Jan. 14, 1964 H. HARRINGTON 3,118,010

METHOD AND APPARATUS FOR CONSTRUCTING A CONCRETE STRUCTURE

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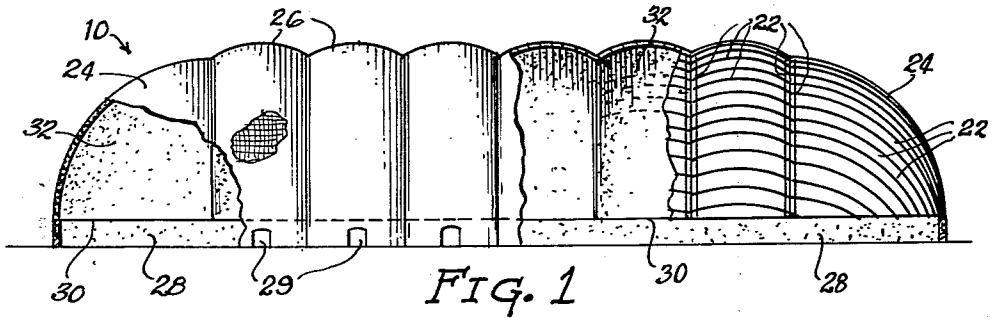


FIG. 1

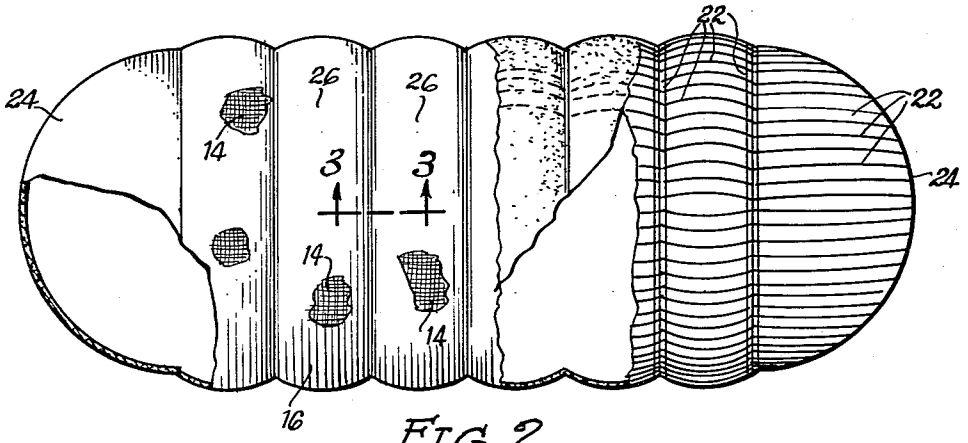


FIG. 2

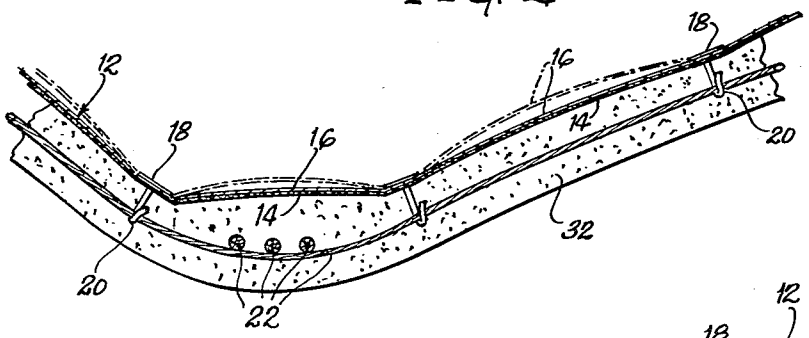


FIG. 3

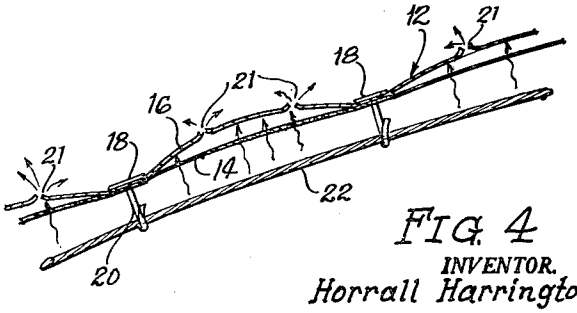


FIG. 4

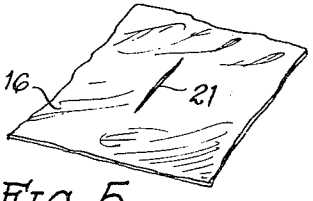


FIG. 5

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METHOD AND APPARATUS FOR CONSTRUCTING A CONCRETE STRUCTURE

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This invention relates to a building structure and method of making the same and, more particularly, to a shell-form self-supporting concrete structure fabricated within an inflatable form.

The method of making shell-form concrete structures upon an inflatable form is known to the prior art. As previously practiced, a pneumatic form anchored to a foundation was inflated to shape and concrete sprayed thereon in thin layers. When the concrete had hardened sufficiently, the form was deflated and removed leaving the hardened shell behind and concrete was then added to form walls of desired thickness. See Neff patent, No. 2,335,300.

This method of making such structures and the structures themselves had many disabling disadvantages. The concrete being required to be sprayed on the outer surface of the form was adversely affected by the weather. Windy conditions would tend to distort the form before the concrete could set. Workmen could not work under rainy or cold conditions and variations in humidity and temperature would adversely affect the concrete and the strength of the hardened material.

In addition, the structure itself developed faults due to the weight of the concrete on the dome and the side wall portions crack and crumble at the plane of rupture.

Attempts have been made to eliminate the cracking by stressing the concrete but without success. The use of tensioning rings resulted in serious deformation of the side walls and pre-stressing the concrete was considered impossible. As the prior art states: "Due to the curvature of the form side wall, it was not considered feasable or even possible to apply wire mesh reinforcement to the pneumatic form in such a manner that it could be pretensioned so as to place the hardened concrete material of the structure side wall under compression following removal of the form."

Accordingly, it is an important object of the present invention to provide a method of building a shell-form concrete self supporting structure which is free from the deficiencies of the prior art, and to provide a structure which will not crack or crumble.

Another object of the invention is to provide a method of building such structures wherein the concrete is applied from the inside of the form as opposed to the outside application of the prior art, thus eliminating or reducing the weather hazards encountered by the prior art.

Another important object of the present invention is the employment of a network of wire ropes on the inside of the form which may be varied so that the shape of the form may in turn be fashioned to accommodate a wide variety of the uses of the finished structure.

Still another important object of the invention is to provide an inflatable form of greater tensile strength, greater dimensional stability, greater resistance to puncture damage during construction, and which has an absorbent surface to which the concrete is applied to aid adhesion of the said concrete.

Still another important object is to provide a form wherein the inflation pressure is greater than that corresponding to the weight of the wet concrete.

A still further object is to provide a structure wherein the concrete is prestressed to prevent any cracking or crumbling.

The foregoing and other objects and advantages of the invention will become apparent from a consideration of the following specifications and the accompanying drawings wherein:

FIG. 1 is a part sectional and part elevational view of a shell-form structure made in accordance with the present invention.

FIG. 2 is a top plan view of the structure shown in FIG. 1, partially broken away.

FIG. 3 is a sectional view taken on line 3—3 of FIG. 2.

FIG. 4 is a cross sectional view of a portion of the inflated form before concrete is applied.

FIG. 5 is a perspective view of a portion of the plastic outer layer of the inflatable form showing a closed air outlet slit.

Referring to the drawings, FIG. 1 discloses a concrete structure indicated generally by the reference numeral 10, erected on a suitable foundation of concrete or other like material. As shown, the structure is erected by applying a cementitious material on the inner surface of an inflatable form of predetermined size and shape. Because the cementitious material is sprayed on the inside surface, it is necessary to provide a form of unique construction whereby the wet cementitious material is caused to adhere strongly to downwardly sloping concave surfaces.

The form provided comprises a laminated envelope 12 having inner textile layer 14 and an outer impervious layer 16, preferably formed of plastic film although other appropriate materials may be used. As may be seen in FIGS. 4 and 5, the outer layer 16 is provided with a plurality of slits or bleeding apertures 21 for reasons hereinafter described. The inner and outer layers of the envelope 12 are secured together at predetermined intervals by means of suitable connectors 18 and a plurality of hooks 20 depending inside the envelope 12 are attached thereto. The hooks 20 are adapted to hold a network or system of wire ropes 22 which assume their final position on the inside of the envelope when said envelope is inflated.

The ropes 22 have a plurality of functions. They reinforce the envelope 12 against internal air pressure of inflation thereby preventing blowouts and permitting the envelope to be made of thinner and less expensive material than would otherwise be possible. Being under inflation pressure, the wire ropes 22 are subjected to considerable tensile stress during the placement of the concrete. Release of the pressure after the concrete has been applied and has hardened subjects the concrete shell to compressive stress in both directions as the wire ropes tend to contract. Thus a prestressing is achieved which eliminates or greatly reduces the probability of subsequent cracking of the shell due to thermal stresses, wind or shrinkage. Furthermore, the placement of the ropes 22 may be varied in a manner to cause the envelope 12 to take on a variety of forms and shapes to suit any particular need so that a standard form envelope may be used to form differently shaped structures.

Any inflated flexible form tends to assume shapes whose elements are circle arcs reflected the fact that a circle is the minimum length of perimeter of a form to encircle a given area. In the embodiment shown in the drawing, the envelope is designed so that ends 24 are quarter spheres and the intermediate portions 26 form a series of connected segments each having the form of a semi-torus. See FIGS. 1 and 2. Such an arrangement is desirable because it takes advantage of the natural form assumed by the inflated envelope and the shape permits a minimum wall area to enclose a maximum floor area, thereby decreasing building costs. Furthermore, the segmented or bellows-like shape allows the building to ex-

pand thermally without requiring the use of expensive expansion joints. The finished shell will be structurally stable with relatively few bending moments regardless of its size.

Giving attention now to the method of constructing the building shell, a suitable foundation 28 is first laid. In large structures, the foundation walls may be of a size to permit doors 29 to be formed therein. The envelope 12 with the wire ropes 22 attached to its inner surface is arranged on the foundation 28 and the lower edge 30 of the envelope is then secured thereto. Compressed air is introduced to the interior of the envelope to inflate it to its predetermined form. The envelope then is ready for processing.

Because the novel method requires that the application of the cementitious material be applied on the inside of the envelope 12, it is necessary that the work be done under inflation pressure. It has been found that inflation pressure in the range of 25 to 50 pounds per square foot produces satisfactory results. Physiologically, such a pressure presents no hazard to the workman since it is a variation in absolute pressure of only 2 to 3% from normal atmospheric pressure. Workmen enter the interior of the inflated form through a suitable entrance provided for that purpose, where they are protected from the weather. The inner surface of the envelope 12 is then sprayed with a lightweight cementitious material 32, preferably one with the expanded shale aggregate because of its low creep properties, and continues until the wire ropes 22 are fully embedded in the cementitious material 32, as seen in FIG. 3.

The inflation of the envelope 12 is maintained during application and hardening of the cementitious material. The inflation pressure within the range above stated will always be greater than that corresponding to the weight of the wet cementitious material per square foot. For example, a lightweight cement weighing 80 pounds per cubic foot will weigh approximately 20 pounds per square foot in a 3-inch thickness. Thus, the inflation pressure within the stated range will always provide a safety factor for sustaining the wet material as well as assuring stability of the envelope aginst the effects of wind and preserving the desired shape of the building as the concrete hardens.

The adherence of the wet cementitious material 32 to the downwardly sloping concave surfaces of the envelope 12 is also aided by the controlled flow of air through the envelope. As shown in the illustrated embodiment as the envelope 12 becomes inflated, air flows through the inner textile layer 14 and puffs the outer layer 16 causing the normally closed edges of slits 21 in the plastic layer to separate permitting air to escape, as is shown in FIG. 4. This flow of air pulls a quantity of the wet cementitious material 32 into the interstices of the textile layer 14 causing the material to strongly adhere to the wall surfaces. The number and size of the slits 21 are predetermined to precisely regulate the air flow through envelope 12 and in that respect the slits perform the function of air valves.

It must then be seen that the flow of air through the envelope 12 is an important step in the process and that in the embodiment shown, such air flow is controlled by the structure of the plastic 16 having the slits or bleeding apertures 21. It has been found that the air flow may also be controlled by controlling the porosity of the textile material, in which case the plastic outer layer 16 may be dispensed with. In such a structure, the air pressure required for a desired form is calculated and the textile material is treated by applying a solution containing a polyvinyl chloride or other similar solution thereto, thereby fixing the porosity of the material within prescribed limits. In such a structure, when the air pressure within the inflated envelope reaches a predetermined range, air will bleed through the interstices of the material just as it will bleed through the slits 21 in the embodiment shown. The nature of the solution used in treating the textile material and its application thereto are well known to workers in this art, and of themselves do not form a part of the present invention.

The control of air flow through the envelope 12 is particularly important when constructing large concrete shells because the envelope must be correspondingly larger. For example, it is contemplated that the shell shown in FIGS. 1 and 2 of the drawings is to be 400 feet long, 200 feet wide and 60 feet high. Without any air flow, as would be the case with an impervious plastic sheet, the cement would have difficulty adhering to the inner surfaces of the form. If the air flow is not controlled, difficulty would be encountered in inflating the envelope without the use of expensive machines which would make the process uneconomical. However, by controlling the air flow, as above described, and keeping it within tolerable and predetermined limits, even very large envelopes may be inflated by machinery which is economical and readily available.

After the cement hardens, the pressure is released and the building retains its shape because of the structural strength of the cementitious material 32, reinforced by the wire ropes 22. Upon the release of pressure, the outer plastic layer 16 moves from its puffed position, shown in dotted line in FIG. 3, to a collapsed solid line position substantially coextensive with the inner textile layer 14. The edges of the slits 21 in the plastic layer 16 then move back together to prevent the entrance of moisture.

As previously stated, the wire ropes 22 are subjected to considerable tensile stress by the inflation of the envelope 22. Upon release of the pressure after the concrete has hardened, these ropes tend to contract subjecting the hardened concrete shell to compressive forces which greatly reinforce and strengthen it. It is apparent that to further support the shell, particularly in large structures, suitable supporting columns (not shown) may be provided in a manner well known in the art.

It is to be noted that the envelope 12 remains a permanent part of the concrete shell 10 and serves as a waterproof exterior cover therefor. Consequently, there is no need for a separately applied expensive waterproof cover or waterproof coating for the shell.

Thus, it will be understood that the present invention comprehends a novel method of constructing a concrete shell upon a novel inflated form wherein concrete is applied upon the inside of the form and whose shape may be varied and tensile strength increased by a system of wire ropes embedded in the concrete. This produces a novel structure wherein the hardened concrete is prestressed to prevent cracking or crumbling.

While the present invention has been explained and described with reference to specific embodiment of method and structure, it will be understood nevertheless that numerous modifications and variations are susceptible of being incorporated without departure from the essential spirit or scope thereof. Accordingly, it is not intended for an understanding of this invention to be limited by the foregoing description nor by the illustrations in the annexed drawings, except as indicated in the hereinafter appended claims.

What is claimed as new and desired to be secured by Letters Patent of the United States is as follows:

1. The method of constructing concrete shell structures, of a shape whose elements are circle arcs, by use of an inflated pneumatic form conforming essentially to the ultimate extensive configuration of the structure, comprising the steps of providing a laminated inflatable member having an inner layer capable of receiving and retaining wet cementitious material, lining said inflatable member with a network of wire ropes in predetermined design, securing said lined member to a suitable foundation, inflating said member with a pressure greater than the corresponding weight of wet cementitious material to be applied thereto and thereby stressing said wire ropes, applying wet cementitious material to the inner surface of

said member and to the said wire ropes, and maintaining said inflation pressure while the said cementitious material hardens whereby the stressed wire ropes are embedded in said material and the hardened material is compressed when inflation pressure is released.

2. A method as in claim 1, wherein the inner layer is a textile material.

3. A method as in claim 2, wherein the outer layer is a plastic film bonded to the inner layer at predetermined intervals and having valve-like slits therein to permit air bleeding and pressure control.

4. A method as in claim 3, wherein the inflation pressure is within the range of 25 to 50 pounds per square foot.

5. The method of constructing concrete shell structures of a shape whose elements are circle arcs by use of an inflated pneumatic form conforming essentially to the ultimate extreme configuration of the structure comprising the steps of securing a laminated inflatable member to a suitable foundation, said member having an inner layer of textile material capable of receiving and retaining wet cementitious material, and an outer layer of plastic film bonded at predetermined intervals to said inner layer and having valve-like slits therein for pressure control, inflating said member to a pressure within the range of 25 to 50 pounds per square foot, applying wet cementitious material to the inner layer of said member and maintaining said inflation pressure until the cementitious material hardens.

6. The method of constructing concrete shell structures of a shape whose elements are circle arcs by use of an inflated pneumatic form conforming essentially to the ultimate extreme configuration of the structure, comprising the steps of providing an inflatable member of textile fabric which has been treated to effect a desired degree of porosity to control the flow of air therethrough and whose surface is capable of receiving and retaining wet cementitious material, lining said member with a network of wire ropes in predetermined design, securing said lined member to a suitable foundation, inflating said member with a pressure greater than the corresponding weight of wet cementitious material to be applied thereto and thereby stressing said wire ropes, applying said cementitious material to the inside surface of said member and to said wire ropes, thereby embedding said wire ropes in said material and maintaining said inflation pressure while the wet cementitious material hardens to maintain the stressed wire ropes embedded in said material, whereby the hardened material is compressed when inflation pressure is removed.

7. A method as in claim 6 wherein the inflation pressure during the application of the wet cementitious material is maintained within the range of 25 to 50 pounds per square foot.

8. An inflatable form for making concrete shell structures comprising a flexible envelope of such size and shape that upon inflation it assumes the size and shape of the finished concrete shell structure, said flexible envelope comprising a porous inner textile layer and an outer air-impervious layer of plastic film, said plastic layer being bonded to said textile layer at predetermined intervals, and a plurality of slits formed in said plastic film so that when the flexible form is inflated the slits function as valve-like members and part far enough to permit a controlled flow of air through the flexible form.

9. An inflatable form for making concrete shell structures comprising a flexible envelope of such size and shape that upon inflation it assumes the shape of the finished concrete shell structure, said flexible envelope comprising a porous inner textile layer and an outer layer of plastic airtight film, said plastic film being attached to said textile layer at predetermined intervals, a plurality of slits formed in said plastic film so that when the flexible envelope is inflated, the slits function as valve-like members and part far enough to permit a controlled flow of air through the envelope, and a plurality of wire ropes attached to the inside of said flexible envelope at predetermined intervals before the envelope is inflated, said ropes being adapted to control the shape of the inflated envelope and to reinforce the concrete applied to said form.

10. An inflated form for making concrete shell structures comprising a flexible envelope of such size and shape that upon inflation it assumes the size and shape of the finished concrete shell structure, said envelope comprising a textile material whose surface has been treated to effect a desired degree of porosity to control the flow of air therethrough, and a network of wire ropes of predetermined design attached to the inside of said envelope at predetermined intervals before the envelope is inflated, said wire ropes being adapted to control the shape of the inflated envelope and to reinforce and prestress the concrete applied to said form.

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