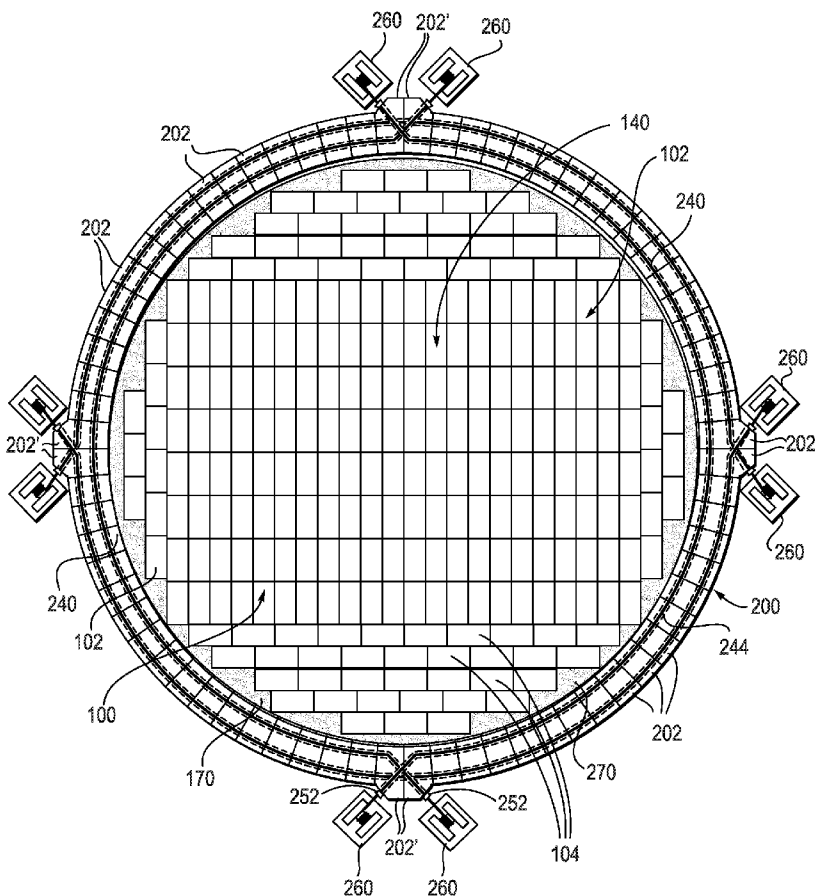


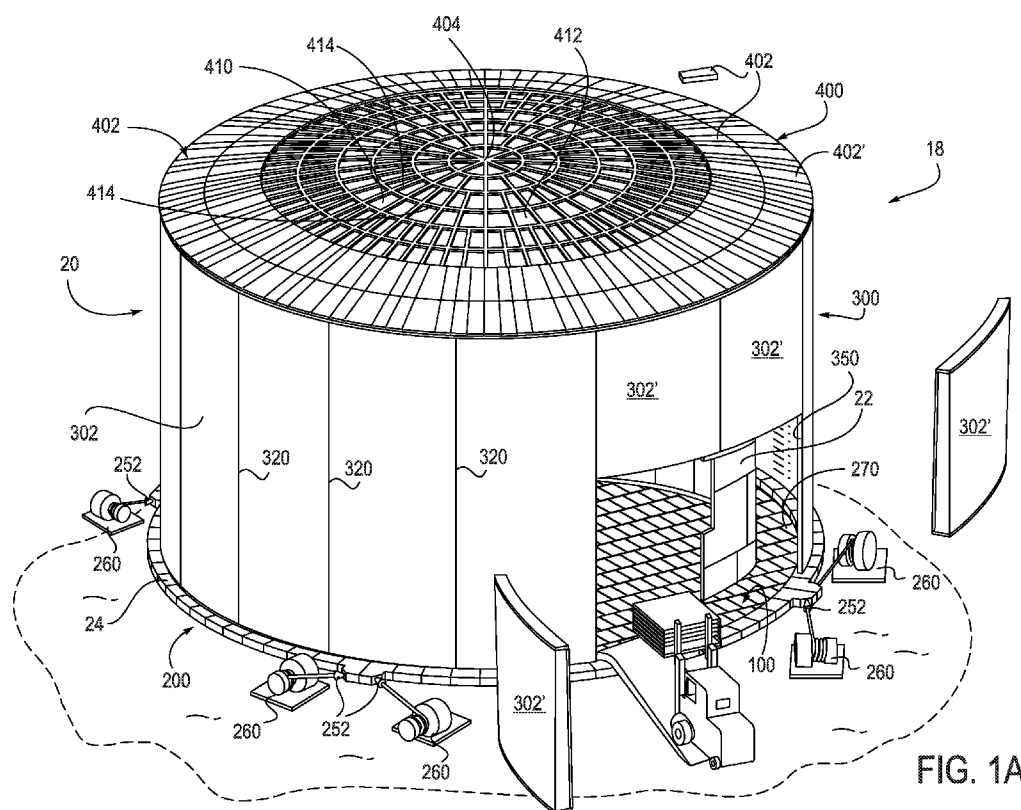


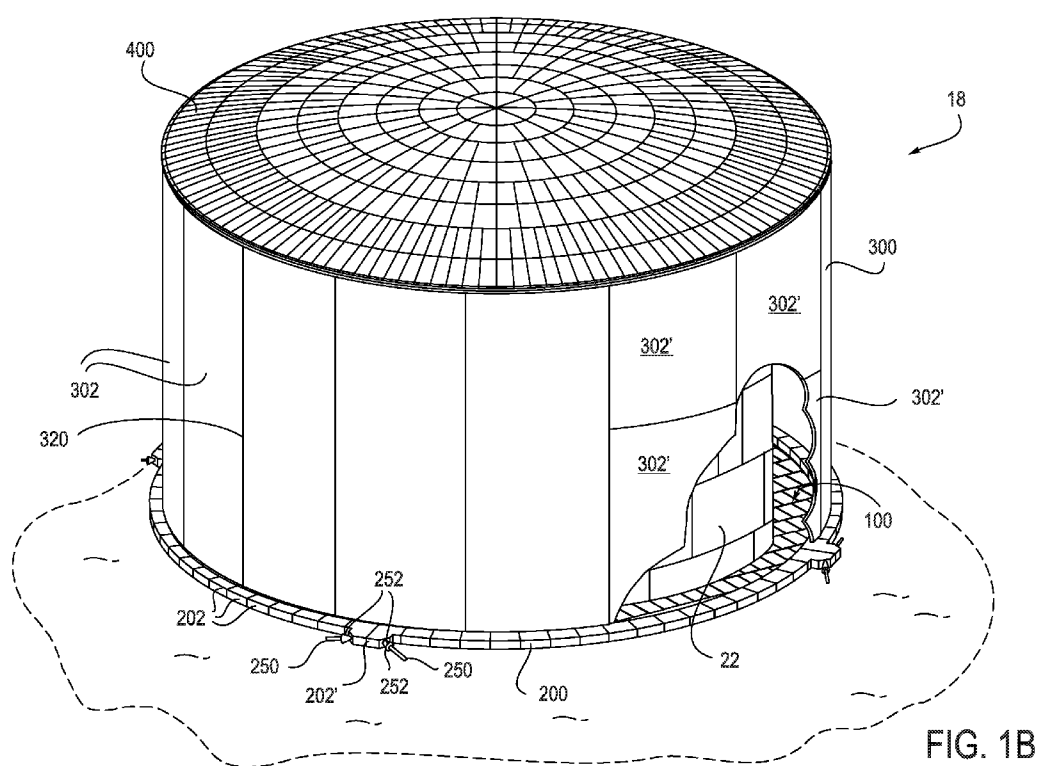
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(19) **United States**(12) **Patent Application Publication**
Shockley et al.(10) **Pub. No.: US 2011/0283638 A1**(43) **Pub. Date: Nov. 24, 2011**(54) **RING BEAM AND METHOD FOR
CONSTRUCTING THE SAME**(52) **U.S. Cl. 52/231; 52/745.21**(76) **Inventors:** **Lestle R. Shockley**, San Ramon,
CA (US); **Vincent Borov**, Martinez,
CA (US)(21) **Appl. No.: 13/140,719**(22) **PCT Filed: Dec. 17, 2009**(86) **PCT No.: PCT/US2009/068567**§ 371 (c)(1),
(2), (4) **Date: Jul. 28, 2011****Related U.S. Application Data**(63) Continuation-in-part of application No. 12/342,476,
filed on Dec. 23, 2008, now abandoned.**Publication Classification**(51) **Int. Cl.**
E04B 1/22 (2006.01)
E04B 1/21 (2006.01)(57) **ABSTRACT**

A ring beam element, a ring beam and a method of constructing a ring beam from a plurality of ring beam elements is disclosed. The ring beam can support a shell or wall of a tank. The ring beam element comprises a reinforced concrete body, preferably having a metal base plate anchored therein, and a plurality of tensile conduits extending circumferentially there through. Ideally, the reinforced concrete body will have interlocking surfaces such that the ring beam elements interlock with one another when circumferentially juxtaposed. Tensile members can be placed through the plurality of tensile conduits and tensioned and anchored by anchors to clamp a plurality of juxtaposed ring beam elements together. Ideally, the base plates of a plurality of the ring beam elements can be connected or welded together to form an annular ring of base plates. The ring beam elements can be mounted upon piles to provide level surfaces to the base plates so that the metal base plates can be readily connected together to form an annular ring beam.







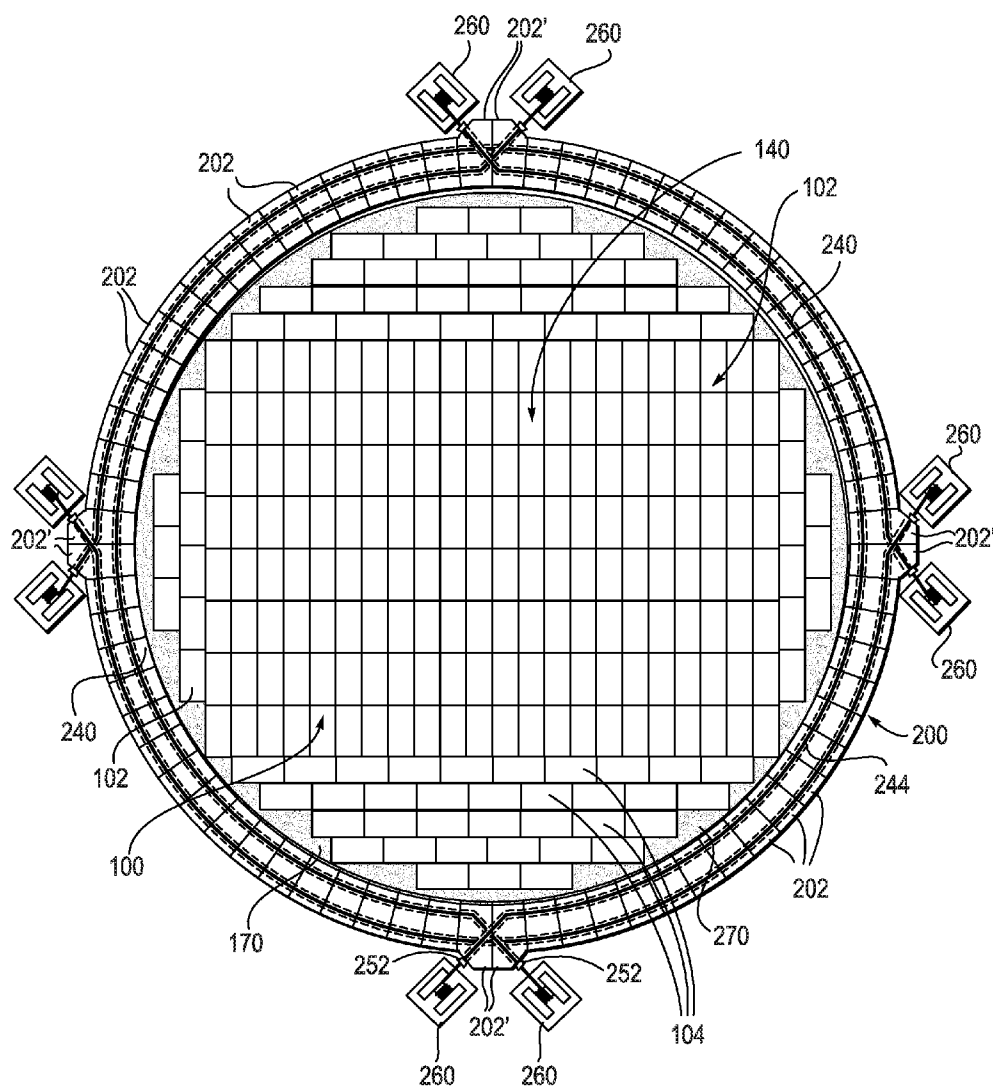


FIG. 2

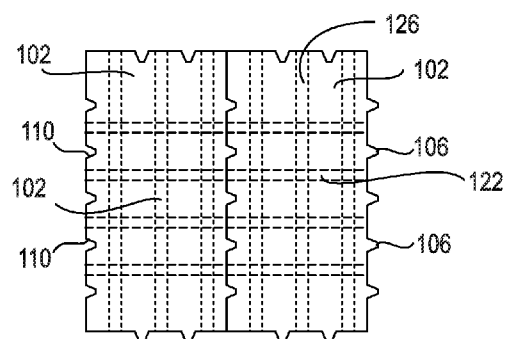


FIG. 3A

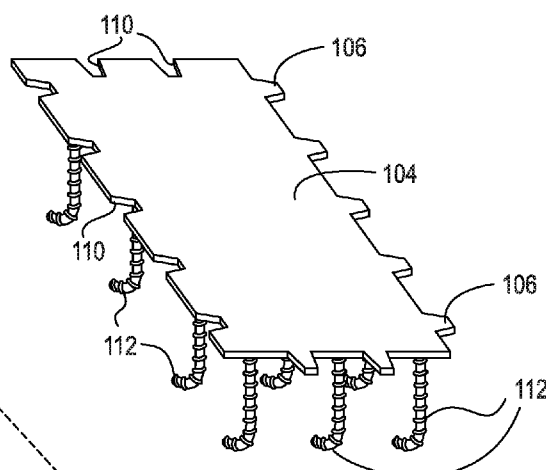


FIG. 3B

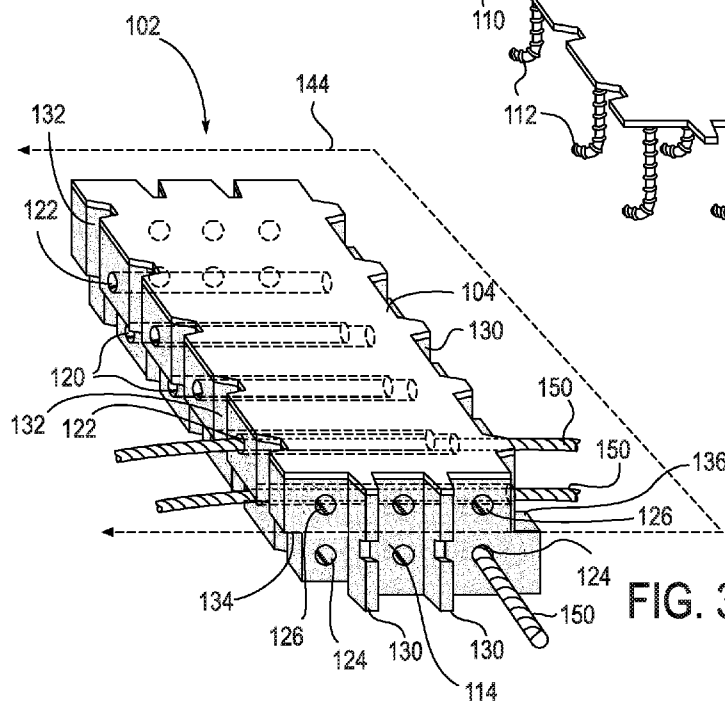


FIG. 3C

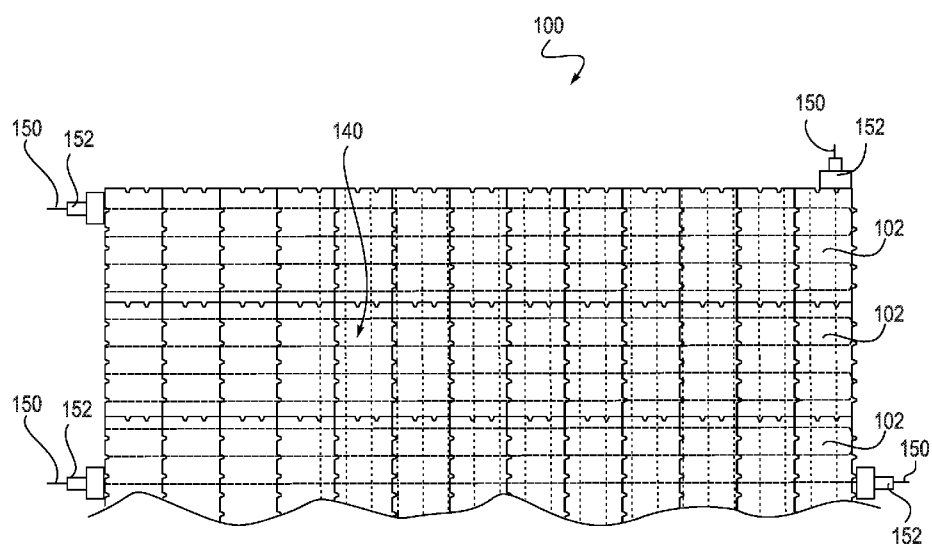


FIG. 3D

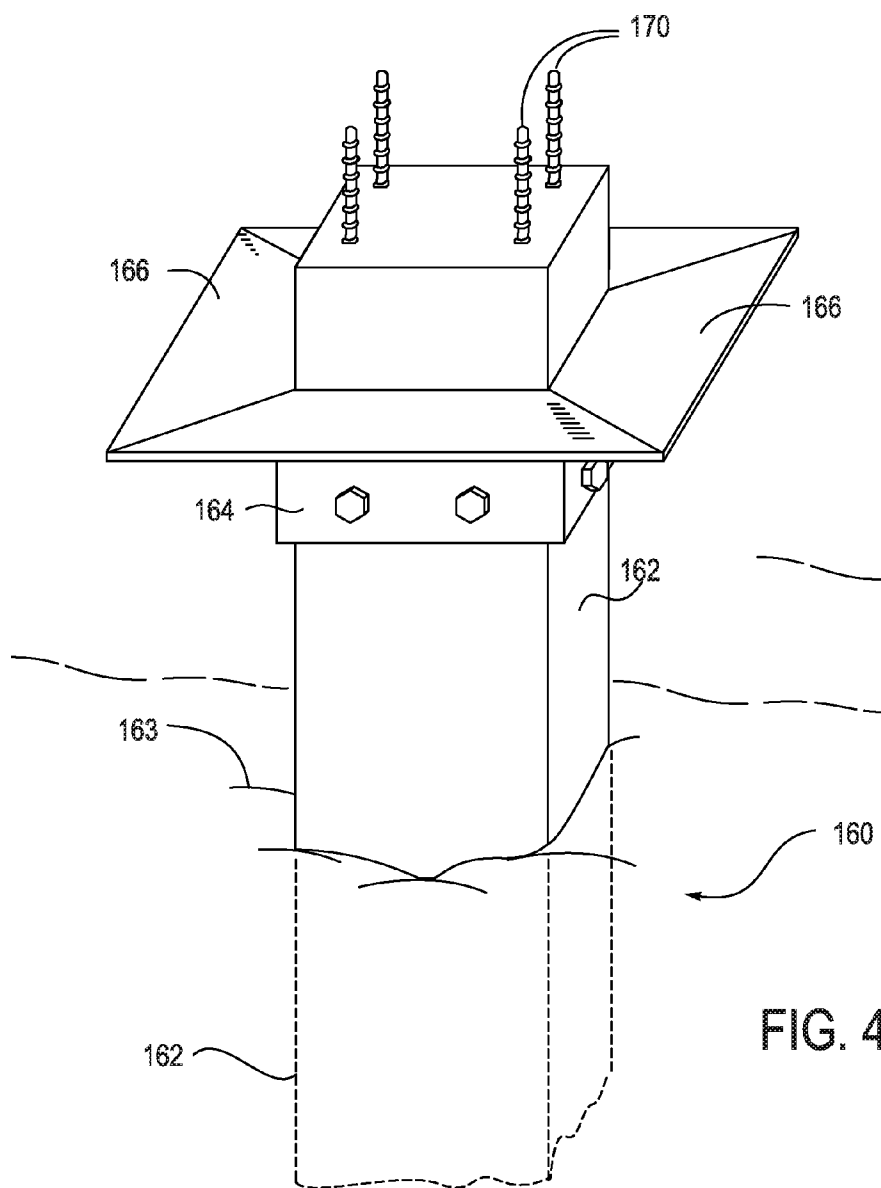


FIG. 4

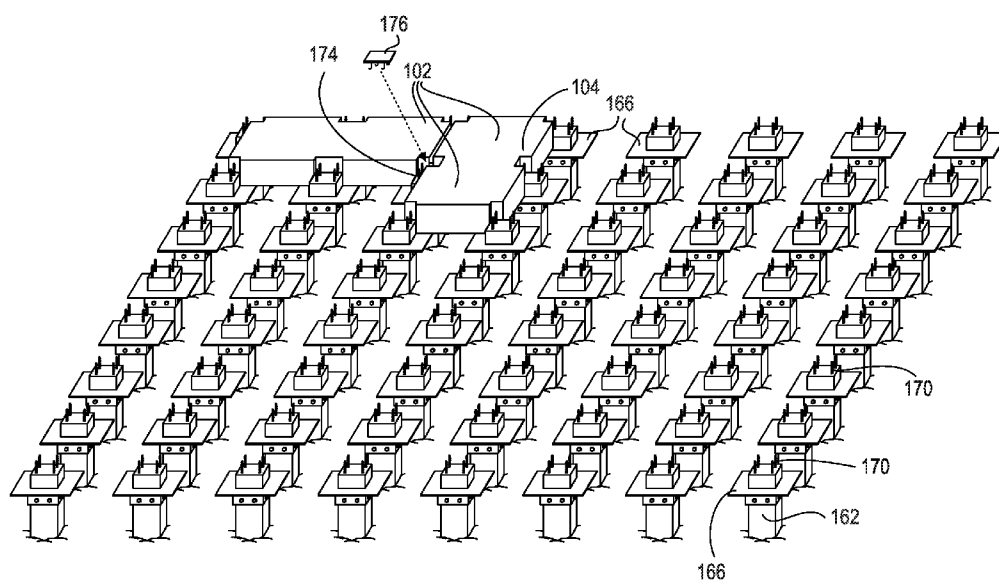


FIG. 5

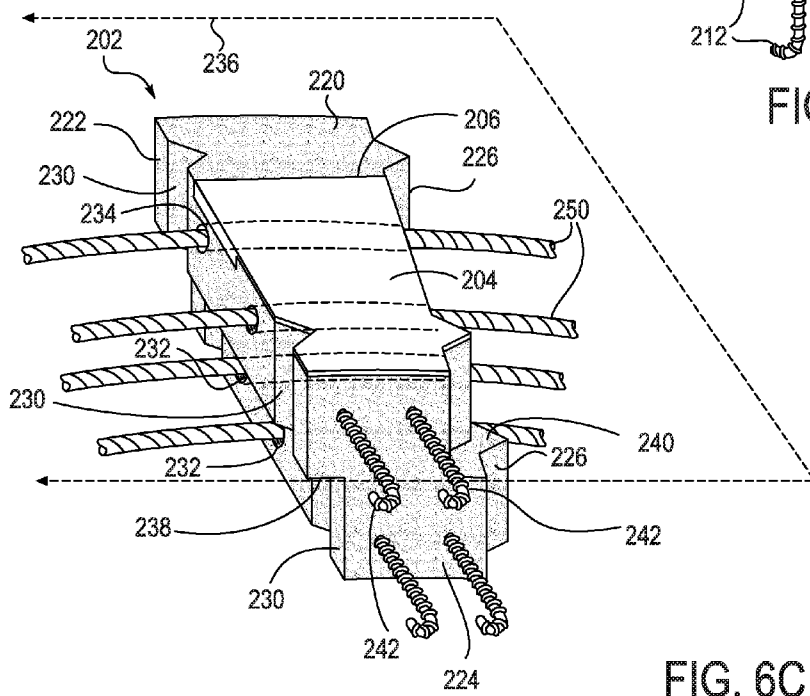
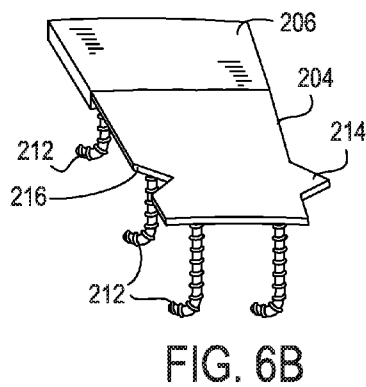
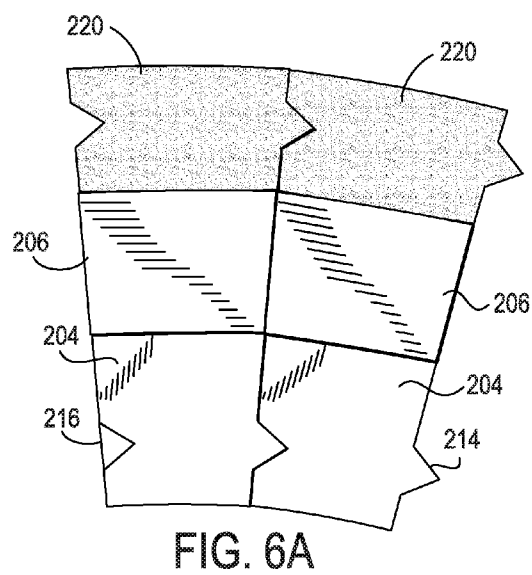


FIG. 7

FIG. 8A

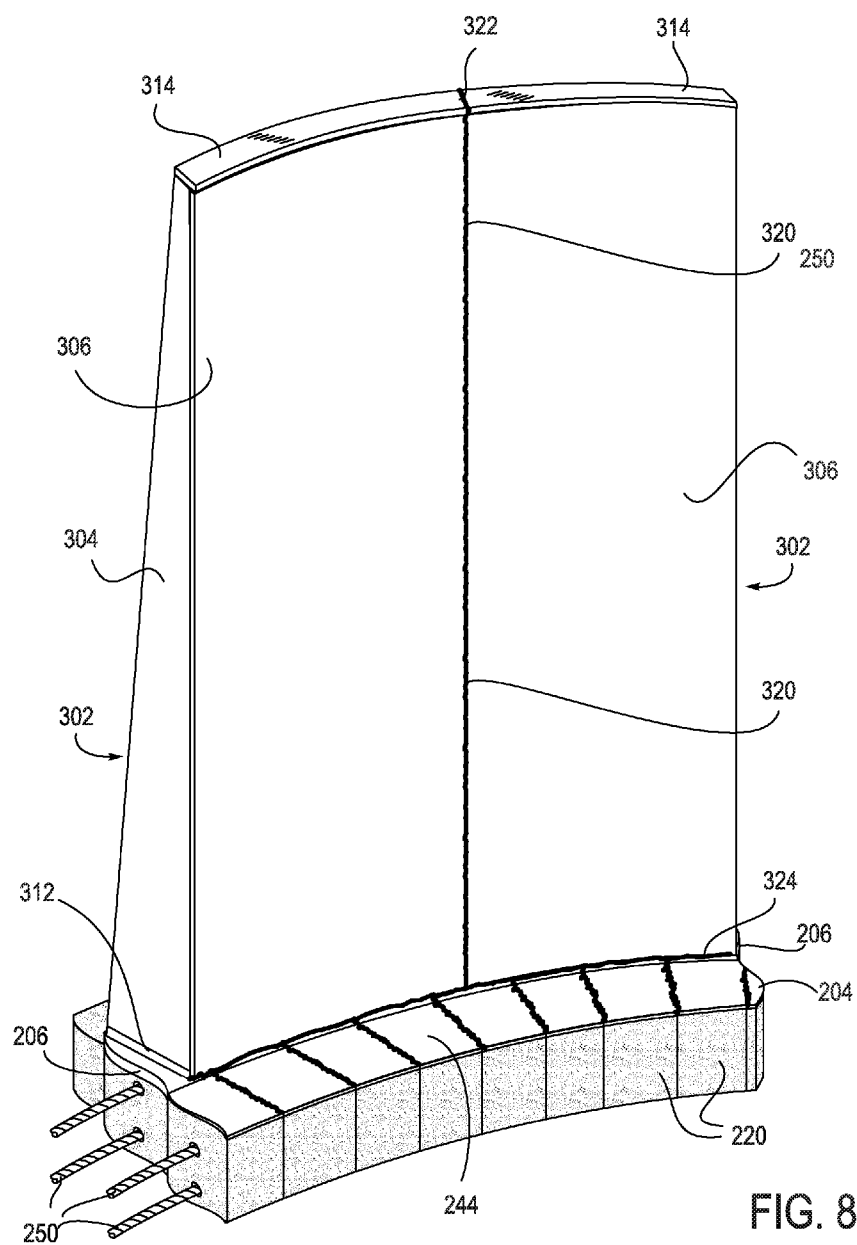
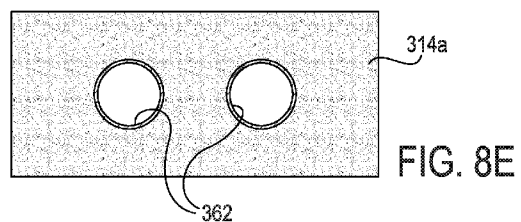
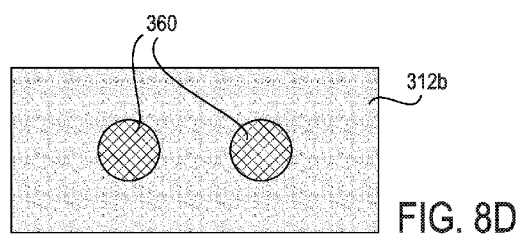
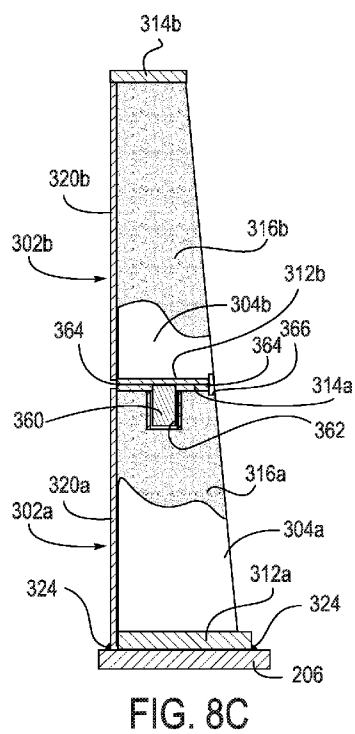


FIG. 8B



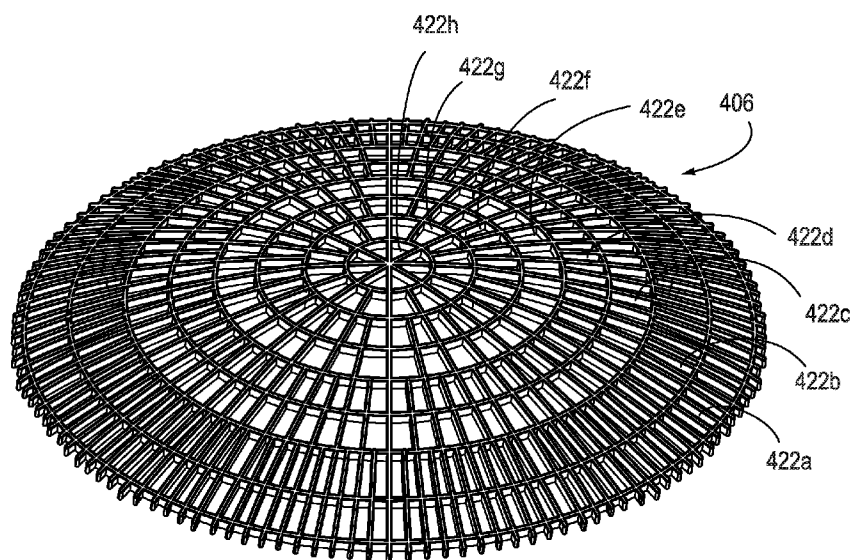


FIG. 9A

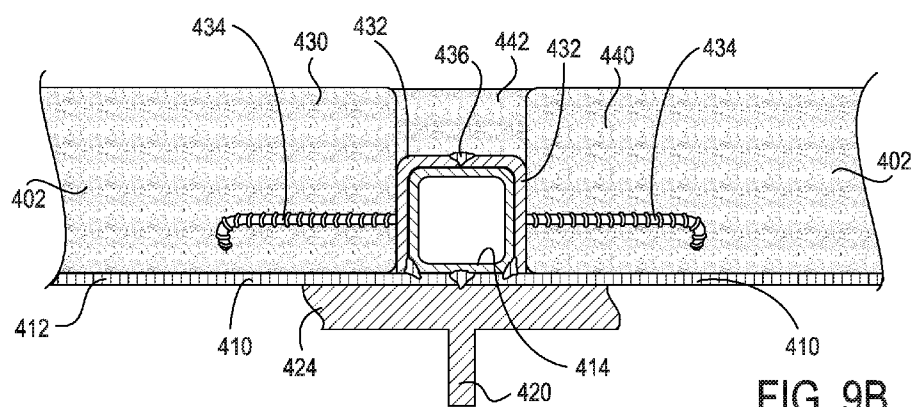
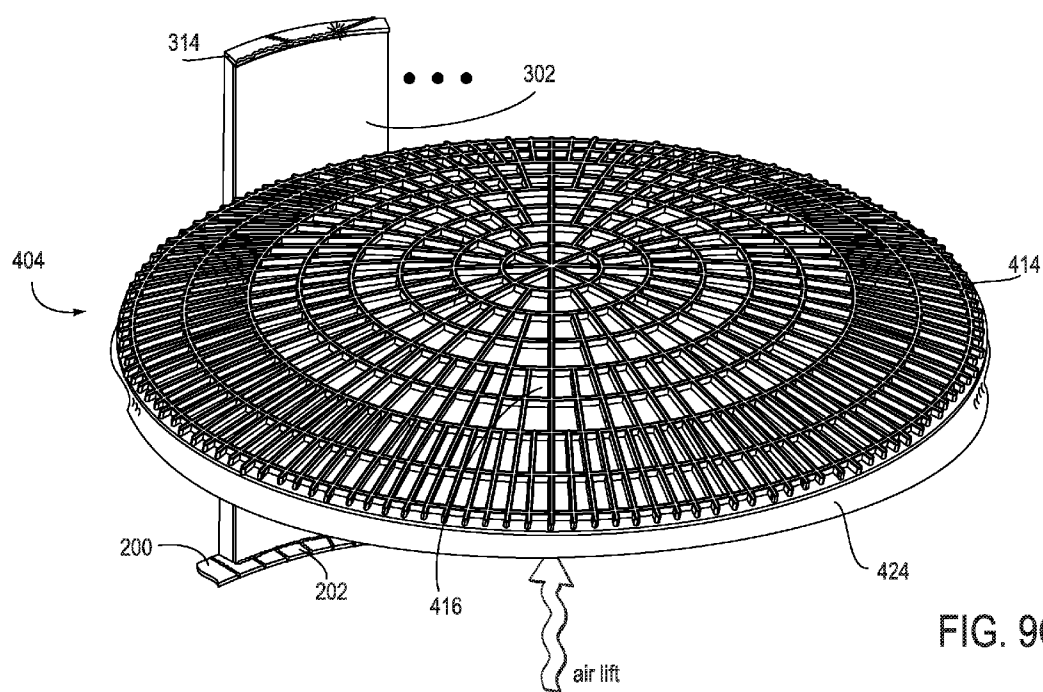


FIG. 9B



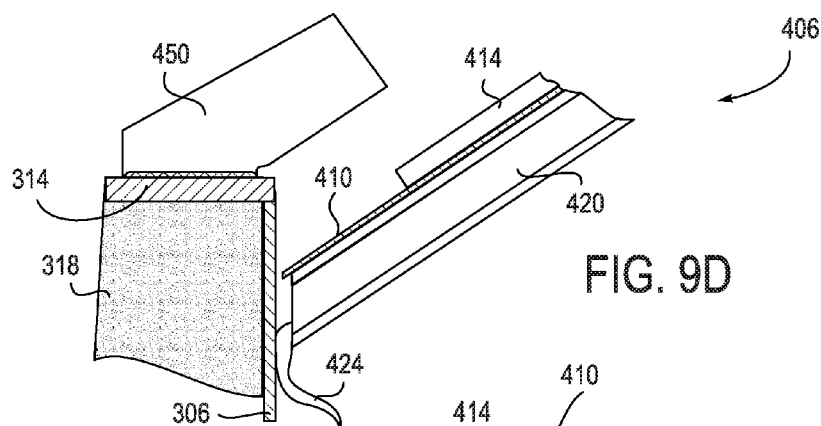


FIG. 9D

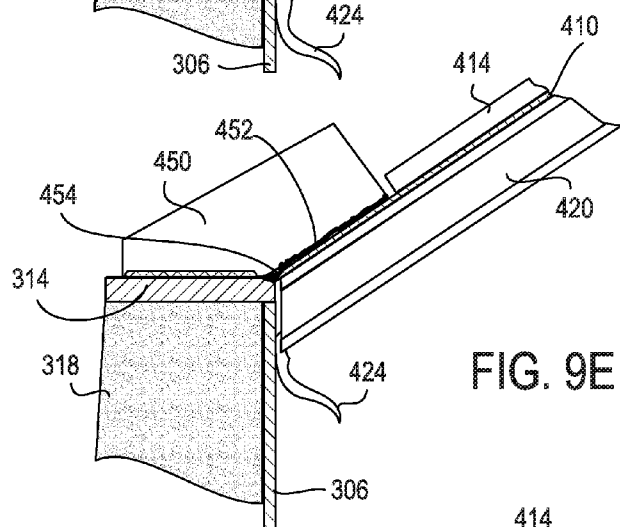


FIG. 9E

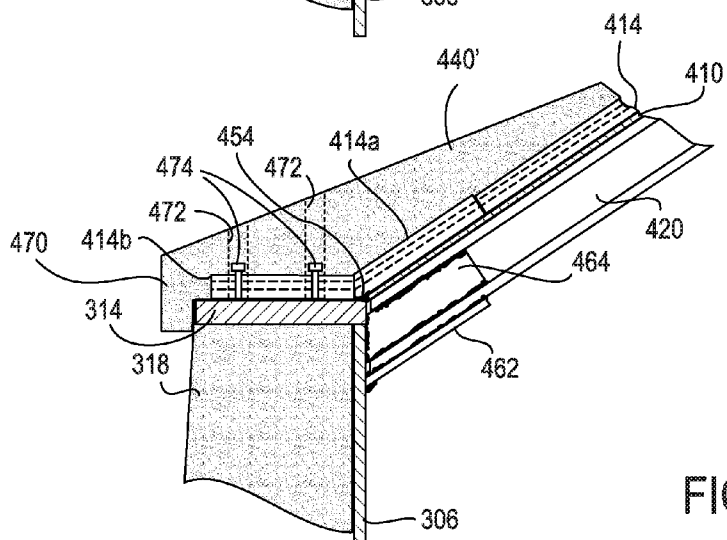


FIG. 9F

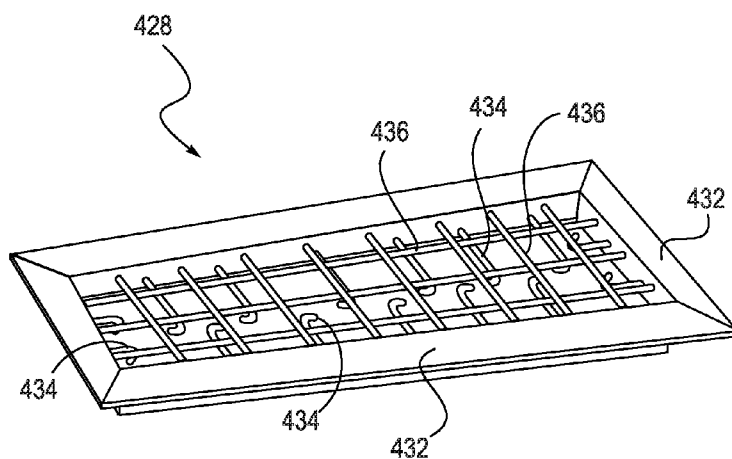


FIG. 10A

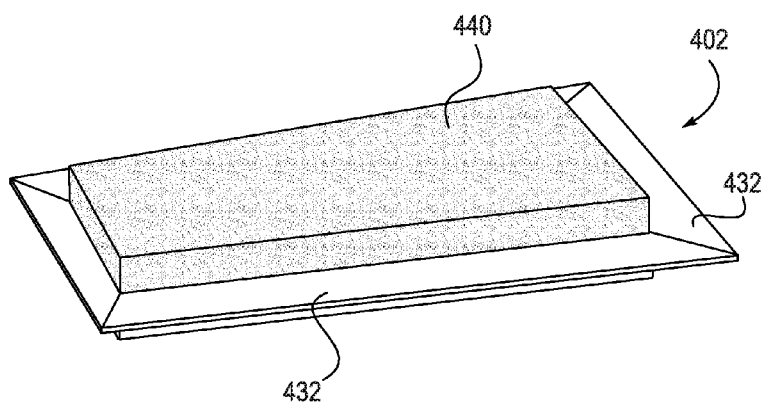


FIG. 10B

RING BEAM AND METHOD FOR CONSTRUCTING THE SAME

TECHNICAL FIELD

[0001] The present invention relates generally to liquefied natural gas (LNG) tanks and methods for constructing LNG tanks, and more particularly, to the construction of ring beam foundations which are used to support shell or tank walls.

BACKGROUND

[0002] Large storage tanks are typically designed with a so-called "ring beam," or "concrete ring wall" which is a reinforced concrete circular wall centered continuously under the shell or wall circumference of a tank. The ring beam provides special support to a heavy tank wall so as to minimize differential settlement between the center of the tank bottom and its periphery. Casting in place a ring beam for a very large tank is a time-consuming process and may be problematic at remote site locations.

[0003] Building with precast concrete elements, in general, is a known approach in the construction of various structures when construction time at a site needs to be minimized and when site conditions and locations are problematic for casting in place. However, ring beam elements are very specific structural elements due to their function and configuration in large storage tank foundations. Accordingly, ring beams are not easily constructed out of precast ring beam elements. Ring beams need to be designed for the active horizontal pressure from the product load on the tank bottom and torsional and bending moments resulting from the loads on the tank wall or shell. If a ring beam is to be constructed from precast ring beam elements, these forces will tend to separate and displace the ring beam elements from one another. In addition, providing a level surface and good alignment of adjacent ring beam elements supporting an overlying tank wall or shell are important design considerations. Construction of a cost-effective, corrosion resistant and strong connection between these ring beam elements is a very challenging task.

SUMMARY

[0004] A ring beam element, a ring beam and a method of constructing a ring beam from a plurality of ring beam elements is disclosed. The ring beam is adapted to support a shell or wall of a tank. The ring beam element comprises a reinforced concrete body preferably having a base plate and/or a liner plate anchored therein and one or more tensile conduits extending circumferentially through the concrete body. The base plate is adapted to be connected to and support a shell of a tank. Ideally, the reinforced concrete body will have interlocking surfaces such that the ring beam elements interlock with one another when circumferentially juxtaposed. Tensile members are placed through a plurality of tensile conduits and tensioned, and anchors are applied to the tensile members to clamp a plurality of juxtaposed ring beam elements together. The liner plates and/or base plates, which are preferably made of carbon steel, are connected, preferably by welding, together to construct the ring beam. Ideally, the liner plates will form a membrane or vapor barrier. The ring beam elements can be mounted upon piles to provide level surfaces to the liner and/or base plates to facilitate their being welded together. Also, mounting the ring beam elements on the piles

helps provide a stronger foundation when soil conditions supporting the ring beam may not provide adequate bearing or support.

[0005] It is an object to provide a ring beam and a method for constructing the ring beam which utilizes ring beam elements which are clamped together by post-tensioned tensile members and anchors. If the ring beam elements include a base plate and/or a liner plate, the clamped together ring beam elements allow the base plates and/or liner plates to be readily welded together to form an annular base plate ring and/or annular liner plate ring and the overall ring beam.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] These and other objects, features and advantages of the present invention will become better understood with regard to the following description, appended claims and accompanying drawings where:

[0007] FIG. 1A is a perspective view of an inner tank being constructed within an outer containment tank as the roof of the outer tank is being constructed;

[0008] FIG. 1B is a perspective view of a completed outer tank, in partial cutaway, showing a base mat assembly, a ring beam, a shell or tank wall and a roof mounted atop the shell as well as the inner tank;

[0009] FIG. 2 is a plan view of the base mat assembly or foundation and a ring beam or ring beam foundation which are to be joined by a cast in place concrete connection (not shown);

[0010] FIG. 3A is a plan view of a pair of base mat elements juxtaposed and interconnecting with one another;

[0011] FIG. 3B is a perspective view of a liner plate and attached J-hooks which are to be cast within a concrete body when making a reinforced concrete base mat element;

[0012] FIG. 3C is a perspective view of a base mat element, including concrete body, showing a pair of tensile members passing through tensile conduits disposed within the concrete body;

[0013] FIG. 3D shows a plurality of base mat elements juxtaposed in lateral and longitudinal directions with tensile members and cooperating anchors clamping the base mat elements together in the lateral and longitudinal directions;

[0014] FIG. 4 shows an exemplary pile with L-shaped brackets mounted thereon which can be used to support base mat elements or ring beam elements at predetermined heights so that the base mat elements or the ring beam elements can be readily welded together;

[0015] FIG. 5 shows a matrix of piles which can be used to support base mat elements which can then be welded together to form the base mat assembly;

[0016] FIG. 6A is a plan view of a pair of cooperating juxtaposed ring beam elements;

[0017] FIG. 6B is a perspective view of a liner plate welded to a thicker base plate and attached J-hooks welded beneath the plates which are used in casting a reinforced concrete ring beam element;

[0018] FIG. 6C is a perspective view of a reinforced concrete ring beam element including the liner plate and base plate anchored to a concrete body with tensile members extending through tensile conduits embedded in the concrete body;

[0019] FIG. 7 is a fragmentary sectional view of a cast concrete joint joining the base mat assembly and the ring beam with a shell element being welded to the ring beam;

[0020] FIG. 8A is a perspective view of a shell element;

[0021] FIG. 8B is a perspective view of a pair of shell elements which are welded together to form part of the outer shell with the shell elements also being welded to base plates of ring beam elements;

[0022] FIG. 8C shows a sectional view of a second embodiment of a shell made with two courses of lower and upper shell elements rather than using a single course as seen in the shell of FIG. 8B;

[0023] FIG. 8D shows a bottom view of the upper shell element which includes a base plate supporting two downwardly depending alignment pipes;

[0024] FIG. 8E shows a plan view of a top end cap plate of a lower shell element having two downwardly depending alignment sockets designed to receive the alignment pipes of the upper shell element;

[0025] FIG. 9A is a roof frame formed by radial and circumferentially extending wide flange beams;

[0026] FIG. 9B illustrates a typical welded connection between a tubular mounting beam of a roof assembly and a pair of roof elements;

[0027] FIG. 9C shows the roof assembly and attached seal being raised by air pressure within the outer shell so that the roof assembly can be welded to temporary gusset plates mounted to the top of the shell;

[0028] FIG. 9D is a fragmentary perspective view of the roof assembly and peripheral seal being raised to be temporarily welded to a gusset plate;

[0029] FIG. 9E is a fragmentary perspective view of a roof membrane of the roof assembly being temporarily welded to a gusset plate;

[0030] FIG. 9F is a fragmentary perspective view of the roof assembly permanently welded to the shell with the temporary gusset plates and seal having been removed and with a roof element attached to the roof assembly and shell;

[0031] FIG. 10A is a perspective view of a roof element frame used in casting a typical roof element; and

[0032] FIG. 10B is a perspective view of an exemplary roof element which is to be mounted to the roof assembly during construction of the roof.

DETAILED DESCRIPTION

I. Overview

[0033] In a first embodiment, a full containment LNG tank 18 is shown in FIGS. 1 and 2. The LNG tank 18 comprises an outer secondary container, hereinafter “outer tank 20” surrounding an inner primary container, hereinafter “inner tank 22”. Inner tank 22 is intended to store LNG. Outer tank 20 is preferably a full containment tank in which both LNG and gas vapor are fully contained in the event of a leak from the inner tank 22.

[0034] In this particular embodiment, outer tank 20 is primarily made of precast reinforced concrete elements which reduce fire risk relative to using a primarily steel outer container or tank. The construction of outer tank 20 involves assembling precast reinforced concrete elements for a foundation 24, including a base mat assembly 100 and an outer ring beam 200, an outer wall or shell 300 and a roof 400. As an example of order of magnitude, outer tank 20 in this embodiment has a diameter of approximately 80 meters, an overall height (to the top of the dome of roof 400) of about 50 meters, and a height to the top of shell 300 of about 40 meters. Those skilled in the art of LNG facilities construction will appreciate that much larger or smaller tanks can be built and

still use the design considerations described herein. However, tanks having diameters of at least 25 meters are particularly well suited to the construction methods described herein which utilize precast reinforced concrete elements. These elements ideally can be welded together to form structural welds thereby minimizing the number of cast in place concrete structural joints which have to be made to form an outer containment tank.

[0035] Ideally, inner tank 22 can be assembled at the same time as roof 400 is being built to save time and money in the overall construction of inner tank 22 and outer tank 20. Note in FIG. 1 roof elements 402 are being added ring by ring to a roof assembly 404 while inner tank 22 is being constructed. A construction access or shell opening 350 in shell 300 allows for materials to be carried into outer tank 20 so that inner tank 22 can be built as roof 400 is being constructed. After inner tank 22 is completed, special half height shell elements 302' can be installed to close opening 350. An annular gap of approximately 1.5 meters exists between inner tank 20 and shell 300 to permit circumferential access to build inner tank 22 and to accommodate insulating materials (not shown) which are to be installed between outer and inner tanks 20 and 22.

[0036] Inner tank 22 can be built in any of a number of ways which may require welding processes to connect individual plates. For example, the plates can be joined using shielded metal arc welding (SMAW) and submerged arc welding (SAW) for 9% nickel tanks of the size described above, i.e. having a diameter greater than 25 meters. In this particular example, inner tank 22 can be friction stir welded (FSW) by plate at a time erection method. A course of plates at a time can be welded with the bottom (thickest) first and then subsequent (thinner) courses welded there above. Scaffolding (not shown) can be used as each course is added. Alternatively, inner tank 22 can be constructed course down either by supporting the tank from the roof to allow insertion of the next course or by supporting on jack stands to allow insertion of the next course. For the last two methods, the scaffolding need be erected only one time. By way of example and not limitation, another alternative method is to use coil material shaped to the curvature required for the tank. Coil tank building occurs from the top course down either using jacking or by roof supported. Expanded perlite insulation is typically used in the annulus formed between inner tank 22 and outer tank 22. Although not shown, an under bottom insulating layer, which can be made of foam glass, is applied on the top of base mat assembly 100 with inner tank 22 prior to inner tank 22 being placed there on.

[0037] Foundation 24, i.e., base mat assembly 100 and ring beam 200, is designed to support inner tank 22 and outer shell 300. Outer shell 300 rests upon and transfers loads directly to outer ring beam 200 preferably through welded connections. A particularly significant load is the torsional load applied to ring beam 200 from outer shell 300. Base mat assembly 100 is secured to and transfers loads to outer ring beam 200 as well through a cast in place joint 270, which is best seen in FIG. 7. Depending on soil conditions, base mat assembly 100 and/or outer ring beam 200 can be supported upon compacted soil or else on piles, as will be described below. Roof 400 of tank 20 includes a roof assembly 404 comprising a skeletal steel frame 406 (FIG. 9A), a membrane 412 (FIG. 9B) of liner plates 410 and radially and circumferentially extending tubular mounting beams 414. Roof 400 is supported atop outer shell 300. Roof assembly 404 supports and is strengthened by

a number of concentric rings or courses of precast reinforced concrete roof elements **402** and **402'**. FIG. 2 shows a completed outer tank **22** with shell opening **350** being sealed and closed by special half shell elements **302'** which are permanently welded to the remainder of shell **300**.

II. Base Mat Assembly 100

[0038] FIG. 2 shows base mat assembly **100** disposed within outer ring beam **200**. A cast in place concrete connection **270** (not shown) is to be formed there between, as best illustrated in FIG. 7. In this particular exemplary embodiment, a large number of generally rectangular base mat elements **102** are connected together to form base mat assembly **100** having a contiguous top membrane **140** made from welded together steel liner plates **104**. Membrane **140** ideally cooperates with similar membranes formed from liner plates on connection **270**, outer ring beam **200**, shell **300** and roof **400** to form an overall air tight vapor barrier within outer tank **20**. As will be described later in greater detail, base mat assembly **100** and outer ring beam **200** preferably have discrete reinforced concrete elements that are clamped together by post-tensioned tensile members **150**, **250**, i.e., steel cables, and anchors **152**, **252**. Precast elements **102**, **202** are then welded to together to form, respectively, base mat assembly **100** and outer ring beam **200**.

A. Base Mat Elements 102

[0039] FIG. 3A shows a pair of juxtaposed base mat elements **102**. FIG. 3B shows a generally rectangular liner plate **104** having a series of projections **106** and recesses **110**. Liner plate **104** is preferably made of carbon steel although it can instead be made of other appropriate metals. The thickness of liner plate **104** in this exemplary embodiment is about 10 mm. As an example, in this embodiment the size of liner plate **104** and base mat elements **102** are approximately 2 meters by 3 meters. A plurality of J-hooks **112** is welded to the lower surface of liner plate **104**.

[0040] FIG. 3C depicts a base mat element **102** having a concrete body **114** cast about J-hooks **112** to anchor liner plate **104** to concrete body **144**. Although not shown to simplify the drawing, formed in the concrete body **114** are two or more layers of reinforcing bars or welded wire fabric running in two generally perpendicular directions. For example, the reinforcing bars can be ASTM A 615 deformed carbon-steel bars for concrete reinforcement. Also formed within concrete body **114** is a plurality of laterally extending lower and upper tensile conduits **120**, **122** and longitudinally extending lower and upper tensile conduits **124**, **126** which extend in generally perpendicular directions to one another. These tensile conduits **120**, **122**, **124** and **126** can be HDPE (high density polyethylene) tubing or steel piping or other appropriate structural conduits.

[0041] Concrete ribs **130** and grooves **132** are also formed on the longitudinally and laterally extending edge surfaces of concrete body **114**. Locating projections **106** and ribs **130** and receiving recesses **110** and grooves **132** allow a plurality of base mat elements **102** to be placed in interlocking juxtaposition as suggested in FIG. 2, FIG. 3A and FIG. 3D when base mat assembly **100** is being constructed. Note that concrete body **114** has downwardly and upwardly opening steps **134** and **136** so mating base mat elements **102** can interlock in the vertical direction as well as in the lateral and longitudinal directions.

[0042] The rows of tensile conduits are disposed below and above the central horizontal plane **144** of concrete body **114**. These laterally and longitudinally extending tensile conduits are designed to receive tensile members **150** there through which allow multiple base mat elements **102** to be clamped together utilizing anchors **152** (FIG. 3D) upon the post-tensioning of the tensile members **150**. Only some of the tensile members **150** are shown in FIG. 3D.

B. Construction of Base Mat Assembly 100

[0043] Base mat assembly **100** is constructed by juxtaposing base mat elements **102** in both first and second generally perpendicular directions as seen in FIG. 2. Locating projections **106** and concrete ribs **130** cooperate with receiving recesses **110** and grooves **132** on adjacent elements **102** to align base mat elements **102** in first and second generally perpendicular directions. Steps **134**, **136** allow base mat elements **102** to interlock in the vertical direction as well.

[0044] Tensile members **150** are fed through tensile conduits **120**, **122**, **124** and **126** as base mat elements **102** are being juxtaposed to one another. After the mating surfaces on the base mat elements **102** are properly located relatively to one another, tensile members **150**, i.e. cables, are post-tensioned and anchored by anchors **152** to clamp base mat elements **102** together. In this particular example, tensioning can be accomplished such as by using a Williams Strand Anchor System available from Williams Form Engineering of Belmont, Mich., USA. Those skilled in the art will appreciate that other tensioning systems can also be used to post-tension and anchor tensile members **150**. After the tensioning is complete, anchors **152** are locked in place on tensile members **150** to maintain the tension in tensile members **150** with anchors **152** bearing upon base mat elements **102**.

[0045] Liner plates **104** of each of base mat elements **102** are then welded together to form a part of a generally contiguous membrane **140** on the top of base mat assembly **100**. As tensile conduits **120**, **122**, **124** and **126** are located above and below the central horizontal plane **144** of concrete body **114**, the top and bottom surfaces of base mat elements **102** are held together and do not separate due to the post tensioning of tensile members **150** with anchors **152** clamping about base mat elements **102**, preferably even under construction and operating loads applied to base mat assembly **100**.

C. Mounting of Base Mat Elements on Piles

[0046] Base mat elements **102** can be assembled on a graded, level surface if the underlying surface or soil is sufficiently stiff. However, if the soil does not provide adequate support, base mat elements **102** can be mounted on piles **160**. The upper portion of a typical pile **160** is seen in FIG. 4. Pile **160** includes a post **162** which is driven into the ground such as in soft soil **163**. Four L-shaped brackets **164** can be bolted or welded to post **162** at an appropriate location with horizontally extending flanges **166** being at a predetermined height. Ideally, a laser positioning system is used to maintain all of the flanges **166** within a predetermined tolerance of height. Mounting base mat elements **102** on flanges **166** will then provide for easy welding of liner plates **104** together as the liner plates **104** should all be at about the same height. Reinforcing bars **170** extend upwardly from post **162** to facilitate later cast in place connections between piles **160** and base mat elements **102**.

[0047] FIG. 5 depicts a couple of base mat elements 102 being mounted upon flanges 166 of a matrix of piles 160. Note in this case of utilizing piles 160 for support, base mat elements 102 are notched in their corners and along their long sides to mate with posts 162, as seen in FIG. 5.

[0048] The corners and long sides of base mat elements 102 will be supported by six cooperating supporting flanges 166. Voids 174 are created by the intersection of the corners and along the sides of cooperating base mat elements 102. In the case where piles are used, base mat elements 102 can include reinforcing bar loops (not shown) which are embedded in concrete body 114 and extend laterally and longitudinally from concrete body 114. The loops will loop over vertically extending reinforcing bars 170. Concrete is cast in these voids 174 about the loops and reinforcing bars 170. Fitted liner plate 176 is anchored by J-hooks in the cast concrete so that liner plates 104 and 176 can be welded together to form generally continuous top membrane 140 on base mat assembly 100.

III. Outer Ring Beam 200

[0049] FIG. 2 shows a plan view of the foundation 24 including base mat assembly 100 and outer ring beam 200. The numbers of base mat and ring beam elements 102, 202 needed to construct these components will vary depending on the size of the desired outer tank 20 and the selected size of the various ring beam elements 202 and base mat elements 102. Various methods can be used to join base mat assembly 100 to outer ring beam 200. Preferably, ring beam elements 202 are clampingly held in a circumferential abutment by post-tensioning tensile members 250 and clamping anchors 252 about the ring beam elements 202. Then base plates 206 are anchored within each of ring beam elements 202 are welded together to form an annular ring of such base plates 206. Similarly, inner liner plates 204 are also welded to one another to increase strength and stiffness and to form a membrane 244 of liner plates 204. Post-tensioned tensile members 250 and anchors 252 assist outer ring beam 200 in resisting bending, shear and torsional forces applied to ring beam 200 by outer shell 300 and by base mat assembly 100 to maintain ring beam elements 202 in the proper abutting relationship with respect to one another.

A. Ring Beam Element 202

[0050] FIGS. 6A-C illustrate an exemplary embodiment of a ring beam element 202. In plan view, FIG. 6A shows a pair of ring beam elements 202 interlocking with one another when placed in side by side position. FIG. 6B shows an inner liner plate 204 secured to a thick base plate 206. Liner plate 204 and base plate 206 are preferably made from carbon steel. Liner plate 204 is approximately 10 mm thick and base plate 206 is about 50 mm thick in this example. J-hooks 212 are welded to the bottom sides of liner plate 204 and base plate 206. Projection 214 and recess 216 are formed on the edges of liner plate 204. FIG. 6C illustrates that ring beam element 202 includes a concrete body 220 in which liner plate 204, base plate 206 and J-hooks 212 are embedded. An outer radial surface 222 and an inner radial surface 224 define what will be part of the radially outer and inner surfaces of ring beam 200. A plurality of locating concrete ribs 226 and receiving recesses 230 allow juxtaposed ring beam elements 202 to be cooperatively interlocked with one another, as seen in FIG. 2 and FIG. 6A, to form outer ring beam 200.

[0051] Also formed within concrete body 220 are circumferentially extending lower and upper tensile conduits 232, 234. In this particular embodiment, there are four such tensile conduits 232, 234. Two of these tensile conduits 232 are generally arranged below and two conduits 234 are arranged above the horizontal center plane 236 of ring beam element 202. Also, two of the tension conduits 232, 234 are arranged beneath base plate 206 and two are located radially inwardly beneath liner plate 204 closer to the inner radial surface 224. These cooperating locations of tensile conduits 232, 234 allow tensioning members 250, i.e., cables, to pass through each of ring beam elements 202 and assist in counter balancing the bending, shearing and torsional loads applied to base plate 206 by outer shell 300. Also, tensile members 250 and anchors 252 cooperate to clamp about ring beam elements 202 to prevent the abutting ring beam elements 202 from displacing with respect to one another. In this particular example, high density polyethylene (HDPE) tubing is used to form the tensile conduits 232, 234 in concrete body 220. Of course, the tensile conduits could be made of other suitable materials such as steel or other structurally strong materials. Downwardly and upwardly opening steps 238 and 240 allow elements 202 to be vertically interlocking as well. Also, located within concrete body 220 is a plurality of reinforcing bars (not shown) which are conventional for adding tensile strength to cast concrete bodies. Extending radially inwardly are reinforcing bars or J-hooks 242 which are later to be included in cast concrete connection 270 which connects base mat assembly 100 with ring beam 200.

[0052] FIG. 6C illustrates a ring beam element 202 having four circumferentially extending tensile conduits 232 and 234 extending there through. This embodiment may be appropriate for cases where outer ring beam 200 is supported by stiff underlying soil or surface. In the event that a softer underlying soil is available at a site, it may be preferably to include an additional pair of tensile conduits located radially outboard of the locations where the tensile conduits 232, 234 are positioned in FIG. 6C. This allows additional clamping force to be applied across the ring beam elements 202. FIG. 7 shows a ring beam element 202 with three pairs of vertical spaced apart tensile conduits 232 and 234. Also, as discussed above with respect to base mat elements 102, ring beam elements 202 can also be mounted on leveled flanges of piles to insure proper support and vertical alignment between ring beam elements 202 which are to have liner plates 204 and base plates 206 welded together.

B. Construction of Outer Ring Beam 200

[0053] Ring beam elements 202 are juxtaposed with respect to one another with locating concrete ribs 226 of one ring beam element being held within locating recess 230 of the adjacent ring beam element. Similarly, cooperating steps 238 and 240 assist in vertical alignment between ring beam elements 202. Tensile members 250 are placed through tensile conduits 232 and 234 as the ring beam elements are being positioned adjacent one another. As seen in FIGS. 1A and 1B, at four locations along the circumference of outer ring beam 200, there are pairs of special abutting ring beam elements 202' through which the ends of tensile members 250 extend. Tensile members 250 are tensioned utilizing tensioning devices 260 and anchors 252 are anchored about ring beam elements 202. In this particular example, tensioning can be accomplished such as by using the aforementioned Williams Strand Anchor System. Those skilled in the art will appreciate

that other tensioning systems can also be used to post-tension and anchor tensile members 250.

[0054] After the individual ring beam elements 202 are aligned and clamped together using tensile members 250 and anchors 252, base plates 206 are welded together along their radially extending abutting edges to form an annular ring which strengthens outer ring beam 200. Finally, liner plates 204 on ring beam elements 202 are also welded together along their radially extending edges to form a continuous membrane 244 on the radial inner side of outer ring beam 200, as best seen in FIG. 8B.

C. Connection Between Base Mat Assembly 100 and Ring Beam 200

[0055] FIG. 7 illustrates an example of how a base mat assembly 100 can be connected to the outer ring beam 200. Concrete is cast in place about reinforcing bars 142, 242 extending outwardly from adjacent base mat elements 102 and radially inwardly from ring beam elements 202 to form a cast in place joint 270 between the base mat assembly 100 and outer ring beam 200. Liner plates 272 are cut to the necessary size and shape to mate between liner plates 104 of base mat assembly 100 and inner liner plates 204 of outer ring beam 100. J-hooks 274 are welded to the bottom side of liner plates 272. Concrete is cast in place between base mat assembly 100 and base ring 200 to create a concrete body 276 anchoring liner plates 272 and J-hooks 274, 142 and 242 in the cast concrete to form joint 270. Although not shown, appropriate reinforcing bars will also be positioned in the space to be occupied by joint 270 prior to the concrete being cast to enhance tensile strength of joint 270.

IV. Outer Shell 300

[0056] FIG. 8A shows a perspective view of a typical shell element 302. FIG. 8B depicts a pair of shell elements 302 which are welded together and form a part of outer tank wall or shell 300. To reduce construction time for outer tank 20, shell 300 is built using precast reinforced concrete shell elements 302 that are joined by welding shell elements 302 together to form a generally annular, tapered thickness annular shell 300. Shell elements 302 are thicker at their bottoms to handle greater loads applied there to near ring beam 100 as compared to the loads imposed by roof 400. Preferably, there is minimal or no need to cast in place any significant structural connections to join shell elements 302 together or to ring beam 200 or to roof 400. Shell elements 302 will be precast to the number, widths and heights required for the size of outer tank 22. Typically, the inner diameter of outer tank 20 will be about 3 meters larger in diameter than inner tank 22 to allow for construction of inner tank 22 and to provide for insulation in the annulus between the tank shells. Precasting of shell elements 302 can be started as soon as the tank diameter and height are known.

A. Shell Element 302

[0057] Each of shell elements 302 includes a pair of tapered carbon steel side plates 304 and a carbon steel liner plate 306 forming a generally U-shaped steel cross-section. In this example, the liner plate 306 is about 10 mm thick and side plates 304 are about 25 mm thick. The width of side plates 304 is about 800 mm at their bottom and 400 mm at the top providing the tapered shape to shell element 302. A base plate 312 connects side plates 304 and liner plate 306 at the bottom

of shell element 302. Numerous reinforcing bars 310 are welded to and extend from side plate 304 to the opposing side plate 304 and from base plate 312 to top end cap 314. Base plate 312 is about 50 mm in thickness in this example. A steel end cap plate 314, also about 50 mm thick, is welded to side plates 304 and steel liner plate 306 at the top of shell element 302. Concrete is cast in place in the U-shaped volume defined by side plates 304 and steel liner plate 306 and about reinforcing bars 310 and J-hooks 316 to form reinforced concrete body 318. Liner plate 306 acts as a vapor/gas barrier

B. Constructing Shell 300

[0058] Shell 300 is constructed by arranging shell elements 302 vertically upon outer ring beam 200. Initially, base plates 312 are arranged radially slightly outside of their final position for welding with shell elements 312 being slightly radially spaced apart. Shell elements 302 are then moved radially inwardly until all base plates 312 and side plates 304 are brought into abutment at the proper radial position atop of base plates 206 of ring beam 202. Erection gear will be used to finally align and pull the side plates 304 closely together to begin welding.

[0059] As seen in FIG. 8B and FIG. 1A, vertically extending weld joints 320 are made on the inside and outside of abutting side plates 304. Weld joints 320 ideally are designed to be strong enough to carry the loads on shell 300 without any or little other significant reinforcement, in particular, the need for post tensioning or utilizing any type of significant cast in place joints. End cap plates 314 are welded to one another forming weld joints 322 and creating a continuous upper ring on shell 300. As best seen in FIG. 7, base plates 312 of shell 300 and base plates 206 of ring beam 200 are welded together along the inner and outer radial surfaces on base plate 312 to form base plate welds 324. Shell elements 302 are splice welded to accommodate load transfer even under earthquake or missile impact. If additional strength is needed, shell elements 302 may be designed to be mechanically interlocking with one another as well as being joined by welds such as weld 320. Ideally, the welded connections between shell elements 302 will be comparable in strength to conventional cast in place connections formed between shells.

[0060] All of shell elements 302 are permanently welded together to form shell 300, with the exception of 2-4 special half shell elements 302'. Half shell elements 302' are similar to shell elements 302 except they are only about half the height of regular shell elements 302.

[0061] These special shell elements 302' will be temporarily sealed with shell opening 350 to accommodate air raising of roof assembly 404, as suggested in FIG. 9C. These special half shell elements 302' are removed after roof assembly 404 is attached to shell 300 to provide access so that inner tank 22 can be concurrently erected as reinforcing roof elements 402 and 402' are welded to roof assembly 404. When inner tank 22 is completed, along with insulation added in the annulus formed between inner tank 22 and outer tank 20, the special half shell elements 302' are permanently welded to the remainder of shell 300 to seal shell opening 350, as shown in FIG. 1B. Although not shown in FIGS. 1A and 1B, manhole access openings will be provided in roof 400 to provide access to perform welds on the interior of outer tank 20. Also, the manhole access openings allow future maintenance to be performed within outer tank 20.

[0062] As an alternative to permanently closing construction opening 350, liner plates can be welded to close shell

opening 350. Then reinforcing bars and steel rib stiffeners can be placed in a form and concrete can be cast in place to form a cast in place shell element similar to that used in the design of the precast shell elements 302. Shell 300 should have great strength when completed due to the welded connections 320 on the inner and outer edges of side plates 304 which cooperate to form a large number of radially extending stiffeners arranged around the circumferential periphery of outer tank 20.

C. Alternate Shell Design

[0063] FIGS. 8C, 8D and 8E show an alternative shell design. Rather than using a single course of precast reinforced concrete shell elements 302 to form shell 300, multiple courses of similar upper and lower shell elements 302a and 302b are utilized. Those skilled in the art of LNG tank construction will appreciate that any number of courses of shell elements could be used to form a shell. However, shorter shell elements are easier to transport and move but require additional welds as compared to using a single course of shells to construct a shell.

[0064] Lower shell element 302a includes a concrete body 316a to which a pair of circumferentially spaced apart side plates 304a, liner plate 320a, upper end cap plate 314a and lower base plate 312a are anchored or embedded (anchors and reinforcement bars not shown). Base plate 312a is welded by welds 324a to base plate 206 of ring beam 200. Upper end cap plate 314a has two downwardly depending sockets 362 formed therein.

[0065] Upper shell element 302b includes a concrete body 316b to which a pair of circumferentially spaced apart side plates 304b, liner plate 320b, upper end cap plate 314b and lower base plate 312b are anchored (anchors and reinforcement bars not shown). Two downwardly depending and circumferentially spaced apart alignment pipes 360 are welded to lower base plate 312b. As seen in FIG. 8C, alignment pipes 360 can be used to align and guide an upper shell element 302b as it is positioned upon lower shell element 302a. Also, alignment pipes 360 held within alignment sockets 362 provide mechanical interlocking between shell elements 302a and 302b. Base plate 312b is welded by horizontal welds 364 to end cap plate 314a of lower shell element 302a along their inner and outer radial edges. A horizontal extending cutout 364 on the outer radial edges of shell elements 302a and 302b permits the outer radial weld 364 to be easily made. After welding, cutout 364 is filled with grout for fire protection.

V. Roof 400

[0066] Referring in general now to FIGS. 9A-F, roof 400 has a roof assembly 404 which includes a skeletal roof frame 406 (FIG. 9A), liner plates 410 covering roof frame 406 (FIGS. 9B and 9C) to form a generally air tight membrane 412 and tubular mounting beams 414 welded atop membrane 412. In this exemplary embodiment, after a temporary skirt or seal is attached to its circumferential periphery, roof assembly 404 is air lifted to the top of shell 300 from upon base mat assembly 100 by pressurizing the inside of shell 300, as suggested in FIG. 9C. Roof membrane 412 of roof assembly 404 is welded to circumferentially spaced apart steel gusset plates 450 (FIGS. 9D and 9F) that are temporarily attached atop end cap plate 314. This prevents the roof seal from blowing out and allows weld joints to be made between the

roof membrane 412 and gusset plates 450. Air pressure is maintained while welds are made between end cap plate 314 and roof membrane 412.

[0067] Once enough weld joints have been formed to safely support roof 400, the pressurization within shell 300 is removed. Personnel can then access the inside of the outer tank 20 to construct inner tank 22. Additional welding is done to complete the circumferential weld joint between the roof membrane 412 and shell membrane 340. Special extra strength roof elements 402' are attached to shell 300 and roof frame 404 forming the radial outermost course of roof elements 402. Then typical roof elements 402 are attached to roof frame 404 with the radial outermost course of roof elements 402 being attached first. Then the successive next radial outermost course of roof elements is added until all the rings of roof elements 402 are in place forming roof 400.

A. Roof Assembly 404

[0068] Roof assembly 404 is built on the ground in this particular preferred exemplary embodiment. Roof frame 406 comprises a plurality of radially and circumferentially extending wide flange beams 420, as best seen in FIG. 9A. In this particular exemplary embodiment, eight concentric rings of openings 422a-h are formed between the wide flange beams 420. Wide flange beams 420 used in the radial direction are W18×76 in the center and gradually increase in size to W18×143 near the outer radial ends. In the circumferential direction each row of wide flange beams 412 has the same section size such as W18×40, W18×50, W18×76 and W18×97 with the larger wide flange beams being used nearer the outer radial edge. Of course, other sizes of wide flange beams can be used, particularly if outer tank 20 is to be of a smaller or larger size than suggested in the present example.

[0069] FIG. 9B shows a typical joint construction for roof assembly 404. Liner plates 410 are appropriately sized and are welded to the top flange 424 of wide flange beams 420 to cover openings 422 and thus provide a generally air tight roof membrane 416. A tubular mounting beam 414 is shown which is welded atop of adjacent liner plates 410. Tubular mounting beams 414 generally run in the same direction as the web of the underlying wide flange beams 420, i.e., radially and circumferentially. As can be seen in FIG. 9B, roof elements 402 are designed to mount and be welded to tubular mounting beams 414, as will be described in greater detail below.

B. Raising and Mounting Roof Assembly 404 to Shell 300

[0070] FIG. 9C shows a roof assembly 404 being raised by air pressure along an outer tank wall or shell element 302. The three dots shown adjacent shell element 302 indicates that shell 300 is comprised of a large number of such shell elements 302, which are not shown. A temporary skirt or seal 424 is attached around the circumferential periphery of roof assembly 404. FIG. 9D shows a fragmentary sectional view of roof assembly 404, seal 424, and end cap plate 314 and liner plate 306. Air pressure is applied to seal 424 from within shell 300. Seal 424 bears against liner plate 306 of shell 300 to minimize the loss of air there between. A temporary gusset plate 450, one of 240 such gusset plates 450 located around the periphery of the ring of end cap plates 314 in this example, is temporarily welded to end cap plate 314 and extends radially inwardly.

[0071] Referring now to FIG. 9E, when roof assembly 404 is raised to the appropriate height, welds 452 are made between liner plates 410 and gusset plates 450. An outer portion of a circumferential weld 454 is then made between end cap plate 314 and roof liner plates 410 to form an air tight seal there between joining shell membrane 340 and roof membrane 412 of roof assembly 404. Ideally, weld 454 is a full fusion, full penetration weld requiring welding from both outside and inside outer tank 22. When sufficient welds have been made to safely secure roof assembly 404 to shell 300, air pressure can be removed from shell 300. Then, seal 424 and gusset plate 450 are removed.

[0072] Half shell elements 302' are removed to provide access from within shell 300. Referring now to FIG. 9F, the inner portion of circumferential weld 454 is then completed between end cap plate 314 and liner plates 410 to form an air tight seal there between joining shell membrane 340 and roof membrane 412. A series of circumferentially spaced apart permanent flange extension plates 462 are welded between liner plate 306 and beneath the lower flanges of wide flange beams 420. Also, web extension plates 464 are welded on to the web of wide flange beam 420 and to liner plate 306. On the outside of roof assembly 404, extension tubular mounting beams 414a and 414b are, respectively, welded atop liner plates 410 and end cap plate 314 extending radially from mounting beam 414. With tubular extensions 414a and 414b in place, the outermost row of roof elements 402' can then be welded to shell 300 and to roof assembly 404, as will be described in greater detail below.

C. Roof Elements 402 and 402'

[0073] Roof elements 402 and 402' are mounted to roof assembly 404 after roof assembly 404 has been affixed by weldments to shell 300. FIG. 10A shows a typical roof element frame 428 which includes four L-shaped brackets 432 welded together to form a generally open rectangular frame. Depending inwardly from brackets 432 are a plurality of J-hooks 434. Reinforcing bars 436 extend laterally and longitudinally between opposing brackets 432.

[0074] Roof element frame 428 is used to construct precast reinforced concrete roof elements 402, as seen in FIG. 10B. Roof element 402 includes a cast concrete body 440 which surrounds J-hooks 434 and reinforcing bars 436 and supports roof element frame 428. The L-shaped brackets 432 are located on all four sides of roof element 402 to provide attachment to tubular mounting beams 414 of roof assembly 404 in the case of typical roof elements 402. The size of each roof element 402 is generally between about 2 meters to about 3 meters in width and between about 5 meters to about 6 meters in length in this exemplary embodiment. Of course, other size roof elements could be selected and will depend on the size of outer tank 22.

[0075] For the outermost concentric course of roof elements 402' which secure to both roof assembly 404 and to shell 300, the design is slightly different from that of roof elements 402 disposed on the inner radial concentric courses. As shown in FIG. 9F, concrete body 440' in this example tapers from a thinner 150 mm on its inner radial end to a maximum thickness of 300 mm adjacent its radial outmost end. The typical concrete body 440 of a typical roof element 402 has a constant thickness of about 150 mm. Second, roof element 402' includes L-shaped bracket 432 on only three edges with the radially outermost fourth side instead having an overhang 470 sized and shaped to fit over end cap plate

314. Provided in concrete body 440' are four access openings 472 (two seen in FIG. 9F) which provide access to four studs 474 which are to be stud welded to end cap plate 314.

D. Mounting of Roof Elements 402 to Roof Assembly 404

[0076] The outer concentric ring or course of roof elements 402' are located adjacent shell 300 and this outer ring of roof elements 402' is first welded to roof assembly 404 and to shell 300. This outer ring of roof elements 402' adds significant strength to roof 400. Subsequently, second through eighth courses of roof elements 402 are sequentially welded to roof assembly 404 starting from the radially outermost course and then each concentric course of roof elements is added until all rows of roof elements 402 are in place to form a complete roof 400 such as seen in FIG. 1B. FIG. 1A shows two courses of roof elements 402', 402 mounted to roof assembly 404.

[0077] L-shaped brackets 432 of roof elements 402 are mounted atop and are welded to tubular mounting beams 414 creating welds such as the weld joint 436 seen in FIG. 9B. In the case of special roof elements 402', roof elements 402' are welded to tubular mounting beams 414, 414a and 414b. Stud 474 are placed in access openings 472 and are stud welded to end cap plate 314. The thickness of tubular mounting beams 414 is less than the thickness of concrete bodies 430, as seen in FIG. 9B. Any voids formed between any of concrete bodies 440, 440' of the roof elements 402, 402' are grouted in place to form concrete joint 442 to provide fire protection to roof 442. An example of a concrete joint 442 is shown in FIG. 9B.

[0078] While in the foregoing specification this invention has been described in relation to certain preferred embodiments thereof, and many details have been set forth for purpose of illustration, it will be apparent to those skilled in the art that the invention is susceptible to alteration and that certain other details described herein can vary considerably without departing from the basic principles of the invention. For example, any one or more of base mat assembly 100, ring beam 200, outer shell 300 or roof 400 could be constructed using conventional cast in place construction techniques while the other components are constructed using the precast elements as described herein. As another example of an alternative embodiment, the roof assembly could be directly built atop shell 300 such as by using a crane. In this instance, roof assembly 404 would not have to be airlifted and attached atop shell 300. However, ideally even in this embodiment, the shell elements 402 could be welded to the roof assembly concurrently with the construction of the inner tank 22 to save construction time on building outer tank 20 and inner tank 22.

[0079] While beam ring 200 described in the above particular exemplary embodiment was used in conjunction with a full containment LNG tank, a beam ring could certainly be used in other applications. For example, the ring beam could be used in cases where neither a liner plate or thick structural base plate is necessary. In this case, the ring beam need only comprise ring beam elements having precast reinforced concrete bodies with embedded tensile conduits which receive tensile members there through so that the tensile members may be tensioned and anchored by anchors to form the beam ring. Although not required, preferably the ring beam elements would be interlocking with one another.

What is claimed is:

1. A method for constructing a ring beam comprising:
 - (a) providing a plurality of ring beam elements, at least two of the ring beam elements each including a reinforced

concrete body having at least one circumferentially extending tensile conduit disposed within the concrete body;

- (b) juxtaposing ring beam elements to form a circumferentially extending series of ring beam elements;
- (c) placing at least one tensile member through tensile conduits of the juxtaposed ring beam elements; and
- (d) tensioning and anchoring the at least one tensile member about the ring beam elements to clamp together the series of ring beam elements in a circumferential direction to form a ring beam.

2. The method of claim 1 wherein:

the at least two ring beam elements each have a base plate anchored to the concrete body; and
the base plates are welded to one another to form an annular ring of base plates.

3. The method of claim 1 wherein:

the at least two ring beam elements each contain a plurality of tension conduits disposed within the concrete bodies; a plurality of tensile members are inserted through the tensile conduits of the at least two ring beam elements; and
the tensile members are tensioned and anchored about the ring beam elements to clamp together the series of ring beam elements.

4. The method of claim 3 wherein:

the tensile conduits in the at least two ring beam elements are located on opposite sides of the horizontal central plane of the concrete body.

5. The method of claim 1 wherein:

the at least two ring beam elements further include interlocking surfaces such that when the at least two ring beam elements are juxtaposed one another, the interlocking surfaces interlock with one another.

6. The method of claim 5 wherein:

the at least two ring beam elements interlock in the horizontal direction.

7. The method of claim 5 wherein:

the at least two ring beam elements interlock in the vertical direction.

8. The method of claim 5 wherein:

the at least two ring beam elements interlock in both the horizontal and vertical directions.

9. The method of claim 1 wherein:

the at least two ring beam elements each have liner plates; and
the liner plates are welded to one another to form an annular ring of liner plates.

10. The method of claim 1 wherein:

the at least two ring beam elements are mounted on piles driven into the earth.

11. The method of claim 2 wherein:

the piles have mounting surfaces which are adjusted to provide a level surface for mounting the at least two ring beam elements on the piles such that the base plates can be readily welded to one another.

12. An annular ring beam comprising:

at least two ring beam elements each including a concrete body having at least one circumferentially extending tensile conduit disposed within the concrete body; and
at least one tensile member which extends through the tensile conduits of the at least two ring beam elements and which is tensioned and anchored to clamp the at least two ring beam elements together.

13. The annular beam ring of claim 12 wherein:

each of the at least two beam ring elements has a metal base plate; and
the metal base plates are connected together to form an annular ring of base plates.

14. The annular beam ring of claim 12 wherein:

each of the beam ring elements has a metal base plate; and
the metal base plates are welded together to form an annular ring of base plates.

15. The annular ring beam of claim 12 wherein:

the at least two ring beam elements each contain a plurality of tensile conduits disposed within the concrete bodies; a plurality of tensile members extend through the tensile conduits of the at least two ring beam elements; and
the tensile members are tensioned and anchored about the ring beam elements clamping together the at least two ring beam elements.

16. The annular ring beam of claim 12 wherein:

the tensile conduits in the at least two ring beam elements are located on opposite sides of the horizontal central plane of the concrete body.

17. The annular ring beam of claim 12 wherein:

the at least two ring beam elements further include interlocking surfaces that interlock with one another.

18. The annular ring beam of claim 17 wherein:

the at least two ring beam elements interlock in the horizontal direction.

19. The annular ring beam of claim 17 wherein:

the at least two ring beam elements interlock in the vertical direction.

20. The annular ring beam of claim 17 wherein:

the at least two ring beam elements interlock in both the horizontal and vertical directions.

21. A ring beam element comprising:

a reinforced concrete body having a metal base plate anchored thereto, the concrete body having a plurality of tensile conduits extending circumferentially there through;

wherein tensile members can be placed through the plurality of tensile conduits and tensioned and anchored to clamp a plurality of juxtaposed ring beam elements together such that base plates of a plurality of the ring beam elements can be welded together and a circumferentially extending ring beam constructed.

22. The ring beam element of claim 21 wherein:

the ring beam element has interlocking surfaces adapted to allow ring beam elements to be circumferentially aligned and interlocked.

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