Sept. 2, 1958 J. H. WIGGINS 2,849,792

METHOD OF BUILDING METAL STORAGE TANKS

Filed May 12, 1955 3 Sheets-Sheet 1

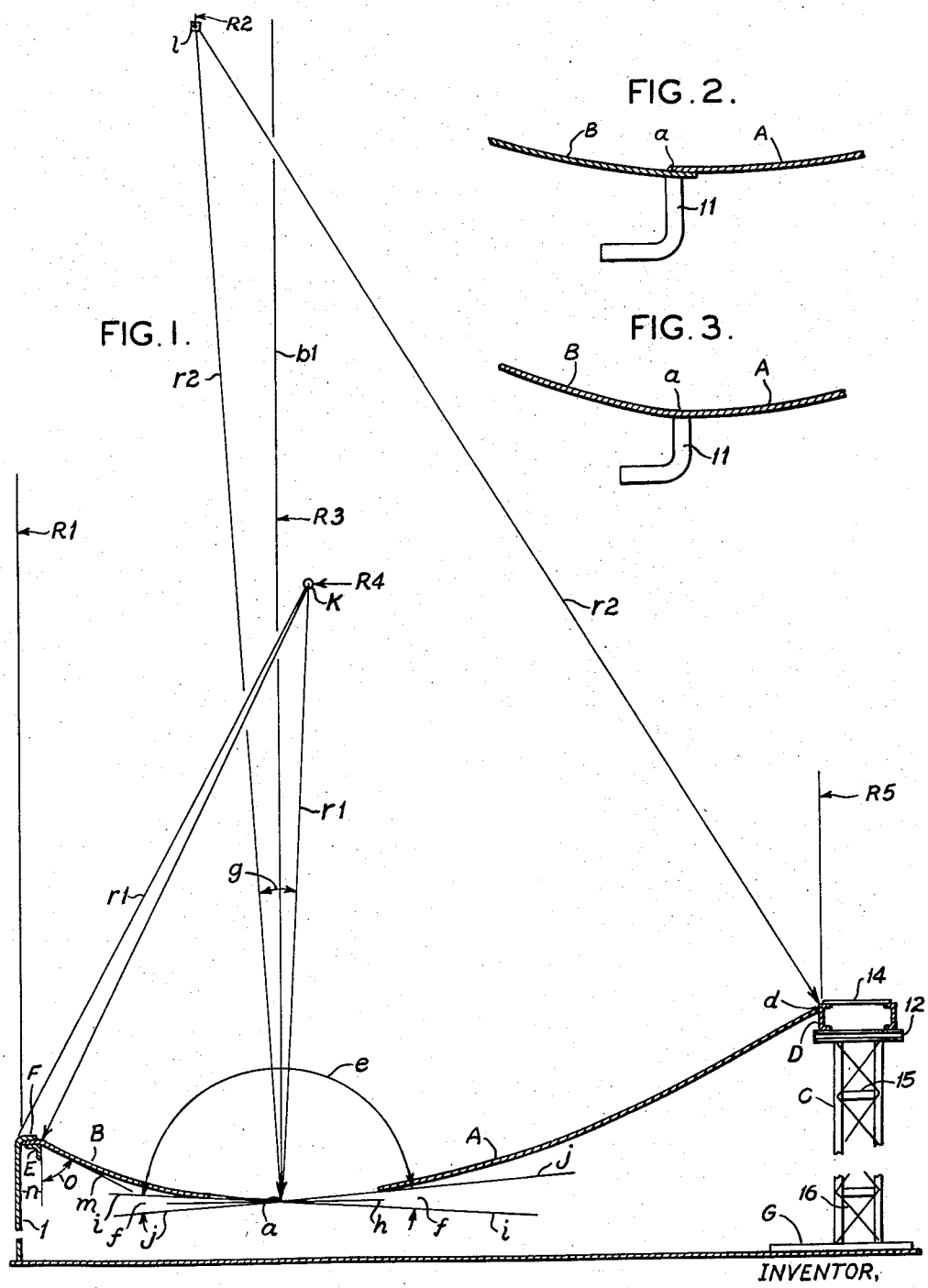

FIG. 1.

FIG. 2.

FIG. 3.

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FIG. 4.

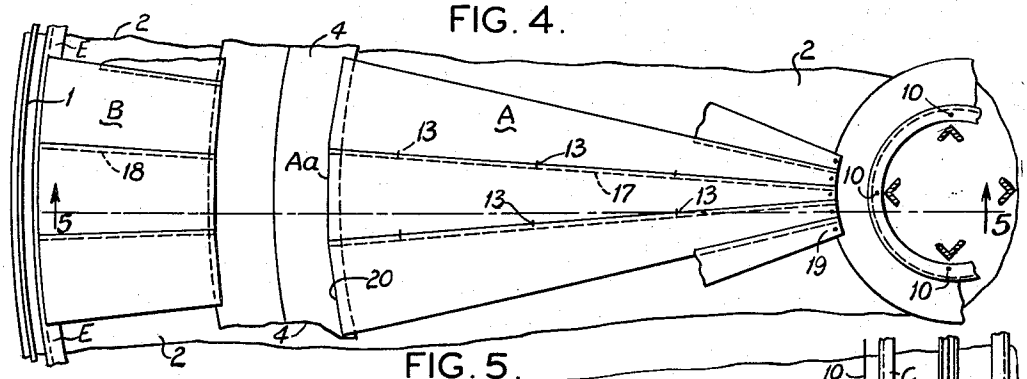

FIG. 5.

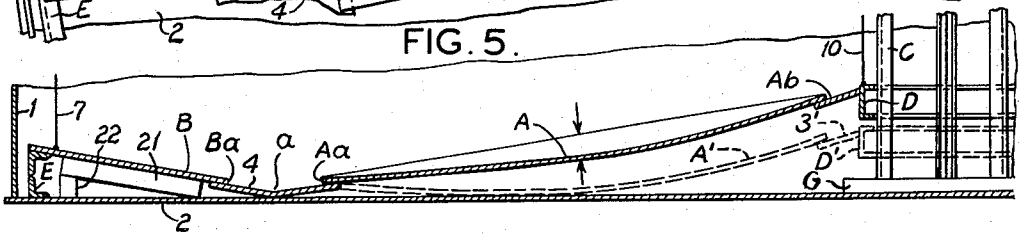

FIG. 6.

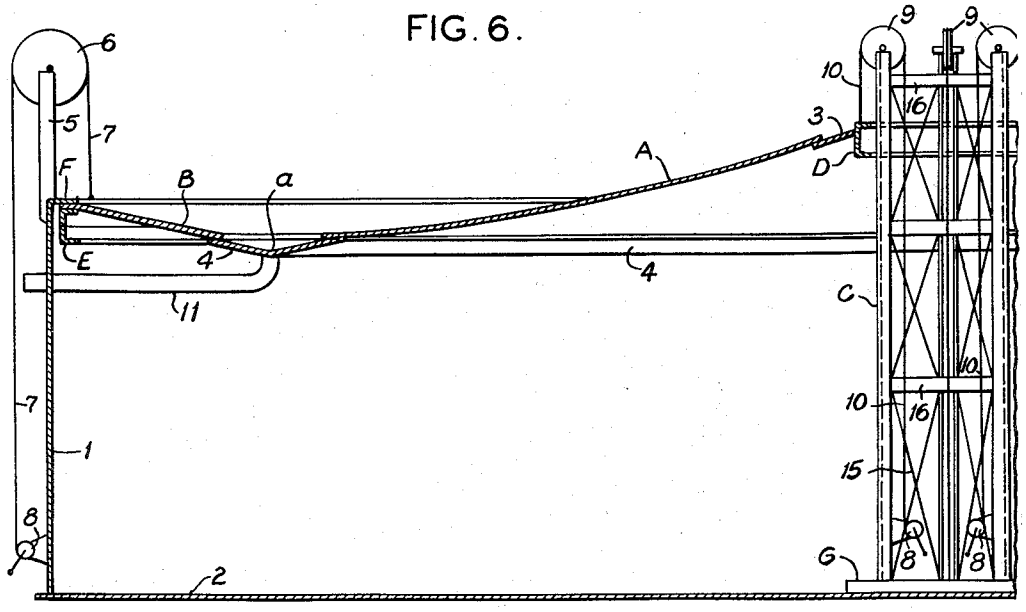

FIG. 10.

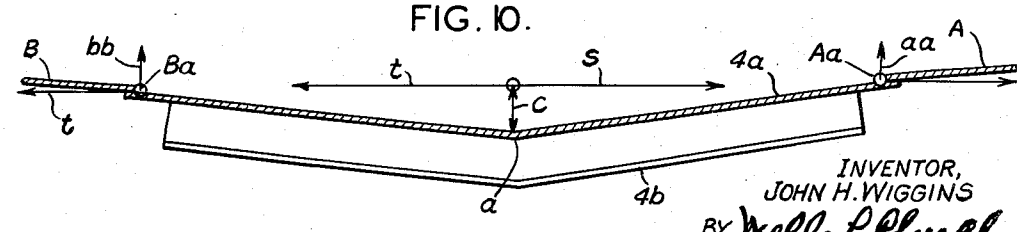

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FIG. 7.

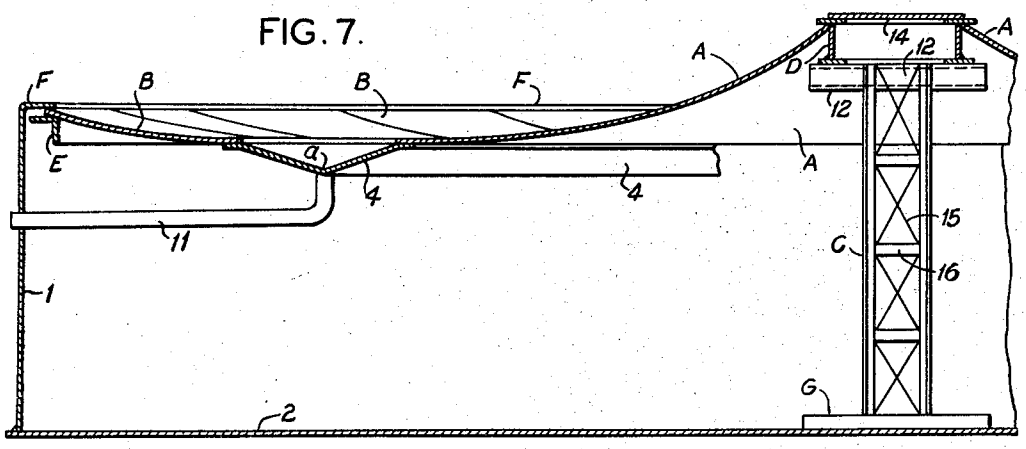

FIG. 8.

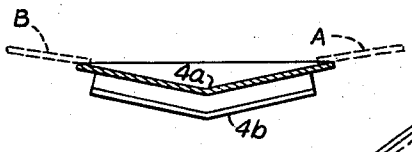

FIG. 9.

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2,849,792

METHOD OF BUILDING METAL STORAGE TANKS

John H. Wiggins, Woodside, Calif.

Application May 12, 1955, Serial No. 507,887

2 Claims. (Cl. 29—429)

This invention relates to a novel method of building metal tanks that are used for holding liquid, grain and various other materials, and particularly storage tanks for petroleum products of the knd that are equipped with a stationary roof as distinguished from a roof which floats on the liquid confined in the tank.

One object of my invention is to reduce the quantity of steel required to built a metal tank roof, reduce the labor cost and also simplify the procedure of building and erecting the roof.

Another object is to provide a method of building metal tanks, that makes it possible for the builder or erector to easily and accurately construct the roof of the tank so that it will comply with the specifications of the designer and will safely carry the designed load it is intended to carry when in service, and

Still another object of my invention is to provide a method of building metal tanks, that enables practically all of the work of fabricating or constructing the roof of the tank to be performed at ground level, thereby overcoming the necessity of erecting expensive scaffolding for the workmen to stand on and making it safer and easier for the workmen to perform the tasks in which they are engaged. Other objects and desirable features of my invention will hereinafter be explained.

To this end I have devised a method of building a metal tank which, briefly described, contemplates the following procedure:

(*a*) Erecting a permanent, vertical roof support at the center of the tank,

(*b*) Building a complete and finished roof unit on the bottom of the tank composed of roof plates welded to each other and to stiff or rigid frame members so as to form a circular diaphragm provided at its periphery with a ring shaped beam and compression member and provided at its center with a ring shaped beam and tension member that surrounds the center roof support,

(*c*) After completion of the side wall of the tank, raising or hoisting said roof unit to the top edge of the tank side wall, and

(*d*) Thereafter combining said roof unit with the center roof support and with the tank wall so as to cause a certain proportion of the load of the roof to be carried by the center roof support and a certain proportion of the load of the roof to be carried by the tank side wall. The above mentioned center and peripheral ring shaped frame members of the roof are arranged in concentric relation with each other and with the center roof support preparatory to assembling the roof plates, and during the fabricating operation the roof plates are welded to each other and to said frame members while the plates rest upon and are supported by said frame members. During the operation of raising or hoisting the roof unit into operative position, said frame members impart sufficient rigidity to the roof unit to maintain the shape and form of same, and in the finished structure said center and peripheral frame members coact with the center roof support and with the tank side wall to reinforce and

strengthen the same and transmit the roof tensions and loads directly to the two structures (center roof support and tank side wall) that carry the roof.

I have herein illustrated and described my improved method as being used to build the metal storage tank that forms the subject matter of my companion application, Serial No. 504,202, filed April 27, 1955, but I wish it to be understood that my method is capable of use for building tanks equipped with roofs of other designs, so long as the roof of the tank consists of a circular diaphragm composed of roof plates and at least two circular frame members at the center and periphery of the diaphragm, welded together while assembled on or adjacent the bottom of the tank, and thereafter, after completion of the tank side wall, raised or hoisted into a position where the peripheral circular frame member of the diaphragm can be joined to the top edge portion of the tank wall and the center circular frame member of the diaphragm can be supported on or joined to a permanent, vertical roof support at the center of the tank.

Briefly described the roof illustrated in said companion application comprises two concentrically arranged, arced surfaces of different radii joined together at a circular or substantially circular line which constitutes the lowest circle in the area of the roof, and disposed in such relationship with each other that the outer arced surface slopes upwardly and outwardly to the top edge of the tank side wall from which it is suspended, and the inner arced surface slopes upwardly and inwardly to the center roof support from which it is suspended. The outer arced surface constitutes the peripheral portion of the roof and the area of said portion is about one half, or less than one half, of the total area of the roof. The radii of the arced elements of said peripheral portion are substantially shorter than the radii of the arced elements of the inner arced surface which constitutes the central portion of the roof, with the result that the centers of the radii of the two portions of the roof lie above and at opposite sides (to the right and left) of the circular line which constitutes the juncture of said two roof portions and the lowest circle of the roof. By constructing the roof in the manner above described it is possible for the tank side wall or the center roof support to settle a substantial amount without shifting the lowest circle of the roof into such a position that the tank side wall will be subjected to a load in excess of the load it was designed to carry or the center roof support will be subjected to a load in excess of the load it was designed to carry.

Figure 1 of the drawings is a fragmentary, vertical transverse sectional view of a tank produced by my improved method or procedure, the two portions of the tank roof being broken away adjacent the lowest circle of the roof so as to permit the use of certain lines and reference characters mentioned in the description of the invention.

Figure 2 is a sectional view showing the two portions of the roof connected together by a lap welded joint,

Figure 3 is a sectional view showing the two portions of the roof merging into each other and with a kink or sharp bend in the roof plates at the lowest circle of the roof.

Figures 4 to 10 inclusive illustrate another form of roof produced by my method wherein the roof comprises an intermediate portion or connecting member of substantially V shape in cross section, disposed circumferentially of the roof between the center portion and peripheral portion of the roof and attached to said portions so as to join same together, said figures also illustrating the procedure of building the roof in the form of a complete unit on the bottom of the tank and subsequently, after completion of the tank side wall, raising or hoisting the roof into its operative position and joining it to the top edge portion of the tank side wall and to the upper end portion of the

vertical roof support at the center of the tank. In this group of figures, Figure 4 is a fragmentary, top, plan view showing the roof while it is being constructed or fabricated on the bottom of the tank.

Figure 5 is a vertical sectional view taken on the line 5—5 of Figure 4.

Figure 6 is a fragmentary, vertical transverse view showing how the roof unit is moved upwardly to its operative position by hoisting mechanism carried by the center roof support and the tank side wall.

Figure 7 is a similar view showing the completed structure with the hoisting mechanism removed, the center ring member of the roof resting on the beams at the upper end of the center roof support and the center closure plate of the roof welded to said center ring member.

Figure 8 is a fragmentary, vertical transverse sectional view showing a different kind of V-shaped connecting member that may be used at the circular line of juncture for joining the central portion and peripheral portion of the roof to each other.

Figure 9 is a fragmentary, top plan view showing a roof whose center and peripheral portions are joined together by a connecting member of the kind shown in Figure 8, and

Figure 10 is a diagrammatic view, on an enlarged scale, illustrating the forces acting on the V-shaped connecting member of the roof.

In Figures 1, 2, and 3 of the drawings, the reference character 1 designates the circular side wall of the tank; 2 designates the bottom of the tank; F designates an inwardly projecting flange at the top edge of the tank side wall, and C designates a vertical roof support at the center of the tank, herein illustrated as being composed of a plurality of vertical uprights joined to each other by horizontally disposed cross members 16 and inclined braces 15 so as to form a tower that rests on a base piece G on the bottom of the tank. The roof of the tank is formed by a metal diaphragm that comprises a central portion A which slopes downwardly and outwardly from the center roof support C, and a peripheral portion B that slopes downwardly and inwardly from the top edge of the tank side wall, said peripheral portion constituting about one half, or less than one half, of the total area of the roof. Said roof portions A and B are joined together at a circular or substantially circular line *a* which constitutes the lowest line or circle in the area of the roof. At the center of said diaphram there is a stiff, ring shaped tension member D and at the periphery of said diaphragm there is a stiff ring shaped compression member E. Both of said ring shaped members are rigidly attached to the roof plates of which the diaphragm is constructed and said ring shaped members are used to suspend the diaphragm between the center roof support and the tank side wall, the tension member D at the center of the diaphragm being attached to the center roof support C in any preferred manner, as for example by horizontally disposed beams 12 on which said tension member rests, and the compression member E at the periphery of the diaphragm being rigidly attached to the flange F at the top edge of the side wall 1 of the tank. After the roof has been installed a cover plate 14 is welded to the top side of the ring shaped tension member D so as to reinforce and strengthen same and close the hole in the center of the roof.

Water that collects at the low point *a* of the roof is conducted away from same through one or more drains 11 shown in Figures 2 and 3.

As shown in Figure 2 the two roof portions may be formed by two separate, concentrically arranged members connected together by a lap welded joint that extends circumferentially around the roof, or as shown in Figure 3 the roof portions A and B may constitute integral portions of a large diaphragm that has a circular bend or kink formed in same to constitute the lowest circle *a* of the roof, the portions of the diaphragm lying on the inside and on the outside of said lowest circle *a* being shaped so as to produce arced surfaces of different radii. So far as my basic idea is concerned it is immaterial what method or procedure is used to fabricate or construct the roof diaphragm so long as said diaphragm comprises a central portion and a peripheral portion of the kind above described.

For a better understanding of the basic idea of the roof, I will refer to Figure 1 of the drawings wherein the line b^1 designates one element of an imaginary cylinder defined by the lowest circle *a* of the roof, said cylinder having a radius R^3. The central portion A of the roof has a surface which is formed by arced elements having radii r^2 whose center 1 lie in a circle R^2 located above and on the outside (to the left) of the previously mentioned line b^1 which designates one element of an imaginary cylinder defined by the lowest circle *a* of the roof, and the peripheral portion B of the roof has a surface which is formed by arced elements having radii r^1 whose centers *k* lie in a circle R^4 located above and on the inside (to the right) of the line b^1 designating said cylinder. In Figure 1 the reference character R^1 designates the radius of the tank side wall, *c* designates the point where the plates of the roof portion B are joined to the compression member E at the peripheral edge of the roof, R^5 designates the radius of the inner edge of the central roof portion A and *d* designates the point where the plates of portion A are joined to the ring shaped tension member D at the center of the roof. Preferably the two arced surfaces A and B of the roof are disposed in such relationship with each other that they form an angle of less than 180 degrees at the point where said arced surfaces are joined together.

If the entire roof were built in the form of a continuous arc or curve whose lowest point or circle was tangential to a horizontal radial line, a substantial settling or downward movement of the roof support would cause the lowest line or circle of the roof to move inwardly a substantial amount, thereby decreasing the load on the center tension member D carried by the center roof support and increasing the load on the peripheral compression member E carried by the tank side wall. Similarly a substantial settling or downward movement of the tank side wall would cause the lowest line or circle of the roof to move outwardly a substantial amount, thereby decreasing the load on the compression member E on the tank side wall and increasing the load on the tension member D carried by the center roof support C. In the roof herein shown the area of the roof is divided into two curved surfaces, each of which has a different radius and at the point where said curved surfaces meet or are joined together, the tangents of said curved surfaces are disposed at an angle to a horizontal line as illustrated in Figure 1 wherein *h* designates a horizontal line passing through the lowest point *a* of the roof that is not tangential to either of the roof portions A and B, and the reference characters *j* and *i* designates tangents to the roof portions A and B respectively at the low point *a* of the roof. In Figure 1 the outside angle *e* between *j* and *i*—less than 180 degrees—equals 180 degrees minus *f* which is the inside angle between *j* and *i*, and said inside angle *f* equals the angle *g* between r^1 and r^2. In such a roof the loads on the two structures that support the roof are effectively stabilized and the compression forces set up in the compression member E by the peripheral roof portion B are reduced, thereby enabling a lighter weight and less expensive structural element to be used to form the compression member E. This is clearly illustrated in Figure 1 wherein it will be seen that making the peripheral portion B of the roof of considerably smaller radius than the central roof portion A and with the centers *k* of the radii of said peripheral portion located at the right of line b^1, causes the roof portion B to be disposed at a much sharper downward pitch or slope than would be the case if the entire roof were built in the form of a continuous arc or curve. In Figure 1 the reference character *m* designates the

tangent to the arc of the roof portion B at the point *c* where the roof plates of portion B are attached to the compression member E, and the reference character *o* designates the angle that tangent *m* makes with a vertical line *n* passing through point *c*.

In Figures 4 to 10 inclusive I have illustrated my method as being used to build a roof whose two portions A and B are joined together by a connecting member **4** that extends circumferentially around the roof and which is located at the circular line of juncture of the roof. In general form the connecting member **4** is of circular shape but in practice it may consist of a polygonal-like structure. Preferably it is of substantially V shape in cross section and constitutes a substantial portion of the total area of the top surface of the roof. On a 120' diameter roof the member **4** will usually constitute about 10% of the total area of the roof. It may be constructed from a heavy plate bent into the form of a wide V-shaped member whose side portions are sloped considerably steeper than the slope or curve of the top surfaces of the portions A and B of the roof, the circular line where the side portions of said V-shaped member **4** merge or join each other being the lowest point of the roof. By making the V of member **4** relatively wide, I obtain a satisfactory factor of safety for maintaining the lowest circle of the roof at the radius for which the roof is designed. For a 120' diameter roof where the radial dimension of the portion B of the roof is 14 feet, I would make each leg or side portion of the V about 2 feet and I would make the depth of the V about 3 inches. This would give a slope nearly the same as the slope where the peripheral portion B of the roof meets the flange F at the top edge of the side wall of the tank. The plate from which the V-shaped member **4** is made would be about 4 feet wide. Figure 8 illustrates another another kind of member that may be used to join the portions A and B of the roof, said member consisting of a V-shaped plate 4^a having transversely disposed stiffeners 4^b attached to its underside and arranged in spaced relation around the circumference of said member as shown in Figure 9, said stiffeners 4^b counteracting any tendency of the V to spread or open up due to the pull of the roof portions A and B on the side legs of member 4^a. Water that collects on the top surface of the roof in the zone of the V-shaped member **4** or 4^a is conducted to the exterior of the tank by one or more drains **11**.

Any suitable means or mechanism may be used to move the roof diaphragm upwardly into its final position and for supporting it while it is being attached to the center roof support and to the tank side wall, but I prefer to use hoisting devices that are removably mounted on the center roof support C and on the tank side wall so that after they have performed their function they can be detached and used in building and erecting other tank roofs. The hoisting mechanism herein shown comprises a plurality of winches **8** mounted on the lower end portion of the center roof support C and a group of cables **10** that lead upwardly from said winches over pulleys **9** removably mounted at the top of the center roof support and thence downwardly to the center tension ring D of the roof diaphragm to which said cables are attached as shown in Figure 6. Said hoisting mechanism also comprises a plurality of winches **8** arranged in spaced relation around the tank side wall at the lower end of same, cables **7** leading upwardly from said winches over pulleys **6** mounted in pulley supports **5** detachably connected to the top edge portion of the tank side wall, and thence downwardly from said pulleys to the peripheral compression frame member E of the diaphragm to which said cables are attached.

In practicing my method I prefer to first construct the bottom **2** of the tank and then weld the peripheral edge of the tank bottom to the lowermost ring of the tank side wall. The side wall may either by built at this time or after fabrication of the roof unit has been completed. The center roof support C is then built and then raised to a vertical position on a base plate G located at the center of the bottom of the tank, the sheaves **9**, winches **8** and cables **10** being attached to or mounted on the center roof support C at this time. The next step is to assemble and join together the parts that form the peripheral compression ring E of the roof diaphragm and the member **4** that joins the central and peripheral portions A and B of said diaphragm, the member **4** being arranged in a level position on the bottom of the tank and the ring E being arranged a slight distance above the bottom of the tank preferably on temporary radially disposed rafters **21** supported by temporary blocks **22** as shown in Figure 5. Care must be taken to see that the member **4** is set inwardly a predetermined distance from the ring E and that the radial rafters **21** have the correct downward slope or pitch, in order that the peripheral portion B of the roof will be of the correct area and will assume a curved form of predetermined average radius when said peripheral portion hangs suspended from the top edge of the tank side wall as shown in Figure 7. After said members **4** and E have been positioned correctly, radially disposed roof plates are laid on same with the longitudinal edges **18** of said plates in overlapped relation as shown in Figure 3. Thereafter the longitudinal edges of the roof plates are welded to each other and the ends of said plates are welded to the members **4** and E. In constructing the central portion A of the roof diaphragm, the segmental members that constitute the center tension ring D are assembled and joined together so that the ring D surrounds the roof support C; also a substantially cone shaped member **3** is attached to said ring D to form a portion on said ring to which the roof plates can easily be attached. At this time the ring D rests on supports on the bottom of the tank and is positioned a slight distance above the bottom of the tank as shown in broken lines in Figure 5 and designated by the reference character D'. Subsequently radially disposed roof plates are laid on the member **4** and center ring D in the manner shown in Figure 5 and designated by the reference character A' in said figure. As each plate is laid, one end is tack welded at **20** to the member **4** and the other end of the plate is tack welded at **19** to the frustro-conical portion **3** of the center ring D as shown in Figure 4. As successive plates are laid with their longitudinal edges overlapping about two inches, these overlapped portions are slidably clamped together at intervals of three to four feet by clamps designated by the reference character **13** in Figure 4. When the complete circle of plates A has been thus assembled then the cables **10** of the center hoisting mechanism are used to raise the center ring D to the position shown in full lines in Figure 5 so as to give a proper curvature to the central portion A of the roof diaphragm. The top surface of this portion A will have a downward and outward slope from the center ring D, all the way to the member **4** that joins the central portion A to the peripheral portion B and each plate of portion A will take a sag as indicated by the arrows in Figure 5 between the cord A^a—A^b and the top surface of the plate. To get proper slope of roof portion A, especially near member **4**, it is necessary to lift a portion of area B to get a load at A^a. This causes a fairly high compression in member **4**. Depending on the surface radial dimensions desired for area A, the center ring D will have been raised from three to six or even nine feet. As the horizontal radius of A increases, the height necessary to raise ring D increases. The plates of surface A are then securely welded to each other and to the member **4** and ring D and the clamps **13** are removed. The fabrication of the roof diaphragm on the bottom of the tank has now been completed and said diaphragm is now ready to be hoisted into its operative position at the top edge of the tank side wall. This operation is accomplished by turning the winches **8** mounted on the center roof support and

on the tank side wall simultaneously. It is not necessary during this operation that the roof unit be maintained in exactly the shape in which it was built. I find in practice that if it is so desired, the entire roof unit can be raised by using the tank side wall winches only until the periphery of the roof unit is raised to its final position, whereupon the center winches can be used to raise the center ring D and set it in such a position or at such an elevation that the two portions A and B of the roof and the member 4 that joins said portions together, will be disposed in a predetermined relationship with each other, which in the preferred form of my invention herein illustrated means that the central portion A of the roof will be a catenary of a predetermined average radius and the peripheral portion B of the roof will be of catenary like form but of a different predetermined average radius. If the roof plates of the peripheral portion B are welded while supported on donwwardly and inwardly sloping rafters 21 as previously explained, the said portion B will be of approximately frusto-conical shape at the completion of the fabricating operation, but in the operation of raising the roof unit said portion B will flex sufficiently to cause its shape to change to a catenary of a predetermined average radius which is less than the average radius of curvature of the central portion A of the roof whose plates were joined together while hanging in a curved form between the member 4 and the center ring D. After the roof unit has been raised to the top edge of the tank side wall, the peripheral ring E of said unit is welded to the overhanging portion F on the tank side wall. The center hoisting cables 10 are then manipulated so as to adjust the center tension ring D of the roof unit at such a height or level that the two portions A and B of the roof will be in a predetermined relationship with each other and the V-shaped member 4 that joins said two portions together will constitute the lowest point of the area of the roof. Thereafter the horizontally disposed beams 12 are installed on the center roof support C to form a bearing surface for the center ring D to rest on. Subsequently the portions of the center roof support that project above the center ring D are cut off and a cover plate 14 is welded to the top side of said ring D so as to reinforce and strengthen same and also close the hole in the center of the roof. Other fittings such as manholes, vent valves, etc. may now be installed in operative position on the roof, and the hoisting mechanism is then removed and subsequently used in building other tanks.

As previously explained, if roof portion B is considered an arc of a circle made up of very fine radially disposed elements, such as fine wires, reaching from E to member 4, it will be seen that all of these elements pull down throughout their entire length, because they slope downwardly and inwardly throughout their entire length. These elements in this manner carry the load of the peripheral portion B of the roof. Similarly, conceive the surface A as being an arc of a circle, similarly constructed of elements that slope downwardly and outwardly from center ring D to the member 4. These elements in this manner carry the load of the central portion A of the roof. The V-shaped member 4 is located in the circle where the slopes of elements composing roof portions A and B meet and hence the elements of said portions A and B are here sloping in opposite directions. The two curved surfaces above referred to have different radii, and they meet at an angle of less than 180° at approximately the bottom of the V-shaped member 4 which constitutes the lowest circle *a* of the roof.

The outer ring E is a continuous series of beams which carry the concentrated vertical loads created by the cables 7. At the same time the downwardly and inwardly directed tensions of the radial elements which compose the portion B create an accumulated circumferential compression in E. Thus during the operation of raising the roof unit, the ring E acts both as a series of beams and as a circular compression member. The center ring D is a continuous series of beams which carry the concentrated vertical loads created by the cables 10. At the same time, the downwardly and outwardly directed tensions of the radial elements which compose the portion A create an accumulated circumferential tension in ring D. Thus during this operation ring D acts both as a series of beams and a circular tension member.

After ring E has been attached conitnuously to the top edge portion of the tank wall, E no longer acts as a series of beams to carry concentrated loads. Hence E now acts as a circular compression member only. This is highly advantageous. While the roof unit is being raised, ring E has to carry only the dead weight of the roof, about 8# per square foot and hence I have strength to spare in E during this operation so that I can also use E as a series of beams as well as a compression member, but in the completed roof, E must resist roof loads which are four or more times the total load during the hoisting operation—about 38# or more per sqaure foot. Thus by relieving E of doing duty as a series of beams in the completed roof, I greatly increases its strength to act as a single duty member. This saves a great amount of steel required in E and hence the cost is much reduced. It should be noted that E is the longest circular member of the roof and hence the saving of a few pounds of steel per foot of circumference, in the aggregate, amounts to a large amount. In addition to the above, when E is attached to the tank sidewall, such joining causes a substantial portion of the plate F which forms the top edge of the tank wall to co-operate with, i. e., act as a unit with E to form an even stronger compression member at the top of the tank, which again saves more steel and further reduces the cost.

Since all of the radial elements which compose peripheral portion B are in tension and sloping downwardly and inwardly from E, all these elements have a vertical component. The summation of all these vertical components constitutes the load of the roof for portion B. This portion B, of the roof load is, therefore, carried by the sidewall of the tank, vertically downward as a circular column to the tank bottom or foundation. Since the center ring D is supported by beams 12, D continues to act as a series of beams. This is no disadvantage, costwise, for the simple reason that D is a member which is very short in circumferential length compared to the ring E. For example, on a 120' diameter tank, E is 376' long whereas D is only about 31' long. Thus it is seen that the extra steel required in ring D in order to have it act while in service, simultaneously as a series of beams as well as a tension member, actually necessitates the use of only a comparatively few extra pounds of steel when the total weight of the roof is considered. Moreover, to support ring D from the center roof support C and eliminate the series of beam actions in D would cost much more money and weight of steel. Furthermore, the cover plate 14 co-acts with ring D to help resist the center tensions of the central roof portion A. This helps decrease the steel required in D. Thus we see that all parts of this roof are co-acting with other parts in such a way that not only reduces the amount of steel required to build the roof, but makes it a stronger roof at much less cost. Since all of the radial elements which compose portion A are in tension and sloping downwardly and outwardly from D, all these elements have a vertical component. The summation of all these vertical components constitutes the load of the roof for portion A. This portion A of the roof load is, therefore, carried by center ring D and hence by beams 12 to the vertical posts of the center roof support C, and thence vertically downward to the base G upon which the center roof support rests.

In a roof of the type where the tank side wall and a center roof support carry respectively certain percentages of the total roof load, it is necessary to hold the lowest circle of the roof at the same radius for all loadings to which the roof will be subjected in service, for if the

lowest circle of the roof under some live loading or for any other reason should move toward the tank side wall, then said wall would take a smaller load than designed for it and the center roof support woud have to take a greater load than the one for which it was designed. Vice versa, if for any reason the lowest circular point of the roof under some live loading or for any other reason should move toward the center roof support, then the tank side wall compression member would have to take more load than the one for which it was designed. In building a roof whose top surface is in the form of a continuous, substantially flat curve, it is almost impossible to predetermine exactly what radius the lowest circle of the roof will assume when erected, and one cannot be sure to what radius the lowest circle of the roof may move under various loadings for reasons such as, First, the variable shortening of the radius of the top edge portion of the tank side wall under live load; Second, a slight difference of settlement of the tank side wall or of the center roof support; or Third, uneven settling of the tank side wall. It is to guard against such contingencies that I use a V-shaped member 4 or 4^a of the kind herein shown to form the intermediate portion of the roof and to join or connect the two oppositely sloped center and peripheral portions of the roof, as this is a positive way as well as the cheapest way, best way and easiest way of insuring that the tank side wall and the center roof support respectively, will carry their designed percentages of the total roof load, and no allowances have to be made for unusual conditions that may arise as would be necessary in a roof where the percentages of the roof load could change a substantial amount. In the tank herein shown the arcs of the top surfaces of the two roof portions A and B meet at an angle less than 180°, and the point where said two roof portions meet constitutes the lowest circle of the roof as designated by the reference character *a* in Figure 1 and in the diagrammatic view, Figure 10. In said view, which is intended to indicate the forces acting on the above mentioned intermediate V-shaped connecting member, the horizontal component of tension in the roof portion A is designated by the arrows S, the vertical component of tension in said roof portion A is designated by the arrow *aa*, the horizontal component of tension in the roof portion B is designated by the arrows *t*, and the vertical component of tension in said roof portion B is designated by the arrow *bb*. The outer edge of the roof portion A is designated by the reference character A^a and the inner edge of the roof portion B is designated by the reference character B^a. Said Figure 10 also shows how the tangents to the curves of A and B at A^a and B^b meet at an angle which is less than 180°. From tests I have made of roofs of the construction above described, I have found that the V-shaped connecting member which constitutes the lowest circle of the roof, greatly improves the operation of the roof when the roof has a large water load, as said member is stiff radially as well as circumferentially and hence will not allow the roof plates to bend down before the water load reaches such a level that the water load will start running over the top edge of the tank side wall. In actual tests I have made of the tank roofs constructed in the manner shown in Figures 4 to 10 inclusive I have found that the stiff V-shaped member *a* or 4^a, reaching well up on the curves of the roof, will decrease by a substantial amount, the total water load capable of collecting on the roof. Thus it will be seen that in such a roof the V-shaped member which joins the two curved portions A and B of the roof performs a number of functions as follows:

(*a*) As a circular compression member when roof portion A is pulled up into shape ready for welding the plates from which said portion is constructed.

(*b*) As an aid to the erector, making it easy and possible to set the lowest circle *a* of the roof at the proper radius.

(*c*) As a means for maintaining the lowest circle of the roof at its proper radius for all loadings to which the roof will be subjected in service, thus assuring that the tank side wall and center roof support will carry their predetermined percentages of the total roof load.

(*d*) As a means for minimizing or decreasing the sag of the roof under a heavy water load.

(*e*) As a member to take compression or excess tension under certain types of live loads on the roof when the roof is in service, and

(*f*) As a means for interrupting the roof surfaces A and B while said surfaces still have considerable downward pitch. In other words, the connecting member 4 or 4^a due to its V form, effectively insures that the radius of the lowest circle of the roof will remain constant and not shift one way or the other and thus maintain the designed percentages of load on the center roof support and tank side wall.

Thus we have the following with the roof in service:

(1) Ring E is in compression only and does not act as a series of beams.

(2) The sidewall of the tank carries its predetermined percentage of the roof load.

(3) Ring D is acting as a tension member and a series of beams simultaneously.

(4) The center roof support C carries its predetermined percentage of the roof load, and

(5) The form of the element 4 or 4^a that joins the two roof portions A and B is such that it insures that the tank side wall and the center roof support will effectively carry their designed proportionate share of the roof load.

The fact that the roof is assembled and welded at ground level not only makes the man hours required for building the roof less than in the building of a roof whose plates are joined together while arranged in an elevated position at the top edge of the tank side wall, but also the following conditions decrease the man hours:

(*a*) There is an extremely small amount of wood framing required during erection of the frusto-conical outer portion B.

(*b*) There is no framing at all required for assembly of the center portion A.

(*c*) Men working on the ground work more efficiently.

(*d*) Men are safer working on the ground.

(*e*) Much time is saved because men do not have to climb up and down.

At no point of the roof plates is the unit tension (lbs. per sq. in.) great. Assume a 120' diameter tank in which the radial dimension of peripheral portion B is 14 feet, the radial dimension from V-shaped connecting member 4 to ring D is 41 feet, and the radial dimension of ring D is 5 feet, and that all of the roof plates for portions A and B are 3/16" thick, except the very small frusto-conical portion 3 of the center ring D which is 1/4" plt. The slope of said portion 3 is 4" in 12". Then the total load on ring D at 38# per square foot (8# dead plus 30# per square foot live) is about 250,000#. The tension then in the frusto-conical portion 3 where it joins ring D is about 2100# per circumferential inch of said portion 3. Tension per inch is about

$$\frac{250{,}000\# \times 3.16}{31.4' \times 12}$$

equals 2100# per inch.

Since this frusto-conical portion 3 is 1/4" thick the unit stress is only about 8400# per square inch, compared to 20,000# per square inch allowable.

The tension in the roof plates decreases as the diameter increases since each successive circumference is greater. The tension of the roof plates where they join the tank wall is as follows: Roof plates 3/16" thick; slope

2" in 12"; maximum load on roof portion B—177,000#. The tension per inch of plt. where it is welded to the tank wall is about 240#. Thus the unit stress is about 1280# per square inch. Tension per inch is about

$$\frac{177{,}000\# \times 6.16}{375' \times 12}$$

equals 240# per inch.

The vertical load passing into the top edge portion of the tank wall per inch of circumference is calculated to be only about 41# per inch, causing practically no bending of the overhanging portion F of the tank wall to which the peripheral ring E of the roof is attached. Usually the overhanging portion F of the tank side wall would be a ¼" thick plate.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is the following:

1. A method of building a tank roof having predetermined portions of its area suspended from the tank side wall and a center support respectively, and also having a peripheral compression ring, a central tension ring, and roof plates, in which the peripheral compression ring includes a circular member forming a part of the tank side wall and the central tension ring includes a circular structure forming part of the center support; characterized by erecting a roof portion on the tank bottom by providing a plurality of ring shaped frame members on the bottom of the tank disposed in concentric relation with each other, and adapted to form parts respectively of the peripheral compression ring of the completed roof and the central tension ring of the completed roof, and said members having sufficient strength for lifting of the roof portion from the bottom wall of the tank with the roof plates assembled therewith, combining roof plates with said frame members so as to form a roof portion comprising two concentrically arranged arced surfaces of different radii disposed in angular relationship with each other and attached to said frame members, subsequently after completion of the side wall of the tank, raising said roof portion, thereafter attaching the frame member forming part of the compression ring to a portion of the side wall of the tank to form therewith a completed peripheral compression ring, and thereafter attaching the frame member forming part of the tension ring to the center support to provide therewith a completed central tension ring, the completion of the compression ring and the tension ring providing additional strength in the roof structure to carry both the dead and live loads of the completed roof.

2. A method of building a tank roof having predetermined portions of its area suspended from the tank side wall and a center support respectively, and also having a peripheral compression ring, a central tension ring, and roof plates, in which the peripheral compression ring includes a circular member forming a part of the tank side wall and the central tension ring includes a circular structure forming part of the center support; characterized by fabricating a circular member to form a part of the compression ring at a slight elevation from the bottom of the tank, assembling roof plates of the outer roof portion on said circular member in a frusto-conical array extending downwardly and inwardly from said member, fabricating a second circular member about said center support to form a part of the central tension ring with said second circular member positioned slightly above the bottom of the tank, assembling roof plates forming a part of the central portion of the roof by tacking the plates to the second circular member and to the outer roof portion with the plates supported at least in part by the bottom wall of the tank, then raising the second circular member a distance to lift the roof plates from the bottom of the tank and impart a sag thereto, thereafter attaching the roof plates permanently in place, and therafter raising the roof to its final position and attaching it to the tank side wall and to the center support respectively.

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