periphery of the sheet to the lining and supporting means fixed to the super-structure for supporting said sheet beneath the structure. If desired, the lining (e.g. the concrete) may extend right down to the walls of the reservoir and even beyond the bottom thereof.

The hole in the surface of the earth is also preferably one wherein the ground formation surrounding the hole contains a liquid (especially water) which will solidify when the reservoir is charged with the cold liquid to be stored.

It is an object of this invention to provide a ground reservoir for the storage of cold liquids and it is a related object to provide a ground reservoir of the type described which has an improved roof structure.

More specifically, it is an object of the invention to provide a roof structure for a ground storage facility which is simple in construction and effective in operation; which makes use of relatively inexpensive and readily available materials that are easily assembled into a sturdy roof capable of use with large ground reservoirs adapted for the storage of cold liquefied gases.

These and other objects and advantages of this invention will hereinafter appear and for purposes of illustration, but not of limitation, an embodiment of the invention is shown in the accompanying drawings in which:

FIG. 1 is a schematic sectional elevational view taken crosswise along about the center of the roof covering a ground reservoir;

FIG. 2 is a top plan view of the roof of FIG. 1 with a part of the insulation layer and roof cut away;

FIG. 3 is an elevational view showing the hanger details for interconnecting the super-structure with the roof supporting structure;

FIG. 4 is an end elevational view of the hanger arrangement shown in FIG. 3; and

FIG. 5 is a sectional view in greater detail showing the sealing relationship between the periphery of the roofing sheet and supporting structure with the side walls of the container.

Referring now to the drawings for a specific illustration of a roof construction embodying the features of this invention, the super-structure **10** which is supported independent of the roof **12** comprises a truss formed of an upper chord **14** and a lower chord **16** interconnected by cross members **18** to provide a rigid structure with grating **20** resting on the bottom chord **16** to provide walkways which also serve to support piping and other fluid and gas processing equipment, such as pumps and the like (not shown). The truss is dimensioned to have a length greater than the cross-sectional dimension of the roof, or the diameter of the roof when the roof is round, and the end portion of the truss is adapted to rest upon pier caps **22** fixed to the upper ends of piers **24** which extend downwardly into the ground **26** alongside the ground reservoir. Since the super-structure will not be exposed to the cold of the liquid in storage, the truss and other elements thereof can be formed of carbon steel and the piers can be formed of such structural steel or reinforced concrete.

The roof comprises a sheet **30** of aluminum, 9% nickel steel, copper, aluminum alloy or the like relatively cold temperature insensitive material overlying a supporting structure formed of radially disposed girders **32** and intervening rafters **34** braced with radially spaced apart circumferential purlins **36** with the sheet **30** being connected at its bottom side to the top side of the girders, rafters and purlins, as by welding or the like metal joining means. The supporting structure including the girders, rafters and purlins, which will be exposed to the cold of the liquid in storage, should be fabricated of such cold insentive materials as 9% nickel steels, stainless steels, aluminum, aluminum alloys or the like materials of which the sheet **30** is formed. As previously pointed out, the sheet **30** may also be formed of other fluid and vapor impervious materials such as of plastics and the like.

A relatively thick layer **41** of thermal insulating material is supported on the top side of the sheet **30**. Such insulation may be formed of batts of fiber glass, mineral wool, rock wool, cork, balsa wood panels, foamed plastics, or others of the materials previously described.

The roof is supported at its central portion from the center of the super-structure thereby indirectly to support the roof in fixed position over the reservoir. For this purpose, use may be made of hanger means illustrated in greater detail in FIGS. 3 and 4 which include hanger bars that interconnect the beams and girders supporting the roof with the bottom chord of the truss. In the illustrated modification, such interconnection between the roofing sheet and the super-structure is effected at four

points A, B, C and D, uniformly distributed about the ring **43** at about the center of the roof. It will be understood that the number of suspension points may be more or less than indicated.

The hanger bar assemblies, illustrated in FIGS. 3 and 4, comprise longitudinally spaced apart pairs of bars **40** with each pair being formed of spaced apart bars **42** secured at their upper ends to the bottom chord of truss **10** to depend downwardly therefrom. Extending lengthwise between the laterally spaced apart bars **42** and dimensioned to have a length greater than the spaced relationship between the longitudinally spaced apart pairs **40** is a hardwood filler block **44** faced on its top side and on its bottom side by metal cover plates such as steel plates **46** and **48** with vertically spaced apart angle irons **50** and **52** being welded or otherwise secured to the bars **42** and plates **46** and **48** to lock the filler block **44** in position therebetween.

Other longitudinally spaced apart pairs of hanger rods **54** with each pair formed of a pair of laterally spaced apart bars **56** are secured at their upper ends to the hardwood filler block by means of the angle irons **58** and **60** which extend crosswise between the bars **56** adjacent the top side and bottom side of the plates **46** and **48** and spaced inwardly from the longitudinal pair of cross-hanger rods **40**. The angle irons **58** interconnect the bars and plates, as by welding or other suitable metal joining means, whereby the hanger bars **56** depend downwardly from the interconnecting filler block **44** through the roof plate **30** into engagement with the roof supporting girders **32** and beams to which they are connected as by welding.

The roof is secured at its outer periphery to the tank wall **70** for support of the roof in a manner peripherally to effect a sealing relationship therebetween. For this purpose, the roof is provided with a slotted anchor plate **72** secured as by welding to the ends of the girders **32** and the upper end of the tank wall is provided with a bearing plate **74** and the bearing plates and the anchor plates are secured one to the other as by means of an anchor bolt **76** which extends through the slotted openings in the anchor plate. To complete the closure between the roof and the wall and to effect a sealing relationship therebetween, there is provided a seal plate **78** of thin gauge metal, secured, as by welding, in sealing relationship at its upper edge to the outer periphery of the roof plate **30** while its lower edge is secured to a liner plate **79** fixed to the tank wall and with a bellows portion or other flexible plate **80** in between to permit possible relative movements.

A peripheral wall **70** of prestressed concrete, having an external plate **82** of temperature insensitive material lined for protection by gunite, may be used to form top wall portion of the tank to which the liner plate **79** is attached. Liquid inlet **84** and liquid outlet **86** pass through the roof into the reservoir containing the liquefied gas **88**. A vapor outlet **90** is provided through the roof for communication with the vapor space **92** at the top of the reservoir.

The reservoir itself is excavated out of the earth **94** and a footing **96** of concrete may be provided on which the wall **70** is built. Around the wall **70**, the ground may be excavated for the insertion of freeze pipes **97** in the event that it is desired, in the preferred construction of the reservoir, to pre-freeze the ground before excavation. Such pre-freezing of the ground is desirable if the tank is to be located in unstable soil since the frozen ground requires less costly bracing. It will be understood that the shoring and pre-freezing is not essential to the construction of the storage facility. The annular space is filled with earth and covered with a layer of thermal insulation **98** of the type previously described. The freeze pipes **97** may also be used to circulate a cold liquid therethrough to freeze the moisture in the earth surrounding the container before liquefied gas in introduced. After a short period of time, the cold of the liquid within the reservoir will be sufficient to maintain a liquid impervious layer of frozen liquid in the walls of the reservoir.

While description has been made of construction associated with the tank wall strucutre, it will be understood that the concepts of this invention are not limited thereto since other tank structures per se may be employed with various modifications in the reinforcement and support. For example, the wall **70** extending upwardly from the earth to extend the height of the reservoir may itself be formed of metal to which the girders **32** and the sheet **78** may be joined without the necessity to make use of side plates or bearing plates.

It will be understood also that various other modifications may be made with respect to the arrangement and location of the pipings, pumping means and the like, and that other changes may be made in the details of construction, arrangement, operation and materials, without departing from the spirit of the invention, especially as defined in the following claims.

We claim:

1. In a ground reservoir for the storage of cold liquids comprising a hole in the ground having side walls, a roof construction comprising a truss-type super-structure having its ends extend beyond the periphery of the side walls, piers at the ends of said super-structure for elevating and supporting the super-structure at the ends thereof above the side walls independently of the reservoir structure, in such manner that the super-structure spans the hole in the ground above the level of the top of the reservoir, a fluid and vapor impervious roof sheet beneath said super-structure dimensioned to cover the ground reservoir, an insulation layer lining one side of the roof sheet, a structurally strong and rigid framework interconnected to and supporting the roof sheet, suspension means interconnecting said framework with the super-structure to position the roof sheet beneath the super-structure, and vapor-proof sealing means interconnecting the periphery of the roof sheet with the side walls of the ground reservoir.

2. A ground reservoir as claimed in claim **1** in which the fluid and vapor impervious roof sheet comprises a sheet of metal of a type which remains ductile at the low temperature of the liquid.

3. A ground reservoir as claimed in claim **1** in which the insulation comprises a porous layer of thermal insulating material lining the top side of the roof sheet.

4. A ground reservoir as claimed in claim **1** in which the framework comprises girders underlying the roof sheet and connected thereto.

5. A ground reservoir as claimed in claim **1** in which the framework is suspended at its central portion from the central portion of the super-structure.

6. A ground reservoir as claimed in claim **1** which includes a wall forming a part of the reservoir and extending upwardly beyond the level of the ground and in which the roof sheet is connected at its peripheral portion to the wall in sealing relation to enclose the reservoir.

7. A ground reservoir as claimed in claim **6** in which means interconnecting the roof sheet with the wall in sealing relation comprises a metal sheet joined at one end continuously to the periphery of the roof sheet and at the other end continuously to the wall and which includes a bellows portion intermediate the ends for enabling relative movements between the roof sheet and the wall.

8. A ground reservoir as claimed in claim **6** in which the means interconnecting the roof sheet with the wall comprises a bearing plate on the top of the wall and means connecting the framework at its outer end to the bearing plate.

9. A ground reservoir as claimed in claim **1**, including a walkway supported by said truss-type super-structure.

10. A ground reservoir as claimed in claim **9**, and piping for conducting fluid to and from said reservoir, said super-structure member supporting said piping.

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CHARLES E. O'CONNELL, *Primary Examiner.*

JACOB SHAPIRO, *Examiner.*