

Dec. 5, 1950

F. L. PLUMMER
FLUID STORAGE TANK

2,532,854

Filed May 27, 1947

2 Sheets-Sheet 1

Fig. 1.

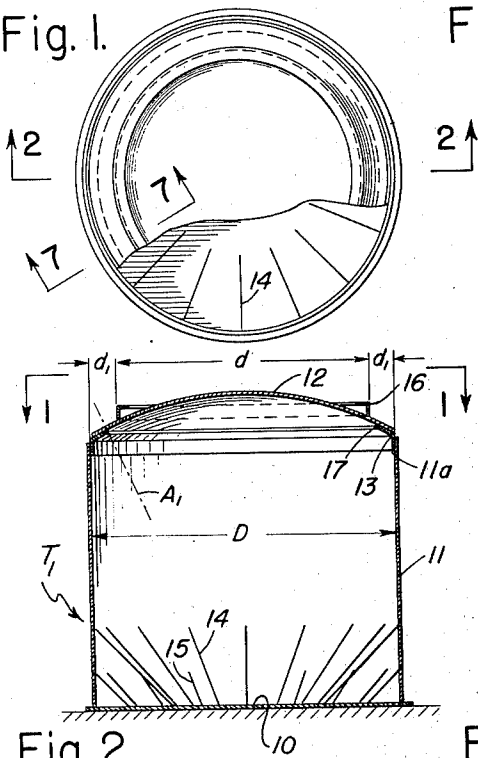


Fig. 3.

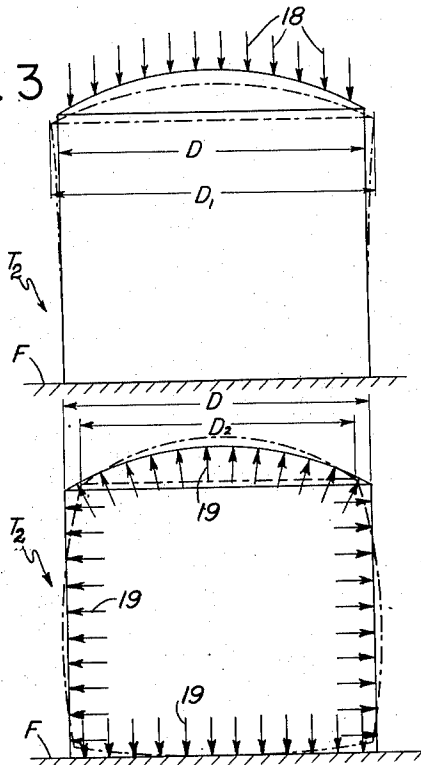


Fig. 2.

Fig. 4.

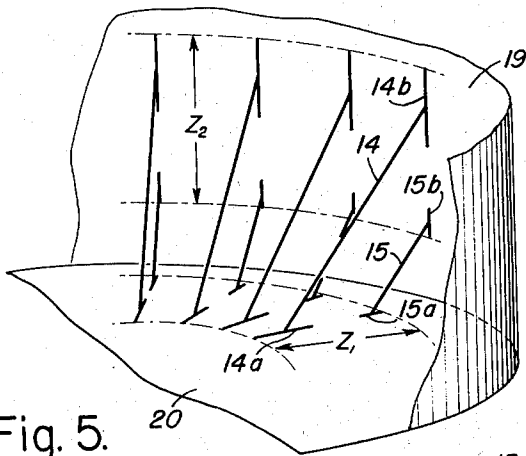
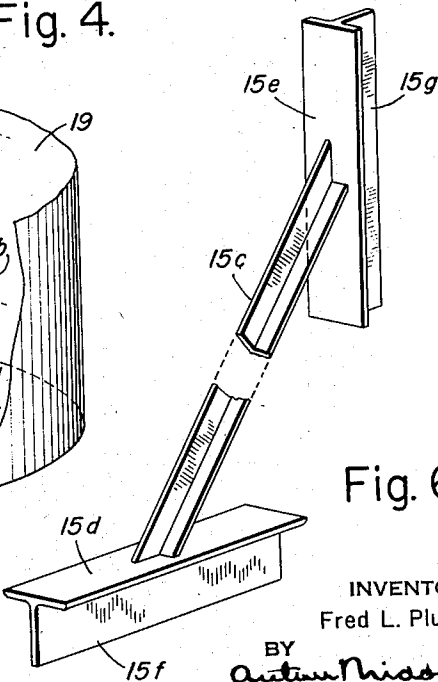


Fig. 5.

Fig. 6.



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2 Sheets-Sheet 2

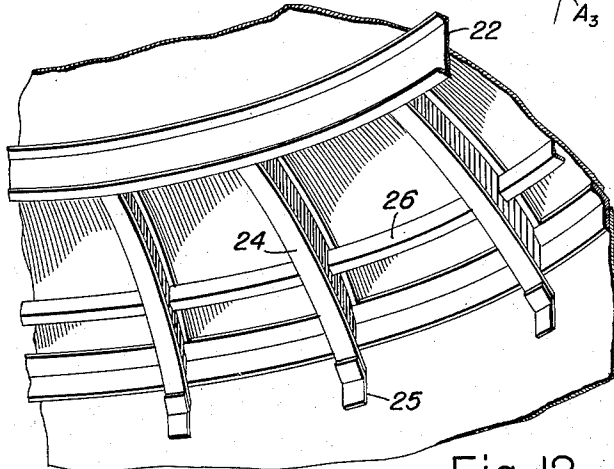
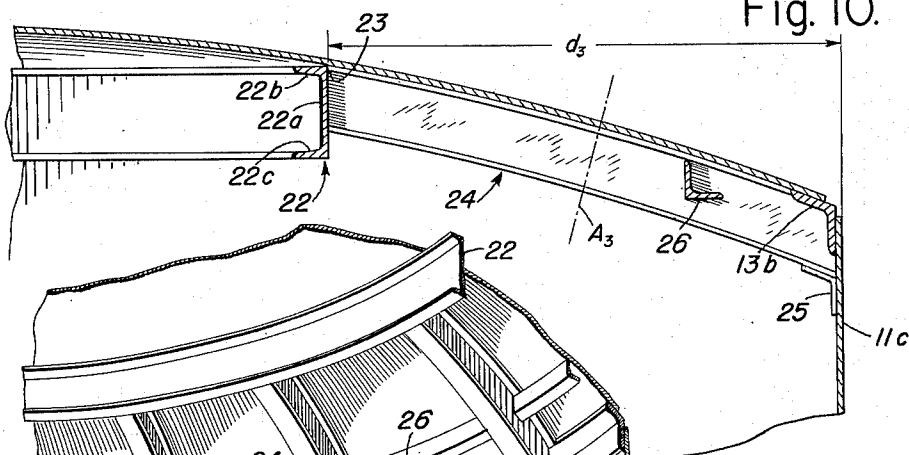
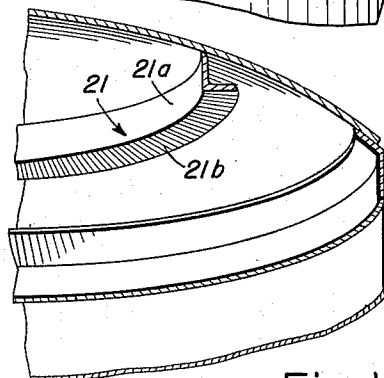
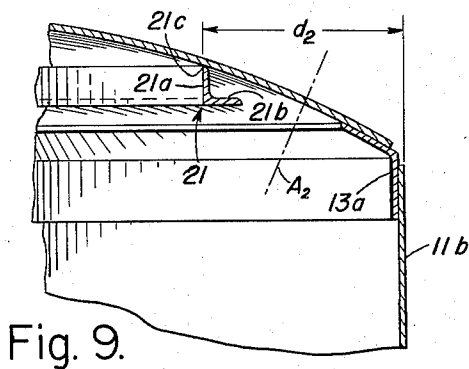
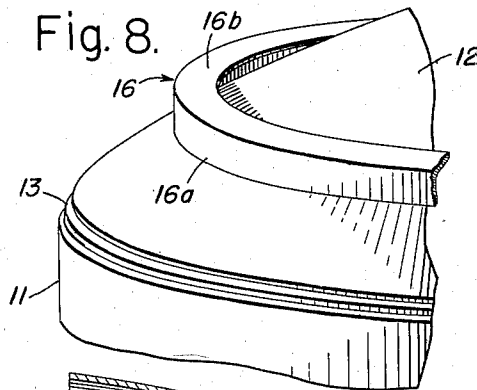
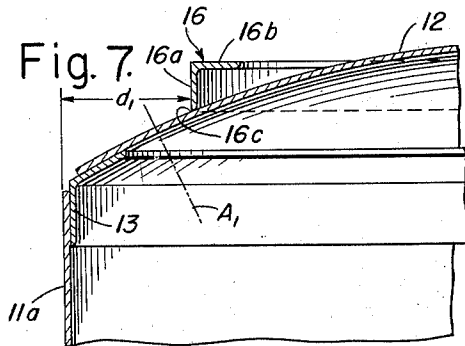


Fig. 11.

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2,532,854

FLUID STORAGE TANK

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Application May 27, 1947, Serial No. 750,679

2 Claims. (Cl. 220—71)

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This invention relates to closed storage tanks for liquids and more particularly to round steel tank constructions of the flat bottom-, cylindrical shell-, and dome roof type.

In such a tank a horizontal flat bottom portion is connected as by welding to a vertical cylindrical body portion or shell forming therewith the peripheral bottom corner portion of the tank, while the top end of the shell is connected as by welding to an outwardly convex top or self-sustained shallow dome portion forming with the shell the peripheral top corner portion of the tank.

If internal vapor pressure as from volatile liquids is developed in such a tank it may subject certain portions thereof to unduly high or concentrated or unfavorable stresses which if unrestrained or not compensated for may produce structural deformations which may lead to failure of the tank or of parts thereof. Especially the peripheral top- and bottom corner portions of the tank become vulnerable rendering the tank liable to failure should internal super-atmospheric pressure prevail.

While any material in order to resist or absorb forces must be deformed in accordance with the internal stresses created in the material, normal deformations in steel are very small and elastic and disappear when the force is removed, and their appearance and disappearance are not necessarily objectionable. However, one must guard against and avoid deformations of a larger inelastic and permanent order remaining after the force is removed, as they may lead to failure of the tank structure.

The general character of the forces, stresses, strains, and potential deformations to which the tank walls or tank structure may be subjected will be understood from the fact that the internal vapor pressure tends to deform the straight sides of the tank towards assuming a curved and non-straight form, thereby subjecting especially the corner portions of the tank to excessive, concentrated and unfavorable stresses and strains through which undue deformation and failure may occur.

It is among the objects of this invention to provide simple and effective anti-deformation means for the tank, and more particularly for the corner portions thereof, so that a tank of the flat bottom-, cylindrical shell-, and dome roof type may be rendered safe even though the operation of the tank involves internal super-atmospheric vapor pressure as a prevalent force.

The character and correctional nature of these

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stresses will be more apparent and clearly understood, if for example, the top portion of the tank is looked upon as a dished or domed member that may be subjected either to outwardly directed radial forces creating tension stresses in the marginal annular portion of the member, or to inwardly directed radial forces creating compression stresses in the marginal annular portion of the member. A dished member thus subjected to tension or compression in the marginal annular portion thereof may absorb tension stresses of a relatively high order without suffering any resultant objectional deformation, yet it may crumple, buckle and become permanently deformed under relatively light compression stresses. Therefore, in the case of such members compression stresses are much more critical than tension stresses, and to illustrate the present instance the compression stresses will herein be termed the critical ones, while tension stresses will be referred to as non-critical.

Reverting to the tank as such, it can be visualized that the peripheral top corner portion is being subjected to non-critical tension stresses when the pressure inside the tank is substantially equal to that of the outer atmosphere, the stresses being assumed to be caused by a roof load such as may be due to the weight of the roof itself, a snow load, or other loads or equipment placed upon the roof or top portion of the tank. Such a load upon the roof tends to flatten the convex shape thereof, and tends to force the peripheral portion of the top or roof outwardly and to impose radial outwardly directed forces upon the peripheral top corner portion of the tank.

By contrast, when internal upward vapor pressure substantially exceeds the oppositely directed roof load, tension stresses are set up in the top or roof along with the tendency of the dome to bulge upwardly and to accentuate the convexity thereof. This is tantamount to a tendency of the peripheral top edge portion to contract or else of its diameter to decrease, and thus to set up compression stresses in the peripheral edge portion or peripheral corner portion of the tank, that is a portion including sections of the roof as well as of the shell joining one another at the top corner of the tank.

It is a more specific object of this invention to obviate or compensate for deformation-producing marginal stresses by providing anti-deformation means which are simple and effective against compression forces for the peripheral top corner portion of the tank, in short to provide a tank top constituting a cup-shaped girder.

Upward internal vapor pressure in the tank also sets up deformational tendencies and strains in the lower peripheral corner portion at the bottom of the tank, especially when the liquid level in the tank is low. Such stresses are due to upward pull transmitted marginally from the roof and vertically through the shell which upward pull tends to raise the peripheral edge portion of the tank bottom off the ground, and thus to deform the normally flat tank bottom into an outwardly or downward bulge, as the deformation of the tank as a whole follows its tendency of being deformed towards the general shape of a sphere.

It is therefore another object of this invention to obviate such potential deformation of the tank bottom by providing efficient and simple anti-deformation means in conjunction with anti-deformation means for the top corner portion.

I attain the foregoing objects by embodying in the top of the tank a cup-shaped or cupped girder having an effective cross-sectional area that presents a relatively high moment of inertia to the compression or buckling forces; and by providing internal corner braces extending between the tank bottom and the shell, which afford efficient force transmission between the shell area and the bottom area of the tank while neutralizing or side-tracking deformation-inducing forces from the peripheral corner portion, or preventing such forces or stresses from acting directly or unfavorably upon the corner portion.

The cupped girder according to this invention has embodied in the marginal annular portion and welded thereto a supplementary concentric steel ring or ring member of suitable steel profile spaced from the extreme edge of the tank top, that is from the peripheral juncture of the tank top with the shell. That is to say, the ring member while unitary and concentric with the tank top is of a diameter significantly smaller than the peripheral or outer diameter of the top so that the ring member is spaced a significant distance from the periphery of the top. The cupped girder further comprises stiffening elements radially extending between the steel ring and the peripheral juncture of the tank top with the shell.

In order to attain efficient force transmission or stiffening interconnection between the respective horizontal and vertical areas of the bottom corner portion, there is provided a representative brace member comprising a foot portion having a radially extending vertical rib or flange the free edge of which is welded to the horizontal tank bottom, and a head portion having a vertically extending rib or flange the free edge of which is welded to the vertical shell.

The invention possesses other objects and features of advantage, some of which with the foregoing will be set forth in the following description. In the following description and in the claims, parts will be identified by specific names for convenience, but they are intended to be as generic in their application to similar parts as the art will permit. In the accompanying drawings there has been illustrated the best embodiment of the invention known to me, but such embodiment is to be regarded as typical only of many possible embodiments, and the invention is not to be limited thereto.

The novel features considered characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of

operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment when read in connection with the accompanying drawings in which:

Fig. 1 is a diagrammatic part-sectional top view of the tank embodying top corner- and bottom corner anti-deformation means;

Fig. 2 is a vertical section of the tank taken upon the line 2—2 of Fig. 1;

Figs. 3 and 4 are diagrams illustrating tentative deformations of the tank due to exterior roof load and to internal super-atmospheric pressure respectively;

Fig. 5 is a detail perspective view of the bottom corner anti-deformation means enlarged relative to Figs. 1 and 2;

Fig. 6 is a further enlarged perspective detail view of a bottom corner brace member;

Fig. 7 is an enlarged detail sectional view of the top corner portion of the tank taken on line 7—7 of Fig. 1;

Fig. 8 is an external perspective view of the corner portion shown in Fig. 7;

Fig. 9 is a sectional view of the top corner portion similar to Fig. 7 although modified with respect to the arrangement of the anti-deformation means;

Fig. 10 is an internal perspective view of the corner portion of Fig. 9;

Fig. 11 is a sectional view of a further modification of the anti-deformation means;

Fig. 12 is an internal perspective view of the corner portion of Fig. 11.

According to the semi-diagrammatic views of Figs. 1 and 2 the tank T₁ comprises a horizontal flat bottom 10, a cylindrical vertical shell or body portion 11 of the diameter D rising from the bottom and welded thereto, and a shallow outwardly convex top or dome portion 12 fixed to and connected with the top end of the shell by means of an annular connecting element 13 of obtuse angular cross-section and welded to the shell and to the dome respectively. The peripheral bottom corner portion of the tank is provided with anti-deformation means as represented by radially and upwardly extending corner brace members 14 and 15, the members 14 being longer than the members 15. A supplementary ring member 16 of angular cross-section is concentric with the shell 11 although of a diameter d smaller than the diameter D of the shell, and is welded to the top side of the dome and thus unitary therewith.

The peripheral top corner portion of the tank thus comprises the annular connecting element 13, the supplementary ring element 16, and the marginal annular portion or peripheral zone 17 of the top or dome defined by the differential of the diameters D and d, that is $D-d=2d$. From a viewpoint of stress analysis this peripheral zone may also be said to include the top edge portion 11^a of the shell 11. The moment of inertia of the cross-section of the cupped girder can be said to be represented by the moment of inertia of the cross-section of the component portions just enumerated.

Figs. 3 and 4 illustrate in exaggerated fashion potential deformations (indicated in dot-and-dash lines) of the tank T₂ when (a) an external vertical roof load prevails as indicated by arrows 18 in Fig. 3, and when (b) internal super-atmospheric vapor pressure prevails as indicated by arrows 19 in Fig. 4.

In Fig. 3 the roof load 18 causes tentative de-

formations of the tank (as indicated in dot-and-dash lines) as it tends to flatten the top or dome, and thus to expand or spread the marginal portion thereof as well as to widen or expand the top edge portion of the shell. This is indicated by the respective diameters D and D_1 of the normal and of the expanded condition of the tank top. Such deformation is resisted by tension stresses in the corner portion or ring girder, which stresses are herein termed non-critical. The vertical load is transmitted down through the vertical walls of the shell to the tank bottom and to the foundation indicated at F ; hence, neither the lower shell portion nor the bottom is shown to undergo any substantial deformation in this instance or load condition.

In Fig. 4 the internal pressure in the closed tank tends to deform the same towards the general shape of a sphere. The deformation of the tank (as indicated in dot-and-dash lines) comprises a barrel-like outward bulging of the vertical shell, an upward bulging or increased convexity of the top, as well as a downward bulging of the bottom. This therefore shows a contraction or decrease of the diameter of the top corner portion, with attendant peripherally directed compression stresses which must be adequately absorbed by the corner portion if undue permanent deformations or buckling or crushing is to be precluded. This deformation is indicated by the respective diameters D and D_2 of the normal and of the contracted conditions of the tank top. Anti-deformation means against such stresses in the top corner portion of the tank are presented in the form of what has herein been termed the cupped girder including the supplementary ring element 16. Anti-deformation means for the bottom corner portion are in the form of the corner brace members 14 and 15 which transfer or disperse the vertical upward pull from an intermediate portion of the shell to a bottom area sufficiently spaced from the periphery to neutralize undesirable deformational corner stresses.

The somewhat enlarged, but still diagrammatic detail (Fig. 5) of the arrangement of the brace members shows an effective manner of transmitting vertical upward pull from a vertical cylindrical area 19 of the shell to a horizontal area 20 of the bottom, since each of the larger brace members 14 has a horizontal and radially extending foot portion 14^a and a vertically extending head portion 14^b. Similarly each of the smaller brace members 15 has a foot portion 15^a and a head portion 15^b. An enlarged representative example of such a brace member is shown in the perspective detail Fig. 6. This member consists of a length of inclined angle iron 15^c representing the body portion, a foot portion 15^d in the form of a length of structural steel of T-shaped profile, and a head portion 15^e of similar shape, the body portion being welded to the foot- and head portions. The foot and head edges 15^f and 15^g respectively of the T-shapes in turn are welded in rib-like fashion to the bottom and to the shell respectively of the tank.

Figs. 7 and 8 represent enlarged details of the improved construction of the top corner portion of the tank such as largely disclosed in Figs. 1 and 2, Fig. 7 indeed being a partial vertical section taken upon Fig. 1. Fig. 8 more fully illustrates by perspective the appearance of an embodiment of the supplementary ring member 16 which being in the form of an annularly bent angle iron comprises a vertical cylindrical portion 16^a and a horizontal flange portion 16^b ex-

tending inwardly from the top end of the cylindrical portion, the portion 16^a being welded to the tank top as at 16^c. The moment of inertia of the peripheral zone of the cupped girder relative to an assumed axis A_1 thus comprises the combined cross-sectional areas of the ring member 16, of the connecting member 13, of the peripheral annular top portion d_1 , and to some extent of the top end portion 11^a of the vertical wall or shell of the tank.

A modification of the cupped girder construction as shown in Figs. 9 and 10 provides for a supplementary ring member 21 to be welded to the underside of the tank top as at 21^c. This ring member is an angle iron bent into ring shape and consisting of a vertical cylindrical portion 21^a welded to the tank top, and of a horizontal flange portion 21^b extending outwardly from the lower end of the cylindrical portion. The parts otherwise shown correspond to similar parts in Figs. 7 and 8. The moment of inertia of the peripheral zone of the cupped girder relative to an assumed axis A_2 thus comprises the combined cross-sectional areas of the ring member 21, of the angle shape of the connecting member 13^a, of the peripheral annular top portion d_2 , and to some extent it may be said to include the cross-sectional area of the top end portion 11^b of the shell or vertical wall of the tank.

Figs. 11 and 12 show a further modification of the cupped girder construction providing a supplementary ring member 22 consisting of a structural steel shape bent into ring form. The cross-section is a channel shape. Thus the ring member comprises a vertical cylindrical portion 22^a, an upper horizontal flange 22^b, a lower horizontal flange 22^c, both flanges extending inwardly from the body portion. This ring member is welded to the underside of the tank top as at 23. Between the ring 22 and the tank wall are provided radially extending stiffening members 24 in the nature of a structural shape having I-profile, and otherwise shown to be shaped or slightly curved in conformity with the shallow curve of the tank top. A clip angle or bracket member 25 fastened to the inner face of the tank wall supports the outer end of the stiffening member and is fastened thereto. The stiffening members 24 are in turn stiffened in a lateral direction, that is with respect to one another as by angle irons 26 welded to the top and to respective web portions of the I-shape of the stiffening members at a point spaced from either end thereof.

The moment of inertia relative to an assumed axis A_3 of the peripheral zone of the cupped girder in this embodiment may be said to comprise the combined cross-sectional areas of the channel profile of the ring 22, of the angle profile of angle irons 26, of the angle profile of the connecting ring or member 13^b, of the annular peripheral top portion d_3 defined substantially by the distance between the ring 22 and the tank wall, and to some extent the top end portion 11^c of the tank shell itself.

Stress conditions in the tank may be further illustrated and analyzed as follows:

Let it be assumed that a tank of the cylindrical, flat bottom, and dome roof type has an open vent or conservation vent set to operate at 1 oz. per square inch or less of either vacuum or pressure. The steel plates that go to make up the shell may be butt-welded together and fillet-welded directly to the bottom. The plates that make up the roof and those that make up the bottom are usually lap-welded to-

gether. The roof is usually connected to the shell as by a continuous angle or angle profile shaped into a ring, the angle being of obtuse configuration. The tank bottom may rest directly on the ground or on a layer of sand, gravel or crushed stone. A usual thickness found in the roof plates is about $\frac{1}{8}$ " to $\frac{1}{4}$ ", bottom plates usually being $\frac{1}{4}$ " to $\frac{1}{8}$ " thick, while the thickness of the shell plates depends upon the size of the tank and the weight of the stored fluid and may vary from $\frac{1}{4}$ " for the top ring or course to 1" or more for the bottom ring or course of welded plates.

Let us assume that there be no liquid in the tank and the tank is filled with air or an air-vapor mixture at or near outside atmospheric pressure. The weight of the roof plates and any such superimposed roof loads as snow or equipment create low compression stresses in the roof plates, let us say 300 pounds per square inch. Because of such a load there is a tendency of the roof to flatten, and of the diameter of the roof to increase where it is connected to the top edge portion of the shell. This tendency creates a relatively low tension stress in the peripheral top corner portion of the tank, that is in the connecting ring and the adjacent associated portions of the roof and of the shell which corner portion acts as a horizontal tension ring and counteracts or prevents the flattening of the roof. The weight of the roof, of the shell and of superimposed roof loads also creates relatively low compression stress, let us say 300 pounds per square inch which act vertically in the cylindrical shell. These stresses together with the weight of the bottom plates are transmitted directly to the ground so that there are no significant stresses in the bottom plates.

Let us now assume the tank to be partially filled with liquid and to have the space above the liquid in the tank filled with air or an air-vapor mixture at or near the outside atmospheric pressure. The weight of the liquid imposes substantially no additional stress upon the bottom plates since that weight is transmitted directly to the soil or foundation. However, additional stresses are those which are due to outward hydrostatic pressure from the liquid tending to burst the vertical shell by creating therein horizontal or ring stresses. The thickness of the plates may be determined so that a maximum stress does not exceed about 18,000 pounds per square inch.

A steel ring of thin plate can safely resist a uniform outwardly directed pressure creating a tension stress of this intensity regardless of the diameter of the ring, since the internal pressure tends to hold the ring to a perfect circular form, or to change it to that form if any small irregularities exist in its shape before the pressure is applied. Yet if the same ring is subjected to a uniform inwardly directed pressure creating a compression stress in the ring, even a ring of perfect circular form may buckle and fail at a relatively low stress intensity, while a ring having initial small irregularities will buckle and fail at even lower stress value. That is to say, the resistance of such a steel ring to buckling and failure depends upon (a) the diameter of the ring, (b) the area of the cross-section of the ring, and (c) the lateral stiffness of the ring such as measured mathematically by the moment of inertia of the cross-sectional area of the ring (for a given area the moment of inertia increases as the depth of the cross-section in radial direction increases).

By comparison let us now consider stress conditions which develop in a tank of the above defined general type, when super-atmospheric gas pressure prevails in the tank:

Again we have a cylindrical, flat bottom, dome roof type tank, however with a conservation vent set to operate at say 2.5 pounds per square inch (40 ounces per square inch pressure) and at 1 ounce per square inch vacuum. The problem of this invention is to utilize that general type of tank in spite of an internal vapor pressure which would normally endanger a tank of such a shape with the hazard of failure by crushing.

Let it be assumed that there is no liquid or very little liquid in the tank, the space within the tank being largely filled with an air-vapor mixture at a pressure of 2.5 pounds per square inch above the pressure of the outside atmosphere. The stresses due to the tank weight and superimposed roof load may be the same as above assumed for this type of tank where internal vapor pressure approximately equals that of the outer atmosphere. However, upward pressure against the underside of the roof caused by the super-atmospheric vapor pressure creates tension stresses, let us say 3,000 pounds per square inch, in the roof plates. This is tantamount to a tendency of the roof to rise, while decreasing its diameter at the periphery where it is connected to the shell. The tendency which under the assumed conditions is much greater than the opposite one resulting from the roof loads, creates compression stresses in the peripheral top corner portion of the tank and adjacent portions of the roof and shell plates. This top corner portion, therefore, is thus called upon to act as a horizontal ring under compression and to resist such compression adequately, that is without permitting undue deformation if the rising of the roof resulting in inward collapse of the shell is to be prevented.

In order to provide anti-deformation means against such happenings, this invention converts the peripheral top corner portion of the tank into a compression- or crush-resisting girder having sufficient radial width as well as adequate cross-sectional area to afford sufficient moment of inertia to prevent the inward collapse of the top end portion of the tank shell. Such a girder may be said to comprise the peripheral annular portion of the dome, the supplementary ring element such as exemplified above by the members 16, 21 and 22 respectively, the connecting ring or member exemplified above at 13, 13^a and 13^b respectively, and adjacent portions of the dome and of the vertical tank shell respectively as far as they can be assumed to contribute to the crush-resistance or moment of inertia of this girder construction in the top corner portion of the tank.

Upward vapor pressure on the roof, in this instance well exceeding the weight of the roof and the shell, also creates tension stresses of, say 1000 pounds per square inch, acting vertically in the shell plates and tending to pull the shell upwardly and off the ground. This upward pull upon a shell according to this invention is to be neutralized by downward pressure upon the tank bottom, since the soil, in the absence of special anchoring means, cannot exert a downward pull upon the bottom along its periphery where the shell tends to pull it up.

In order to compensate for or neutralize this potential effect this invention provides radial members upon and unitary with the bottom of

the tank to extend radially in that critical intermediate zone of the tank bottom where it is to be rendered resistant. These radial members are represented by the horizontal and radially extending foot portions 14^a and 15^a of the inclined brace members 14 and 15, the length and spacing from one another of these horizontal radial members being such that the bottom plates are thereby given adequate strength and ability to transfer the downward pressure from the shell to the bottom safely and without allowing critical deformations to occur. From the foot portions or base members extend the inclined brace members proper to transmit the downward forces acting upon the base members to a zone of the shell which is spaced an adequate distance upwardly from the bottom. The forces acting through the inclined brace members are thus well distributed to a cylindrical zone of the shell the height of which zone is defined by the height of the head portions 14^b and 15^b of the brace members 14 and 15 respectively. Thus it will be visualized that the inclined brace members transfer the critical forces from an annular horizontal zone Z₁ of the bottom area 20 to a vertical cylindrical zone Z₂ of the shell area 19, these zones being defined by the length of the foot portions and the head portions respectively of the brace members.

By combining the cupped girder in the top and the bracing connections between zones Z₁ and Z₂ at the bottom portion of the tank one may utilize an otherwise standard tank safely under internal super-atmospheric pressure conditions where this general type of tank would otherwise be unsafe or be liable to failure.

I claim:

1. In a closed liquid storage tank adapted to be subjected to internal super-atmospheric pressure, a top portion comprising a cylindrical shell portion, a convexly shaped sheet metal top fixed peripherally to the shell portion, reinforcing means for said top comprising a ring member of structural profile unitary and concentric with the top and of a diameter significantly smaller than the peripheral diameter of the top so that said ring is spaced a significant distance from the periphery of the top, said ring member in

cross-section comprising a vertically extending portion welded edgewise to said top and a free horizontal portion extending from said vertical portion at the end thereof which is pointing away from said top, said ring member being disposed at the underside of the top, with the addition of radial vertically curved reinforcing members of I-shaped profile extending between the ring and the shell.

2. In a closed liquid storage tank adapted to be subjected to internal super-atmospheric pressure, a top portion comprising a cylindrical shell portion, a convexly shaped sheet metal top fixed peripherally to the shell portion, reinforcing means for said top comprising a ring member of structural profile unitary and concentric with the top and of a diameter significantly smaller than the peripheral diameter of the top so that said ring is spaced a significant distance from the periphery of the top, said ring member in cross-section comprising a vertically extending portion welded edgewise to said top and a free horizontal portion extending from said vertical portion at the end thereof which is pointing away from said top, said ring member having the profile of a structural channel disposed at the underside of the top and having inwardly directed free flanges, with the addition of radial vertically curved reinforcing members extending between the ring and the shell.

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