Jan. 4, 1966 R. A. ROSE ETAL 3,226,892

SHELL ROOF CONSTRUCTION

Filed March 20, 1963 4 Sheets-Sheet 1

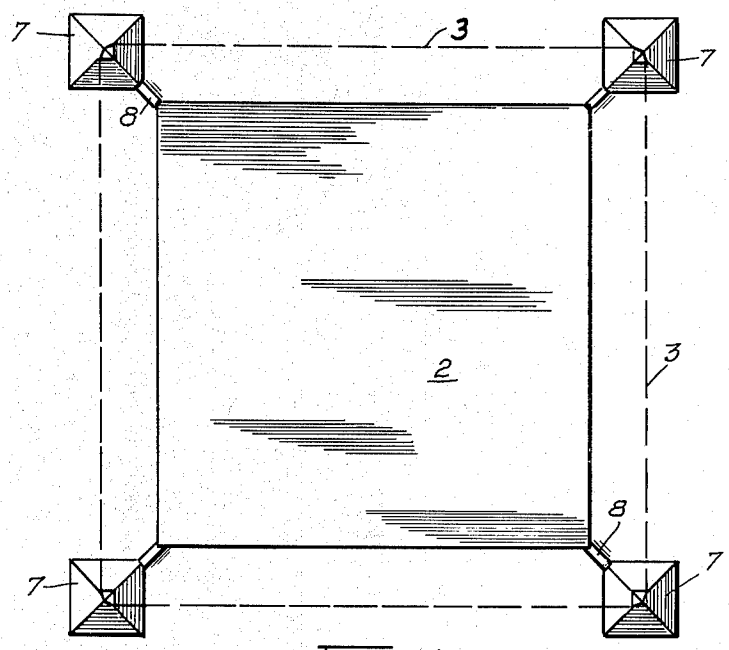

FIG. 1

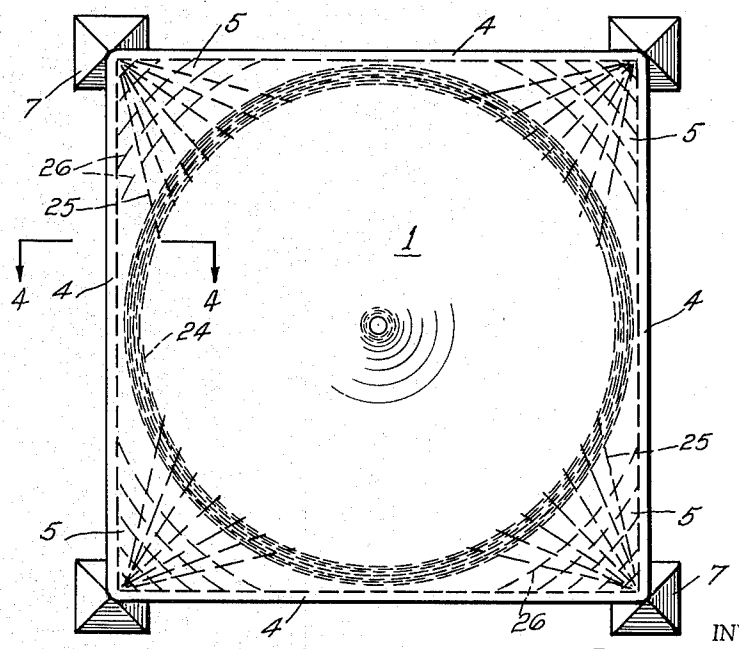

FIG. 2

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SHELL ROOF CONSTRUCTION

Filed March 20, 1963 4 Sheets-Sheet 2

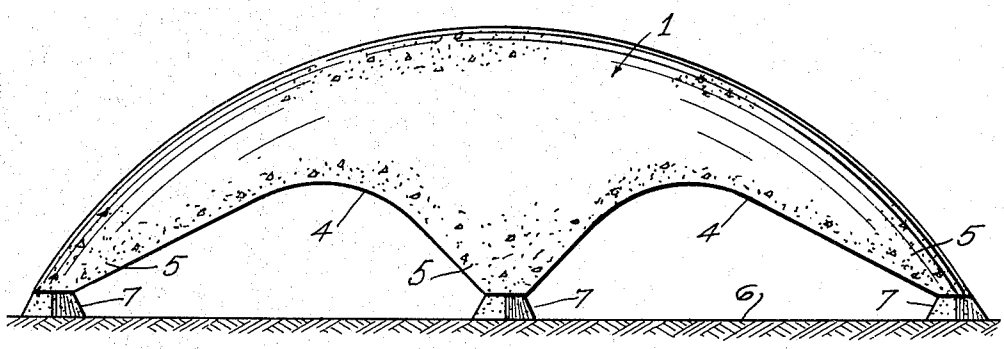

FIG. 3

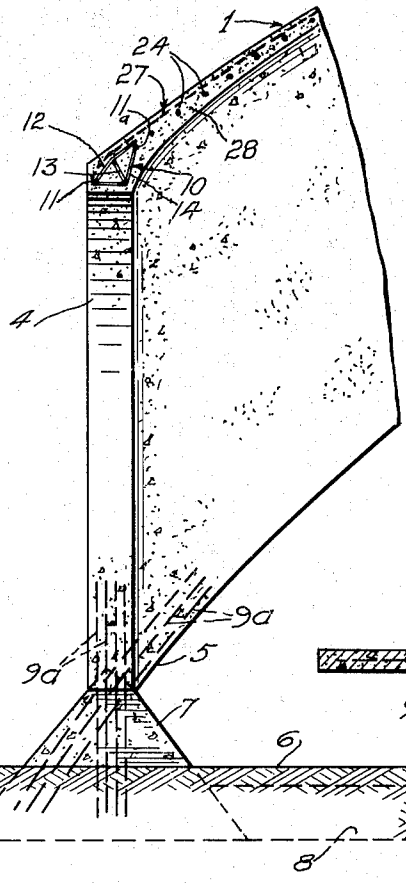

FIG. 4

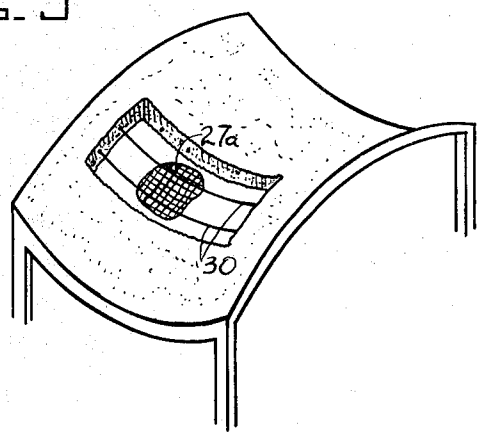

FIG. 4A

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SHELL ROOF CONSTRUCTION

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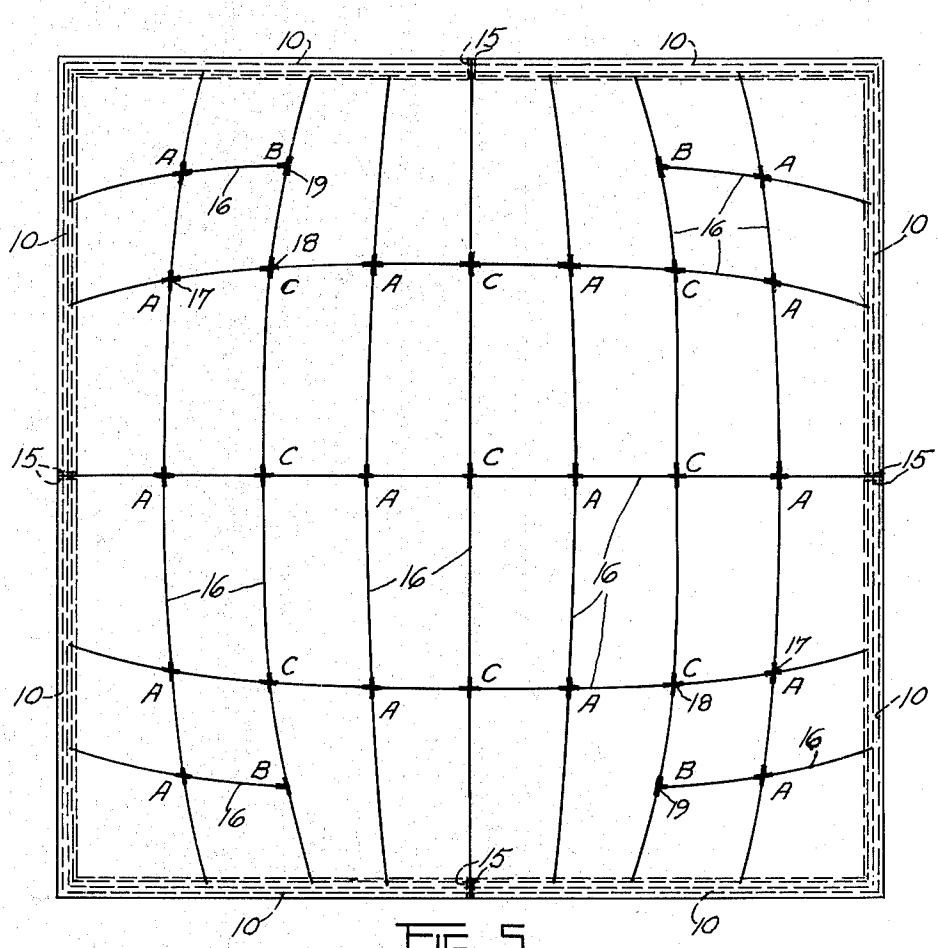

FIG. 5

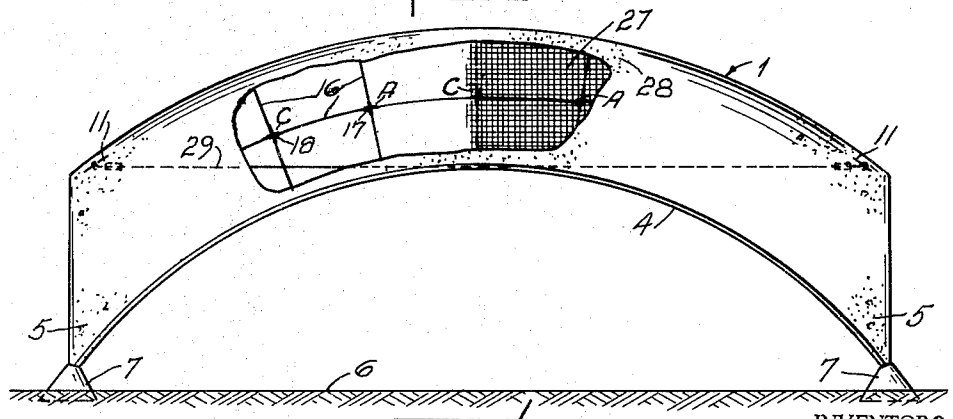

FIG. 6

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SHELL ROOF CONSTRUCTION

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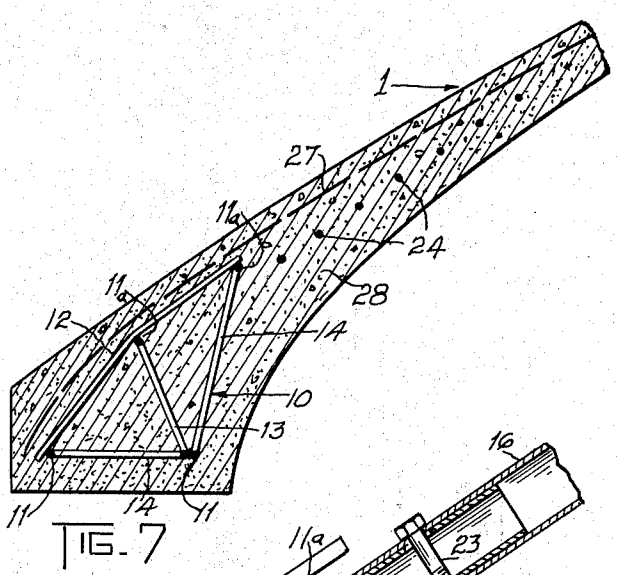

FIG. 7

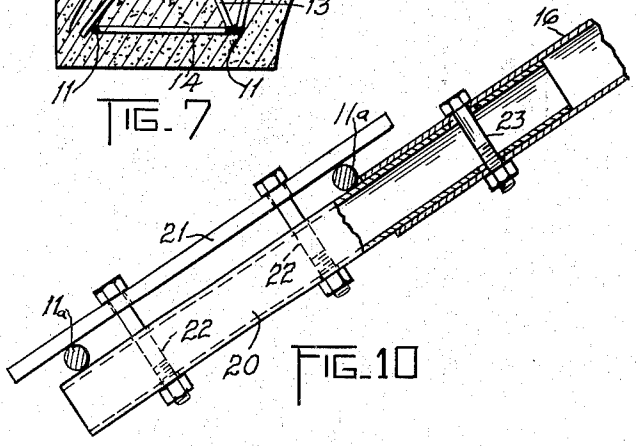

FIG. 10

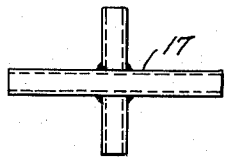

FIG. 11A

FIG. 12

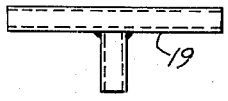

FIG. 11B

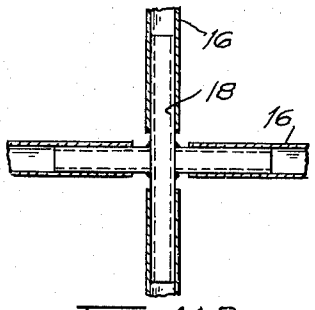

FIG. 11C

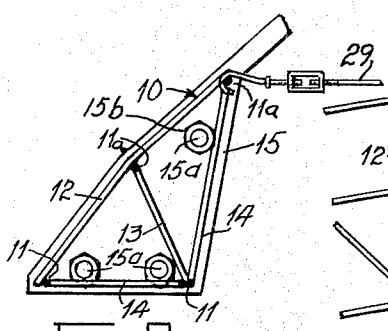

FIG. 9

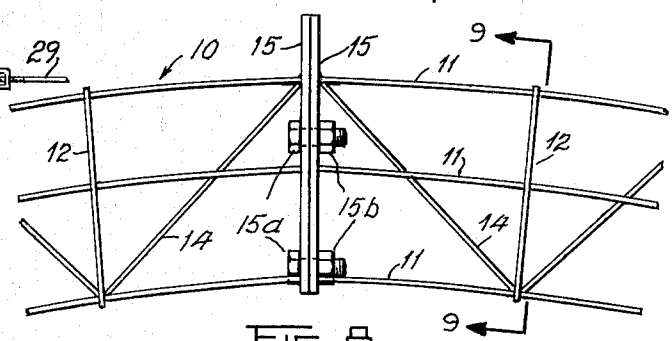

FIG. 8

FIG. 13

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3,226,892

Patented Jan. 4, 1966

3,226,892

SHELL ROOF CONSTRUCTION

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Filed Mar. 20, 1963, Ser. No. 266,643
4 Claims. (Cl. 52—80)

The present invention relates to shell structures and more particularly to a new and improved method of reinforcement employed in the construction of shell type roofs.

The design and construction of shell structures has increased in recent years.

Although the principal material used has been steel reinforced concrete, an increasing variety of other materials is becoming available, among which are plastics and metal alloys. The number of sizes and shapes of this type of structure is virtually unlimited. For ease of analysis and design, however, those forms which lend themselves to less complex mathematical expressions have most often been used, i.e. spheres, paraboloids, ellipses, conoids, hyperboloids.

Because of the great flexibility in size and shape, the functional and aesthetic potential of shell structures is tremendous. The economic potential is also great because, in its final condition, the shell requires a minimum of material. This economic potential has not fully been realized due to the fact that no really practical method of construction, especially for roofs, has as yet, been devised but which it is a main object of the instant invention to accomplish.

All methods of shell construction utilized thus far employ an external means for supporting the shell during its erection. These methods have included wood frames, earth mounds, balloons, cranes, etc. The forms and supports must be carefully laid out and constructed in the field. The materials comprising the shell itself are then placed. Finally, after waiting a period of time for the shell materials to develop their strength, these external forms or supports, must be carefully removed. This involves a great deal of labor and material, most of which, is in a sense, wasted, since it does not contribute to the function of the shell in its final form.

To provide a new method for the design and construction of shell structures requiring no external means of support, and which effects great economies in the erection of these structures, as well as offering other advantages to be described, is an important object of the invention.

Shells are composed basically of two structural elements which, when placed together in the desired shape and form, interact with each other so as to give stability to the structure as a whole. One of these elements is the shell membrane. This must usually be capable of withstanding direct compressive forces, the material most often used for this membrane being concrete or plastic. The other basic shell element is the reinforcing, usually a metal or rigidized plastic, the function of which is to impart to the shell the means of resisting bending, twisting tension and temperature stresses.

In the design of the shell, according to our new and improved method, the major bending and torsional stresses occur at the boundary or perimeter portions of the shell. The heaviest shell reinforcing is, therefore, at these locations. It is another object of the invention to provide such reinforcing by means of a series of space frames capable of supporting the weight of all materials in the shell itself.

Reinforcing within the shell proper is needed primarily to withstand tension and temperature stresses. This reinforcing is designed as an auxiliary support system and it

is a further object of the invention to provide a system of this character which, in conjunction with the space frames, determines the shape and dimensions of the shell.

A further object of the invention is the inclusion in the auxiliary support system of means such as metal lath, wire or plastic fabric which can of itself contain and support the membrane material in its initial state.

And a still further object of the invention is the provision of a shell structure in which reinforcement such as above described can to a large extent be prefabricated in parts and assembled in the field, all of which leads to advantages relating to establishment of the outer limits of the shell and more accurate dimensional control.

Since there is no external falsework or supports to be removed, and consequently no waiting time while the membrane "cures," whatever construction is to take place under or within the shell, can proceed immediately without any delay, this being a further and important object of the invention.

And, a still further object of the invention is the advantage obtained in the virtual elimination of damaging secondary stresses and deformations. In an externally supported shell a stress pattern is developed during construction, which is changed with relative suddenness upon removal of the external supports. With the method described here, the stress patterns developed during construction are similar to those of the final design and function. Deformations can be seen and compensated for as construction progresses, since the lack of external supports permits these deformations to manifest themselves at a time when they are most easily corrected.

These, and other objects and advantages of the invention will be made apparent from the following more detailed description, taken in connection with the accompanying drawings, and particularly defined in the appended claims.

The drawings are as follows:

FIGURE 1 is a plan view showing the corner abutment footings for the four arched sides of a shell roof constructed in accordance with the invention, and the floor slab of a building structure to be erected under the roof the latter being shown only in dotted line.

FIGURE 2 is a plan view illustrating tension ring placing and shell corner reinforcement.

FIGURE 3 shows the shell roof in elevation, the view being diagonally of the abutment footings.

FIGURE 4 is an enlarged vertical sectional detail taken on line 4—4, FIGURE 2.

FIGURE 4A shows one type of downwardly curved shell.

FIGURE 5 shows diagrammatically the steel centering placing plan.

FIGURE 6 is an elevation of the roof as viewed from one side, a portion of the shell being broken away to show parts of the auxiliary support system.

FIGURE 7 is an enlarged sectional detail similar to FIGURE 4, but through the shell roof only, and showing additional elements of the shell reinforcement.

FIGURE 8 is a joint detail of the space frame shown in front elevation.

FIGURE 9 is a sectional view on line 9—9, FIGURE 6.

FIGURE 10 is an enlarged detail in side view of the connection between a shell supporting tube and the space frame.

FIGURES 11A, 11B and 11C are details in plane view of supporting tube connectors at designations A, B, and C respectively, of FIGURE 5.

FIGURE 12 is a side view of the tube connector seen in FIGURE 11A.

FIGURE 13 is a side view of a support tube section.

Similar reference numerals refer to similar parts throughout the drawing.

Numeral **1** represents generally a concrete shell providing a dome roof for a structure to be erected under the roof, the floor slab **2** only of such a structure being shown.

The shell **1** is squared along chord lines **3**. This results in the roof being four sides and with each side forming an arch **4**, the outer faces of these arches being coincident with the lines **3**.

At the four corners of the arched sides the roof **1** terminates in gradually narrowing leg portions **5** supported as illustrated in FIGURES 3, 4, and 6, above finished grade line **6**, upon abutment footings **7**. These footings **7**, are shown connected through strap anchors **8** with the foundation wall **9** upon which the floor slab **2** is built. And, as seen in FIGURE 4, the portions of arches **4** terminating at each abutment **7** are reinforced by dowels *9a* in accordance with standard practice.

The arches **4** define the perimeter of the shell **1** and the method of construction, according to the present invention, requires that the perimeter reinforcing be designed as a series of space frames capable of supporting the weight of materials in the shell. Consequently the skeleton frame structures outline and give shape to the arches. The space frames are preferably prefabricated in sections that can readily be joined together in the field.

For each arch **4** there are two similar space frame sections **10**, each such section includes a plurality, five in this instance, of reinforcing bars **11** paralleling the curvature of the arch. These bars **11**, as shown in FIGURE 9, are rigidly held in spaced triangular relation by radial ties **12** and **13** and trussed ties **14**.

The bars **11**, at one end of each frame section **10**, terminate at the foot of the arch, their other ends being welded to a wide face of a butt plate **15**. The plates **15**, **15**, of each pair of frame sections **10**, abut each other and are secured together by suitable fastening means, such as the bolts *15a* on which nuts *15b* are threaded.

Alignment cables **29** are connected to opposite points on the space frames to maintain the space frames in vertical alignment during placement of the shell membrane.

The next step in our method of shell construction is the erection of the auxiliary support system which provides the reinforcing elements needed primarily to withstand tension and stresses within the shell proper. This reinforcement is so designed that, in conjunction with the space frames, the shape and dimensions of the shell are determined.

The just above mentioned support system includes a plurality of arched tubes **16**, extending from the frame sections **10** aligned with one arch **4** to corresponding points on the like sections **10** outlining the opposite arch. Similarly, the space framing outlining the other two arches **4**, is connected. This arrangement of arched tubes **16**, forms the grid or steel centering pattern shown diagrammatically in FIGURE 5. The arched tubes **16** are preferably made of metal or plastic and, because of their length and curvature, are in sections which can be more accurate if precut and then assembled in the field.

At arched tube crossings A and C, FIGURE 5, the arched tubes **16**, have telescopic connection with tubular connectors **17** and **18**, respectively, made in the form of crosses as seen in FIGURES 11A, 11C and 12. At crossings B the connectors **19** are T-shape as in FIGURE 11B. This means of connection support for the arched tubes **16**, adds strength to the grid and holds it in shape.

The tubular connections **17**, **18** and **19** also enable the structure to have a minimum of thickness and therefore a minimum of material and weight.

The grid formed by the crossed arched tubes **16**, is supported by the space frame sections **10** in the manner

shown in FIGURE 10, the ends of the arched tubes **16** having telescopic connection with tubular sleeves **20**, between which and a plate **21**, for each connection, the two uppermost and aligned bars *11a* of the space frame are clamped by bolts **22**. A bolt **23** extended through openings in the tubular bar **16** and its respective sleeve **20** retains the two members in proper relative adjustment.

As further reinforcement a series of concentrically arranged tension rings formed of bars **24** encircle the shell above but in proximity to the space frame sections **10**. Also a plurality of upwardly diverging bars **25** crossed by segmental bars **26**, see FIGURE 2, may be provided as additional reinforcement for the leg portions **5** of the shell **1**. The rings **24** and bars **25** and **26**, would be retained in place by wires or other means attaching them to fixed parts such as the bars **16**, these attachments not being shown but well known in the art.

It may also be added that cables **30** in FIGURE 4A as shown, can supplement, or replace, the tubing **16** should the curvature of the shell **1** be reversed from that shown in the illustrated dome **1**, i.e. curved downward, as in FIGURE 4A, which shows a hyperbolic paraboloid. FIGURE 4A illustrates one type of downwardly curved shell. In FIGURE 4A cables **30** support latticed material or mesh *27a* to which concrete or other plastic is applied in the same manner as above for other shapes.

The auxiliary support system also includes covering the reinforcing framework thus far described with metal lath, wire or plastic fabric which can of itself contain and support the membrane forming material in its initial state, this covering material being indicated at **27** in FIGURES 6 and 7. The shell roof **1**, at this stage of construction has become a latticed structure conforming to the desired shell configuration.

The final step in the instant construction method is applying the membrane material **28** to the latticed material **27** by spraying, spreading or pouring, the membrane when cured providing coverage of predetermined thickness to the entire reinforcing framework.

This membrane may be composed of pneumatically applied concrete, plastics, such as styrene, polyvinyl, fiberglass, urethene, asphalt, or other similar materials, used by themselves or in combination.

The particular spherical dome and hyperbolic paraboloid presented here are but two applications of this invention for the construction of shells. The invention is also applicable in the design and construction of any size shell of any other mathematically expressible shape such as paraboloids, hyperboloids, conoids, elliptoids, barrel vaults, flat plates, folded plates, etc.

Since there is no external falsework or supports to be removed, and consequently no waiting time while the membrane "cures," whatever construction is to take place under or within the shell, can proceed immediately without any delay.

We claim:

1. A shell structure requiring no false work, framework or external supports which includes, in combination with footing abutments,

an arched shell comprising arched space frame members supporting the weight of materials forming the shell itself and supported at their ends upon said abutments,

additional members including arched members and members crossing said arched members forming an open grid connected between said arched space frame members and supported thereby,

a lattice covering for said arched members and said arched space frame members conforming to the desired shell configuration,

and means embedding said arched members and arched space frame members forming said shell thereby enabling said structure to carry the total design loads while acting in conjunction with said shell supporting space frame members because of stress induced within said means.

2. The shell structure of claim 1, wherein said means embedding said arched space frame members, and said additional members is a concrete material.

3. The shell structure of claim 1, further characterized by said arched space frame members forming each arch being in two prefabricated sections, each such section including a plurality of parallel bars held in spaced relation by tie and truss rods, said bars each being attached at one of their ends to a butt plate, and said butt plate from each of two sections being bolted together.

4. The shell structure of claim 1, further characterized by said arched space frame members positioned to outline the perimeter portions of said shell.

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