METHOD FOR MANUFACTURING CONCRETE PRESSURE VESSELS

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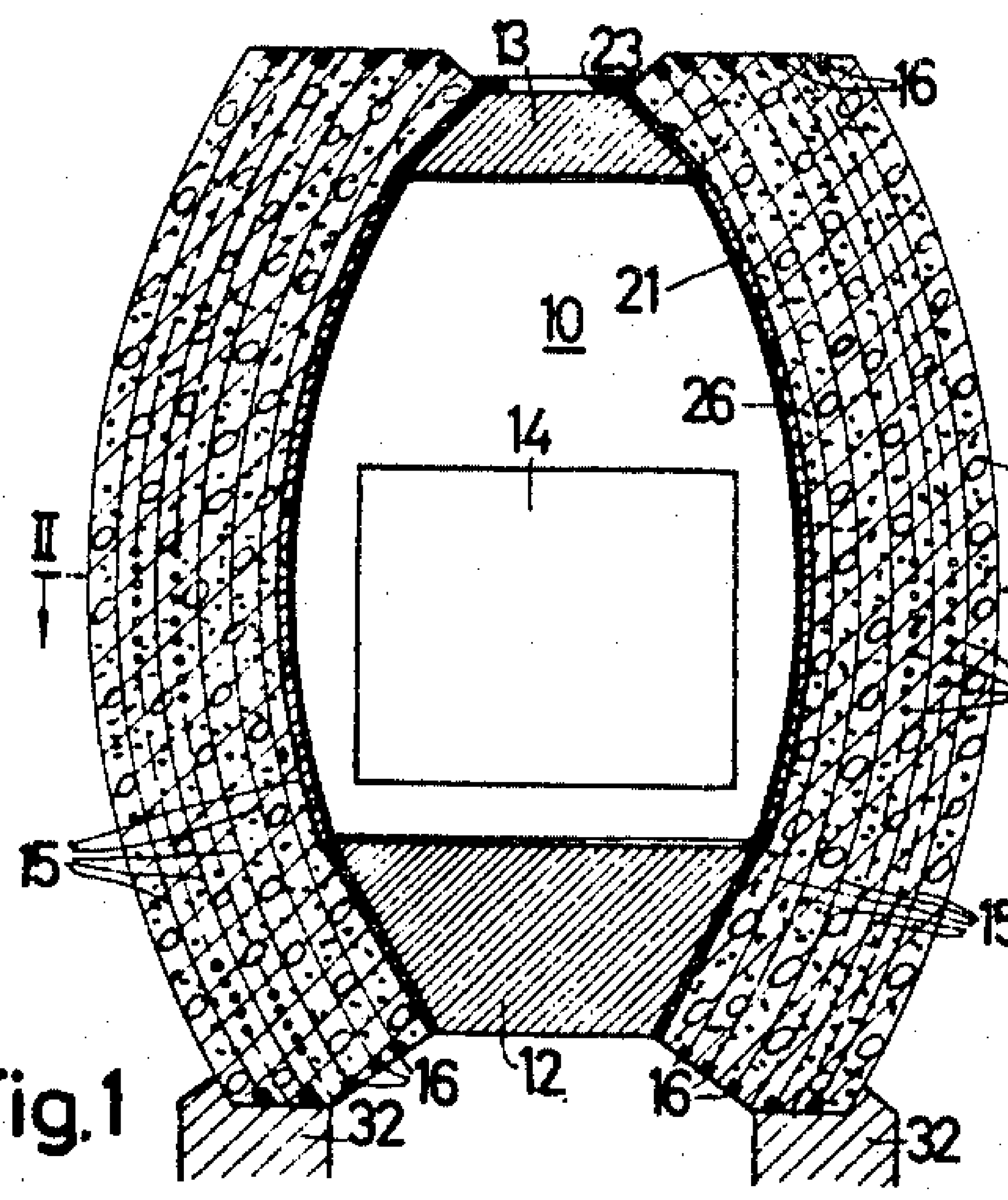

Fig.1

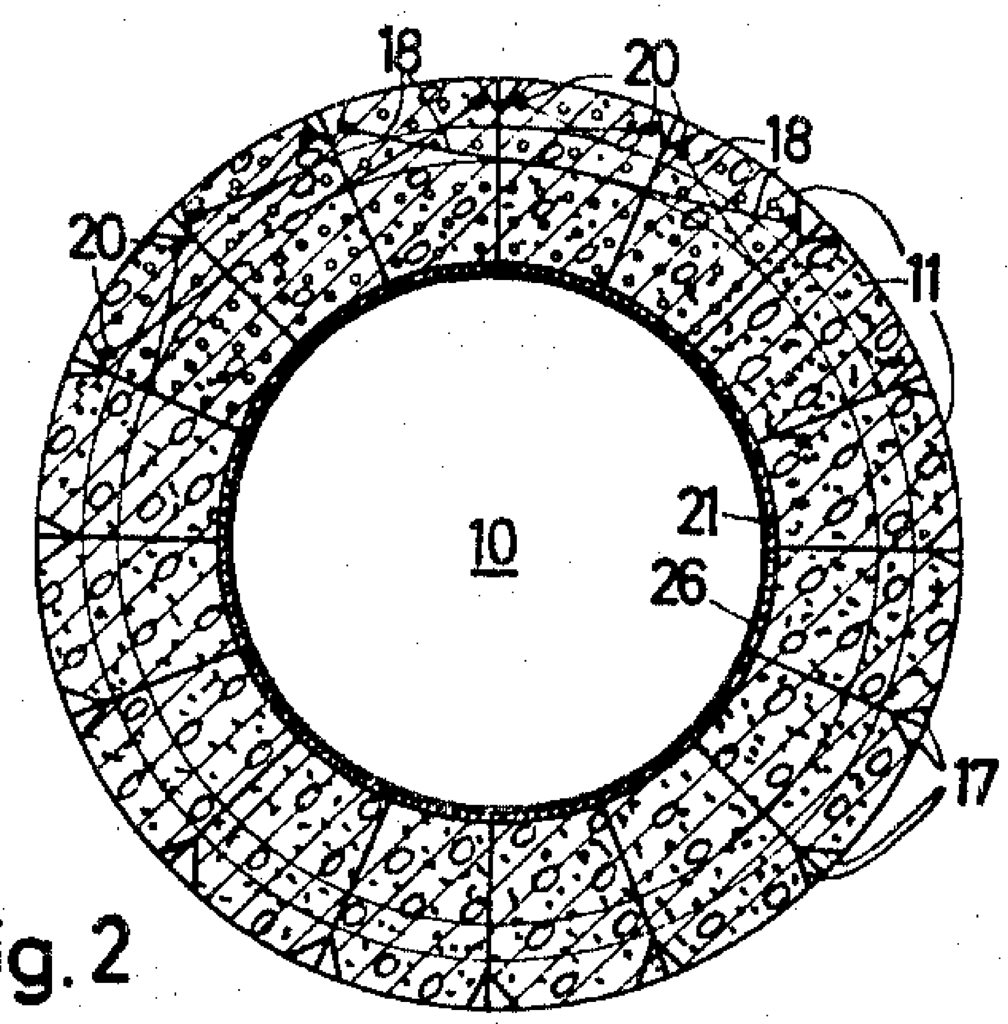

Fig. 2

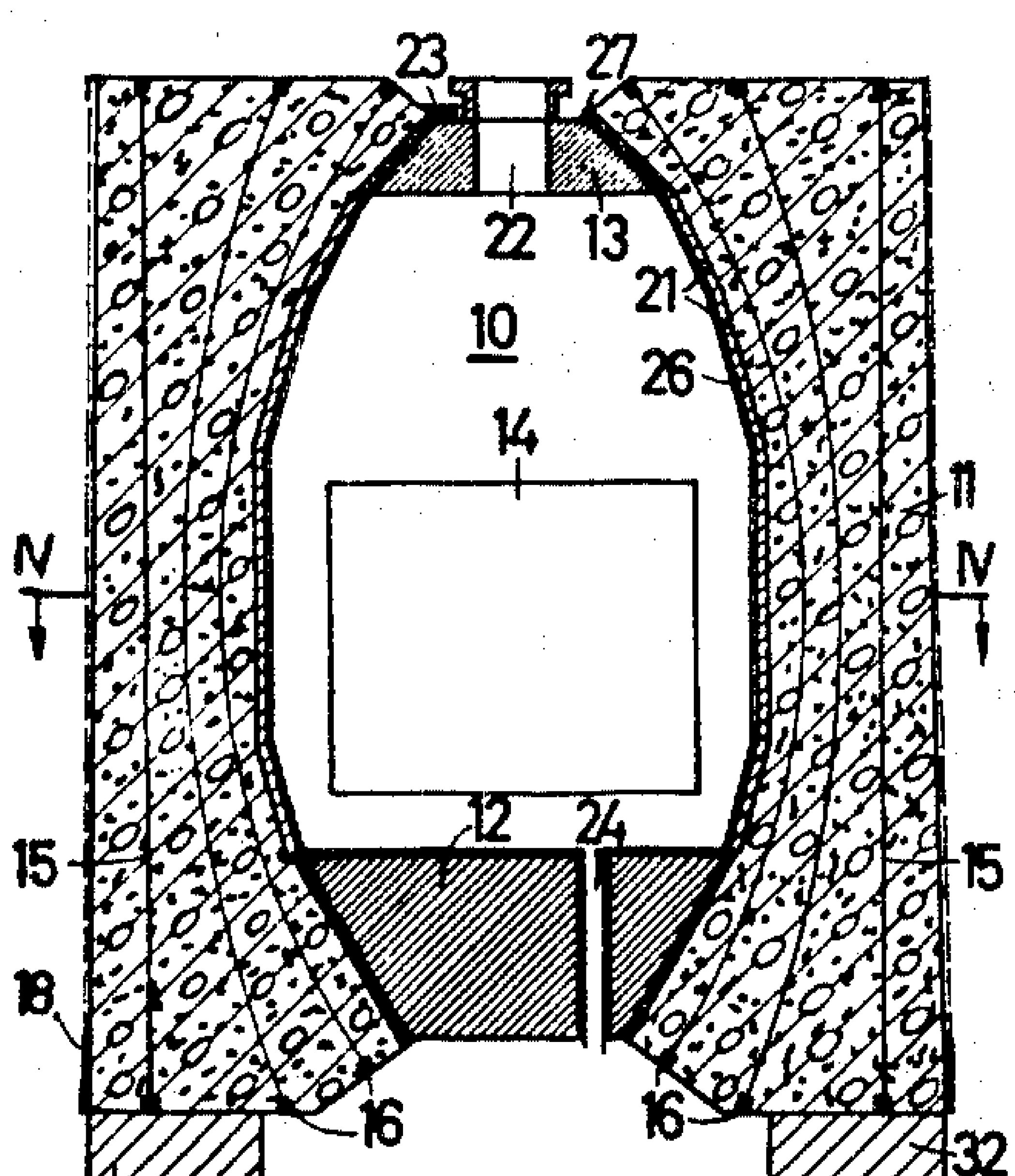

Fig.3

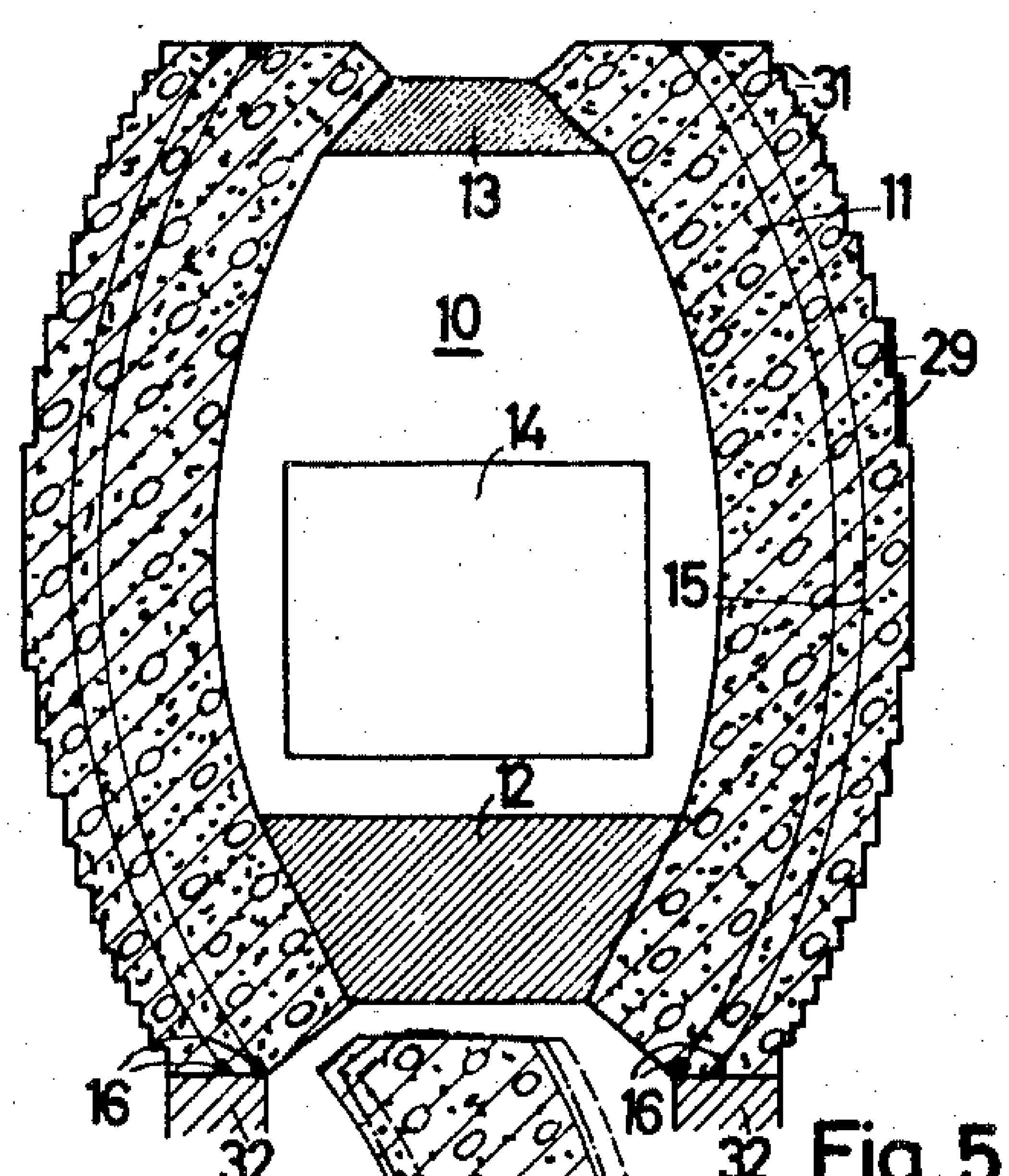

Fig.5

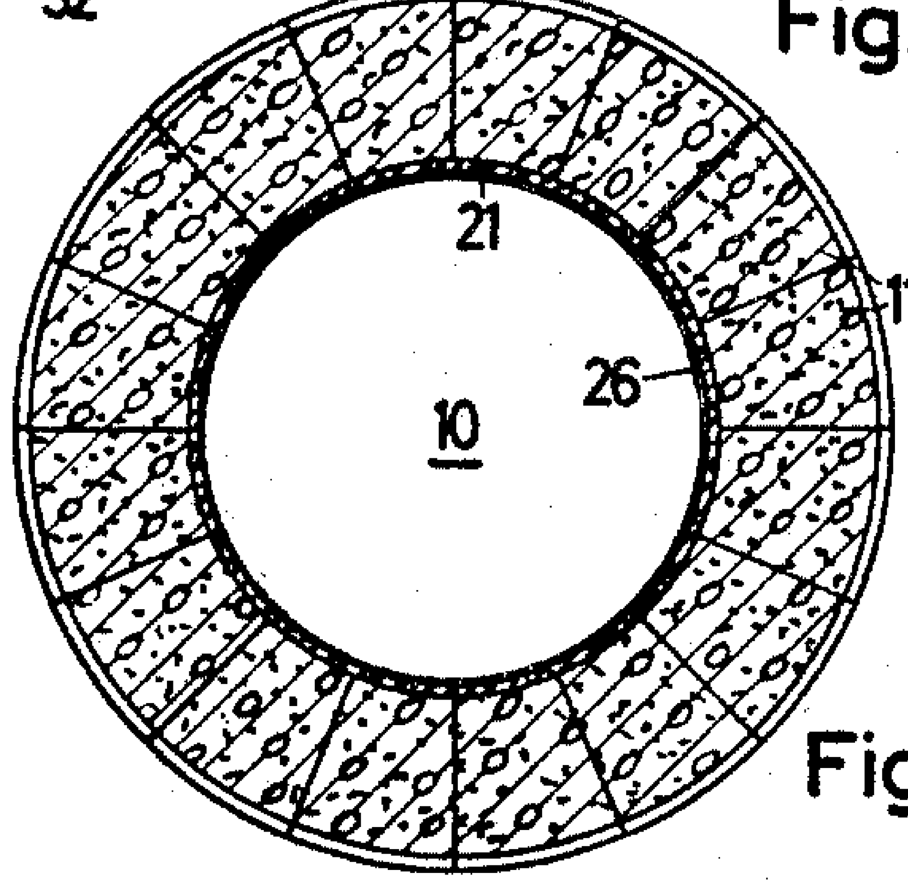

Fig.4

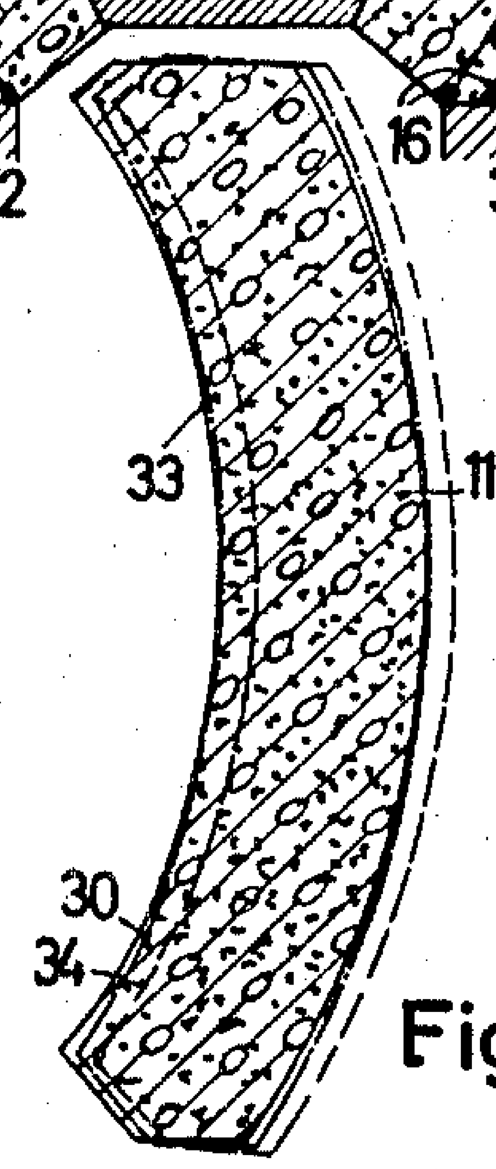

Fig.6

METHOD FOR MANUFACTURING CONCRETE PRESSURE VESSELS

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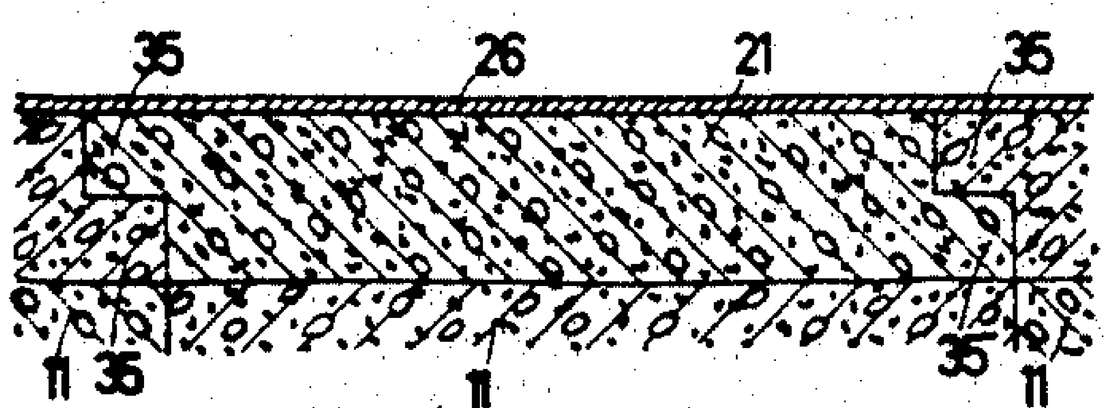

Fig.7

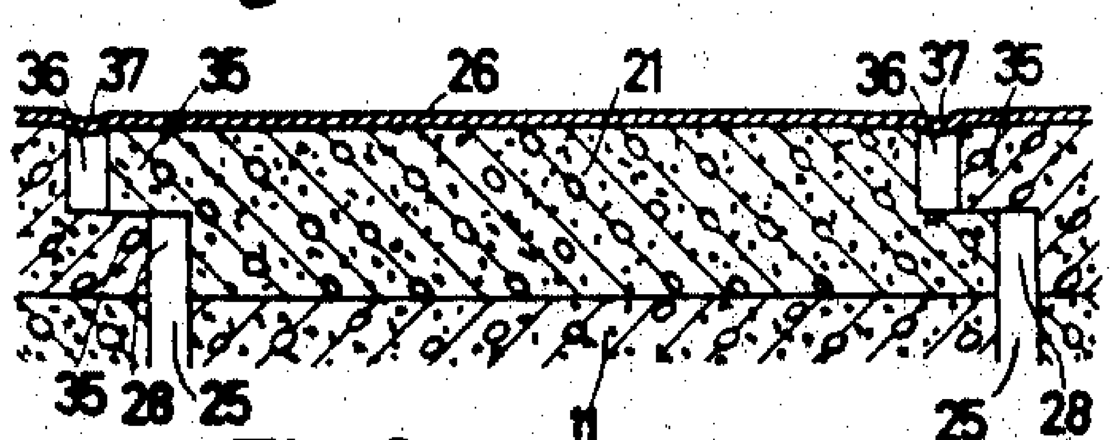

Fig.8

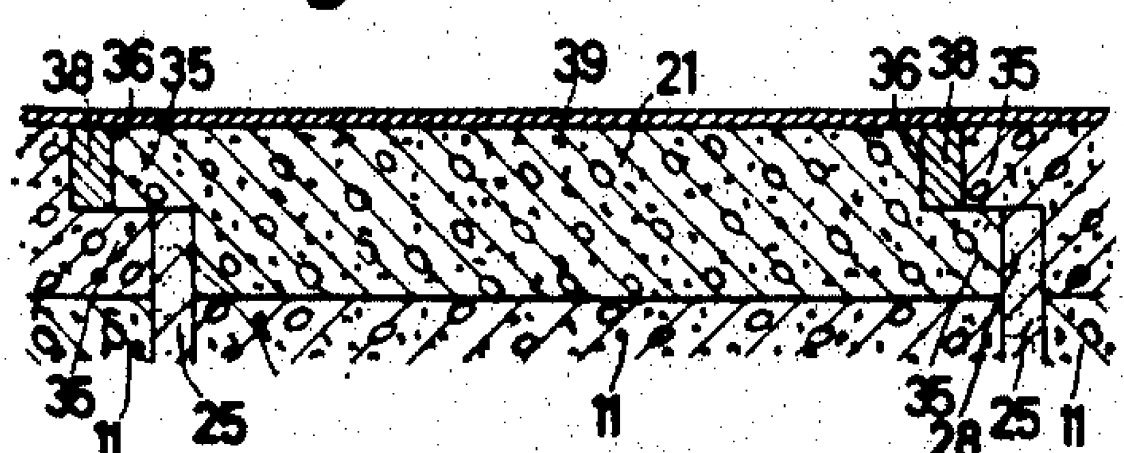

Fig.9

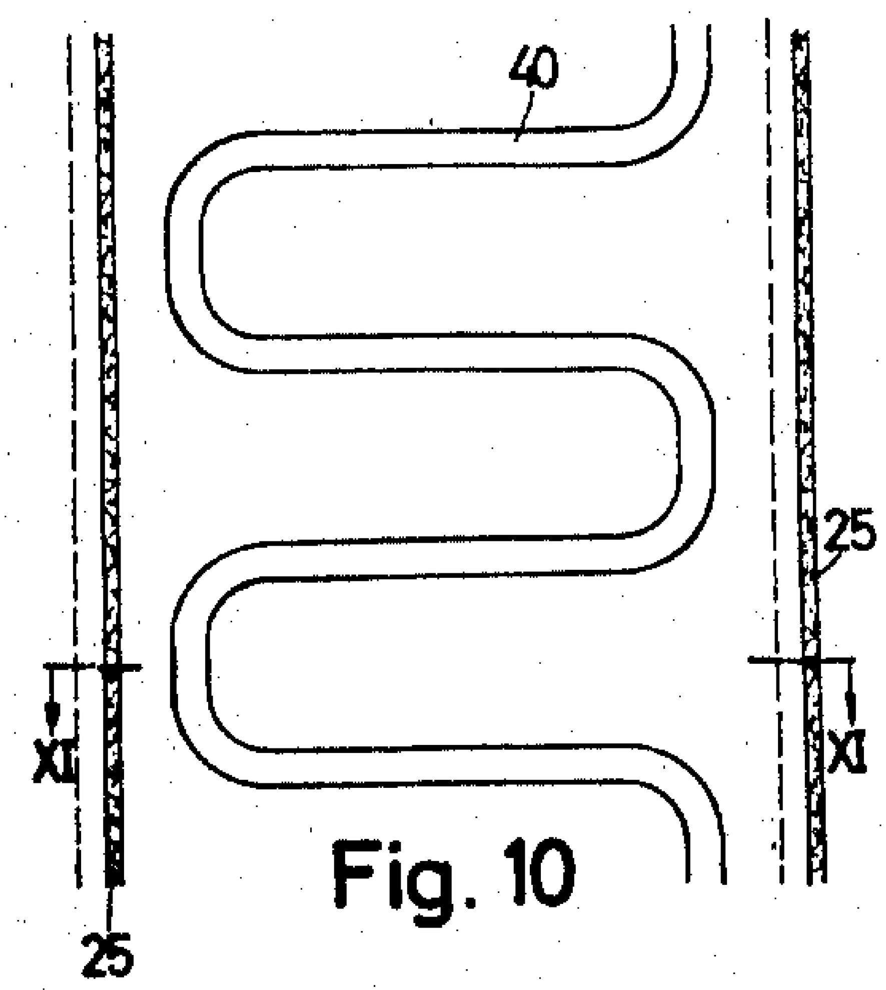

Fig. 10

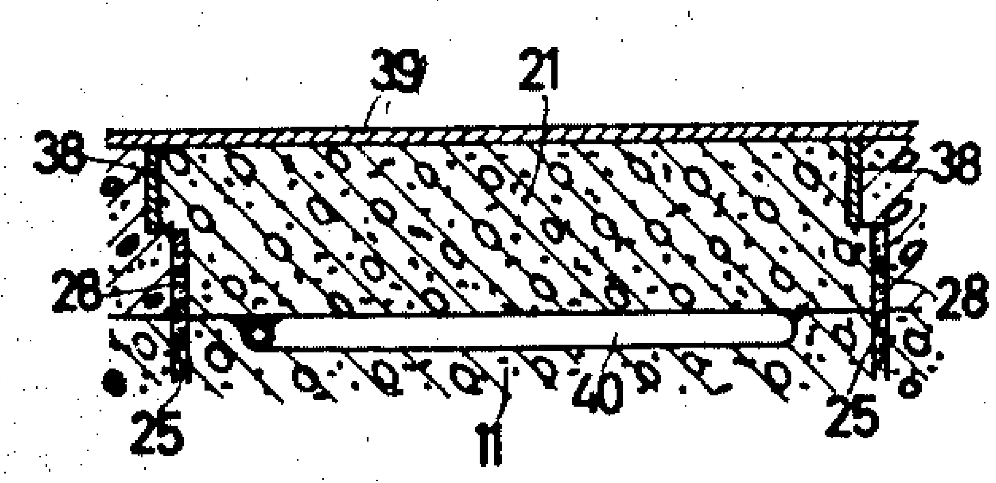

Fig. 11

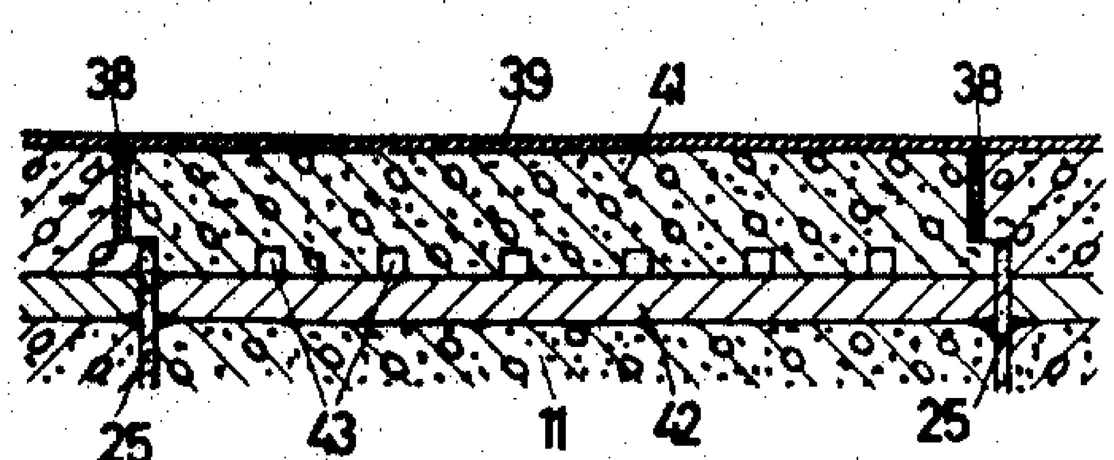

Fig. 12

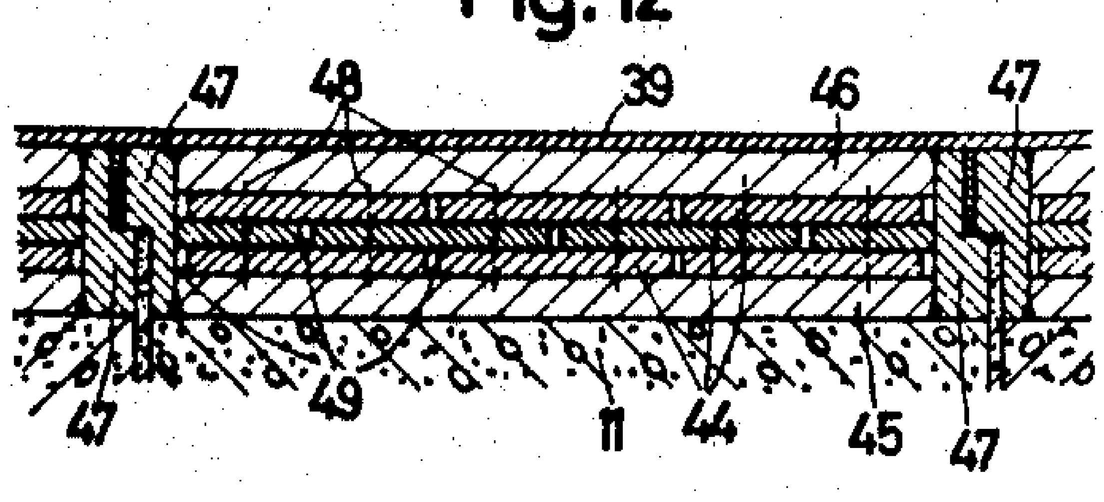

Fig. 13

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3,390,211

METHOD FOR MANUFACTURING CONCRETE PRESSURE VESSELS

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Claims priority, application Germany, Mar. 2, 1963, S 83,973
4 Claims. (Cl. 264—32)

My invention relates to a method of manufacturing concrete pressure vessels, and more particularly to prestressed concrete pressure vessels for nuclear reactors.

Pressure vessels of exceptionally large diameter are often necessary for nuclear power reactors. Pressure vessels consisting of steel, which cannot be of high grade type generally because of the effect of fast neutrons, can be transported great distances only if their diameter does not exceed about five meters. The manufacture and transportation of larger vessels present considerable difficulties, and these vessels must be at least partly welded together at the construction site, in which case additional difficulties and cost are encountered by the necessity of eliminating tension of annealing the welded structures.

Construction of concrete radiation shielding simultaneously with the pressure vessels for gas-cooled nuclear reactors has been attempted. These pressure vessels are erected with concrete that is prepared at the construction site. For pressurized water reactors difficulties arise in this method of construction, due to the high pressure of over 100 kp./cm.^{2} (metric kilopounds per sq. cm.), because the bracing or reinforcing wires in the concrete must be very thick and the compressive stress of the concrete can amount to as much as 300 kp./cm.^{2}.

It is an object of my invention to provide a method of manufacturing a pressure vessel of prestressed concrete suitable for pressurized water reactors and a method of constructing the same at the erection site of the reactor thereby avoiding the aforementioned difficulties.

To this end, and according to a feature of my invention, the inner cavity of the vessel is assembled of prefabricated parts and is equipped with prestressing elements; and the vessel, after being assembled, is put under the rated pressure, whereafter the thereby widened butt gaps which develop between the components or parts thereof are filled with pressure-resistant material. For applying internal pressure to the vessel up to the rated pressure value, a balloon of leakproof and eleastic material, for example rubber, is inserted into the interior of the vessel and is inflated with a fluid, preferably with water. The widened butt gaps are covered on the inside of the vessel with strips of pressure-resistant material, for example of steel, while the pressure is being built up. The component parts of the vessel include, for example, segments of the vessel wall that are trapezoidal in cross section and at least one insert adapted to fit into an opening in the wall.

According to a further aspect of my invention, the trapezoidal segments may be prestressed by a type of prestressing means referred to hereinafter as prestressing means of a first kind such as longitudinally extending bracing wires or the like. With trapezoidal components of this type, vessels of spherical, cylindrical or ellipsoidal shape and of various other shapes can be assembled. Such a vessel can however also be assembled of prestressed or non-prestressed, annular or semiannular wall segments or of wall segments shaped like regular polygons, such as equilateral triangles, regular hexagons, and the like. In those cases in which the wall segments proper are not prestressed, the prestressing means for the assembled vessel can be, for example,

steel bands disposed in a reticular or grid-like arrangement, or a steel shell tightly covering the outer wall surface. After the assembly of cylindrical or ellipsoidal vessels in which prestressed wall segments of this type are used, there are mounted thereon additional prestressing elements referred to hereinafter as prestressing means of a second kind which have, for example the form of annular cables or cable loops.

According to another aspect of my invention, in order to reduce the intensity of radiation coming from the reactor to such an extent that the heat evolving in the concrete does not exceed a predetermined quantity, the inner surfaces of the casing segments are clad with at least one layer of a substance of great density and high thermal conductivity. The layer can, for example consist of a thick steel plate or of several thin plates superimposed one on the other. The steel plates which can have a thickness up to about 20 centimeters can be prewelded and can be used as so-called "dead sheathing." At the abutting edges of the steel plates there are advantageously provided guiding strips which overlap one another after the pressure vessel has been assembled. The side of the plates facing the concrete is preferably cooled by water or gas. For this purpose, cooling pipes can for example be welded to the back of the steel plates and may be embedded in the poured concrete. When several superimposed steel plates are provided, the coolant can also be conducted through channels that are disposed between the individual steel plates. The inner and outer surfaces of the wall segments are, for example, curved in such a manner that both the inner chamber and the outer contour of the vessel are ellipsoidal in form.

According to a further aspect of my invention, the lower insert is made of concrete, for example, and the upper insert of steel. An access opening is provided, for example in the upper insert, while passageways are provided in the lower insert and, possibly also in the upper insert or in the vessel wall, for the necessary coolant inlet and discharge pipes, for electrical lines and the like. A thin layer of austenitic steel is coated on the inner side of the steel plates inside the chamber of the pressure vessel. This sealing layer extends outwardly between the inner surfaces of the wall segments and the upper insert, and is secured to the layer of steel plates above the upper insert by means of a suitable end welding process. The pressure vessel can consequently then be opened by simply lowering the upper insert into the vessel.

A number of embodiments of my inventive pressure vessel is shown in the drawings which will further explain the invention as follows. They show:

FIG. 1 is a longitudinal sectional view of one embodiment of a prestressed concrete pressure vessel constructed in accordance with my invention;

FIG. 2 is a transverse sectional view of FIG. 1 along the line II—II taken in the direction of the arrows;

FIG. 3 is a longitudinal section of a second embodiment of the invention;

FIG. 4 is a transverse sectional view of FIG. 3 along the line IV–IV taken in the direction of the arrows;

FIG. 5 is a longitudinal sectional view of yet another embodiment of the invention;

FIG. 6 is a side view of a wall segment of the invention, showing in dot-dash and in broken lines, the outline of the wall segment under different conditions of prestressing;

FIG. 7 is a fragmentary sectional view of the inner lining of a pressure vessel constructed in accordance with the invention before stressing;

FIG. 8 shows the lining of FIG. 7 after stressing;

FIG. 9 shows the lining of FIG. 7 in final condition;

FIG. 10 is a fragmentary section through the vessel wall showing a modified inner lining which is provided with cooling pipes;

FIG. 11 is a transverse view of FIG. 10 along the line XI—XI taken in the direction of the arrows;

FIGS. 12 and 13 are fragmentary sections of two additional modifications of the inner lining, in which the inner lining is formed of a plurality of layers and is also provided with cooling channels.

Referring first to FIGS. 1 and 2, there is shown a pressure vessel **10** for a nuclear reactor assembled for example of sixteen wall segments **11** having a trapezoidal cross section, a lower end block **12** and an upper end block **13**. The prefabricated wall segments **11** are shaped in such manner that both the inner chamber and the outer shape of the vessel are ellipsoidal in form. The segments **11** are prestressed in the longitudinal direction with bracing wires **15** that are embedded in the concrete, and are provided at their ends with suitable locking means **16**. The outer edges of the casing segments **11** are bevelled or chamfered. Extending from the chamfered outer edges **17** are annular cables **18** which are introduced into pipes **19** that are embedded in concrete and provided for this purpose, and after having been wound around once or several times, are secured, respectively, by their ends to the chamfered outer edges **17** by suitable locking means such as the turnbuckle **20**.

The surfaces of the casing segments that face the core or nuclear fission zone **14** of the reactor are clad with thick steel plates **21** which provide a complementary inner lining for the pressure vessel and thereby protect the concrete against the effects of radiation and heat. The inner lining of the vessel can also consist of several plates superimposed one on the other. Instead of steel, another material with great density and high thermal conductivity can be employed. For cooling the inner lining **21**, cooling pipes **40** (FIGS. 10 and 11) supplied with a liquid or gaseous coolant are provided, for example on the side that faces the concrete, or, where the lining consists of several layers provision is made for cooling channels **43**, **49** in FIGS. 12 and 13 respectively that are arranged between these layers. The abutting edges of the steel plates **21** which are welded to the casing segments **11** and which can also be used as dead sheathing, are provided with guiding strips **35** (FIG. 7) which overlap when the wall segments are assembled.

On the side facing the inner chamber, the inner lining **21** and the upper surface of the lower insert **12** are covered with a shell **26** made of austenitic steel, for example. At the upper end of the vessel, the steel shell **26** protrudes upwardly between the lining **21** and the upper insert **13** and is secured to the lining **21** by means of a suitable, preferably beaded, weld **27** (FIG. 3). The upper end block **13**, which is made of steel for example, and the outer surface of which conforms with the ellipsoidal shape of the vessel, is provided with an access opening **22**, as shown in FIG. 3. In order to prevent the upper end block from falling into the vessel, while the vessel is not pressurized, there is provided, for example, an annular supporting member **23** to which the end block is secured for example with screws. The lower end block **12** which is made of concrete, for example, or both the lower and upper end blocks are formed with feed-through passages **24** for the inlet and discharge pipes which carry the coolant needed in the operation of the reactor and for the required electrical wiring (FIG. 3).

Complete tensioning of the annular cable **18** to the full prestressing condition with the help of the bracing turnbuckles **20** for example, is not feasible because of the wide angle of encirclement by the cable. Therefore, in order to effect the necessary prestressing I propose a different procedure which is in accordance with my invention. With my method the annular cables are at first only stressed to such an extent that they will be pulled fairly tight. Then the inner chamber, which is coated with the sheathing of steel plate **26**, or a rubber balloon inserted in the inner chamber, is filled with water and brought up gradually to the full rated pressure, preferably with due allowance for frictional effects and the like. The casing segments **11** are thereby radially outwardly displaced from one another and the annular cables are resiliently stretched until full counter-tension or prestressing is achieved. The gaps **25** (FIG. 8) which consequently form between the wall segments and the joints **28** which face the concrete and which are widened so that a gap is formed between the metal plates, are pressure-filled with concrete (FIG. 9), so that even after the inner pressure is relieved prestressing of the annular cables is maintained. With the application of the pressure, the conical end blocks **12**, **13** are displaced from each other in the axial direction of the vessel. The curvature of the conical wall surface or outer surfaces of the end blocks must therefore be pre-selected to suit this final assembly condition. The end blocks are mainly stressed in compression and only slightly subjected to bending. To effect uniform prestressing of the annular cables, the relative elongation ($\Delta L/L$) of all the annular cables must be equal. Since the diameters of the individual annular cables are different, the absolute elongation when the wall segments are radially outwardly displaced is the same for all of the annular cables, but the respective relative elongations thereof are consequently quite different. In order that the relative elongation of the various annular cables should be the same, all of the annular cables are, for example, initially stressed to the same amount of tension by suitably tightening the prestressing lock means or turnbuckles, and then the stress of the cables of smaller diameter is reduced by turning the turnbuckles a predetermined number of turns.

The embodiment of FIGS. 3 and 4 corresponds for the most part with the embodiment of FIGS. 1 and 2, except that the outer surfaces of the wall segments **11** are formed in such a manner that the outer peripheral surface of the vessel is of a cylindrical configuration which tapers slightly in the upward direction. Only half of the ring **23** supporting the upper end block **13** is shown in FIG. 3 so that the weld **27** can be seen. Due to the cylindrical form of the outer vessel wall in the embodiment of FIGS. 3 and 4, the above-mentioned difficulties regarding uniform prestressing of the annular cables **18** are not applicable for this embodiment. The cables **18** which are out in suitable lengths and secured with their ends by splicing or any other fastening means to form rings or loops, are pushed from above down around the outer wall surface of the vessel. The desired prestressing is then achieved in the manner described above with regard to the embodiment of FIG. 1.

A particularly desirable feature is that the outer surface of the vessel can be formed into steps while nevertheless retaining the basic ellipsoidal outline, and the prestressing means of the second kind, for example annular cables, can be supported on the cylindrical stepped surfaces. The ends of the wall segments then project over the outer end surface of the inserts.

The pressure vessel shown in FIG. 5 differs from the vessel of FIG. 1 in that its outer wall surface, while retaining its general ellipsoidal outline, is formed with steps. In this way, the masses of concrete that are found at the ends of the casing segments **11** in the embodiment of FIG. 3 are avoided. The bracing wires **15** which are provided within the wall segments are located on the outside of the neutral chamfer line. Under the prestressing action, the wall segments **11** are bent outwardly as is shown in FIG. 6 by the dot-and-dash lines **30**. The deflection at the ends of the wall segments is approximately 1 to 2 cm. for a length of about 14 m. The steps that are located on the outside of the wall segments **11** and which start at the center of the vessel and extend both upwardly and downwardly thereon, form cylindrical surfaces **31** which taper slightly in a direction toward the ends of the wall segments. The annular cables **29** for the upper half of the vessel can be fitted thereon from above after assembly of the vessel, while the annular cables **29** for the lower half of the vessel, which are prepared in advance on the base **32** thereof before the vessel is assembled, are fitted on the respective cylindrical surfaces from below after the vessel is assembled. All of the annular cables **29** are of such predetermined lengths that they are seated on the respective cylindrical surfaces with substantially the same tight fit. When fluid is pumped into the vessel in order to suitably prestress the annular cables, the relative elongation of the upper and lower cables, which are of a smaller diameter, is somewhat greater than the relative elongation of the annular cables which are located adjacent the middle portion of the vessel. Consequently, a bending moment is exerted on the casing segments **11** which counteracts the deflection caused by the longitudinally extending wires **15**. When correctly measured, both bending moments are equal. By backwardly bending the ends of the wall segments, the relative elongation of all the annular cables can be made the same in the final condition so that all the annular cables are equally stressed. In the region of the upper and lower end blocks **12, 13**, the pressure exerted on the inner surfaces of the wall segments is greater than in the center portion thereof. In order to be able to place at these ends as great a number of annular cables or cable loops as possible, these ends are made to project above the outer faces of the end blocks **12, 13**.

In FIG. 6 there is shown a single wall segment **11** in non-stressed condition (as indicated by the solid line **33**), as prestressed by longitudinally extending cables (the dot-and-dash line **30**), and slightly displaced, as stressed by longitudinally extending cables and annular cables (the broken line **34**).

In FIGS. 7 to 9 are shown the stages, on an enlarged scale and in section, that the inner lining **21** of the pressure vessel goes through in the course of its production. FIG. 7 shows the inner surface of the wall segments clad with a steel plate **21**, the abutting edges of which are offset, so that the respective extensions **35** of the steel plates overlap each other after the wall segments **11** have been assembled. On the inside of the vessel, the steel plates are covered with a thin layer **26** consisting of austenitic steel, for example. The extensions **35** are so formed that they remain in overlapping engagement with one another even after the fluid has been pumped into the pressure vessel until the rated pressure is reached, as shown in FIG. 8. Gaps **25** are formed between the wall segments **11** and gaps **28** and **36** are formed between the steel plates **21** as fluid is pumped into the pressure vessel. Adjacent the gaps **36**, slight grooves or indentations **37** form in the thin layer **26**. The gaps **25** and **28** are filled with concrete as shown in FIG. 9, the filling operation taking place as long as the pressure vessel remains under pressure. After the pressure is relieved, the thin layer **26** is milled or cut along the grooves **37** and then subsequently removed. The thus freely exposed gaps **36** are filled, as shown in FIG. 9 with filler strips **38** consisting of steel, which are preselected to exactly fit the dimensions of the gaps **36**. After the steel strips **38** have been inserted, the inner surface of the steel plates is covered with a new layer **39** of austenitic steel which constitutes the final inner cladding or sheathing of the pressure vessel.

FIGS. 10 and 11 also illustrate sections of the inner lining of a pressure vessel constructed in accordance with my invention. The sections show a cooling pipe **40**, arranged for example in meandering form on the side of the steel plate **21** which faces the wall segment. The coolant which flows through the cooling pipe can be either liquid or gaseous.

If instead of one thick steel plate **21**, several thin plates such as the two plates **41, 42** (FIG. 12) are used, then for example cooling channels **43** can be provided on the side of one of the plates which faces the other plate. FIG. 13 shows a further embodiment of my invention in which the inner lining of the vessel is formed of several layers, for example of five layers (not including the layer **39** which is of austenitic steel). The three inner layers of the lining are made up of substantially identical plates **44**, for example. The lateral edges of both outer layers **45, 46** are welded to offset strips or ledges **47** which form the abutting edges for the respective adjoining parts associated with each wall segment **11**. The plates **44** in each of the inner layers are maintained in spaced relationship with respect to each other by the bolts **48**. Gaps **49** which are thus formed between the individual plates and are located in staggered relationship with respect to each other, and which are also formed between some of the plates and the ledges **47** may be used as cooling channels.

When constructing the ellipsoidal pressure vessel, the wall segments and the upper and lower inserts are assembled on a previously prepared base at the construction site of the reactor, and annular cables are then applied thereto. Afterwards, the inner chamber of the pressure vessel is clad with a closely fitting shell, for example consisting of steel sheets and is gradually filled with water until the rated pressure is reached, preferably with due allowance being given to friction effects and the like. Instead of a sheet metal shell, a rubber balloon can be employed. During the pumping, the wall segments are radially expanded and pushed apart from one another so that the annular cables are elastically stretched until the full counter-tension is reached. Assuming an inner diameter of approximately 7 m., the radial expansion is about 15 mm. and the gap between the individual wall segments is about 6 mm. These gaps are filled with concrete so that after the pressure is relieved, the prestressing effect of the annular cables is maintained. The gaps which arise between the adjacent end faces of the steel plates by pumping fluid into the vessel and by the consequent sliding of the guiding ledges of the steel plates on one another during the prestressing operation, are filled with filler strips consisting of steel. The gaps between the adjacent edges of the steel plates are noticeable from within by slight indentations of the sheet metal shell. The metal shell is milled or cut along these indentations in order to permit insertion of the filler strips therein. After the gaps have been thus filled this metal shell is replaced with a final austenitic steel shell. For guiding the wall segments on the base plate, central guide rails are provided on the individual wall segments so that the wall segments can slide thereon in the radial direction while the inflation is taking place.

The various components of the pressure vessel embodying my invention can be prefabricated. Consequently, the size of the casing segments can be preselected so as to be suitable for available transportation facilities. No cable prestressing or tensioning equipment is necessary at the installation site of the pressure vessel since the bracing wires that are embedded in the wall segments have been previously prestressed and since the annular cables or all of the prestressing members are prestressed by pumping fluid into the pressure vessel, after the vessel has been assembled. In prestressing the annular cable, the friction losses which otherwise amount to as much as 20% are practically equal to zero. Since the prestressing elements are either embedded deep in the outer concrete layers of the wall segments or are located on the outer surface of the pressure vessel respectively, high-grade steels can be used for the prestressing elements without hesitation. The prestressing elements which lie on the outside are furthermore readily accessible for inspection, and by lowering the upper insert, a fairly large access opening is made available for assembly and mounting purposes and possibly also for reactor maintenance and repair work that may be required at a later time. The prefabricated components and the consequent facilitation of the assembly process result in considerable reduction in the time needed for constructing a vessel of this type. Furthermore, the aggregate costs of a pressure vessel of this type is roughly not even half as much as the cost of constructing a corresponding steel vessel.

While my invention has been illustrated and described as a method of manufacturing a pressure vessel of prestressed concrete for nuclear reactors, it is not intended to be limited to the details shown, since various modifications in my method may be made without departing in any way from the spirit of the present invention. Such adaptations should and are intended to be comprehended within the meaning and range of equivalents of the following claims.

I claim:

1. A method of manufacturing a prestressed concrete pressure vessel for nuclear reactors, which comprises assembling the pressure vessel in situ from prefabricated components including prestressing elements and concrete wall segments having adjacent edge portions the prefabricated components being so formed as to provide an opening at respective upper and lower ends of said vessel, introducing an elastic inflatable container into the interior of said pressure vessel; covering the adjacent edge portions of said wall segments with strips of pressure-resistant material; inflating said container by pumping fluid therein so as to expand said vessel and form gaps between the edge portions of said wall segments, and filling said gaps with a pressure-resistant material, the method also comprising the steps of lining the interior surface of said vessel with a layer of steel plates having adjacent edges and, after prestressing the vessel, lining said layer of steel plates with a layer of austenitic steel projecting out of said upper opening, and sealingly connecting said layer of steel plates and said layer of austenitic steel outside of said upper opening.

2. Method according to claim 1 wherein the interior surface of said vessel is lined with a plurality of steel plates having edges provided with guiding strips and placing said steel plates with said edges adjacent one another so that the respective guiding strips overlap.

3. Method according to claim 1 including closing the lower opening with a tightly inserted closure member and closing the upper opening with a removable cover member.

4. Method according to claim 3 wherein the prefabricated wall segments are so formed that the outer surface of the assembled vessel is ellipsoidal and is formed with substantially cylindrical stepped tiers, and the vessel wall projects beyond the outer surface of said closure and cover members, and which includes prestressing the vessel with a group of annular prestressing elements located on the stepped tiers.

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