This invention relates to reinforced concrete shell constructions and is particularly adapted for use in connection with reinforced concrete shell roofs covering large areas, cupolas, bridges, ships, silos, towers and other curved containers, retaining walls, pipes and the like.

It is known to construct large reinforced concrete roofs by means of arc covering shell structures connected over their entire transverse sections with trusses arranged at large intervals or with the rafter walls. In the case of large spans heavy reinforced longitudinal strengthening ribs were introduced at the ridge and springings. Furthermore transverse strengthening ribs were also introduced and, in the case of a cupola, the effect is attained by reason of the double curvature. The form of a cupola is usually employed in part-cylindrical, it spans between transverse supporting members or stiffener diaphragms spaced far apart and is kept free from bending stresses by the latter. The effect produced in the shell cupola by reason of its double curvature and ring stresses is caused by inclined stresses which increase gradually towards the springings and at the springings themselves is a minimum. This decrease of the horizontal arch thrust is caused by inclined stresses which being caused. In the case of a cupola this effect is attained by reason of the double curvature. The superimposed loads together with the weight of the shell itself produce stresses in the structure of such an amount that at each cross section the line of thrust coincides with the center plane of the shell. These characteristics of the shell cupola are already known and are dealt with in text books relating to the design of such structures.

Barrel vault shell structures are designed on the principle of the shell cupola, namely, that the shell vault carries its loads without producing bending stresses in the shell structure. The form of a shell vault usually employed is paraboloidal, it spans between transverse supporting members or stiffener diaphragms spaced far apart and is kept free from bending stresses by the latter. The effect produced in the shell vault by reason of its double curvature and ring stresses is caused by inclined stresses which increase gradually towards the springings and at the springings themselves is a minimum. This decrease of the horizontal arch thrust is caused by inclined stresses which
transfer the thrust through the shell towards the transverse supporting member so that the tie or abutments required in ordinary vaults is here rendered superfluous.

(c) Allogether loaded asymmetrically or by irregularly superimposed loads no bending stresses are found owing to the transverse supporting members in the form of walls, trusses or the like. That no bending moments are caused in the shell vault is proved by the fact that the deflections, measured in the direction of the generating line of vault shells of this type, are negligible.

The theoretical assumptions in the membrane theory of the barrel vault shell, especially the limiting conditions, must be complied with in practice otherwise disturbances in the distribution of the stresses are liable to appear.

If the cross sectional curvature of the barrel vault is cambered relative to the line of thrust and the vault curvature increases with an increase of the aperture angle \( \xi \) (i.e., the angle between a perpendicular to a tangent to the cross sectional curve and the vertical at the horizontal thrust \( H \) in the vault decreases according to the aperture angle \( \xi \) increases. If the tangents at the springings of the vault section are vertical, as in the case of a semi-circle, ellipse, cycloid, the angle \( \xi \) is 90° and the horizontal vault thrust is nil. In this case the vault thrust produced by the total weight of the vault shell plus the superimposed load is transferred by inclined stresses towards the transverse supporting members and is no support is therefore required along the horizontal springings. From the transverse supporting members the entire load is transferred vertically to four columns which provide the only support required for the structure. Of course, the supporting members may be carried on existing walls or the like.

In the direction of the generating line the barrel vault shell functions in a manner similar to a hollow beam of very high moment of inertia carried by the transverse supporting members. The total shear in this hollow beam is equal to the sum of all vertical components of the tangential stresses \( S \) and the bending moment is equal to the moment produced by the axial forces \( T \) the direction of which coincides with the generating line. The only essential difference as compared with an ordinary beam is that of the different distribution of the shear forces \( S \) and of the axial forces \( T \).

The sum of the axial forces \( T \) produces a total tensile force \( Z \) which has to be taken by longitudinal members at the vault springings, which members also act as side stiffeners for the vault shell. For the case of equally distributed loading the tensile force \( Z \) increases in the side stiffeners from the transverse supporting member to the centre of the span according to a parabola, reaching a maximum at the centre of the span, the bending moments and axial forces \( T \) increase in like manner. Therefore the tensile force is proportional to the bending moment and at every section this tensile force together with the axial forces \( T \) at the same section are in equilibrium with the bending moment produced by the superimposed load together with the weight of the shell itself. At each section across the span of the vault shell, the forces \( Z \) acting in each side tension member must neutralize the total of all the forces \( T \) at the same cross section. In shell vaults with vertical ends tangents the force, \( Z \) in each of the side stiffening members is completely independent of the transverse vault span and of the cross sectional shape of the vault but it is a function of the distance between the transverse supporting members and of the total load per unit area at the springings.

For large spans the total tensile force \( Z \) reaches a high figure and a large concrete stiffening member having itself a considerable dead weight is required to take the reinforcement at each springing. The membrane theory on which the vault shell design is based provides for no local loadings on the vault sides. Therefore the additional side load occasioned by the heavy longitudinal tension members, are distributed by bending moments over the curved vault section and thence transferred, as in the case of the evenly distributed loads, towards the transverse supporting members by direct stresses. The stiffness required in the transverse direction of the barrel vault shell itself is provided for by additional reinforcement, as subsequently described.

Calculations and tests have shown that a barrel vault shell whose transverse section forms an ellipse, gives the most favourable results.

Shell structures designed and manufactured in accordance with this invention are comparatively thin curved reinforced concrete shells freely spanning over large panels with their depth-span ratio exceeding the usual limit of 1 to 40. For example, an area of say 30 x 100 feet can easily be covered by a single barrel vault shell roof of 1½ inches thickness carried through a transverse supporting member at each end on four columns only. For barrel vault shells according to the present invention the depth span ratio, in transverse and longitudinal directions, is from 1:250 and 1:750 or even less respectively.

For this purpose it will be sufficient if they are supported by a side wall consisting, for example, of brick panels between the supporting columns.

Shell structures of the cupola and barrel vault type, in the various forms previously referred to and according to the principles of design set forth are manufactured in accordance with the present invention using high tensile wire reinforcements prestressed up to a maximum of 225,000 to 285,000 lbs per square inch. Ordinary mild steel wires or other steel wire reinforcements may also be employed. The most suitable shell forms for use in connection with pre-stressed wire reinforcement are those generated from straight lines namely cylinders, cones, hyperboloids and the like of various cross sections or parts of them or corrugated shapes.

In the barrel vault structures referred to the major axis is usually horizontal but structures in accordance with this invention may also have their major axes vertical or at an angle between the horizontal and vertical.

In carrying the invention into effect different methods of construction may be employed according to the circumstances of the particular case being dealt with. Shell structures according to the invention may be pre-cast and cast in situ or without the use of moulds or alternatively they may be cast in situ with or without the use of moulds.

To illustrate the practical application of the invention the manufacture of various shell constructions and structures will now be described along with the accompanying diagrammatic sketches, an example commencing with a partly cylindrical barrel vault roof in situ without the use of moulds.
Fig. 1 represents an isometric view of a barrel vault during construction;
Fig. 2 is a side elevation of the pre-stressed shell roof shown in Fig. 1;
Fig. 3 is a cross-section taken along III—III through the span;
Fig. 4 represents an enlargement of the shell detail at IV in Fig. 3.

The transverse supporting members or stiffeners diaphragms $S_1$ of part cylindrical form in accordance with the roof contour are located on the supports $S_2$ the distance apart being predetermined by the design. Longitudinal reinforcement wires $S_3$ are stretched between these stiffener diaphragms along the generating lines of the roof and pre-tensioned. As these longitudinal wires are to form the roof skeleton they must be placed at such intervals apart that they will secure the correct cross-sectional configuration of the roof. In all cases the wires must be pre-tensioned so that sagging is reduced to a minimum. When roofs of large span are being manufactured it may be advisable to provide temporary supports or suspensions for the longitudinal wires $S_3$ at a few cross-sections to prevent sagging although high prestresses may be applied.

When the reinforcement in an in situ vault is required by the design is then fixed to the prestressed wire skeleton. For example, reinforcement $S_6$ in the transverse or vault direction is provided for stiffening the shell and distributing local loads; further reinforcement $S_7$ to take main tensile stresses in various parts of the structure may be added. Tough textile material $S_8$ possessing good tensile strength such as sheets of Hessian jute, flax, coarse linen, hemp or the like is then stretched over the steel skeleton roof and clipped to wires. Wearing the textile prior to the application of mortar causes shrinkage and prevents the textile material sagging between the wires. Close mesh expanded metal or wire reinforcement of any suitable type may also be used for the same purpose.

Mortar, cement, plaster $S_9$ or the like is then applied to the skeleton either by hand or a cement gun or by a combination of both methods until the predetermined shell thickness is reached. The cement, concrete, plaster or the like is usually applied from a smooth surface $S_9$ of the reinforcement but may be applied to both sides of $S_8$ and $S_9$ if desired so that the reinforcement forms the core of the shell structure. In the latter case open mesh textile reinforcement is to be preferred.

Towards the springings the shell thickness may, if necessary, be increased to enclose the larger amount of wire reinforcement $S_4$ located there. When the shell structure has sufficiently hardened the ends of the horizontal wires are released from the prestressing plant and the concrete takes its pre-compression from the pre-tensioned wire reinforcement. The bond between the reinforcement and the concrete is improved by the cross-sectional expansion of both wires and surrounding concrete, at the time when the pre-tensioned wires are taken from the anchorage and lateral compression upon the sufficiently hardened concrete. The projecting wire ends are used for any connection desired to the end gables or transverse stiffeners $S_1$ as the case may be. In the case referred to the complicated moulds are dispensed with but costly scaffolding is required to manufacture the structure in situ.

To construct a part cylindrical barrel vault roof in situ using moulds the latter are fixed in position in the ordinary way between transverse supporting members or end gable walls. The longitudinal wires are stretched along the generating lines, at the desired distance apart and between and over the transverse members and prestressed to the desired amount. Any additional reinforcement is then placed in position as previously described but in this case the textile or secondary metallic reinforcement is reduced to a minimum; the cement, concrete or the like is then poured until the desired shell thickness is reached.

The moulds are removed when the shell has sufficiently set and the wires disengaged from the prestressing plant with the same results as above mentioned. As the moulds support the weight of the shell structure and prevent sagging the longitudinal wires located near the crown of the roof need not be so numerous as when mouldless construction is employed. When manufacturing prestressed shell structures existing walls or foundations may be employed as anchorages for the prestressing plant.

When it is desired to pre-cast the shell structure without using moulds, for example, a part cylindrical barrel vault, patterns of the desired contour are prepared. The longitudinal wires, spaced the requisite distance apart, are stretched over and between these patterns and then prestressed to the required extent. The additional reinforcement, textile or other material and finally the concrete are then applied as previously described. After the concrete has hardened sufficiently the prestressed reinforcement is disengaged from the prestressing plant and the shell structure is hoisted into position over the transverse supporting members. Reinforcement hooks or the like may be specially provided for this hoisting operation and wire or other reinforcement may be left projecting for any connection required with the supporting structure. In the case of pre-cast manufacture without moulds the two most expensive items in the construction of shell structures, namely, scaffolding and moulds, are reduced to a minimum and therefore this method of construction should be preferred to the other methods described. In manufacturing with moulds whether in situ or pre-cast, the concrete or cement is supported by the moulds until hardening has taken place and the textile and/or secondary metallic reinforcement is reduced to a minimum.

Shell structures, as for example, barrel vault roofs, may extend over or between several transverse supporting members and may cantilever from the end members. Furthermore, shell structures of a great variety of shapes may be manufactured by the intersection of or connecting together of curved shell parts. For example, a railway platform might be covered by two interpenetrating shell segments carried on one central line of columns.

Reinforcement stiffening a barrel vault or other shell in the transverse direction may consist of wires or rods bent to the shell contour and spaced apart as required by the design to distribute local loadings over the vault. These wires are carried on the longitudinal reinforcement. Alternatively, angle irons or light steel joists or other suitable sections may be employed for transverse stiffening purposes and may be carried by the side longitudinal tension members or by longitudinal walls where such are employed or by temporary supports. Such last metal arch stiffeners or other suitable supports spaced comparatively short dis-
tances apart may be utilised to temporarily carry both the longitudinal and other reinforcement. In such cases the main longitudinal reinforcement is confined principally to the side members at floor or deck levels while the prestressed longitudinal reinforcement near the crown of the vault is reduced to a minimum. The temporary tensile stresses, during construction without moulds, are in these circumstances carried by the textile or other material stretched over the whole vault and forming the core of the concrete shell. The transverse metal arch stiffeners may be left in the finished shell structure when so required by the design or may be removed when the shell structure has hardened sufficiently.

When casting a shell structure without the use of moulds the cement or concrete may advantageously be applied in two or more layers. A thin layer is first applied to the longitudinal and textile or other secondary reinforcement and allowed to harden so that the first layer shell becomes rigid and self-supporting. Any additional reinforcement is then placed in position and further layers of cement or concrete applied either mechanically or manually until the desired thickness is attained.

In the construction of a cupola of conical shape, for example, the wires stretch along the generating lines of the cone from a point on a temporary centre post to the apex to the prestressing plant at the periphery of the base and are tensioned to the required extent. The textile or metal reinforcement is then placed in position on the wire skeleton and the cement or mortar added as previously described.

When hardening has taken place the centre post and any other anchorage for attaching the wires are removed and a self-supporting shell structure results.

Truncated conical structures, conoid and hyperboloid shapes may be constructed on the same principle, the prestressed wires following the generating lines of the structure and being connected to a top and bottom reinforcing ring. As in the case of barrel vault shells these structures can be manufactured in situ or pre-cast with or without the use of moulds. The truncated forms can be used to provide a sky-light at the apex.

The invention may further be applied to the construction of reinforced concrete ships, barges and the like. By way of example, the construction of a pre-stressed reinforced concrete barge is shown in the diagrammatic drawings attached: Fig. 5 represents a typical midship section; Fig. 6 shows a plan of this barge; and Fig. 7 represents the enlarged detail VII of the side walls of the barge.

The concrete shell forms the hull of the ship and the bulkheads act as the transverse supporting members or stiffener diaphragms. It will of course be an advantage to pre-cast the bulkheads and use them as patterns during the construction of the hull. The longitudinal wires are stretched the requisite distance apart along the bulkheads and prestressed evenly to the desired extent. The metallic reinforcement is then placed in position as previously described. The decrease in cross-section towards the prow 75 and/or stern 76 is automatically effected by reason of the sizes of the bulkheads there located.

The variation of the cross-sectional shape of the shell and the shape of the inside is determined by the shape of the bulkheads 67 and the intermediate ribs 68 which with advancement are pre-cast. These members act as the transverse supporting and stiffener diaphragms and form the pattern for the reinforcement of the hull. The high tensile wires 53 are stretched along the ship and kept at predetermined stresses, as applied at 55 in Figs. 1 and 2, while transverse wire reinforcement 56 and 57 of mild steel quality are placed to follow the cross-sectional shape and the principal tensile stresses respectively; in addition metal mesh reinforcements 58 are clipped to the steel skeleton. There are no preliminaries of other than these mild steel reinforcements. The decrease in cross-section towards the prow 75 and stern 76 is automatically effected by reason of the smaller ribs 69 there located.

The pre-tensioned wires 53 positioned in the side walls 77, floor 78, and deck 79, are dead parallel and horizontal in the straight centre part of the hull, and turn slightly inwards, respectively upwards, towards stem and stern. The anchorages plates and blocks for these main wires are situated at such a distance from the last bulkhead that the converging wires are collected in an area of conveniently small dimensions. In the case of several small vessels being constructed in one row, one behind the other, the anchorages are placed only on each end of the row, and all longitudinal wires run continuously through all hulls.

Two layers of concrete 59 and 60 are shot against the close steel skeleton from outside and inside respectively so that the whole steel is encased. Another layer of high tensile steel wires is pre-tensioned along and outside of the thin gunite shell and mild steel reinforcements are tied to them in transverse and oblique directions as required by the design. This reinforcing layer is encased by a new layer of gunite and the same process is repeated until the full thickness of side walls 77, gunwales 70, hatch beams 72, and deck 78, have been obtained. The floor 78, bilges 71, and keelsons 73, may be cast in situ in the conventional way encasing both pre-tensioned and ordinary reinforcements.

Owing to the peculiar statics of this design of ship structures the greater part of the pre-tensioned main wires 84 should be connected to the gunwales 70 and bilges 71, as well as in the continuous hatch beams 72 and keelsons 73.

The invention may also be employed for the erection of structures of closed prismatic, pyramidal, cylindrical, conical, hyperboloid and like shape with their truncated variations the height of which structures is great compared with the area covered in plan for example, chimneys, towers, silos and the like.

By way of example the construction of a pre-stressed cylindrical chimney is illustrated in the diagrammatic drawings attached:

Fig. 8 represents a sectional elevation taken at VIII—VIII of Fig. 9 of the chimney during erection;

Fig. 9 is a horizontal cross-section at IX—IX of Fig. 8 through the shaft;

Fig. 10 represents the enlarged detail at X of the chimney and is similar to Fig. 8.

To cast a cylindrical chimney in situ in accordance with this invention the bottom extremities of the main wires 53 extending along the generating lines are anchored 84 to the required extent in the chimney foundation 83 while their upper forms 85 are of a suitable type—steel tubular for example. The prestressing plant 89 may be inside or outside the
structure, in the latter case it is detachable and may be re-used.

To reduce the number of separate wires and prestressing devices one wire may extend several times up and down the length of the structure; in fact the entire longitudinal reinforcement may, in extreme case, comprise one continuous wire of great length threaded through patterns at the top and bottom of the building. This method of using one continuous wire for several reinforcing units may be applied of course to all prestressed structures or articles with straight wire reinforcement.

After prestressing the wires 53, textile 58 and/or metallic secondary mesh reinforcement 59 is clipped or attached to the pre-tensioned wires 53, preferably on the outside of the latter, and concrete, cement, plaster or the like 59 and 60 is applied in one or several layers, whereby, usually, the pre-tensioned main wires and other reinforcement is encased in the outer side layers 59 and the inside layers 60, thus forming the core of the shell. After the concrete has sufficiently hardened the main wire reinforcement 53 is released from the tensioning devices with the previously described effect of pre-compressing the concrete shell 59 and 60.

The wire reinforcement is permanently maintained in tension, and the concrete in compression by the intimate bond between both. This bond is greatly increased by the present pre-stressing process as described previously.

When the chimneys, towers, silos and the like structures of great height are being built in accordance with this invention their construction may advantageously be carried out in vertical sections; the scaffolding 54 resisting to the pretension of the longitudinal main wires 53, extends only over one or the two last built upper sections 93 and is supported by the bars 91 by the latest built up section 92 and raised section by section until the entire structure is completed.

The lower reaction of the sectional prestresses is taken by the lower part of the already built structure. This lower part has already sufficiently hardened and its concrete has been compressed by releasing the lower ends of the reinforcement from the anchorages. In this method of construction the longitudinal wires 53 of requisite length are rolled and kept at the top of the scaffolding 54; they are unwound and pre-tensioned in length sufficient for the one or two vertical building sections above referred to.

As in reinforced concrete shell roof constructions, moulds and scaffolding are the two most costly items in reinforced concrete tower and similar structures. In the sectional construction of the shell herein described such moulds are altogether dispensed with while the scaffolding is reduced to the amount required for the one or two building sections.

Towers, silos, chimneys built in accordance with this invention are particularly adapted to withstand the wind pressures to be expected in such high structures. The practical limiting factor in such reinforced concrete structures is the tensile stresses resulting from wind pressure on the windward side; not the compressive stresses caused by the dead weight plus the wind bending moments on the lee side. The present invention results in improved resistance of such structures by reason of the fact that the critical tension can be eliminated completely or to any extent required by the design by the introduction of calculated prestresses in the main reinforcement wires as described.

It is a characteristic feature of the prestressing principle that any loading conditions fore-shadowed in a structure are produced in the reverse state during construction or manufacture. Prestressing of beams, slabs and like articles or structures is effected by a system of prestresses of variable amount in various cross-sectional zones in accordance with the known or assumed direction of the loading to be expected. As wind pressure may come from any side of a tower or like structure the prestress in the reinforcement wires, resulting in the pre-compression of the concrete shell, is usually made the same all around the structure for each separate horizontal section but it usually varies with the vertical position of the sections and the reinforcement percentage usually decreases with its height over bottom level. Additional strength for the tower, silos, chimney or the like may be provided by applying additional layers of concrete, cement, plaster or the like inside or outside of the prestressed shell whilst the latter are held on the anchorage or after they have been released therefrom.

Containers, silos and storage tank walls are usually subjected to tensile stresses because of the outward pressure of the stored material. According to the present invention such a structure could comprise a number of part-cylindrical shells arranged so that the internal end of each such part is on the exterior of the structure. The several shell parts may be pre-cast and afterwards erected in position, vertical ribs cast in situ connecting each pair of adjoining shell parts. The walls of such a container are subjected to compressive stresses only and the ring tension is taken by ties connecting diametrically opposite ribs or by tie rings connecting the vertical ribs or by any other convenient arrangement.

The invention may further be applied to the production of pipes, poles, hollow piles or the like pre-cast or cast in situ both without moulds. The main wire reinforcement is arranged on patterns and prestressed along the generat- lines of the article and the textile and/or metal secondary mesh reinforcement is stretched round and attached to the longitudinal wires thus forming the case of the shell structure and replacing the moulds. This method may be combined with known production methods for hollow reinforced concrete bodies for example spinning and like methods. When combined with the spinning method the patterns, carrying the pre-stressed wires together with the textile and/or secondary mesh reinforcement, are rotated by synchronised motors, while the concrete or the like is applied inside to the required thickness. After the concrete has hardened sufficiently the wires are released from the anchorages. The outer finish may be applied to the article either by a cement gun or by hand whilst the wires are connected to the anchorages or after they have been released. When completed the main wires and textile and/or metallic secondary reinforcement are completely encased.

I claim:

1. Concrete construction of the type described and for the purposes set forth herein comprising a plurality of pre-tensioned longitudinally disposed reinforcement means defining a part-cylindrical shell, a secondary mesh reinforcement attached to said reinforcement means extending
co-extensively with the part-cylindrical area thereof, a monolithic slab of concrete embedding and in bonding relationship with said reinforcements to thereby provide a formless pre-stressed concrete shell structure, the said longitudinal reinforcement means being permanently maintained under permanent compression after all shrinkage has taken place and during its loaded condition, the said pre-tensioned reinforcement defining the shape and forming a skeleton for the said construction and the said secondary mesh reinforcement constituting a core for the sole support thereof whereby the necessity for a concrete form is obviated.

2. A mould-less self-supporting reinforced concrete curved shell construction of the type described and for the purposes set forth herein comprising pre-stressed reinforcement wires spaced along the generating lines of said shell defining the shape of said construction and forming the sole supporting skeleton of said construction, mesh reinforcement attached to the said pre-stressed wires, a predetermined thickness of concrete disposed on both sides of said wire and mesh reinforcements which cooperate to form a core for the application of said concrete from both sides thereof, the said pre-stressing of said wires being constant throughout said shell and of a magnitude of the order of up to 285,000 pounds per square inch, the said wires being permanently maintained under said tension alone by the bond between said reinforcement and concrete after the setting and hardening of said concrete, the said reinforcement wires pre-stressed when the said concrete has taken place, said concrete remaining under permanent compression after all shrinkage thereof has taken place and in its externally loaded condition, the said mesh reinforcement forming the mould for said concrete shell construction and the said pre-tensioned reinforcement wires forming a skeleton of the construction and the sole support for the application of said concrete whereby the necessity for an external form is obviated.

3. The method of constructing a reinforced concrete marine hull comprising the steps of pre-casting a plurality of varyingly curved transverse members, arranging said transverse members in longitudinally spaced parallel positions to define the shape of the hull shell, positioning a plurality of longitudinal high tensile reinforcement wires across the edges of said transverse members, pre-stressing said longitudinal wires to a predetermined extent to form a skeleton of said hull shell converging toward a prow and a stern, anchoring said pre-stressed wires in the region of said prow and stern, applying mild steel wire and mesh reinforcement externally to said pre-stressed skeleton to form a core for said hull shell, attaching the said external wire and mesh reinforcement to said pre-stressed reinforcement, applying concrete by the gunite process to said skeleton and core both internally and externally of said hull shell to thereby avoid the use of forms and hardening said concrete in the predetermined shape of said hull shell.

4. A shell construction as set forth in claim 2 for a roof characterized by said pre-stressed wires extending between and over transverse supporting members of part-cylindrical form and a plurality of pre-stressed wires located at the springings of said construction to thereby constitute longitudinal tension members and side stiffeners.

5. The method of manufacturing in situ, a shell structure comprising the steps of locating at predetermined distances apart transverse supporting members curved to form a tour, stretching between and over said supporting members longitudinal reinforcement wires along the generating lines of said shell structure, spacing said reinforcement wires at intervals and pre-stressing to a predetermined extent defining the predetermined cross-sectional configuration of said shell structure, to provide a skeleton therefor stretching and attaching secondary mesh reinforcement over said pre-stressed wires to provide a core for said structure, applying cementitious material to both sides of said reinforcement to a predetermined shell thickness, permitting said cementitious shell structure to harden and releasing the ends of said pre-stressed wires from the source of said predetermined pre-stressing to thereby provide a shell structure without the use of a mould.

6. The method of manufacturing a mould-less pre-stressed reinforced concrete shell structure as set forth in claim 5 characterized by the initial application of a relatively thin layer of cementitious material to the said pre-stressed wires and said secondary reinforcement, permitting said initial layer to set, applying further reinforcement to said initial layer and applying a further layer of cementitious material to the predetermined thickness of said shell structure.

KURT BILLIG.

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