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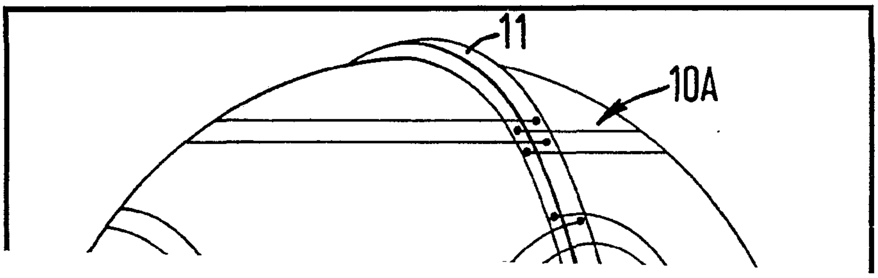
(54) Containment vessel

(57) A concrete containment vessel is disclosed that is spherical and that has prestressing tendons (10A, 10C, 10B) disposed in first, second and third sets, the tendons of each set being all substantially concentric and centred around a respective one of the three orthogonal axes of the sphere; the tendons (10A) of the first set being anchored at each end at a first anchor rib (11) running around a circumference of the vessel, the tendons of the second set (10C) being anchored at each end at a second anchor rib (12) running around a circumference of the sphere and disposed at 90° to the first rib, and the tendons (10B) of the third set being anchored some to the first rib and the remainder to the second rib. Since in this vessel all the prestressing tendons lie on fixed radius small circles true radial prestresses are applied to the vessel and no non-radial or tangential forces are induced.



ERRATUM

SPECIFICATION NO 2044512A

Front page, heading (71) Applicants *for* Tayor *read* Taylor

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7 Aug 1981

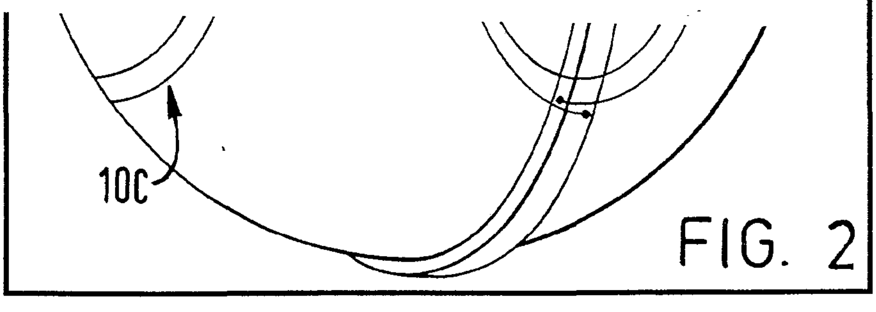

FIG. 2

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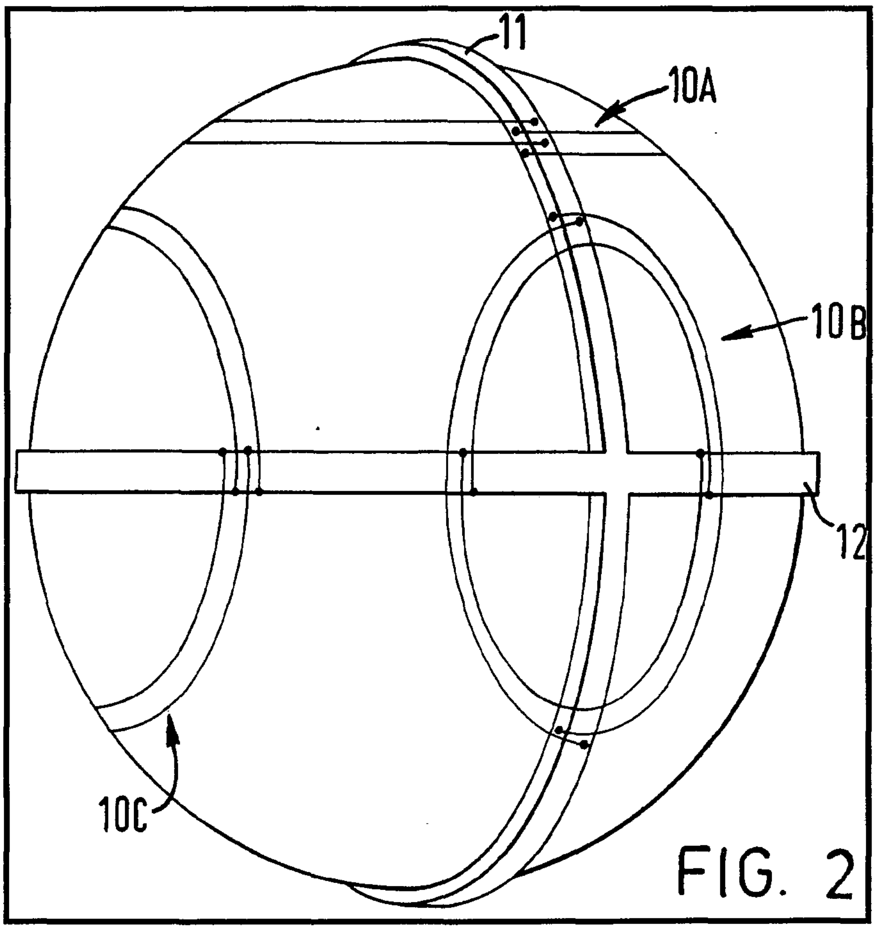

FIG. 2

The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

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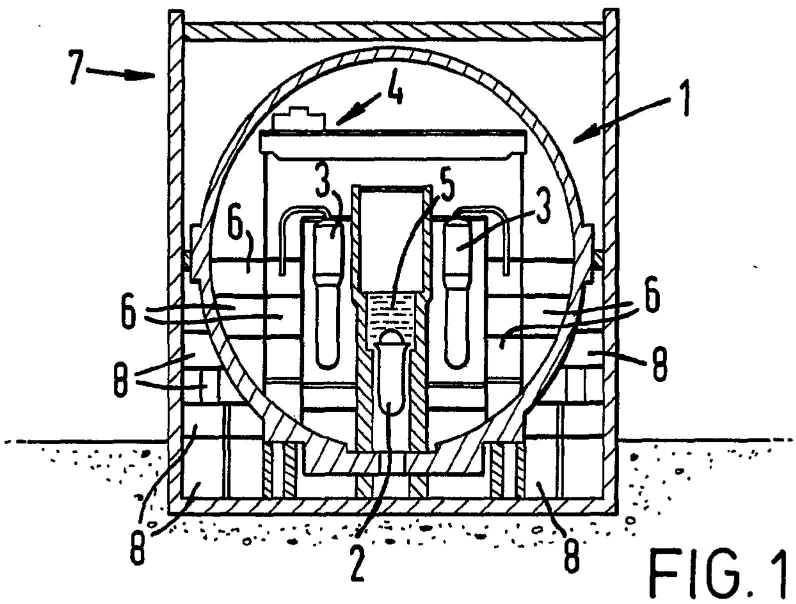


FIG. 1

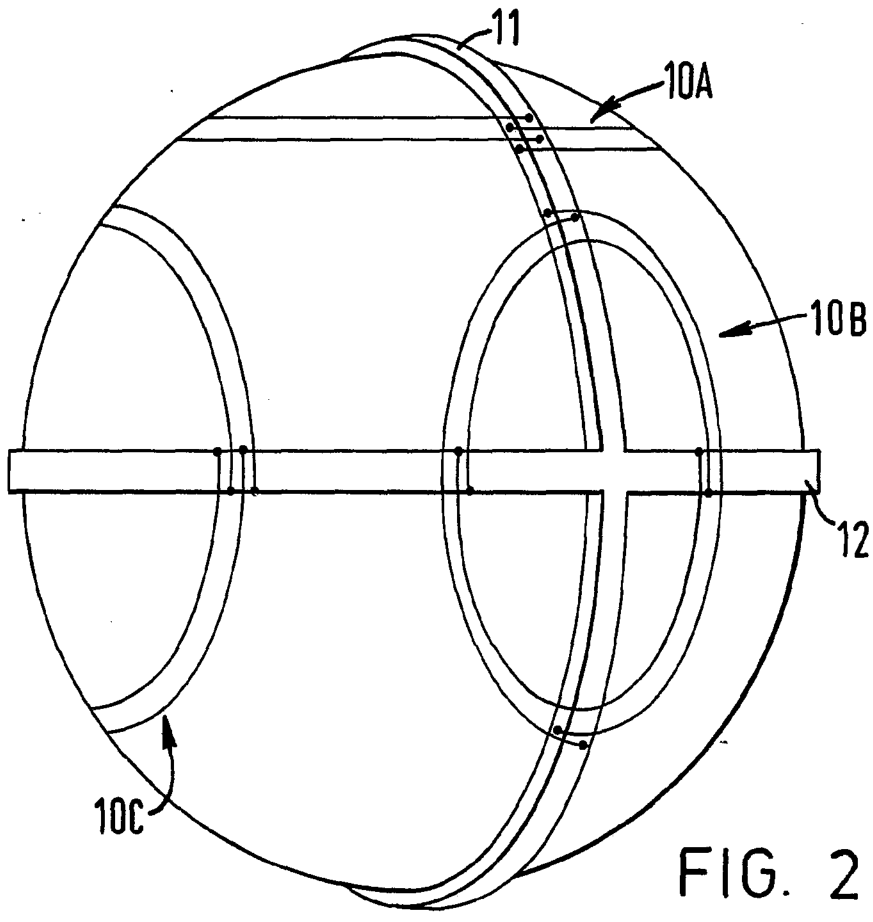
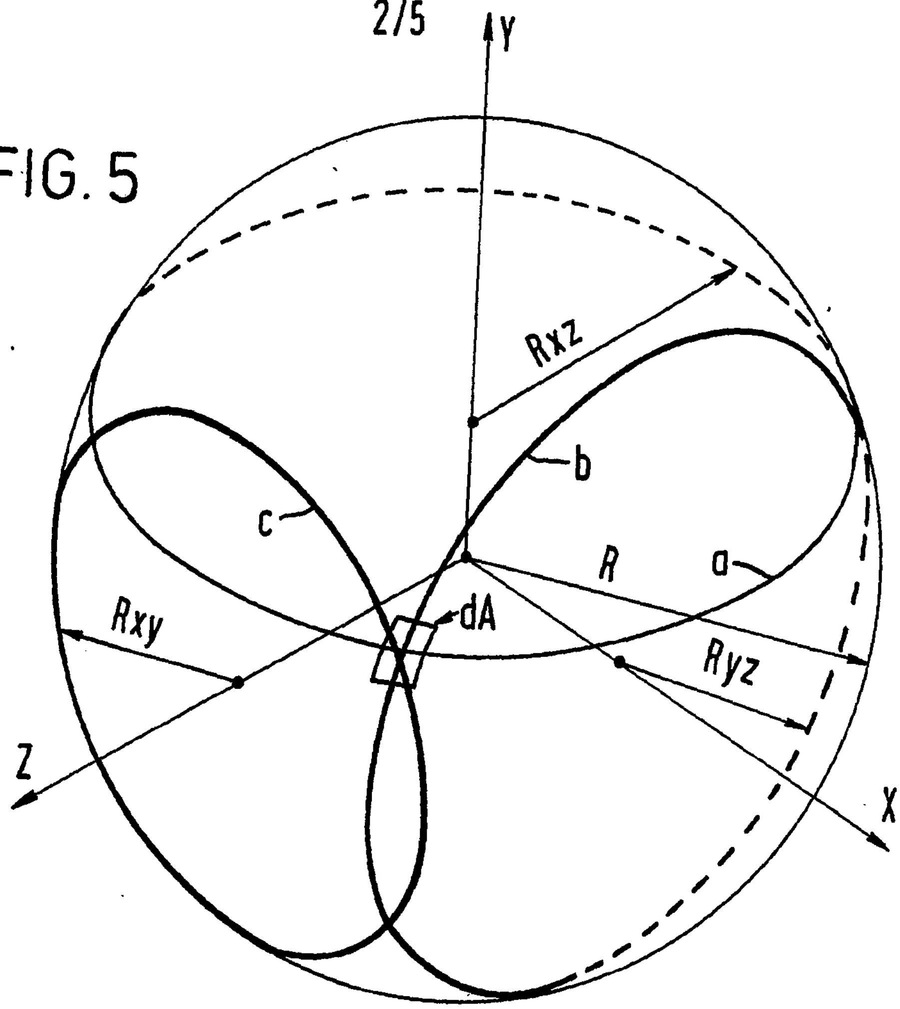


FIG. 2

FIG. 5



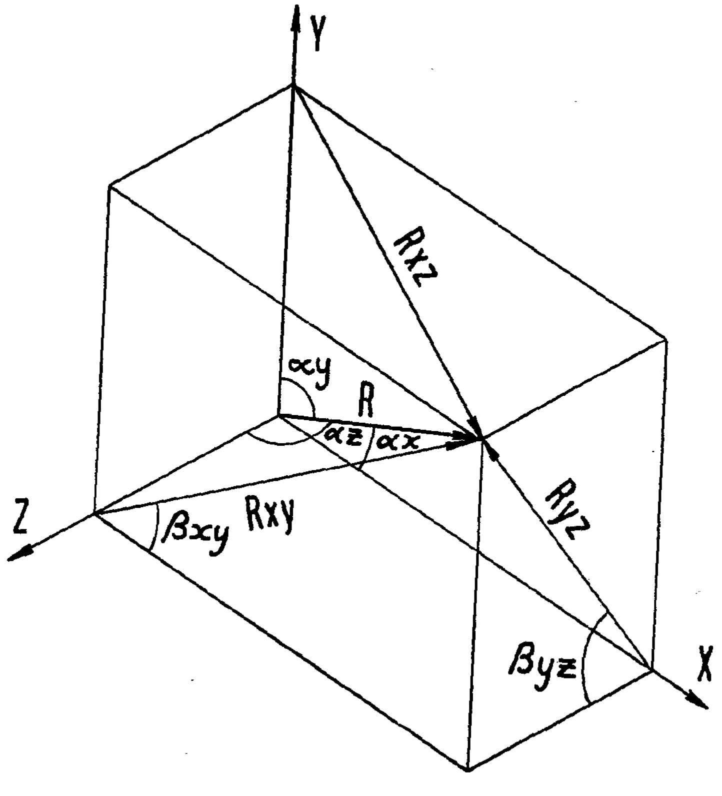


FIG. 6

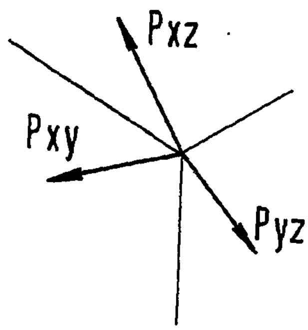


FIG.7

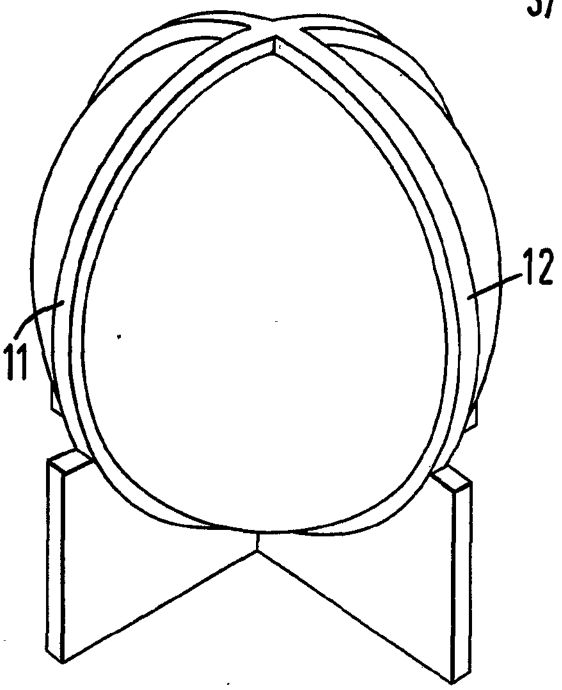


FIG. 3

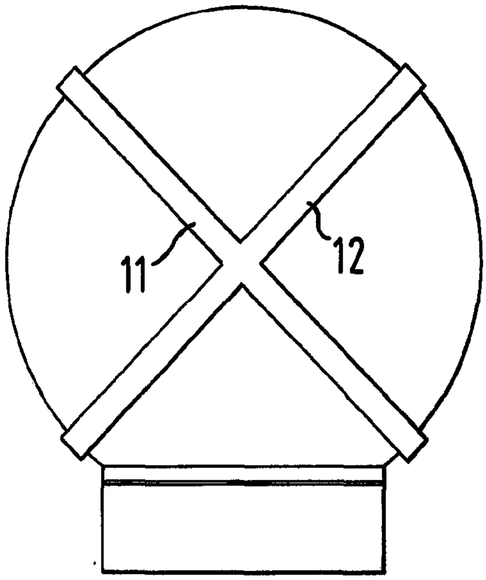


FIG. 4

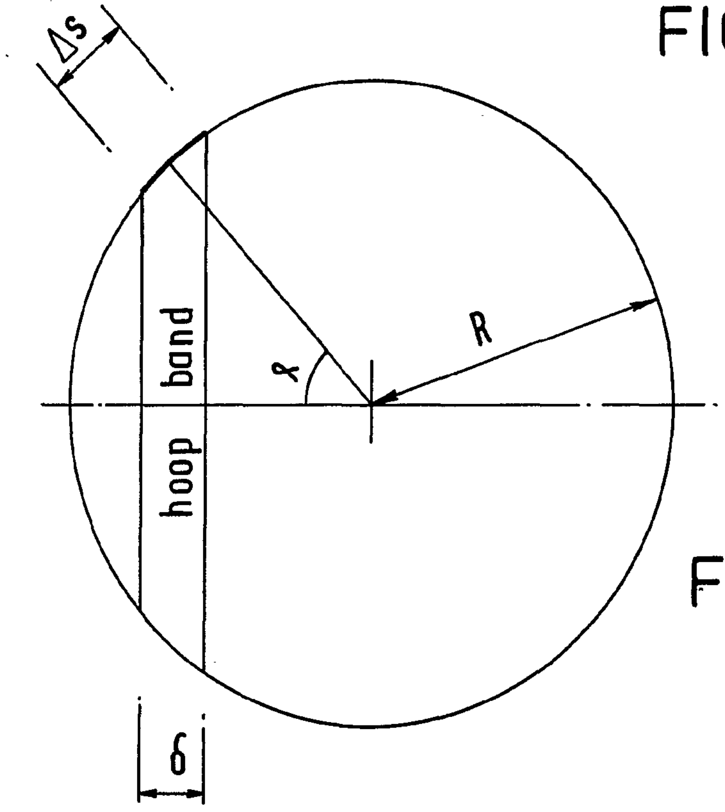


FIG. 8

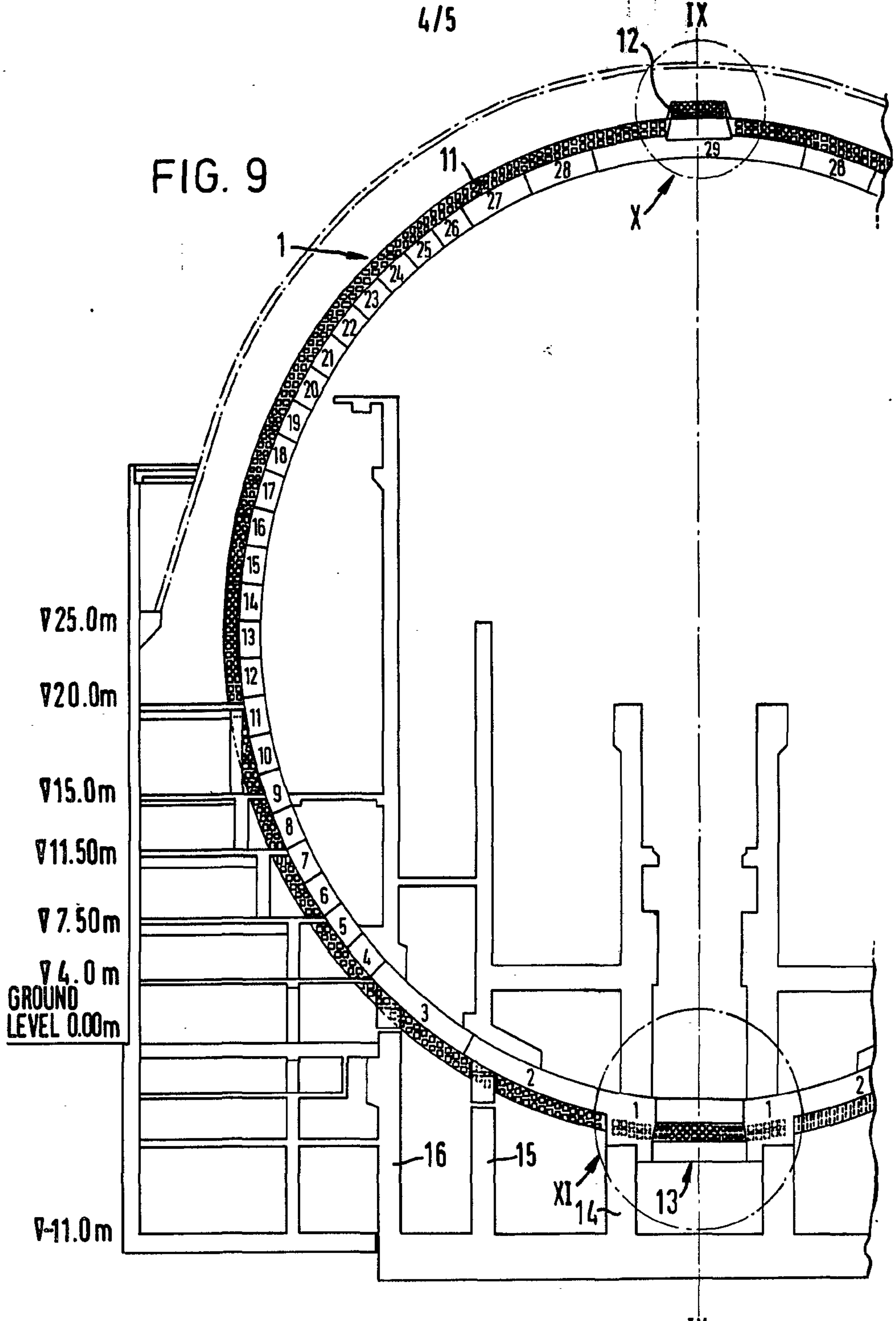

IX
12
11
X
1
28
29
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
∇25.0m
∇20.0m
∇15.0m
∇11.50m
∇7.50m
∇4.0m
GROUND LEVEL 0.00m
∇-11.0m
16
15
XI
14
13
IX

FIG. 9

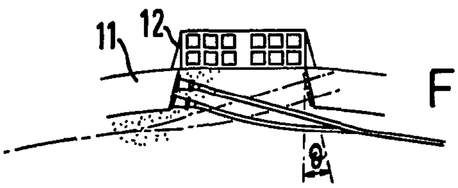

11
12
θ

FIG. 10

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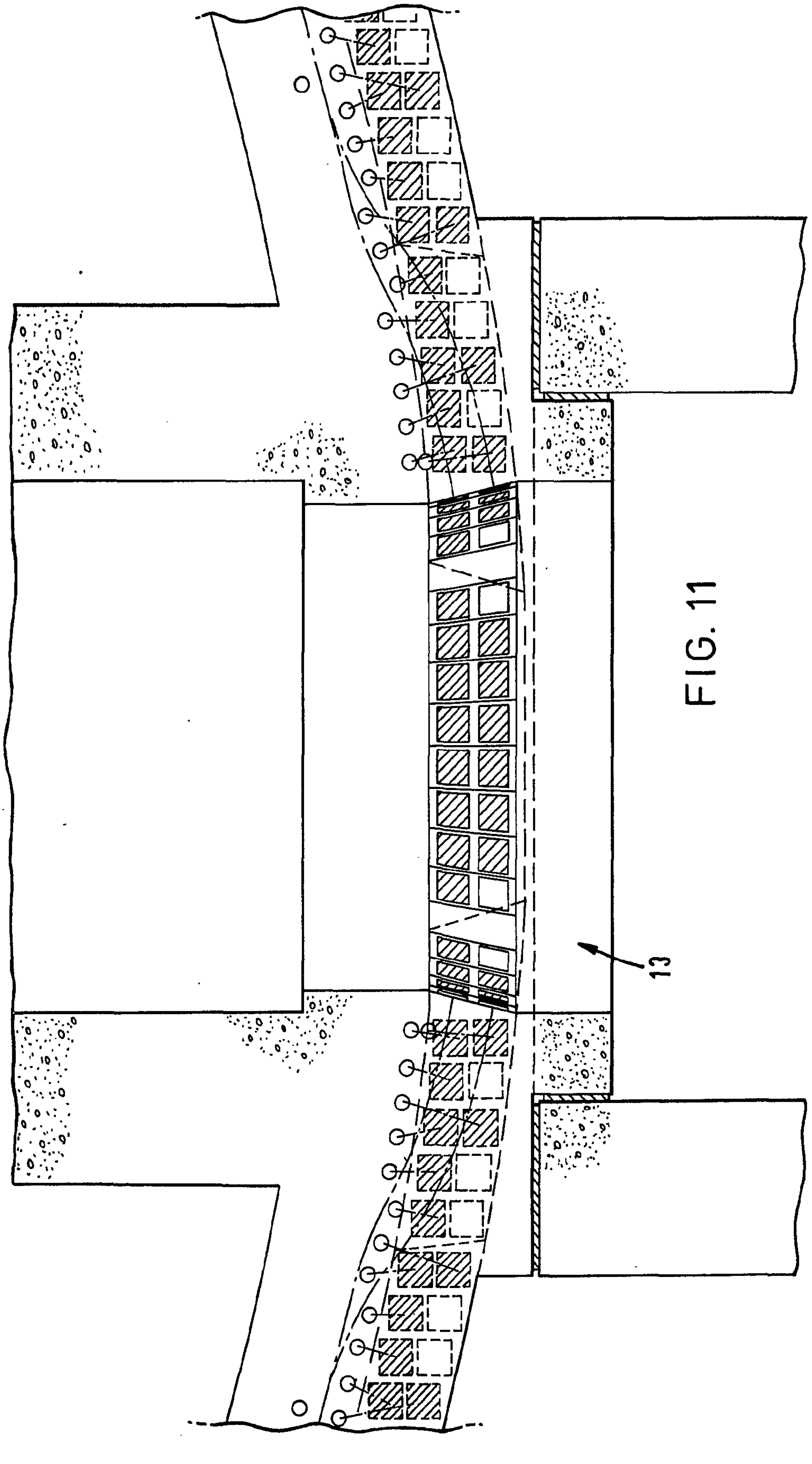

FIG. 11

SPECIFICATION

Concrete containment vessels

This invention relates to concrete containment vessels and is particularly concerned with vessels utilisable as containment structures for nuclear reactor powered electricity generating plants. The main function of such a containment structure is to limit and control the release of radioactivity to the environment in the event of an accident, it therefore being necessary that the structure is capable of resisting high internal pressure. This requirement, combined with the large size of the vessel, suggests that possible shapes for such a vessel are spherical, cylindrical, conical or some combination of these. In general the shape selected in practice has been a reinforced or prestressed concrete cylinder, capped with a hemispherical or torispherical dome and supported on a flat foundation slab. Generally such a concrete containment vessel has been lined with a steel liner, used to seal the more permeable concrete against gas leakage.

An alternative to a lined concrete membrane is a separate steel or prestressed concrete shell, virtually the sole function of which is to retain internal pressure in the event of an accident. Located outside and separate from this is an unlined concrete shell which acts as a biological shield and protects the concrete shell from external hazards such as missile or aircraft impact, external explosions and severe environmental loadings.

Another principal feature of nuclear reactor powered electricity generating plant containment structures is that penetrations have to be provided through the structures. These can range from several centimetres in diameter (for example, for electrical ducts) to in excess of six metres for the main equipment access hatch.

Containment structures in service or currently under construction are of the following types.

A. Reinforced concrete cylinder, with a plain steel liner, hemispherical dome and flat base slab.
B. As in "A" above, but with the addition of vertical prestress applied only to the cylinder wall.
C. Steel lined, prestressed concrete, cylindrical structure with either a hemispherical or torispherical dome and a flat base slab.
D. Similar to "C" above, but with the vessel wall liner located towards the middle of the cylinder wall.
E. Double skinned concrete vessel of the general configuration of "C" above and consisting of a steel lined prestressed concrete inner shell and an un-lined reinforced concrete outer shell.
F. Separate cylindrical or spherical steel pressure retaining shell located inside a reinforced concrete cylinder capped with a hemispherical dome.

Briefly, principal problems with the various structures in the above list are as follows.

Structures in category A have a zone of maximum discontinuity, near the cylinder/base slab junction, at which large bending moments and shear forces can be generated under the action of internal pressure and temperature and measures such as providing thermal insulation have to be adopted to reduce the magnitude of liner and concrete stress in this region. A more major problem, however, results from the containment pressure test, required both in the U.S.A. and in Europe, in which the containment is subjected to a test pressure, the magnitude of which is approximately 1.15 times the design pressure. For a pressurised water reactor system this pressure is in the range of 0.15–0.475 N/mm^2. This test pressure causes cracking of the concrete and on removal of the pressure loading only partial recovery of the vessel is achieved. Although permissible stress levels in the reinforcement will not be exceeded, and further pressure cycles would give repeatable behaviour, the initial onset of cracking can affect the overall integrity of the structure.

In general the problems so far mentioned can be overcome by adopting a prestressed concrete design style. With the utilisation of prestress, bonded reinforcement is required as distribution steel, to carry any shear stresses developed in the shell and to accommodate local stress concentration effects at penetrations and discontinuities. In these applications mechanical splicing of bars, required in reinforced structures, is not generally needed.

The application of prestress allows the geometry of the structure to be better optimised, ensures a very high degree of structural integrity and on containments over about 35 metres in diameter offers economic advantages.

Structures in category B are of a hybrid form apparently combining disadvantages of both reinforced and prestressed concrete designs, the major ones being (a) peak membrane circumferential stresses are carried by reinforcement which therefore has to be mechanically spliced, (b) liner insulation is required to reduce liner and concrete thermal stresses, (c) no flexibility of dome design can be effected as the dome is reinforced only, and (d) uniaxial prestress induces relatively large stress concentrations around penetrations during normal operation and this has to be compensated for by the provision of additional bonded reinforcement in an already congested area.

From what has been so far stated it will be appreciated that the prestressed concrete structures of categories C, D and E above, by utilising prestressing principals, offer structures of very high integrity and give a greater degree of freedom in structural optimisation. However, in many cases large anchoring butresses for the prestressing have to be provided which can have a detrimental effect on power station layout.

Structures in category F have a high integrity so far as internal hazards are concerned, but no provision is made for seismic disturbances, or external impacts.

None of the structures so far considered is of a configuration that minimises the quantity of material, particularly concrete, used.

According to the present invention there is provided a concrete containment vessel that is spherical and that has prestressing tendons disposed in first, second and third sets, the tendons of each set being all substantially concentric and centred around a respective one of the three orthogonal axes of the sphere; the tendons of the first set being anchored at each end at a first anchor rib running around a circumference of the vessel, the tendons of the second set being anchored at each end at a second anchor rib running around a circumference of the sphere and disposed at 90° to the first rib, and the tendons of the third set being anchored some to the first rib and the remainder to the second rib.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings in which:–

Figure 1 is a diagrammatic sectional side view through part of a nuclear powered electricity generating plant incorporating a concrete containment vessel.

Figure 2 is a schematic illustration of a concrete containment vessel.

Figures 3 and 4 are schematic illustrations of two different possible dispositions for the vessel of Fig. 2;

Figure 5 shows the relative dispositions of three prestressing cables around a vessel such as that illustrated in Fig. 2;

Figures 6 and 7 are diagrams developed from Fig. 5;

Figure 8 illustrates how to desired cable spacing can be established;

Figure 9 is a schematic sectional side view through part of a nuclear power plant incorporating a concrete containment vessel similar to the vesel of Fig. 1, the plant being shown at a stage in its construction and, at this stage, being substantially symmetrical about the line IX–IX;

Figure 10 is a scrap view, taken as of the detail encircled at X in Fig. 9, showing how prestressing tendons run from anchorages; and

Figure 11 is a sectional side view on a larger scale of the detail encircled at XI in Fig. 9.

Referring first to Fig. 1, this Figure illustrates how efficient use can be made of space where the concrete contanment vessel is a spherical containment structure 1 used in a nuclear powered electricity generating plant. In the Figure there is indicated a reactor vessel 2, steam generating equipment 3, a polar crane 4, a refuelling canal 5 and chambers 6 within the structure 1 for housing equipment. The spherical structure 1 is within a cylindrical secondary containment structure 7 and further chambers 8 for equipment are provided in the lower part of the structure 7 outside the structure 6.

A system of prestressing a containment vessel where the vessel is to be a truly spherical concrete containment vessel as illustrated in Fig. 1 will now be described with reference to Fig. 2. The basis of this system is to enclose the sphere within a mesh of three sets of small circle hoop tendons 10A, 10B, 10C. Each set is centred around one of the three orthogonal axes of the sphere with the plane in which each circle of a set lies disposed parallel to the planes containing the other circles of the same set. The planes of each set are mutually orthogonal to the planes of the other two sets and the result is that a uniform prestress arrangement is obtained. In the vessel of Fig. 2 two anchor ribs 11, 12 for the tendons each run completely around a full circumference, these ribs being set at 90° to each other. This arrangement allows two complete small circle tendon systems (the sets of tendons 10A and 10C) to be anchored off one in each rib (the ribs 11 and 12 respectively) with the third system (the set of tendons 10B) anchored off equally in both ribs. Each tendon travels through substantially 180° between anchorages and, it will be understood, runs either in a groove or in a duct that stabilises the location of the tendon on the vessel. From a practical point of view the resulting vessel has several advantageous features:–

A. All tendons lie on fixed radius small circles.
B. All tendon systems are identical with regard to numbers of tendons and geometry.
C. All tendons pass each other on the sphere surface at substantially 90°.
D. All anchorages are fixed perpendicular to the rib surface.
E. The small circle system applies 'true' radial prestresses to the vessel and no non-radial or tangential forces are induced.

In a vessel of the form of Fig. 2 various options are available with regard to the orientation of the ribs relative to a support for the vessel. The preferred orientation, illustrated in Fig. 3, is with the ribs 11 and 12 vertical. An alternative, illustrated in Fig. 4, is with the ribs 11 and 12 at 45°.

Referring next to Figs. 5 to 7, in Fig. 5 there are shown three tendons a, b, c, one from each of three sets of tendons such as the sets 10A, 10B and 10C, on the surface of a sphere and crossing at an area dA. These tendons will, in practice, be tensioned cables, and the hoop forces in these cables will be:–

$$T_{xy} = \frac{PR}{2} \operatorname{Sin}^2\alpha_z$$

$$T_{xz} = \frac{PR}{2} \operatorname{Sin}^2\alpha_y$$

$$T_{yz} = \frac{PR}{2} \operatorname{Sin}^2\alpha_x$$

where:

T = respective cable force
R = sphere radius
P = design radial pressure on sphere
α = angles between a line from the centre of the sphere to the centre of the area dA for the respective axes x, y and z.

The radial prestress produced by the three cables can be proved to be uniform over the surface of the sphere, and does not create residual tangential forces. From the equations above it can be seen that the pressure on the vessel is a function of the angle α. The pressure can be arranged to be uniform over the sphere by adjusting either the force in the cables or the spacing of the cables.

The spacing of the cables can be described by the following equations:– (See Fig. 8)

$$n\delta i = s\,\frac{Ti\delta}{ff} = \frac{PR}{2F}\delta \operatorname{Sin}\alpha_i$$

$$n\triangle i = \frac{Ti \triangle s}{F} = \frac{PR}{2F}\triangle s \operatorname{Sin}^2\alpha_i$$

where:

F = design force
$n\delta i$ = number of cables per unit with 'δ' measured along the axis perpendicular to the plane of the hoops i.
$n\triangle i$ = number of cables per width '$\triangle s$' measured along a great circle which is in a plane parallel to the axis of the cable set.

Turning now to Figs. 9, 10 and 11, these Figures show a vessel with its ribs vertical as in Fig. 3. At the base there is a large access penetration 13 that is immediately below the reactor core. The diameter of this penetration is, in the particular vessel illustrated, 9.0m and this requires local concrete thickening adjacent to the penetration. Furthermore, as the penetration is at the intersection of the anchorage ribs, considerable re-arrangement of the prestressing tendons in this region is required, the anchorages for the tendons in this region being best illustrated in Fig. 11. The disposition of anchorages is chosen to provide seismic restraint. Shaded rectangles represent anchorages used. The anchorages represented by unshaded rectangles are not used.

It is to be noted that the inclination of the anchorage faces of each rib with respect to the spherical surface of the vessel has a considerable influence on the bending stresses induced around the rib. This inclination is shown much exaggerated in Fig. 10, the angle θ in practice being $\frac{1}{2}$°.

In more detail, the vessel of Figs. 9 to 11 is a prestressed sphere 1 of 58m diameter with two meridional ribs 11, 12 running in vertical planes between the top and bottom pole positions. The ribs are 4m wide by 1m deep and form the anchorage zone for the prestressed tendon ends. This particular design is based on a nineteen strand 18mm tendon system the ultimate capacity of each tendon being, for example, 7220 KN. Each tendon system is laid out on a single layer, the minimum tendon centre to centre distance being 400mm.

Each rib takes on one face eighty-seven tendon anchorages receiving fifty-eight tendons from one small circle system plus twenty-nine tendons from the other small circle system lying in the common plane. All tendons run through 180°. The ribs are formed of pre-cast units as numbered "1" to "29" in Fig. 9, which during construction are positioned in advance of the general shell concrete.

The sphere is supported on three circular support walls 14, 15, 16 and consistency in load distribution is achieved by selecting bearing pads (not shown) with appropriate stiffness characteristics.

CLAIMS

1. A concrete containment vessel that is spherical and that has prestressing tendons disposed in first, second and third sets, the tendons of each set being all substantially concentric and centred around a respective one of three orthogonal axes of the sphere; the tendons of the first set being anchored at each end at a first anchor rib running around a circumference of the vessel, the tendons of the second set being anchored at each end at a second anchor rib running around a circumference of the sphere and disposed at 90° to the first rib, and the tendons of the third set being anchored some to the first rib and the remainder to the second rib.

2. A vessel as claimed in claim 1, wherein the ribs are vertical.

3. A vessel as claimed in claim 1, wherein the ribs are at 45° to the vertical.

4. A vessel as claimed in claim 1, 2 or 3, wherein each tendon is anchored to a rib face that is inclined with respect to the spherical surface of the vessel.

5. A vessel as claimed in claim 4, wherein the angle of inclination of each said rib face to the vessel surface is $\frac{1}{2}$°.

6. A concrete containment vessel substantially as hereinbefore described with reference to Figs. 1 to 3 and Figs. 5 to 11, or Fig. 4, of the accompanying drawings.

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