Oct. 7, 1969 J. S. ENDICOTT ET AL 3,471,053

LIQUID STORAGE TANK USING METAL RING BAND INSTEAD OF THICKER LOWER COURSES

Filed March 4, 1968 3 Sheets-Sheet 1

Fig. 1

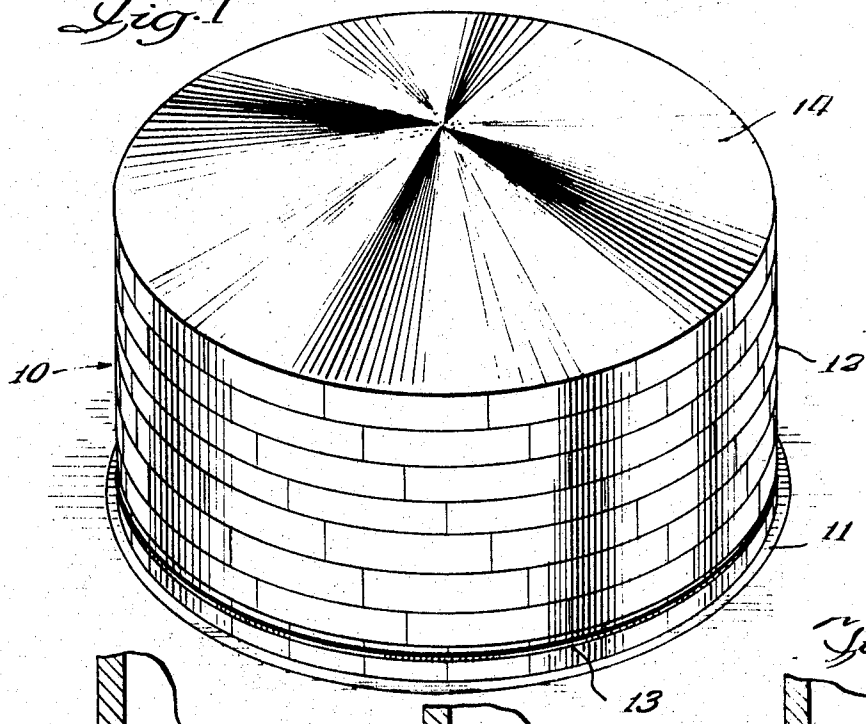


Fig. 8

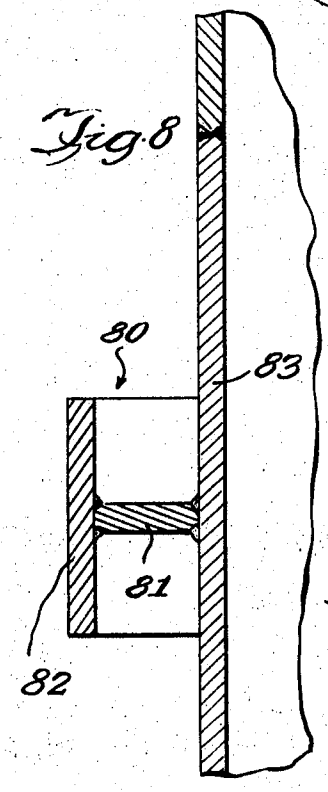


Fig. 9

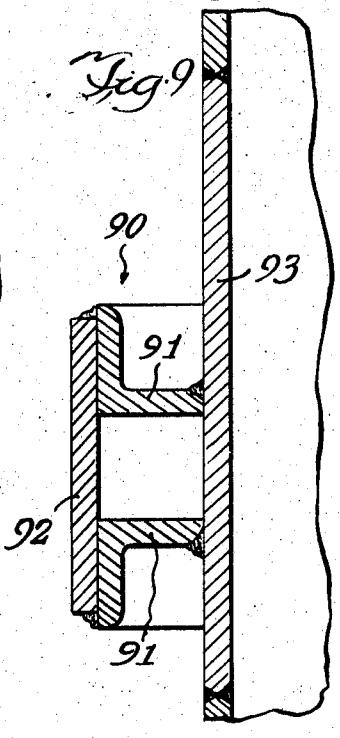
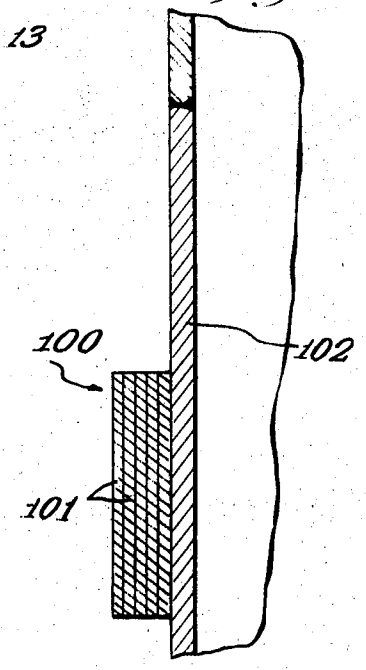


Fig. 10



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Filed March 4, 1968 3 Sheets-Sheet 2

Fig. 4

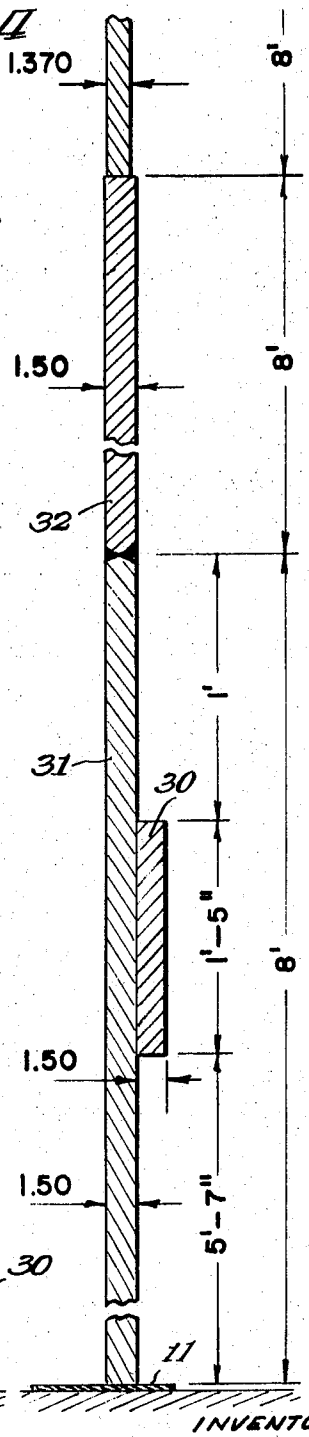


Fig. 2

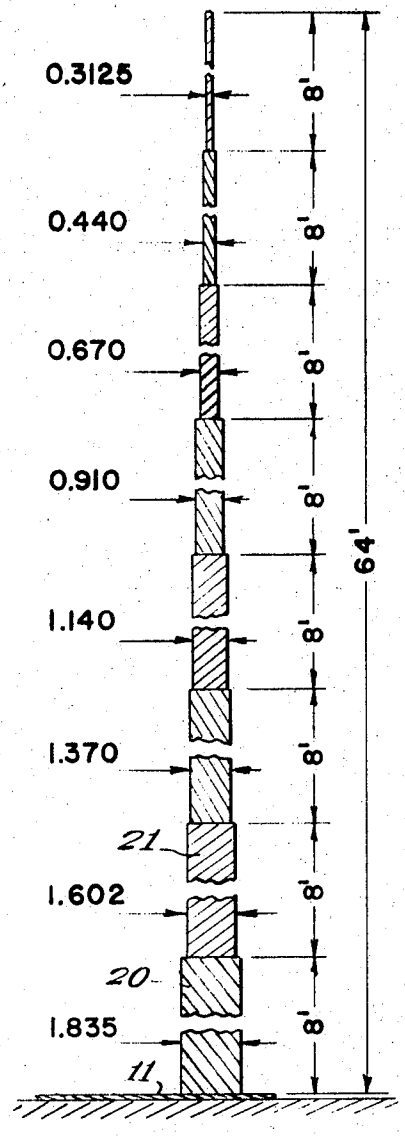
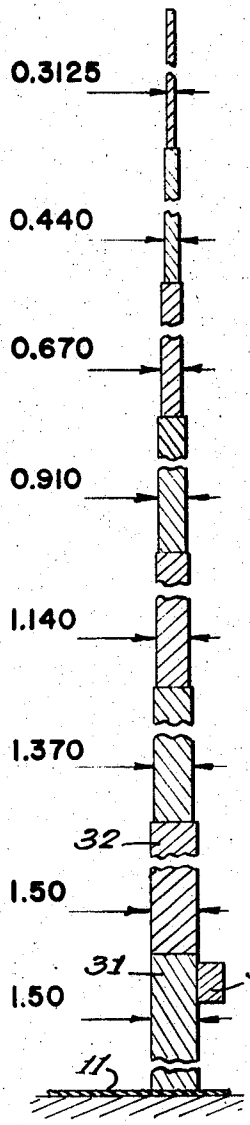


Fig. 3



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LIQUID STORAGE TANK USING METAL RING BAND INSTEAD OF THICKER LOWER COURSES

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Fig. 7

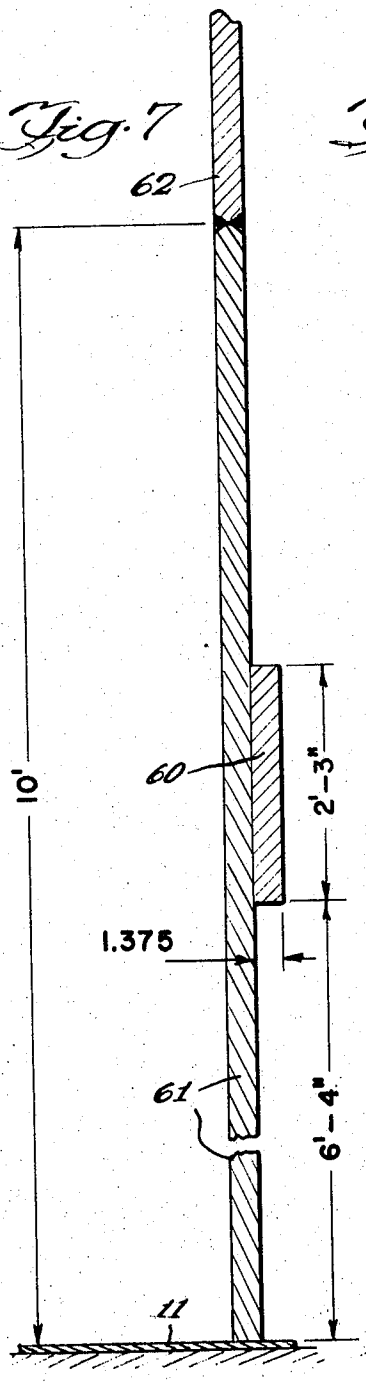


Fig. 5

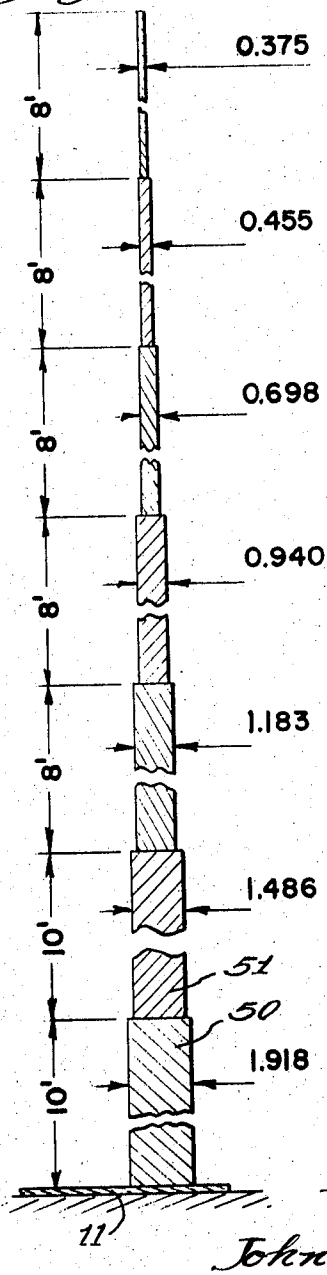
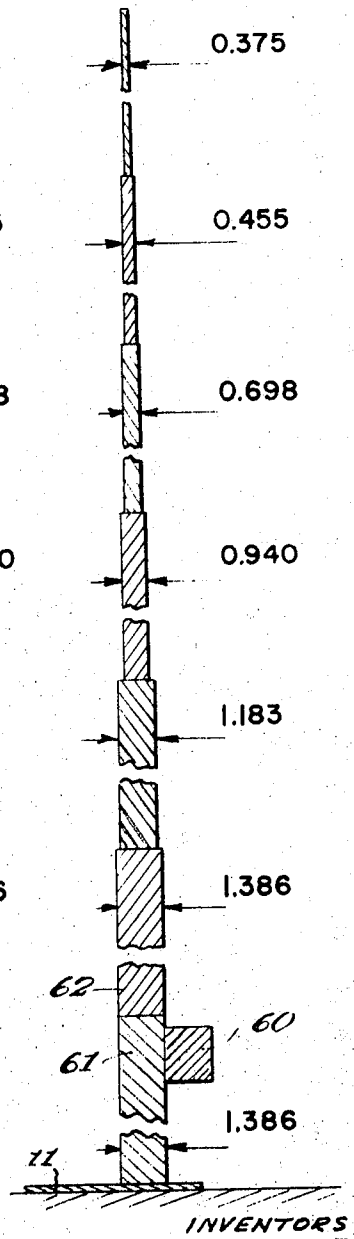


Fig. 6



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3,471,053

LIQUID STORAGE TANK USING METAL RING BAND INSTEAD OF THICKER LOWER COURSES

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Int. Cl. B65d 7/48
U.S. Cl. 220—5 12 Claims

ABSTRACT OF THE DISCLOSURE

Disclosed is an improved upright cylindrical tank having a metal band in contact with the lower portion of the tank wall. By use of a band, the thickness of the bottom portion of the shell can be made thinner but will still meet stress requirements for a maximum load to be stored in a tank of the same size without a band. This permits use of thinner plates which are less expensive and more readily obtained than thicker plates. There is also a substantially reduction in shell weight.

This invention relates to large storage tanks. More particularly, this invention is concerned with an improved upright cylindrical tank having a closed bottom.

Many liquids and solids are stored at atmospheric pressure in large upright cylindrical metal tanks. The tanks have a vertical shell positioned circularly about a vertical axis and generally are made of metal plates. The lower edge of the shell is joined to a bottom, usually of metal plates, which fully encloses the tank. The top of the tank can be open or closed such as by a cone roof or floating roof.

The cylindrical shells of large diameter tanks are normally constructed of a series of horizontal rings or courses of metal plate. The edges of adjoining courses are joined, usually by girth seam butt welds. The height of each course can vary but usually will be about eight to ten feet high. Each course is of uniform thickness but the courses are successfully graduated in decreasing thickness from the bottom course to the top course of the tank. The uppermost course usually has some specified minimum thickness required for general stability of the tank shell or wall. The thickness of each course is determined from the allowable stress of the metal used, the density of the material to be stored in the tank, the diameter of the tank and the height of material to be stored in the tank measured from the top of the tank to the bottom of the course less one foot. The specifications for producing such tanks are well known in the art.

When a large diameter tank produced according to standard procedures is filled with a material to the design limit, the cylindrical shell can grow considerably, except at the bottom where growth increases an insignificant amount. This causes the cylindrical shell to form a curved shape or transition between the restraining bottom and the freely expanding upper portions. Even though the restraining action of the bottom has been understood, very little practical use of this action has been made previously in building large cylindrical tanks.

It has been found according to this invention that by placing a narrow circumferential-stress resisting metal band around and in contact with the lower portion of a shell of a cylindrical metal tank that the thickness of the bottom portion of the shell can have a thickness less than required to meet circumferential-stress requirements predetermined for the maximum load to be stored in the tank without the circumferential-stress resisting metal band. Furthermore, the weight of the metal band is less than the difference between the weight of the thinner shell

employing the band and the weight of a shell of the same metal required to withstand an equivalent predetermined circumferential-stress requirement without the band.

The weight of the metal band is usually at least 20% less than the said difference in weight and by careful sizing and positioning of the band can even be up to about 50–70% less than the difference between the banded shell and an unbanded shell designed for equivalent stresses. This permits use of less metal and the use of thinner plates which are often more readily available and less expensive than heavier plates.

In addition, the new tank structure permits construction of large diameter tanks using the same design stress with plates of the same thickness and material as would be used for small diameter tanks having no band. Thus, the invention has the advantage that the shell for larger tanks can often be reduced to a thickness which avoids the need to stress relieve the joints after welding.

The invention has its greatest use at present in storage tanks having a circular metal bottom and a vertical cylindrical shell extending around the bottom and joined thereto, said shell comprising a series of metal courses or rings of the same diameter positioned vertically with the upper courses set on the upper edge of and joined at its bottom edge to the course below it, each course being of uniform thickness for its height and circumference and a narrow circumferential-stress resisting metal band encircling, and in contact with, the lower portion of the wall, with the thickness of the bottom portion of the wall being less than required to meet circumferential-stress requirements predetermined for the maximum load to be stored in the tank without the circumferential-stress resisting metal band.

The invention will be described further in conjunction with the attached drawings in which:

FIGURE 1 is an isometric view of a vertical cylindrical storage tank having a narrow circumferential-stress resisting metal band encircling the lower portion of the tank wall;

FIGURE 2 is a sectional view of a tank wall of a 200 feet diameter tank showing the height and thickness of the plates in the courses of a banded tank with the horizontal dimension in expanded scale for clarity;

FIGURE 3 is a sectional view of a tank wall of a 200 feet diameter tank constructed according to this invention;

FIGURE 4 is a vertical sectional view of the lower part of the tank wall of FIGURE 3;

FIGURE 5 is a sectional view of a tank wall of an unbanded 350 feet diameter tank;

FIGURE 6 is a sectional view of a tank wall of a 350 feet diameter tank constructed according to this invention;

FIGURE 7 is a vertical sectional view of the lower part of the tank wall of FIGURE 6;

FIGURE 8 is a sectional view of a tank wall showing a band in the form of a T;

FIGURE 9 is a sectional view of a tank wall showing a band fabricated of two angles and a metal strip or plate; and

FIGURE 10 is a sectional view of a tank wall showing a band made of a plurality of metal strips wrapped tightly around the tank.

So far as is practical the same numbers will be used to identify the same or similar parts or elements in the drawings.

The wall structures of FIGURES 2, 3, 5 and 6 have been drawn with an expanded horizontal scale compared to the vertical scale in order to show more clearly the relative thickness of the tank wall structures.

The drawings show in FIGURE 1 a vertical cylindrical storage tank **10** according to this invention. The tank has

a circular metal bottom **11** which extends beyond the lower edge of the wall **12**. The wall **12** comprises a plurality of metal rings or courses made of metal plates. The lower portion of wall **12** has a circumferential-stress resisting metal band **13** positioned in contact with the wall. The use of metal band **13** permits the use of thinner metal plates for one or more of the lower courses as will be shown hereinafter. The tank is shown covered with a cone roof **14** although other types of roofs, including a floating roof, can be used since the roof structure is not directly involved in the essence of the invention.

The tank wall structure of FIGURE 2 is for an unbanded 200 feet diameter, 64 feet high cylindrical tank using conventional design rules in which the design pressure is calculated one foot above the bottom of the course. The tank is designed to withstand stresses that would be induced in the tank if filled with water. The steel plates of each course are 8 feet high and each course is of decreasing thickness from the bottom course to the top course as shown by the dimensions in the drawings. The thickness of each course is determined by the allowable stress of the material used, the liquid to be stored in the tank, the liquid height at the design level and the diameter of the tank although the uppermost course has a minimum thickness required for general stability of the tank shell. The dimensions given in FIGURE 2 are those required according to the American Petroleum Institute Standard 650, Third Edition, July 1966, page 13 "Welded Steel Tanks for Oil Storage." The lowermost course or ring **20** requires a thickness of 1.835 inches while the next higher course **21** requires a thickness of 1.602 inches to meet the specified standard rules. However, the maximum thickness permitted by the standard is one and one-half inches.

The shell structure of FIGURES 3 and 4 illustrates one embodiment of the invention as applied to the same size tank, designed to store the same liquid and meet the same stress requirements as the tank of FIGURE 2. The shell or wall of FIGURES 3 and 4 has a circumferential steel band **30** placed around the lowermost course **31**. By use of such a band the thickness of the course **31** can be 1.50 inches, instead of 1.835 inches for the same course **20**, in FIGURE 2. In addition the second course **32** of the wall structure of FIGURES 3 and 4 can be 1.50 inches instead of 1.602 inches as needed for the same course **21** in the structure of FIGURE 2. The higher courses have the same thicknesses as in FIGURE 2. Since the band **30** permits the use of thinner plates in the courses **31** and **32** there is a significant saving in the cost of the plates, welding and weight. By carefully sizing and positioning the band **30** a very substantial savings can be realized. FIGURE 4 shows that a band 1.50 inches thick and 1 foot 5 inches high positioned around the course **31** with the lower edge of the band located 5 feet 7 inches above the tank bottom **11** can be used in conjunction with the thinner plates **31** and **32**. The weight of the two lower courses **31** and **32** plus the band **30** would be about 35,000 pounds less than the weight of courses **20** and **21** in FIGURE 2. Nevertheless, such a wall structure can withstand the same stresses as the wall structure of FIGURE 2. The weight of the two 1.5 inches courses **31** and **32** is about 615,000 pounds and the weight of the band is about 55,000 pounds for a total weight of 670,000 pounds for the two courses and the band. The 1.835 inches course **20** of FIGURE 2 weighs about 376,000 pounds and the 1.602 inches course **21** weighs about 329,000 pounds for a total of 705,000 pounds. The weight of the band is thus about 39% less than the difference in weight between the two lower courses of the wall structures of FIGURES 2 and 3 as shown by the calculation:

$$\text{Percent}=\frac{(705{,}000-615{,}000)-55{,}000}{90{,}000}\times 100$$

$$\text{Percent}=39.0$$

An unbanded tank structure using conventional design rules for a 350 feet diameter, 60 feet high steel tank is shown in FIGURE 5. The two lower courses **50** and **51** are 10 feet high and the upper five courses are each 8 feet high. The dimensions given in FIGURE 5 are designed to meet the API–650 Appendix G dated December 1967, requirements for a tank of this size using water as the stored product for design purposes.

FIGURE 6 shows a banded tank, according to this invention, having a 350 feet diameter, a 60 feet height and courses of the same heights as used in the tank of FIGURE 5. The tank of FIGURE 6 is also designed for stresses induced by water as the stored product. By using a circumferentially positioned steel band **60** around the upper part of the first course **61** as shown in FIGURE 6, the thickness of this course can be made 1.386 inches, instead of 1.918 inches as for course **50** in FIGURE 5, and the next course **62** can be made 1.386 inches instead of 1.486 inches as required for course **51** in the tank wall structure of FIGURE 5. The other courses in the wall of FIGURE 6 have the same thicknesses as those in FIGURE 5. FIGURE 7 shows that band **60** can be 1.375 inches thick and 2 feet 3 inches high with the bottom edge of the band placed 6 feet 4 inches above the bottom **11**. The weight of courses **50** and **51** and band **60** of the wall structure of FIGURES 6 and 7, when made of steel, will be about 144,000 pounds less than the wall shown in FIGURE 5. The weight of the 1.918 inches course **50** in FIGURE 5 is about 860,000 pounds and the 1.486 inches course **51** is about 667,000 pounds, giving a total of 1,527,000 pounds for these two courses. The 1.386 inches courses **61** and **62** in FIGURE 6 together weigh about 1,244,000 pounds and the band weighs 139,000 pounds giving a total weight of 1,383,000 pounds for courses **61** and **62** and the band. The weight of the band is thus about 51% less than the difference in weight between the two lower courses of the wall structures of FIGURES 5 and 6 as shown by the calculation:

$$\text{Percent}=\frac{(1{,}527{,}000-1{,}244{,}000)-139{,}000}{283{,}000}\times 100$$

$$\text{Percent}=50.9$$

The particular shape and construction of the circumferential band is not limited since various types of bands can be used as shown in FIGURES 8–10. The band **80** shown in FIGURE 8 is T shaped and is fabricated using a horizontal plate **81** welded at one edge to course **83** and at its other end to vertical plate **82**. In FIGURE 9 a band **90** is shown fabricated of two similar angles **91** welded both to course **93** and to plate **92**. The band **100** of FIGURE 10 is composed of a plurality of strips **101** which are wrapped tightly around course **102**.

Although the particular shape of the band is not critical it is important to position the band in a location where it will appropriately resist the stresses exerted against the tank shell when loaded. Furthermore, the cross-sectional area of the band must be adequate to withstand the stresses to which it will be subjected when used with the thinner lower or bottom portion of the tank shell or wall. By "bottom portion" is meant that portion of the wall or shell of uniform thickness extending from the tank bottom upwardly to a change in thickness of the wall or shell such as at a course seam or horizontal girth weld. The "bottom portion" in some instances will be the lowermost course and in other instances will be the lowermost two, three or more courses depending on the height of each course.

In producing a tank shell of steel or aluminum according to this invention with the lower portion of the tank shell extending from the tank or shell bottom to a distance kH upward on the shell, designed for an allowable stress S, a uniform thickness of at least t, having a metal band which reduces the circumferential maximum average stress to a value not exceeding S, the metal band has an area of A, the distance from the centroid of the

band to the bottom of the tank is about L, the allowable average circumferential stress in the band is s, and the tensile force in the band when the tank is empty is F, the following formulas and values can be used:

L is not greater than $(3.77-4.06/b)H/b$

$k>L/H$

$b=1.285\ H/\sqrt{rt}$

r is the radius of the tank

$$t=\frac{1.651}{r}(H/b)^2$$

H is the effective storage height of the shell

A is not greater than $(0.061+3.21/b)\gamma H^2kr/S$ where γ is the density of the material to be stored in the tank.

The thickness t of the lowest portion of the tank can be reduced without exceeding the allowable average circumferential-stress S by placing a metal reinforcing ring around the tank so long as the distance L from the bottom of the tank to the centroid of the reinforcing band is not greater than $(3.77-4.06/b)H/b$ and $k>L/H$, where $b=1.285\ H/\sqrt{rt}$.

The total quantity of material needed to construct the tank can be reduced without exceeding the allowable average circumferential stresses S or s by placing a reinforcing band around the tank so long as the area A of the band does not exceed $(0.061+3.21/b)\gamma H^2kr/S$ and $s\geqslant S$, where $b=1.285\ H/\sqrt{rt}$.

With no prestress ($F=0$) and with the allowable average circumferential stresses of tne lower portion of the tank and the reinforcing band equal ($S=s$), the quantity of material needed to construct the tank with a given kH without exceeding the allowable stress S will be minimal if:

$$A=2\left(\frac{H}{b}\right)^2\left[\frac{\gamma rb}{S}\left(\frac{1.0665-2.322/b+2.75/b^2}{1-.078\,(b-b_1)^3}\right)-\frac{1.651}{r}\left(\frac{H}{b}\right)\right]$$

$$L=\left(\frac{H}{b}\right)(2.015-2.05/b+.0147b)$$

$$t=\frac{1.651}{r}\left(\frac{H}{b}\right)^2$$

and

$k>(3.772-2/b+.015)/b$ (see Note 1 below)

where

$$b=b_1-\frac{4.737M}{b_1^2}+\sqrt{\frac{4.737N}{b_1}}$$

$$b_1=1.474+1.293\sqrt{\frac{HS}{\gamma r^2}}$$

$$M=1-\frac{5.793}{b_1}+\frac{2.322}{b_1^2}\left(\frac{HS}{\gamma r^2}\right)(kb_1-4)$$

$$N=1-\frac{3.986}{b_1}+\frac{1.548}{b_1^2}\left(\frac{HS}{\gamma r^2}\right)(kb_1-3)$$

The thickness t of the lower portion of the tank will be minimal if:

$$t=(0.989-5.0/b)\frac{\gamma Hr}{S}$$

$$A=\frac{2\gamma Hr}{s}\left(\frac{H}{b}\right)(0.0695+13.6/b)$$

$$F=2\left(\frac{\gamma H^2r}{b}\right)\frac{\left[\frac{2Ht}{Ab}(0.0695+13.61/b)-.96+16.14/b\right]}{\frac{2Ht}{Ab}+1}$$

$$L=\frac{H}{b}(3.215-4.8/b)$$

$k>(7.49-5.7/b)/b$ (see Note 1 below)

where

$$b=2.53+\sqrt{6.39+1.67\frac{HS}{\gamma r^2}}$$

Note 1: While k must be this large to be mathematically correct, practically it may be somewnat smaller without introducing an error greater than normal engineering tolerances.

Although the tank structure of this invention is particularly suitable for construction of tanks from steel and especially steel tanks having at least a 150 feet diameter, using a steel band, it is also within the invention to make the tank and band of other metals, particularly aluminum.

Additional advantages can be realized from the invention by prestressing the band. Doing this will permit even further reduction in the plate thickness used in the lower portion of the tank shell or wall. Thus, by prestressing to an allowable circumferential stress in the band of 80,000 p.s.i., the area of the band **30** in FIGURE 4 can be reduced from 25.5 sq. in. to 17.8 sq. in. and the thickness of the plates **31** and **32** can be reduced from 1.50 inches to 1.448 inches.

What is claimed is:

1. A storage tank substantially smooth-surfaced in appearance externally having:

a circular bottom and a vertical self-supporting circular shell extending around the bottom and joined thereto;

the shell comprising a series of metal courses or rings of the same diameter positioned vertically one on top of the other with the lower edge of upper courses set on, and joined to, the upper edge of the lower courses;

each course being of uniform thickness for its height and circumference;

a narrow circumferential-stress resisting metal band encircling, and in contact with, a lower portion of the shell;

the thickness of the band-encircled lower portion of the shell being less than required to meet circumferential-stress requirements predetermined for the maximum load to be stored in the tank without the circumferential-stress resisting metal band;

said lower portion of the shell comprising at least a course around which the band is positioned;

each shell course being thinner than the course below it except that each course in the said lower portion of the shell is no thicker than any course below it; and

said shell is devoid of axially positioned stiffeners placed around the shell for providing support.

2. A storage tank according to claim **1** in which the lower portion comprises at least the bottom course and the metal band encircles the bottom course.

3. A storage tank according to claim **1** in which the weight of the metal band is at least 20% less than the difference between the weight of the shell employing the band and the weight of a shell of the same metal without the band when both shells are designed to withstand an equivalent predetermined load within the same circumferential-stress requirement.

4. A storage tank according to claim **1** in which the lower portion comprises at least the two lowermost courses and the metal band encircles one of these courses.

5. A storage tank according to claim **4** in which the thickness of the two lowermost courses is the same.

6. A storage tank according to claim 4 in which the metal band encircles the bottom course.

7. A storage tank according to claim 1 having at least eight courses, in which the lower portion comprises at least the two lowermost courses, the band encircles the bottom course and the weight of the metal band is at least 20% less than the difference between the weight of the two lowest courses of a tank employing the band and the weight of these lowest two courses of a tank of the same metal without the band when both shells are designed to withstand an equivalent predetermined load within the same circumferential-stress requirement.

8. A storage tank substantially smooth-surfaced in appearance externally having:

a circular bottom and a vertical self-supporting circular shell extending around the bottom and joined thereto;

the shell comprising a series of metal courses or rings of the same diameter positioned vertically one on top of the other with the lower edge of upper courses set on the upper edge of, and joined to, the lower courses;

each course being of uniform thickness for its height and circumference;

a narrow circumferential-stress resisting metal band encircling, and in contact with, the lower portion of the shell;

the thickness of the band encircled lower portion of the shell being less than required to meet circumferential-stress requirements predetermined for the maximum load to be stored in the tank without the circumferential-stress resisting metal band;

each shell course which is governed by stress being thinner than the course below it except that each course in the said lower portion of the shell is no thicker than any course below it;

said shell is devoid of axially positioned stiffeners placed around the shell for providing support; and

said lower portion of the tank shell being that portion of the shell measured from the shell bottom to a distance kH upward on the shell, has an allowable stress S, a uniform thickness of at least t, is reinforced with a metal band which reduces the circumferential maximum average stress to a value not exceeding S, the metal band has an area A, the distance from the centroid of the band to the bottom of the tank is

about L, the allowable average circumferential-stress in the band is s, wherein

$$L \text{ is not greater than } (3.77-4.06/b)\frac{H}{b}$$

$$k>\frac{L}{H}$$

$b=1.285\ H/\sqrt{rt}$

r is the radius of the tank

$$t=\frac{1.651}{r}(H/b)^2$$

H is the effective storage height of the shell

A is not greater than $(0.061+3.21/b)\gamma H^2kr/S$ where γ is the density of the material to be stored in the tank.

9. A storage tank according to claim 8 in which the lower portion of the shell consists of the first, or lowermost, course.

10. A storage tank according to claim 8 in which the lower portion of the shell consists of the two lowermost courses.

11. A storage tank according to claim 8 made of steel and having a diameter of at least 150 feet.

12. A storage tank according to claim 8 in which the weight of the metal band is at least 20% less than the difference between the weight of the shell employing the band and the weight of a shell of the same metal without the band when both shells are designed to withstand an equivalent predetermined load within the same circumferential-stress requirement without the band.

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GEORGE E. LOWRANCE, Primary Examiner

U.S. Cl. X.R.

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