United States Patent

Heifetz

[15] **3,643,910**

[45] **Feb. 22, 1972**

[54] **INFLATABLE FORMS**

[72] Inventor: **Haim Heifetz,** 24 Shderot Hazvi, Haifa, Israel

[22] Filed: **Mar. 7, 1969**

[21] Appl. No.: **805,143**

[30] **Foreign Application Priority Data**

Mar. 7, 1968 Israel 29599/68

[52] **U.S. Cl.** ....**249/65,** 25/1 B, 25/130 A, 249/13, 264/32, 264/314

[51] **Int. Cl.** **B28b 7/32**

[58] **Field of Search** ....249/1, 13, 18, 65; 25/1 B, 25/128 D, 130 A, 131.5 A, 131.5 B, 131.5 C, 131.5 D, 131.5 G; 52/2; 264/32, 314

[56] **References Cited**

UNITED STATES PATENTS

2,335,300	11/1943	Neff	249/65 UX
2,948,047	9/1960	Peeler et al.	249/65 UX
3,478,472	11/1969	Kwake	52/2 X
3,462,521	8/1969	Bini	264/32

Primary Examiner—J. Spencer Overholser
Assistant Examiner—Lucius R. Frye
Attorney—Ward, Haselton, McElhannon, Orme, Brooks and Fitzpatrick

[57] **ABSTRACT**

Inflatable forms for use in the construction of shells, such as shells used in building, from material such as concrete, plastic materials or the like which is cast or gunned on the form after the latter has been inflated. In particular the invention deals with base ring structures for use with such forms.

13 Claims, 26 Drawing Figures

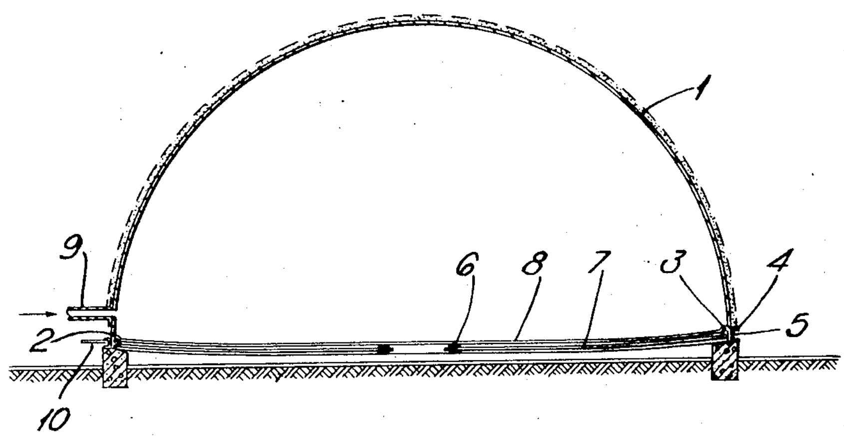


Fig.1.

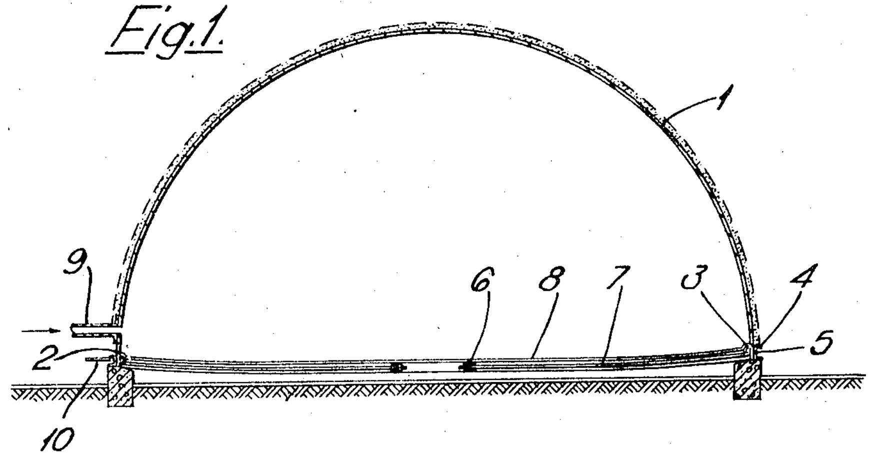


Fig.2.

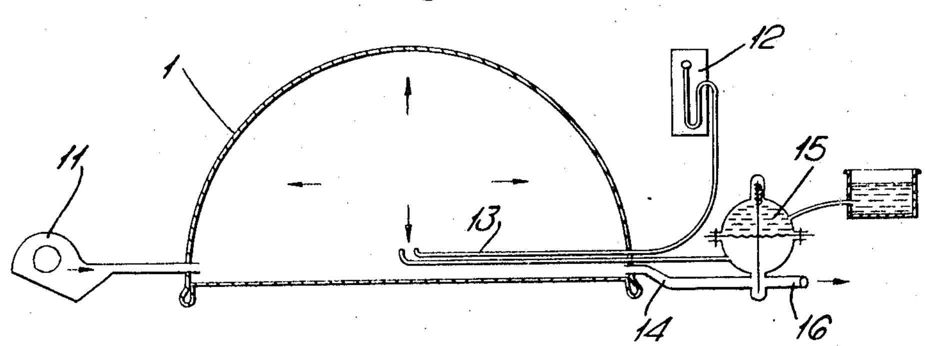
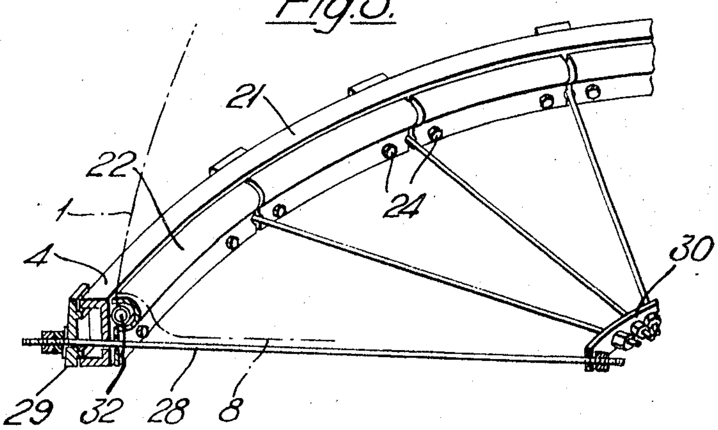


Fig.3.



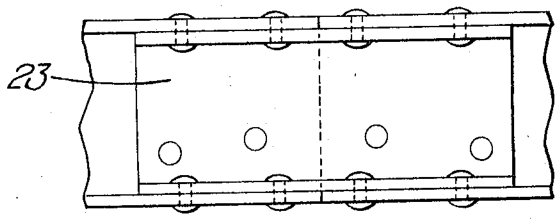


Fig.4.

Fig.5.

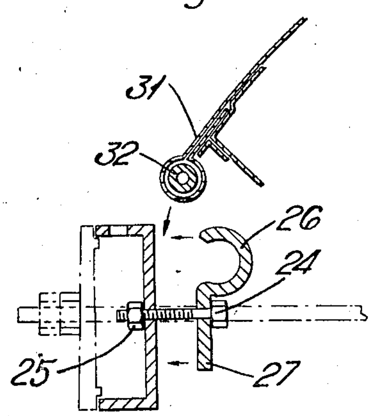


Fig.6.

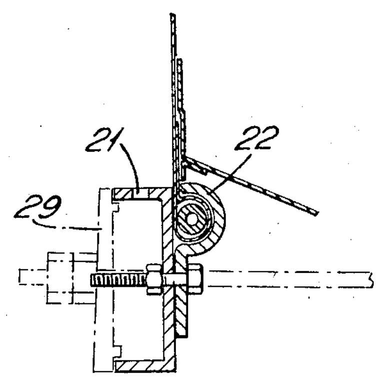


Fig.7.

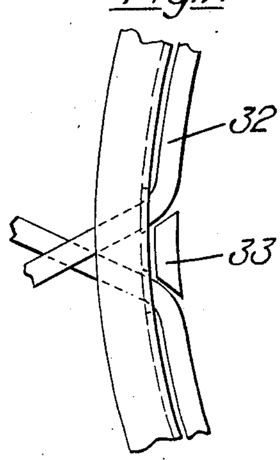


Fig.8.

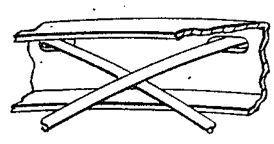


Fig. 9.

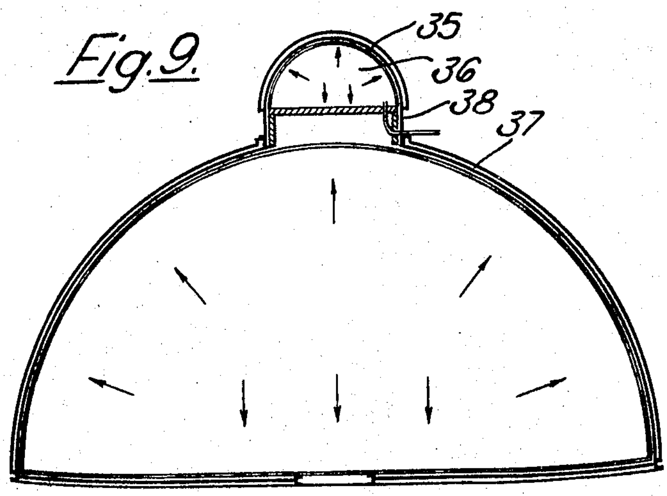


Fig. 10.

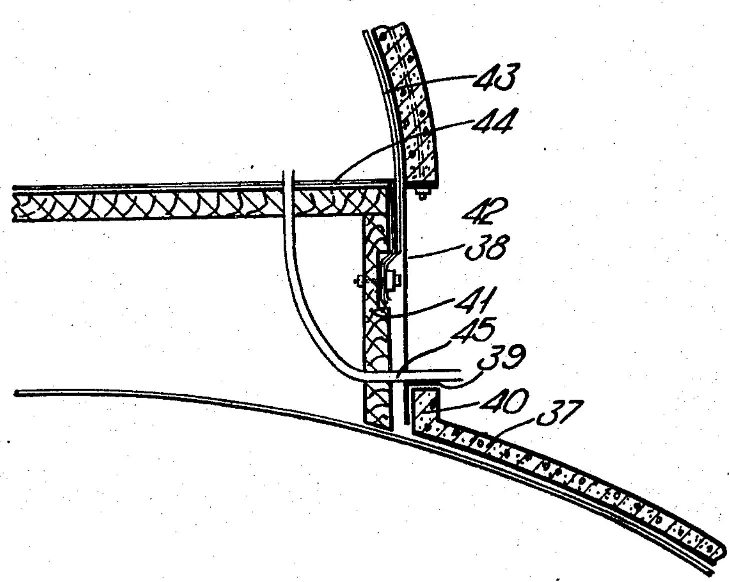


Fig.11.

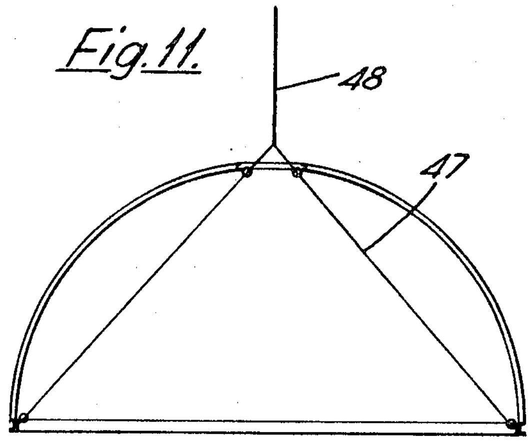


Fig.12.

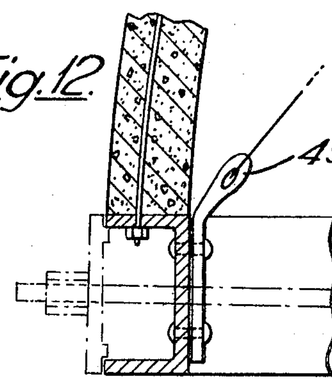


Fig.13A.

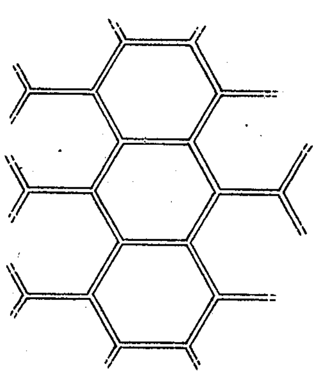


Fig.13B.

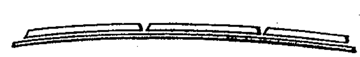


Fig. 14.

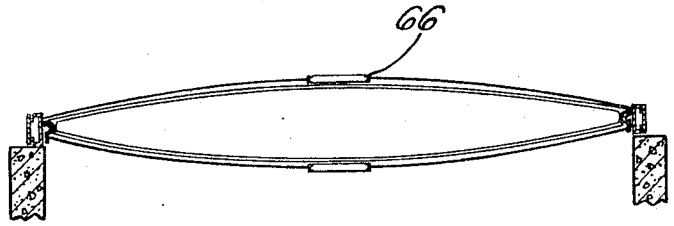


Fig. 15.

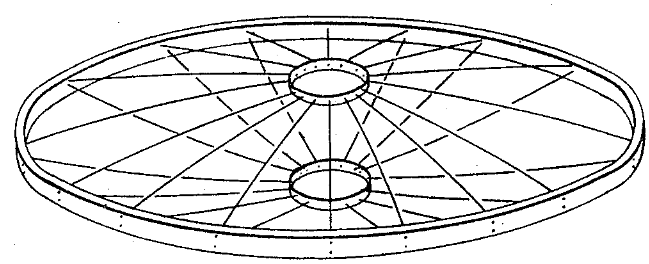


Fig.16.

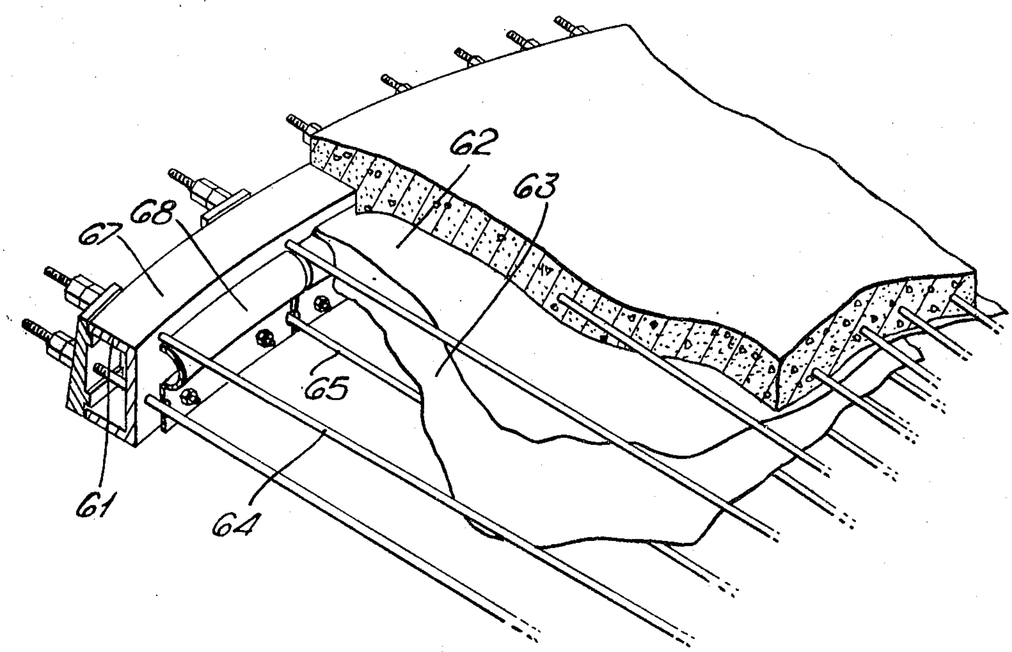


Fig.17.

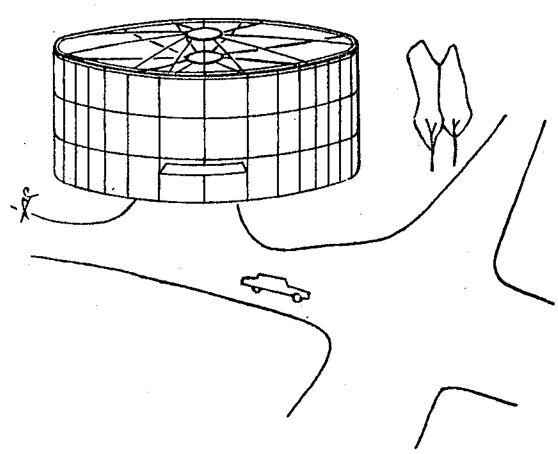


Fig. 18.

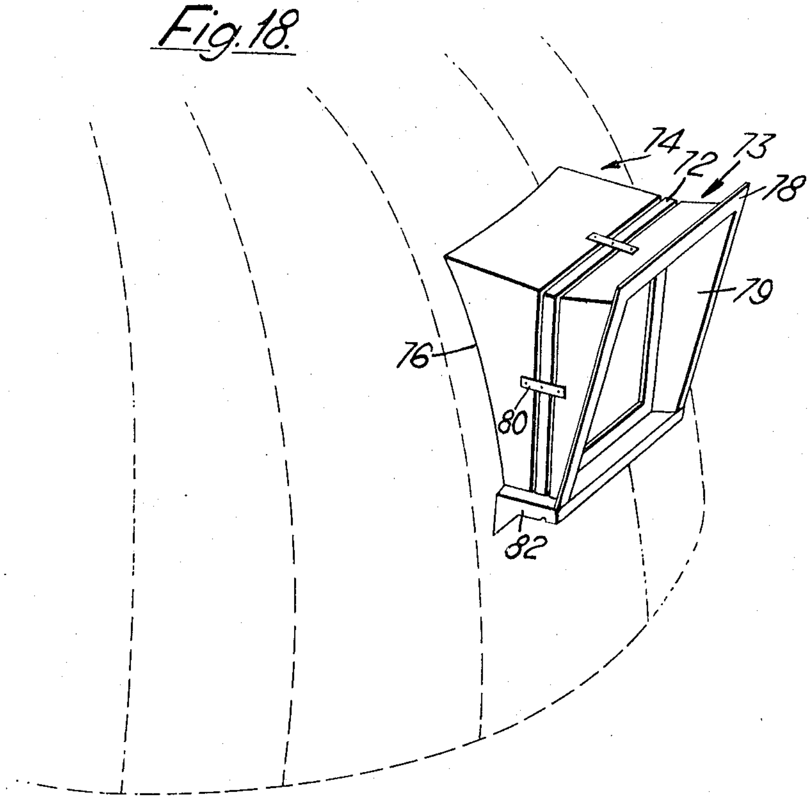


Fig. 19.

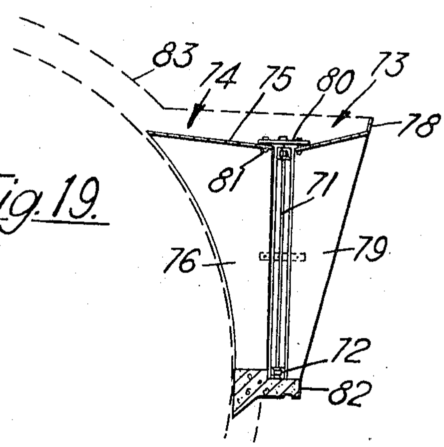


Fig. 20.

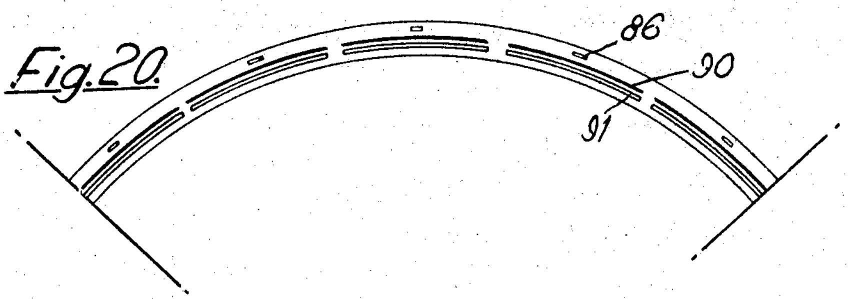


Fig. 21.

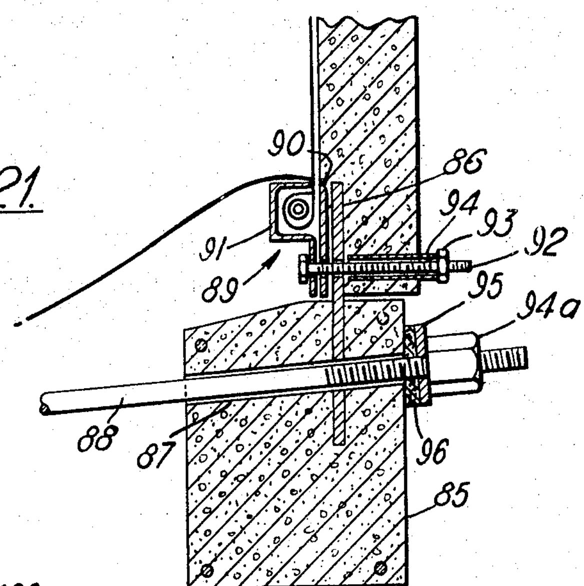


Fig. 22.

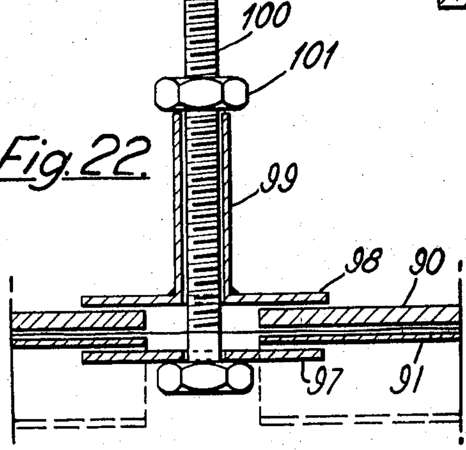


Fig. 23.

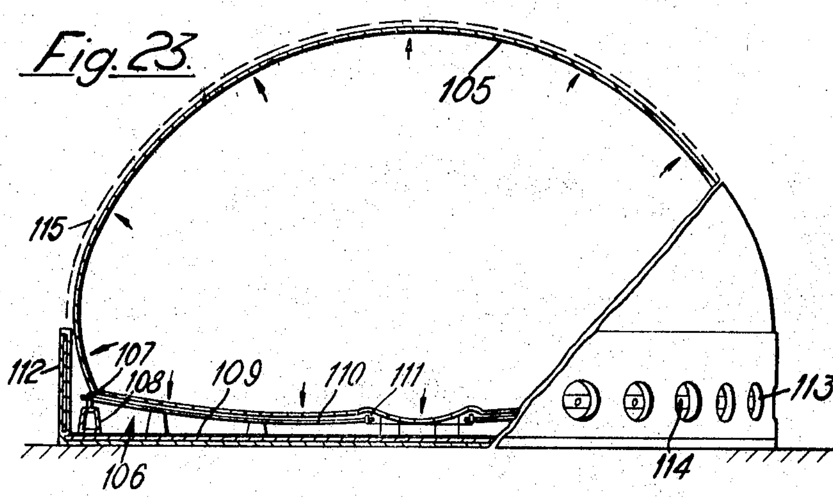


Fig. 24.

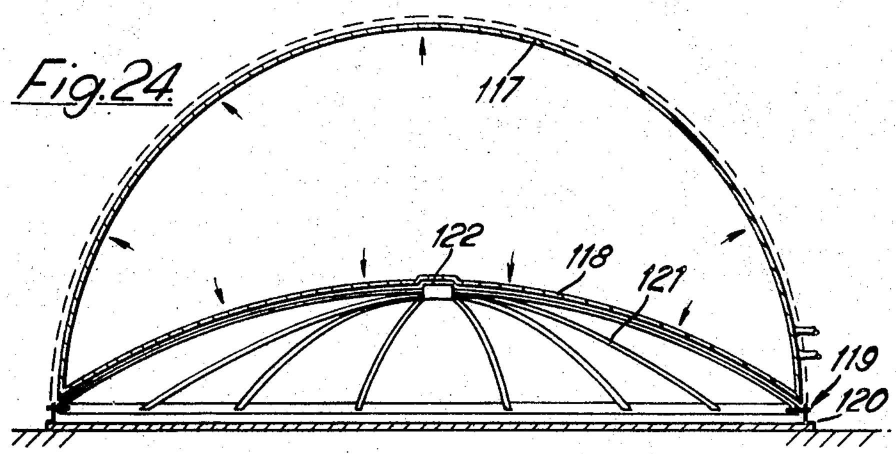
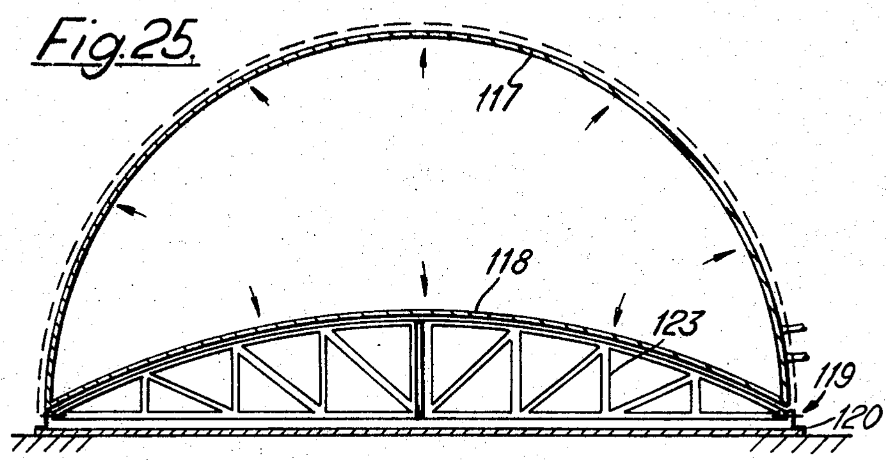


Fig. 25.



INFLATABLE FORMS

This invention relates to inflatable forms of the kind which have been proposed for use in the construction of shells for use in building, such shells being formed by the casting or gunning of cementitious or plastic materials or the like on the form after the latter has been inflated. Various proposals have hitherto been made for the use of inflatable forms in building construction. None of these prior proposals, however, have led to a practical economic method of construction and, in consequence, there has been very little exploitation or development of the idea.

It has now been found that the successful use of inflatable molds in building construction depends on satisfying the following conditions:

1. The facility for ready inflation and deflation of the form and its removal from the cast shell for subsequent reuse;

2. The maintenance of a predetermined shape, location and set of dimensions of the inflated form during casting and setting of the shell and the predetermined shaping of any openings therein; and

3. The ability of the form and associated structure to withstand and/or counteract the very substantial elevating forces which act thereon as a consequence of inflation, such forces becoming critical with large forms and tending to raise the form and its foundations from the ground.

None of the prior proposals satisfy in their entirety any of these conditions and certainly fail to satisfy all the conditions.

As far as the first condition is concerned, no practical provision seems to have been made in accordance with the prior proposal for the designing of the form in such a fashion as to facilitate its ready removal from the cast shell and its subsequent reuse. It will be readily appreciated that an inability to reuse the form would weaken, if not entirely remove, the economic basis for the system. Furthermore, in most of the prior proposals where means are suggested for disassembling and removing the form after use, the form is described as being anchored to a base at discrete anchoring points. In other words, there is a concentration of tension at these specific points consequent upon inflation of the form with a consequent increased likelihood of rupture of the form at these points thereby rendering the form incapable of further use. Alternatively, any form which is designed so as to avoid these dangers would be of entirely uneconomical weight and strength.

In accordance with some of these prior proposals the second condition referred to above was to be satisfied by inflating the form to a very high pressure (pressures of between 2 to 5 lbs per square inch having been proposed). Such proposals have been recognized as impracticable seeing that they involve the provision of forms made of flexible materials capable of withstanding very considerable forces and such materials, even if available, are prohibitively expensive. In contrast, other proposals have involved inflating the form to a relatively low pressure (pressures of the order of 2 oz. per sq. inch have been proposed in this connection). With such low pressures, however, it has proved to be very difficult if not impossible to control the shape, location and dimensions of the form, these being very susceptible to distortion by the weight of the applied materials and the force of application as well as to external influences such as variations in temperature, winds or the like. In consequence, domes produced under such conditions are subject to disintegration in view of the development of planes of rupture and it has in fact been proposed to provide such forms with expensive reinforcing rings designed to support the shell during application and setting.

In none of the prior proposals is the third condition referred to above mentioned, let alone any construction suggested so as to enable the form to meet this condition.

It is an object of the present invention to provide a new and improved inflatable form for the purpose referred to which is capable of use so as to satisfy some or all of the conditions referred to above.

According to the present invention there is provided an inflatable form for the purpose referred to and having a rim portion secured to or adapted to be secured continuously to a rigid or rigidizable base ring associated therewith and being so constructed as to be capable of resisting compressive or tensioning forces exerted thereon.

The base ring can, if required, be anchored to an appropriate foundation. Alternatively, the base ring can be maintained completely detached from any such foundation thereby facilitating the use of the form in the production of prefabricated shells designed for subsequent transport to a site.

The form is preferably manufactured of a material which is minimally extendable. Seeing that it is to all intents and purposes impossible to utilize for this purpose a completely unextendible material, which would still be within the realm of economic feasibility, steps have to be taken to ensure that the extension or stretching of the form material during inflation should be entirely predetermined and as uniform as possible. In view of the fact that it is precisely at the rim region of the form, where it is connected to the base ring, that stretching is inhibited it is essential, in order to ensure a uniform deformation of the material during inflation, to have these rim portions prestretched to a degree comparable with the stretching of the remainder of the form during inflation.

A form of this kind in accordance with the present invention is particularly adapted for use with pressures of inflation which are not so high as to require form materials of exceptional strength or so low as to render difficult if not impossible the maintenance of the form shape against the distorting effect of the weight of the applied material and against extraneous disturbing influences, such as winds, temperature variations or the like.

Thus, pressures of inflation of the order of 30–60 g./cm.^{2} can suitably be employed, the actual pressure depending, inter alia, on the size (diameter) of the form.

It will be understood that suitable control means must be provided to ensure that the pressure of inflation is maintained within well-defined limits (e.g., $\pm$ 1 g./cm.^{2}) during casting and setting of the shell. Similarly, measures have to be taken so as to ensure that the ultimate shape of the inflated form is as predetermined. Such measures are particularly required during the critical setting stage when the materials while inelastic are nevertheless still very sensitive to deformation.

The feature of having the form secured to or adapted to be secured to a rigid or rigidizable base ring facilitates the ready removal of the form from the constructed shell after the latter has set while the fact that the form is continuously secured at its rim to this base ring ensures the uniform distribution of stress in the form and thereby greatly reduces the danger of rupture of the form which arises when the form is secured at discrete points to a base.

A form provided with a base ring in accordance with the present invention can readily be adapted to withstand the very considerable elevating forces acting on the form and on its base ring when the form is inflated. For this purpose the form, which in this case is integral with a base portion so that the form and the base portion constitute a sealed whole has its base ring associated with a plurality of transversely directed cables, rods or the like anchored thereto, the arrangement being such that when said cables are tensioned said ring is placed in compression.

With such an arrangement the elevating forces previously referred to are transmitted through the base portion of the inflated form, which would otherwise assume a spherical shape, to the transversely directed cables and this downwardly directed force is transformed into transversely directed tensioning forces in the cables which in turn serves to put the base ring into compression. Alternatively, the base ring is associated with a plurality of radially directed struts or trusses, as a result of which, the downwardly directed forces are transformed into radially directed compressive forces which serve to tension the base ring. In effect, therefore, the form and its associated base structure (base ring and transverse cables or struts) constitute a closed force system, i.e., all forces developed in the system are retained therein and are substantially not transmitted outside the system, e.g., to the ground. By virtue of this arrangement it is possible to provide forms of very considerable dimensions in which the effect of the elevating forces on the foundations of the form would be otherwise so large as to require either the provision of extremely heavy foundations or anchoring devices or the excavation of a hemispherical cavity below the form. None of these solutions are economically feasible.

In accordance with a preferred embodiment of the present invention said form is provided with an integrally formed flexible base, the form and base constituting an inflatable sealed unit and being located between respective sets of transversely directed tensioning cables, rods or the like anchored to a base structure.

Such an embodiment can be readily employed for the construction of ceilings, roofs, floors or the like on, or for transport to a site. Thus, upon inflation, the upper set of tensioning cables limits the maximum curvature of the form and the concrete or other cementitious material can be applied to the form, the upper set of cables becoming embedded therein and serving as reinforcements. On the other hand the lower set of cables serve to take up the downwardly directed forces consequent upon inflation of the form transforming them into tensioning forces which in their turn serve to put the base ring of the form into compression. In the case of this embodiment as in the case of the previous embodiment the entire assembly constitutes a closed force system.

Various embodiments of the present invention will now be described by way of example and with reference to the accompanying drawings in which:

FIG. 1 is a schematic sectional view of an inflated form and associated base structure in accordance with the present invention,

FIG. 2 is a schematic flow diagram of the air supply and control system used for inflating the form,

FIG. 3 is a perspective view of a portion of the base structure of the form shown in FIG. 1,

FIG. 4 is a front elevation of a detail of the base structure shown in FIG. 3 showing the mode of coupling together of the constituent segments of the base structure,

FIG. 5 is a cross-sectional view of the base structure shown in FIG. 3 in a position ready to receive the form rim,

FIG. 6 is a similar view to that of FIG. 5 but with the form rim shown firmly clamped in position,

FIG. 7 shows, in schematic plan view, a length of anchoring pipe associated with the form rim,

FIG. 8 is a perspective view showing the mode of entry and exit of the anchoring pipe through the base structure,

FIG. 9 is a longitudinal sectional view of a form of the kind shown in FIG. 1 with a superimposed smaller form,

FIG. 10 is a detail of the view shown in FIG. 9 on an enlarged scale,

FIG. 11 shows schematically a hemispherical shell formed on a form in accordance with the invention and provided with lifting cables,

FIG. 12 is a view, on an enlarged scale, of a detail of the shell as shown in FIG. 11,

FIGS. 13*a* 13*b* are respective plan and sectional views of the surface of a form reinforced with hexagonal plates,

FIG. 14 is a sectioned side elevation of a composite form and associated cable structure,

FIG. 15 is a perspective view of the cable structure shown in FIG. 14,

FIG. 16 is a perspective view of a portion of the composite form and cable structure shown in FIG. 14 with a portion of a cast shell roof or radial slab,

FIG. 17 is a perspective view of a building showing the use of a composite form and cable structure for constructing the roof,

FIG. 18 is a perspective view of a window form and clamp associated with an inflatable form,

FIG. 19 is a longitudinal sectional view of the clamp and form shown in FIG. 18 embedded in concrete,

FIG. 20 is a plan view of a portion of a modified and reusable base structure in accordance with the invention,

FIG. 21 is a cross-sectional detailed view of a portion of the base structure shown in FIG. 20 taken along the line XXI—XXI,

FIG. 22 is an enlarged plan view of a detail of the base structure shown in FIG. 20, and

FIGS. 23, 24 and 25 are schematic longitudinal sectional views respectively of three modifications of inflated form and associated reusable base structure in accordance with the invention facilitating the construction of a substantially "foundation-less" structure.

As seen schematically in FIG. 1 of the drawings, a flexible hemispherical form 1 is anchored at its rim 2 to a base structure 3. The structure 3 consists of an annular base ring 4 and a transverse cable-tensioning structure 5. The latter consists of an inner ring 6 and radially directed tensioning cables 7. Each cable is secured at its inner end to the inner ring 6 and at its outer end to the annular base ring 4. The form 1 is formed integrally with a flexible base 8 adapted to rest on the transverse cable tensioning structure 5.

The form 1 is provided with an air inlet conduit 9 whose association with the form, and whose coupling to a source of compressed air via a suitable pressure control means is illustrated in detail in FIG. 2 of the drawings.

The form rim 2 is associated with an anchoring pipe illustrated in detail in FIGS. 6 and 7 of the drawings and a pressure fluid supply for this anchoring pipe is introduced via a supply conduit 10.

As seen schematically in FIG. 2 of the drawings, the form 1 is supplied with compressed air from a compressor 11. The form 1 is coupled to an automatic control valve 12 via a control conduit 13 which projects into the interior of the form 1 and is capable of sensing the pressure conditions prevailing in the form interior a conduit 14 couples the interior of the form 1 with a control mechanism 15. The control valve 12 is regulatable by means of the control mechanism 15 which is provided with an outlet 16. In use, the automatic control valve is set to regulate at a given pressure level by means of the control mechanism 15 and, upon actuation of the compressor 11, the form is inflated, the pressure level in the form being thereafter maintained substantially constant.

Reference will now be made to FIGS. 3 to 8 of the drawings for a clear illustration of the base structure of the form and its coupling to the form itself. As can be seen in the drawings, the base structure consists of a base ring 4 comprising a plurality of channel-shaped segments 21 and a plurality of clamping elements 22. The channel-shaped segments 21 are coupled together so as to form a ring by means of coupling elements 23 of U-shaped cross section which, as can be seen in FIG. 4 of the drawings, are inserted in the adjacent ends of respective pairs of segments, and are bolted thereto. The clamping elements 22 are coupled to the channel-shaped segments 21 by means of clamping bolts 24, which extend through corresponding apertures formed in the segments 21, clamping nuts 25 being provided for the bolts 24. Thus in the position shown in FIG. 5 of the drawings, the clamping element 22 is displaced from the channel-shaped segment 21 so as to be ready to receive the form rim, while, as shown in FIG. 6 of the drawings, the clamping elements 22 are clamped tightly against the channel-shaped segments 21 firmly retaining the form rim in position. Each clamping element 22 has a "question-mark" profile the curved section 26 of which is designed to receive the form rim, whilst the vertical limb 27 of which is designed to be clamped against the channel-shaped segment 21.

The clamping of the form rim by the clamping elements not only serves to anchor the form to the base structure, but also serves to impart to the form rim a degree of prestretching. This prestretching is in many instances essential, in order to ensure that the inflated form achieves the predetermined shape.

One set of ends of radially directed tensioning cables 28 extend respectively between adjacent clamping elements 22 through apertures formed in the channel-shaped segments 21 and associated coupling elements 23 and clamping plates 29 to which they are firmly bolted. The outer and inner set of ends of the radially directed cables 28 are respectively secured to an inner ring 30.

The lowermost edge or rim of the form 1 and form base 8 is formed integrally with a double walled skirt portion 31 in which is located a flexible anchoring pipe 32 the ends of which extend out through appropriate elongated apertures formed in the channel-shaped segment 21 to be connected to a pressurized water or other fluid source. As clearly seen in FIG. 7 of the drawings, a dummy pipe section 33 is interposed in the clamping element so as to fill the space between the bent over portions of the clamping pipe 32.

The assembly of the form takes place as follows. The form, made of a minimally stretchable material, together with the form base 8 and anchoring pipe 32 as described above, is brought to the site and is spread out thereon. The clamping elements 24 are loosened and, in their loosened position, the rim of the form (including the anchoring pipe 32) is inserted into the curved section 26 of the clamping elements 22, the two ends of the anchoring pipe emerging through the apertures as shown. With the form rim in position the clamping elements 22 are clamped firmly against the channel-shaped segments 21 by a tightening of the clamping bolts and water, or other fluid under pressure is forced into the anchoring pipe 32 causing it to expand so as to fill the space between the curved section of the clamping elements and the channel-shaped segment and thereby securely anchors the form to the base structure. As an alternative to the use of a fluid filled anchoring pipe a flexible cable made for example of rubber may be employed.

With the form 1 thus anchored to the base ring and with the tensioning cables 28 having been previously given a predetermined degree of slackness by turning the clamping bolts which are distributed around the periphery of the channel-shaped segments 21, the form 1 is inflated to the required working pressure depending on the size of the form (for example 30–60 g./cm.[1]). The control valve 12 is employed to ensure that the pressure remains substantially constant at the required level during the subsequent application of the cementitious or other material and its setting.

In addition to ensuring that the form is inflated to and maintained at the required pressure it is also necessary to ensure that the form acquires, upon inflation, the required stability and its predetermined shape and for this purpose visual observation means are employed. With the inflation of the form, the downwardly directed forces, acting on the form base and tending to force that base to assume a spherical shape, are transmitted to the tensioning cables 28 and result in the further tensioning of these cables, these tensioning forces being transmitted to the base ring which absorbs these forces. Thus, the form and its associated base structure constitute a closed force system and forces developed in this system as a result of the inflation of the form are substantially maintained within the system and not transmitted out of the system. In other words these downwardly directed forces are prevented from acting on the ground and thereby subjecting any foundations of the form to overwhelming elevating forces. The construction of this closed force system renders it possible to ignore completely the effects of these elevating forces and as a consequence there is no necessity of anchoring the base ring to the ground. This anchoring can take place if desired or can be dispensed with if not required.

With the form anchored and inflated as described above, a layer of quick-hardening material such as for example gypsum is applied to the form and when this has set to form a shell the form is deflated, the clamping elements loosened, the anchoring pipe emptied of its water and the form removed from the shell via an opening which has been left in the shell for this purpose. There can then be applied to the shell one or more layers of cementitious material. If desired pretensioned reinforced rods can be embedded in the layers of the cementitious material thus applied having been preliminarily anchored to the base ring. In this way hemispherical dome can be easily and inexpensively constructed on an inflatable form. In the example just described this dome is formed on the channel-shaped base ring which sits freely on the ground and the dome can therefore be transported to any suitable site. If desired, however, the base ring can preliminarily be embedded in a concrete foundation, in which case the dome is permanently cast on the predetermined site.

With the casting and setting of the shell the tensioning cables and central ring can, if desired, be removed. Alternatively, these tensioning cables which are now in a tensioned state, can be allowed to remain so as to become embedded in a subsequently cast concrete floor thereby providing reinforcement for the floor which is suspended on its base ring.

FIGS. 9 and 10 show how a small superstructure 35 can be cast on an auxiliary inflatable form 36 anchored to a dome 37 which has been previously cast on a main inflatable form. Thus, as can be seen in the drawings, and in particular in FIG. 9 thereof, a cylindrical (preferably transparent) base ring 38 is supported by means of a lower flange 39 on the rim of an upper central aperture 40 of the dome 37. This cylindrical "-base ring" 38 surrounds a cylindrical wooden form 41 having a circular wooden lid 42. An auxiliary inflatable hemispherical form 43 is secured at its rim to the cylindrical wooden form 41, the base 44 of the auxiliary form 43 bearing on the upper surface of the wooden lid 42. An auxiliary air inlet pipe 45 passes through the "base ring" 38 and the wooden lid 42 into the inner space of the auxiliary form 43 and in this way the auxiliary form 43 can be inflated. After inflation to the required pressure the cementitious material is cast on the auxiliary form 43 and after it has set the auxiliary form 43 together with the wooden form 42 are removed leaving the auxiliary domelike superstructure 35 and the cylindrical transparent fanlight 38.

As indicated above the shell can be prefabricated on a base ring and can then be transported to a site on which it is to be erected. A convenient method of transporting such shells, especially to relatively inaccessible sites can be by helicopter. For this purpose, and as seen in FIGS. 11 and 12 of the drawings, the shell is provided with lifting cables 47 which are coupled to a single suspension cable 48 designed to be coupled to a helicopter. FIG. 12 shows clearly how the lifting cables 47 are secured to lugs 49 which are in their turn secured to the base ring.

A particularly advantageous use of such transportable shells is in connection with sealed medical units such as for example field-operating theaters. For this purpose the shells can be prefabricated in the manner described above from a lightweight material such as, for example, polystyrene reinforced with glass fibers. The shell thus produced is provided with a lightweight flooring (e.g., of polyethylene) which rests on the tensioning cables and which serves to seal the unit which will have been rendered sterile. The unit can be fully equipped with all the necessary medical equipment and can be readily transported by helicopter together with the medical team so that any injured person can be operated on, on the site.

From the description which has just been given it will be realized that the base ring, which constitutes an essential element of the base structure associated with the form, serves a plurality of vital functions among which are the following:

1. A rigid annular structure to which the form can be continuously anchored;

2. An annular structure to which can be anchored transversely directed tensioning cables (or, as will be described below, radial struts or trusses) designed to take up the elevating forces which would otherwise act on the foundations of the form and to transform them into compressive or tensioning forces for the ring;

3. A base from which can be secured reinforcing cables to be embedded in the cementitious material forming the dome which is set for a suitable means for securing the dome to a base to which it is to be anchored.

While in the arrangements specifically described above the form is clamped to a rigid base structure, the base ring can conveniently be formed as a rigidizable structure. Thus, under certain circumstances, the metal base ring can be dispensed with and the anchoring pipe can be adapted so as itself to constitute the base ring on the structure, which can in its turn form an anchoring ring for the transversely directed cables.

The form should be constructed of a flexible material of low elasticity. A suitable material is natural or synthetic rubber which can, if required, be suitably reinforced by means, for example, of natural or synthetic fibers. Thus, the form can be constituted for example of a fabric formed of cotton or nylon fibers, the fabric being impregnated and covered with natural or synthetic rubber. The degree of reinforcement and strength of the form is of course determined by the stresses to be imparted to the form as a result of inflation thereof and casing thereon of the concrete shell. Suitably the form is constructed in the form of segments which are secured together by bonding, welding, sewing or the like so as to constitute the shape required. The segments can be arranged to overlap so as to impart a further degree of reinforcement to the form itself.

In the embodiment schematically illustrated in FIGS. **13***a* and **13***b* of the drawings, the form is constituted by rigid hexagonal plates **57** which can be formed of a suitable rigid material (e.g., hard rubber) which are bonded onto a flexible base at such a spacing that the entire structure remains flexible but assumes a hemispherical form when inflated.

Reference will now be made to FIGS. **14**, **15** and **16** of the drawings wherein are illustrated the construction of a composite form and cable structure and its use in the construction of reinforced concrete, roofs or floors. The composite structure comprises a peripheral base ring **61** to which is peripherally secured an upper flexible form **62** and an integrally formed lower flexible form base **63**. The upper form **62** and lower form base **63** are respectively enclosed between an upper set of form limiting cables **64** and a lower set of tensioning cables **65**. Both sets of cables are respectively secured at their outer sets of ends to the base ring **61**.

In a similar manner to that described above, the cables of each set are radially disposed and are secured at their inner ends to an inner ring **66** and at their outer ends to the base ring **61**. FIG. **15** shows clearly the construction of the two sets of cables **64** and **65** with the interposed form and base removed.

As can be clearly seen in FIG. **16** of the drawings, the base ring **61** consists of segments **67** of rectangular cross-sectioned shape, which are coupled together (by means not shown) so as to conform to the desired peripheral shape of the form. Secured to the segments **67**, in a manner similar to that described above, is a plurality of clamping elements **68** which are substantially identical in construction with the clamping of the combined rim of the upper form **62** and lower form base **63**. The outer ends of the two sets of cables pass through the segments **67** and are secured thereto, tensioning of the cables being possible at their inner ends.

In the use the composite form and cable structure is assembled so that the base ring **61** rests on a prepared structure on which the floor or ceiling is to be cast. Thus, as can be seen in FIG. **17** of the drawings, the composite structure is placed on the upper edge of a cylindrical building and is used to cast a roof for the building. The form is then inflated, it being ensured that inflation takes place to the desired pressure and this pressure is maintained during casting of the material and subsequent setting. The upper set of cables **64** serve to delimit the degree of inflation of the form and thereby ensure the relative flatness of the form and the structure subsequently to be cast thereon. The lower set of cables **65** on the other hand serve to take up the downwardly directed elevating forces which are created in the form base as a result of its inflation, these forces being converted into tensioning forces of the cables which are in turn transmitted to the base ring **61**. Cementitious material, such as concrete, is cast on the form, the upper form limiting cables becoming embedded in the concrete and serving to reinforce the concrete. If necessary and desired (especially in connection with large structures) the radially directed, form limiting, and concrete reinforcing cables can be bridged by transverse reinforcing elements in the form of cables, wire mesh or the like.

After the cementitious material, such as concrete has been cast on the form to the required depth, completely embedding the upper set of cables, the material is allowed to set after which the form is deflated and removed, leaving the cast roof or floor in position.

It can be shown theoretically that a structure cast on a composite form and cable structure in accordance with the present invention and as just described, enjoys special strength characteristics over and above structures constructed in a conventional manner. Thus it is possible to use this method for covering very substantial areas, such as sports stadiums, swimming pools, shelters or the like. The method is particularly economical as it can be carried out using a very thin layer of concrete and the degree of support for such a structure is also minimum.

While in the examples specifically described above the tensioning cables have always been shown to be disposed radially, embodiments can equally well be conceived where the tensioning cables are disposed in other transverse directions.

The provision of a domelike shell, constructed in accordance with the present invention, with windows can be effected by means of the combined window form and clamp shown in FIGS. **18** and **19** of the drawings. As seen in these drawings, a window **71** already fitted in a rectangular metallic window frame **72** is clamped between a pair of window form-clamp components **73** and **74**. The components **73**, **74** are both of inverted V-shape. The component **74** has an upwardly tilted, limb **75** and a pair of vertical limbs **76**, the outer edges of the limbs **75** and **76** being curved so as to conform with the shape of the flexible form to which it is to be attached. The component **73** consists of a substantially upwardly tilted limb **77** which terminates in an upwardly directed flange **78** and substantially vertical limbs **79** whose outer edges slope downwardly towards the flexible form. The two components **74** and **73** are secured to each other and to the metallic window frame **72** by means of straps **80** which are bolted to the adjacent components and the frame by means of bolts **81**, these bolts being removable from inside the window form-clamp.

The window form-clamp together with the window rests on a precast window sill **82**, the latter being supported in the required position against the flexible form by support means (not shown). Cementitious or plastic material is applied to the flexible form and to the window form-clamp so as to adopt the outer contour shown by the broken line **83**. When the cementitious or plastic material has set and the flexible form removed, the form-clamp components **73** and **74** (which can be made, for example, of suitable fiber glass material) can be detached by removal of the bolts **81**. The component **73** can be removed from the outside of the shell whilst the component **74** can be removed from the inside of the shell. Thus, the window **71** and its frame **72** are left firmly set in the wall of the shell within an appropriate window niche. If desired the form-clamp components can be left in position. Where, however, the form-clamp components are removed they can be reused on further occasions.

In the embodiment show in FIGS. **20**, **21** and **22** of the drawings, a simplified and modified form of base structure is employed. With this base structure an annular concrete base ring **85** is preliminarily cast and, if desired, is anchored in the ground. Embedded in and projecting upwardly from the concrete ring **85** and equiangularly spaced around the ring **85** are mounting posts **86**. The concrete base ring **85**, when being cast is provided with through-going bores **87** through which tensioning cables **88** are arranged to pass. As shown in the drawings the through-going bore **87** as well as the upper surface of the concrete ring **85** slope slightly upwardly in a direction away from the center of the ring. Coupled to the mounting posts **86** is a form clamping structure **89** which consists of a plurality of annular segments **90** and a plurality of clamping elements **91** having the characteristic questionmark profile referred to above. The segments **90** and clamping elements **91** are coupled together and to the mounting posts **86** by means of elongated bolts **92** which pass through the juxtaposed elements and which are provided with tightening nuts **93** and elongated sleeves **94**.

The end of each tensioning cable **88** which emerges from the base ring **85** is externally threaded and is provided with a nut **94***a*, a steel washer **95** and a flexible washer **96**. As seen in FIG. **22** of the drawings, adjacent segments of the clamping mechanism **89** are rigidly coupled together by means of pairs of coupling plates **97** and **98**, the coupling plate **98** being formed integrally with an elongated tubular sleeve **99**. A coupling bolt **100** extends through the coupling plates **97** and **98**. Clamping of the two plates together is effected by means of a nut **101** which, bearing against the end of the sleeve **99**, presses the two coupling plates **97** and **98** together, thereby securing together the two elements **90** and **91** of the clamping structure.

In operation, the rim of an inflatable form is clamped in the clamping structure **89** in a manner as described above (ensuring the required pretensioning of the form rim) and the clamping structure itself is secured to the mounting posts **86** by tightening of the clamping nuts **93**. Successive segmental sections of the clamping structure are rigidly secured together by tightening of the clamping nuts **101** on the clamping bolts **100**. The tensioning cables **88** are then given a predetermined degree of slackness by turning of the nuts **94***a* and upon the inflation of the form, the cables **88** are tensioned by the downwardly directed force on the form base. The cementitious or other suitable material is then applied to the form so as to form a shell **97**. When this has set, loosening of the nut **93** results in the unclamping of the rim of the flexible form which thereupon can be removed as can the clamping structure **89** and the tensioning cables **88**, the resulting concrete shell having been formed on the concrete base ring **85**.

Whilst in the embodiments described above the shell is formed on a base ring which can, if desired, be anchored to an appropriate foundation and which serves for anchoring the rim of the inflatable form, there will now be described, with reference to FIG. **23** of the drawings, an embodiment wherein the shell is formed on a base structure which is entirely separate from the base ring, thereby allowing the base ring to be removed together with the inflatable form after the setting of the shell for reuse.

As seen in FIG. **23** an inflatable form **105** is anchored to a base structure **106**, the latter being of the kind described above, for example, with reference to FIG. **3** of the drawings. The base ring **107** of the base structure **106** is supported on the jacks **108** by virtue of which the base ring is raised sufficiently from off the ground **109** to take account of the downward displacement of the tensioning cables **110** and inner ring **111** upon inflation of the form. The base structure **106** is located within a cylindrical wall **112** which can be constructed by conventional means and which, in addition to any preformed apertures for doors etc., is provided with apertures **113** by means of which access can be had to tensioning nuts **114** located on the base ring **107** and by means of which the slackness of the tensioning cables **110** can be adjusted to a required level.

As can be seen from the drawing the wall **112** is sufficiently spaced from the base ring **107** for the vertical wall to be directed substantially tangentially to the inflated form **105** and so that the layer of cementitious material **115** applied to the form **105** continues initially, substantially continuously from the cylindrical wall **112**. In other words the form must "swell" towards the cylindrical wall.

This modification renders the process cheaper and faster to carry out seeing that it is possible to retrieve and reuse the base structures of the inflatable form whilst the use of jacks for raising the base structure above the floor facilitates the use of this method with floors which are preformed. The cylindrical wall can be formed by any conventional method such as, for example, the use of preformed segmental blocks.

Whilst in all the specific embodiments described above there has been described a base structure having a base ring so constructed as to be capable of withstanding the compressive forces arising out of the tensioning of the tensioning cables, the present invention is equally applicable in the case of a base structure having a base ring constructed to be capable of withstanding the forces arising out of compressing the cable.

FIGS. **24** and **25** of the drawings show schematically such a modification. As seen in FIG. **24** a form **117** having a base **118** is anchored to a base structure **119** consisting of a base ring **120** to which are secured the ends of a plurality of radial compression struts **121** whose inner ends are coupled at a central hub **122**. As seen in the drawing, upon inflation of the form **117** the base **118** thereof adopts a convex shape (as opposed to the concave shape adopted by the base in all the previous embodiments) and this base presses down on the compression struts **121** as a result of which these struts press against the ring **120** which is in consequence tensioned.

In the embodiment shown in FIG. **25** the struts **121** of the embodiment shown in FIG. **24** are replaced by radial trusses **123** which also serve to convert the downwardly directed forces acting thereon into tensioning forces on ring **120**.

The ring **120** which is made of metal can easily withstand such tensioning forces and in consequence the forces which would otherwise tend to lift the form are easily overcome without any necessity for anchoring the base structure in the ground.

It will readily be seen that embodiments of the kind shown in FIGS. **24** and **25** enjoy the advantage that the base ring can be placed directly on the ground there being no necessity for allowing for the downward displacement of the tensioning cables.

It should be realized that the invention is not only applicable in the case of construction of hemispherical domes or structures with a circular peripheral shape but structures of other shapes can equally well be constructed.

Finally, while the invention has been specifically described in connection with the use of an inflatable form, on which, after inflation a cementitious plastic material is applied and is allowed to set, the invention is equally applicable in the case where the form is used as a basis round which there is constructed, for example, a geodesic construction. Alternatively the invention is applicable in the case wherein the cementitious material is applied to the form prior to its inflation and the form is subsequently inflated and the material is allowed to set.

I claim

1. Pneumatically inflatable form apparatus for use in the construction of shell-form structures, said apparatus comprising a stress resisting base assembly which includes a rigid, perimeter defining structure and a transverse structure extending across and connected to said perimeter defining structure, said perimeter-defining structure comprising a rigid base ring of predetermined shape and said transverse structure comprising a plurality of elongated stress transmitting members extending across and anchored to the base ring, a flexible inflatable form having a peripheral rim and a flexible base, means securing said rim to said perimeter defining structure with said flexible base resting on said transverse structure, said base assembly being sufficiently rigid to oppose, independently of external forces, deflection of said flexible base upon inflation of said form, said base assembly together with said form constituting a closed force system which prevents interiorly exerted pneumatic forces within said form from acting as elevating forces on said perimeter defining structure.

2. Apparatus according to claim **1**, wherein said base ring comprises a plurality of rigid curved segments and means coupling said segments together.

3. Apparatus according to claim **2**, wherein said means securing said rim to said perimeter defining structure comprises a plurality of clamping elements attached to the segments and means for tightening the clamping elements against the segments with said peripheral rim squeezed between said segments and said clamping elements.

4. Apparatus according to claim **1**, wherein said transverse structure comprises a plurality of elongated tensioning members extending across and anchored to the base ring.

5. Apparatus according to claim **4**, wherein said transverse structure further includes a centrally located hub and wherein said tensioning members extend radially from said hub to said base ring.

6. Apparatus according to claim **1**, wherein said transverse structure comprises a plurality of radial struts with outer ends bearing on the base ring and inner ends located out of the plane of said base ring in the direction of said form.

7. Apparatus according to claim **6**, wherein said radial struts are configured to form a low dome-shaped structure which fits within said form.

8. Apparatus according to claim **1**, wherein said base assembly is collapsible and removable from a shell-form structure constructed about said apparatus.

9. Apparatus according to claim **2**, wherein said peripheral rim is formed in the configuration of an annular pocket which extends around the form where the flexible base joins the form.

10. Apparatus according to claim **9**, wherein said pocket contains an anchoring pipe.

11. Apparatus according to claim **10**, wherein the anchoring pipe is a flexible hollow tube connected to a source of fluid pressure.

12. Apparatus according to claim **10**, wherein said annular pocket and anchoring pipe are held by clamping elements connected to the base ring.

13. Apparatus according to claim **1**, further including a plurality of transversely extending members anchored to the perimeter defining structure and located above the inflatable form, said form being positioned to inflate downwardly with said flexible base pressing upwardly against said transversely extending members whereby said transversely extending members become embedded in casting material poured over the apparatus and as so embedded, serve as reinforcing members for the casting material.

* * * * *