April 22, 1952 H. C. BOARDMAN 2,593,408
SQUAROID
Filed March 24, 1949

Fig. 1.

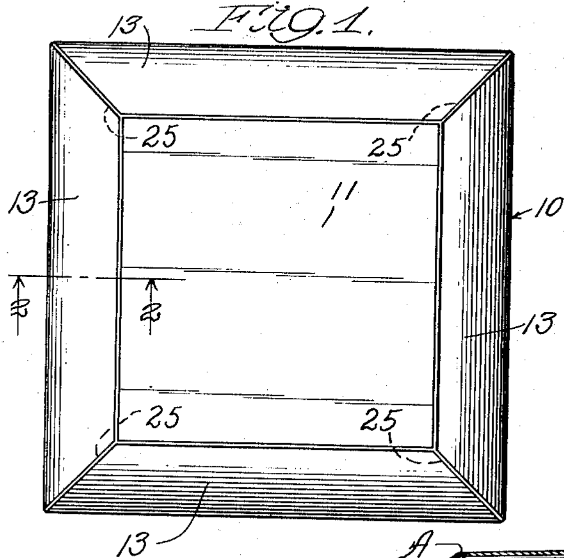


Fig. 3.

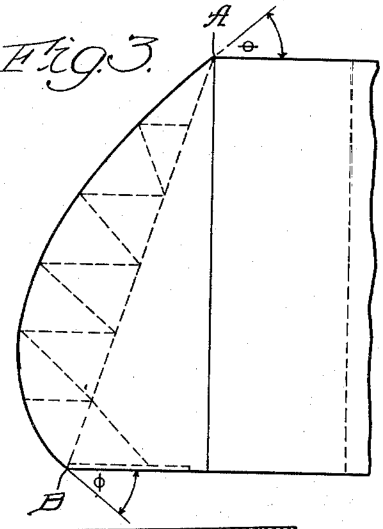
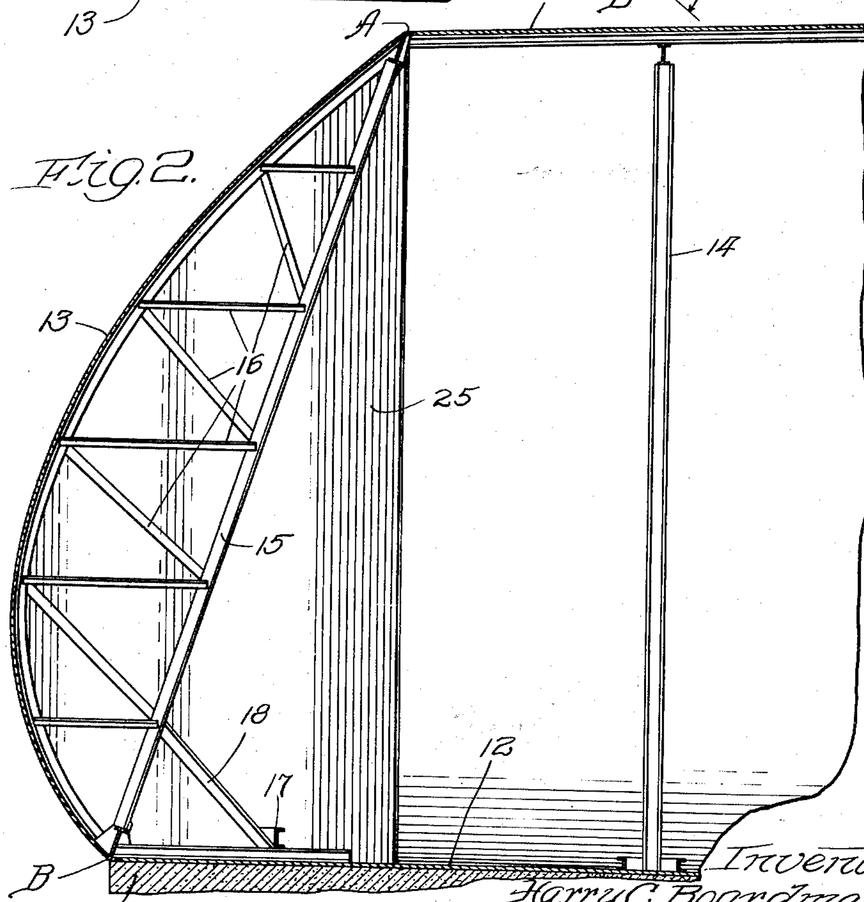


Fig. 2.



Inventor:
Harry C. Boardman,
By Schroeder, Merriam,
Hofgren & Brady, Attys.

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2,593,408

SQUAROID

Harry C. Boardman, Chicago, Ill., assignor to Chicago Bridge & Iron Company, a corporation of Illinois

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11 Claims. (Cl. 220—1)

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This invention relates to a liquid storage tank of large capacity and particularly to such a tank in the form of a squaroid.

This application is a continuation-in-part of my previous application, Serial No. 638,227, filed on December 29, 1945, now abandoned.

While the prevailing form of liquid storage vessels is circular in plan, rectangular and polygonal storage vessels are desirable under certain circumstances, particularly where they are to be erected in restricted areas. The design of a rectangular or polygonal tank presents difficulties, particularly in designing a structure which will function equally well when full or partially full. If such vessel is designed to hold a full load of liquid, bending, sagging, and other stresses are introduced at intermediate liquid levels. The present vessel is designed to operate satisfactorily under liquid loads at all levels.

The invention is illustrated in the accompanying drawings in which:

Fig. 1 is a top plan view of the storage vessel;

Fig. 2 is a vertical section along line 2—2 of Fig. 1; and

Fig. 3 is a view like Fig. 2 used to illustrate the engineering and mathematical principles involved.

The vessel 10 comprises a flat top 11, a flat bottom 12, joined by curved sidewalls 13. In the preferred embodiment shown a slight pitch is provided in the roof 11 to permit drainage of the roof although, for all practical purposes in computing the various stresses, the roof and bottom may be considered as being parallel to each other. Supporting columns such as the columns 14 may be used between the top and bottom of the tank.

It will be noted that the curvature of the sidewalls 13 is not constant from top to bottom. The sidewalls are designed to have decreasing radii of curvature from top to bottom. The radius of curvature of the sidewalls is also designed so that the sidewalls are in equilibrium at the liquid pressures exerted when the tank is full of liquid. The general equation of the curve at any point along the sidewalls is

$$R=\frac{T}{wy}$$

where T is the vertical stress in lbs. per horizontal foot of side, "w" is the weight of the liquid to be stored therein in lbs. per cubic foot, y is the vertical distance between the top and the level under consideration in feet, and R is the radius of curvature of the sidewall at the level under

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consideration in feet. This radius is normal to the sidewall.

A strut or chord 15 has its upper end connected at A to the juncture of the sidewalls 13 and the top 11 and has its lower end connected at B to the juncture of the sidewalls and the bottom 12. When the vessel is full of liquid the strut 15 serves to connect the top and bottom edges of the sidewalls. Inasmuch as under conditions of complete filling the top has a tendency to move downward and the bottom upwards, the strut is under compression when the vessel is full.

At the corners special stress conditions are involved, and these are met by the use of diaphragms 25 which are welded to the junctions of the side walls and carried up to the respective junctions of the side walls with the roof and with the bottom.

In the particular embodiment shown it will be noted by reference to Fig. 3 that the angle θ formed between the top and a line tangent to the sidewalls at A is equal to the angle ϕ formed between the bottom and a line tangent to the sidewalls at B. When these two angles are equal the upward force exerted by the bottom of the sidewalls and the downward force exerted by the top of the sidewalls when the vessel is full are precisely equal and are carried from one to the other by the strut 15. The general equation relating this common angle to the vessel's height and the side stress T is:

$$\cos\theta=\cos\phi=\frac{wH^2}{4T}$$

in which w and T are as in the previous equation and H is the vertical distance between the top and bottom in feet.

Theoretically the angles θ and ϕ can be arbitrarily given any value from zero to 90°. If the angles are zero the roof, sides and bottom would be equally stressed and the sides would be tangent to the roof at an infinite horizontal distance from the juncture of the side and the bottom. On the other hand, if θ and ϕ are 90° the sidewalls would be vertical and hence T, which would be reflected in the thickness required for the sidewalls, would be prohibitively great.

By virtue of the formulae given, however, the values of θ and ϕ and the corresponding value of T are so chosen as to result in the minimum cost of the structure and θ and ϕ can be varied so as to produce the most economical figure for T which results, of course, in the ability to use minimum plate thicknesses.

Under partial liquid loads, that is, when the vessel is only partly filled with liquid, the curve of the sidewalls is not the equilibrium curve for the liquid pressures exerted. Consequently, the side plates tend to sag downward. Accordingly, I provide a kangaroo truss 16 connecting the sidewalls to the strut 15. Thus, the vertically downward force exerted by the sidewalls is carried through the truss 16 to the strut 15 and thus downward to the bottom 12. In order to spread this additional downward force when the vessel is partially filled over a large area of the bottom, I provide the bottom with a plurality of angle irons 17 welded thereto near its outer edge, which irons are connected by means of a truss member 18 to the strut 15. When the vessel is completely filled, the strut 15 is under compression due to the tendency of the roof to move downward and the bottom to move upward at their junctions with the sidewalls, and the vertically downward load on the foundation is constant over the entire bottom. As the curve of the sidewalls is the equilibrium curve for full conditions, the strut 15 is the only member of the strut-truss system doing any work and the truss members 16 and 18 are not performing any function. It is only when the vessel is partially filled and the curvature of the sidewalls is thus no longer the equilibrium curve for the pressures then existing that the truss members serve to support the sidewalls against sag and transmit that stress to the strut. The inwardly projecting truss member 18 spreads the vertical load carried by the strut over sufficient area of the bottom to keep the downward pressure on the foundation 19 under all conditions of partial loading from exceeding the uniform pressure on the foundation when the vessel is full.

Obviously, a number of strut-truss systems 15 and 16 are provided about the periphery of the vessel, the number of such systems depending to a large degree upon the strength of the individual members thereof and the size and capacity of the vessel.

While I have shown and described certain embodiments of my invention, it is to be understood that it is capable of many modifications. Changes, therefore, in the construction and arrangement may be made without departing from the spirit and scope of the invention as disclosed in the appended claims.

I claim:

1. A vessel for storing liquids at substantially atmospheric pressure having a flat top, a flat bottom, and curved sidewalls, the vessel being polygonal in plan and the curvature of the sidewalls increasing from top to bottom to equalize tension therein when the vessel is full of liquid, with the angle at the juncture of the sidewalls to the roof being equal to the angle at the juncture of the sidewalls to the bottom, and strengthening means bracing each corner of the vessel.

2. A vessel for storing liquids at substantially atmospheric pressure having a flat top, a flat bottom larger than the top, and outwardly curved sidewalls, the vessel being polygonal in plan and the curvature of the sidewalls increasing from top to bottom to equalize tension therein when the vessel is full of liquid with the angle at the juncture of the sidewalls to the roof being equal to the angle at the juncture of the sidewalls to the bottom, a diaphragm bracing each corner of the vessel, and a strut connecting the juncture of the sidewalls to the top to the juncture of the sidewalls to the bottom.

3. A vessel for storing liquids at substantially atmospheric pressure having a top, a bottom, and curved sidewalls, the vessel being polygonal in plan and the radius of curvature in feet at vertically spaced points along said sidewalls being equal to

$$\frac{T}{wy}$$

where T is the stress in lbs. per horizontal foot of sidewall, w is the weight in lbs. per cubic foot of the liquid to be contained in the vessel, and y is the vertical distance in feet from the point under consideration on the sidewall to the top of the designed liquid level, and the angle between horizontal and the tangent to the sidewall at the designed liquid level being equal to the angle between horizontal and the tangent to the sidewall at the bottom thereof.

4. A vessel for storing liquids at substantially atmospheric pressure having a flat top, a flat bottom, and outwardly curved sidewalls, the vessel being polygonal in plan and the curvature of the sidewalls increasing from top to bottom to equalize tension therein when the vessel is full of liquid with the angle at the juncture of the sidewalls to the roof being equal to the angle at the juncture of the sidewalls to the bottom, the cosine of said angle being equal to

$$\frac{wH^2}{4T}$$

where w is the weight in lbs. per cubic foot of the liquid to be contained in the vessel, H is the vertical distance in feet between the top and bottom of the vessel, and T is the stress in lbs. per horizontal foot of sidewall.

5. A vessel for storing liquids at substantially atmospheric pressure having a flat top, a flat bottom, and curved sidewalls, the vessel being polygonal in plan and the curvature of the sidewalls increasing from top to bottom, the radius of curvature at vertically spaced points along said sidewalls being equal to

$$\frac{T}{wy}$$

where T is the stress in lbs. per horizontal foot of sidewall, w is the weight in lbs. per cubic foot of the liquid to be contained in the vessel, and y is the vertical distance in feet between the juncture of the roof to the sidewalls and the point under consideration on the sidewall with the angle at the juncture of the sidewalls to the roof being equal to the angle at the juncture of the sidewalls to bottom, the cosine of said angle being equal to

$$\frac{wH^2}{4T}$$

where w is the weight in lbs. per cubic foot of the liquid to be contained in the vessel, H is the vertical distance in feet between the top and bottom of the vessel, and T is the stress in lbs. per horizontal foot of sidewall, and a strut connecting the juncture of the sidewalls to the roof to the juncture of the sidewalls to the bottom.

6. A vessel for storing liquids at substantially atmospheric pressure having a flat top, a flat bottom larger than the top, and curved sidewalls, the vessel being polygonal in plan and the curvature of the sidewalls increasing from top to bottom to equalize tension therein when the vessel is full of liquid with the angle at the juncture of the sidewalls to the roof being equal to the angle at the juncture of the sidewalls to the bottom, a strut connecting the juncture of the sidewalls to

the roof to the juncture of the sidewalls to the bottom, truss members connected to the strut and the bottom, and strengthening means bracing each corner of the vessel.

7. A vessel for storing liquids at substantially atmospheric pressure having a top, a bottom extending outwardly beyond the top, and sidewalls of polygonal configuration, the sidewalls being curved from the bottom to the top to equalize tension therein when the vessel is full of liquid, there being truss members at intervals along the sidewalls connected to a substantially straight chord, said chord being connected at its top to the junction of the sidewalls and the roof and at its bottom to the bottom of the vessel at a point outside of the vertically downward projection of the roof and within the vertical downwardly projection of the sidewalls, and a foundation for the vessel having a portion beneath the point of the connection of the chord to the bottom, whereby stresses induced when said vessel is partially filled with the liquid are carried outwardly and downwardly by the chords to the foundation.

8. A vessel for storing liquids at substantially atmospheric pressure having a top, a bottom extending outwardly beyond the top, and sidewalls, the sidewalls being curved from the bottom to the top to equalize tension therein when the vessel is full of liquid, there being truss members at intervals along the sidewalls connected to a substantially straight chord, said chord being connected at its top to the junction of the sidewalls and the roof and at its bottom to the bottom of the vessel at a point outside of the vertically downward projection of the roof and within the vertical downwardly projection of the sidewalls, and a foundation for the vessel having a portion beneath the point of the connection of the chord to the bottom, whereby stresses induced when said vessel is partially filled with the liquid are carried outwardly and downwardly by the chords to the foundation.

9. A vessel for storing liquids at substantially atmospheric pressure having a top, a bottom extending outwardly beyond the top, and sidewalls, the sidewalls being curved from the bottom to the top to equalize tension therein when the vessel is full of liquid and the angle at the juncture of the sidewall to the top being equal to the angle at the juncture of the sidewall to the bottom, there being truss members at intervals along the sidewalls connected to a substantially straight strut, said strut being connected at its top to the juncture of the sidewalls and the roof and at its bottom to the bottom of the vessel at a point outside of the vertically downward projection of the roof and within the vertical downwardly projection of the sidewalls, and a foundation for the vessel having a portion beneath the point of the connection of the strut to the bottom, whereby stresses induced when said vessel is partially filled with the liquid are carried outwardly and downwardly by the struts to the foundation.

10. The vessel of claim 7 in which the top and bottom are substantially flat.

11. The vessel of claim 7 in which the corners of the vessel are angular and are braced by a diaphragm welded thereto and to the bottom and roof of the vessel.

HARRY C. BOARDMAN.

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