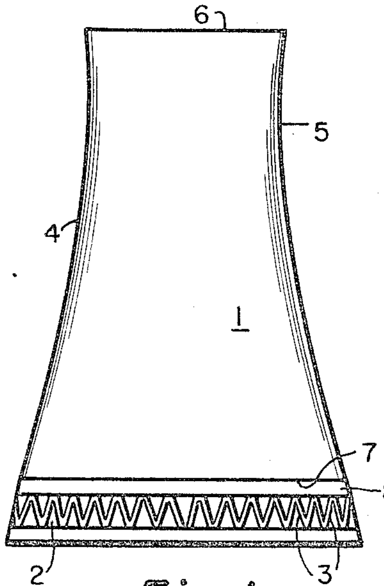

Fig. 1

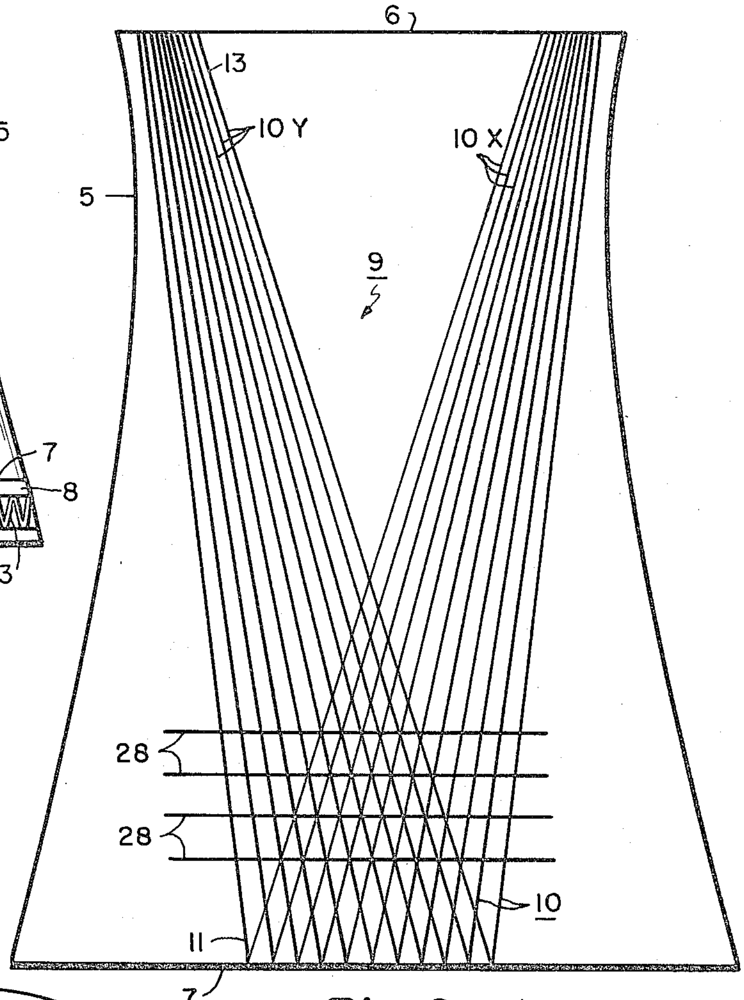

Fig. 2

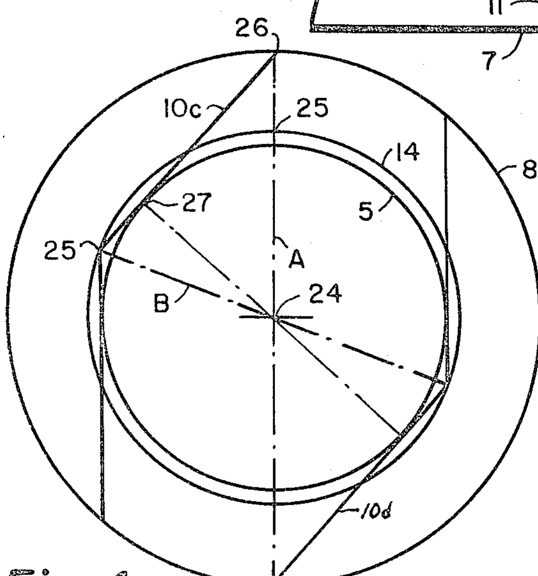

Fig. 4

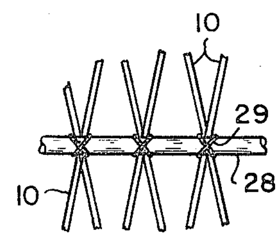

Fig. 3

INVENTOR.
John M. Sweeney

BY Webb, Mackey & Burden
HIS ATTORNEYS

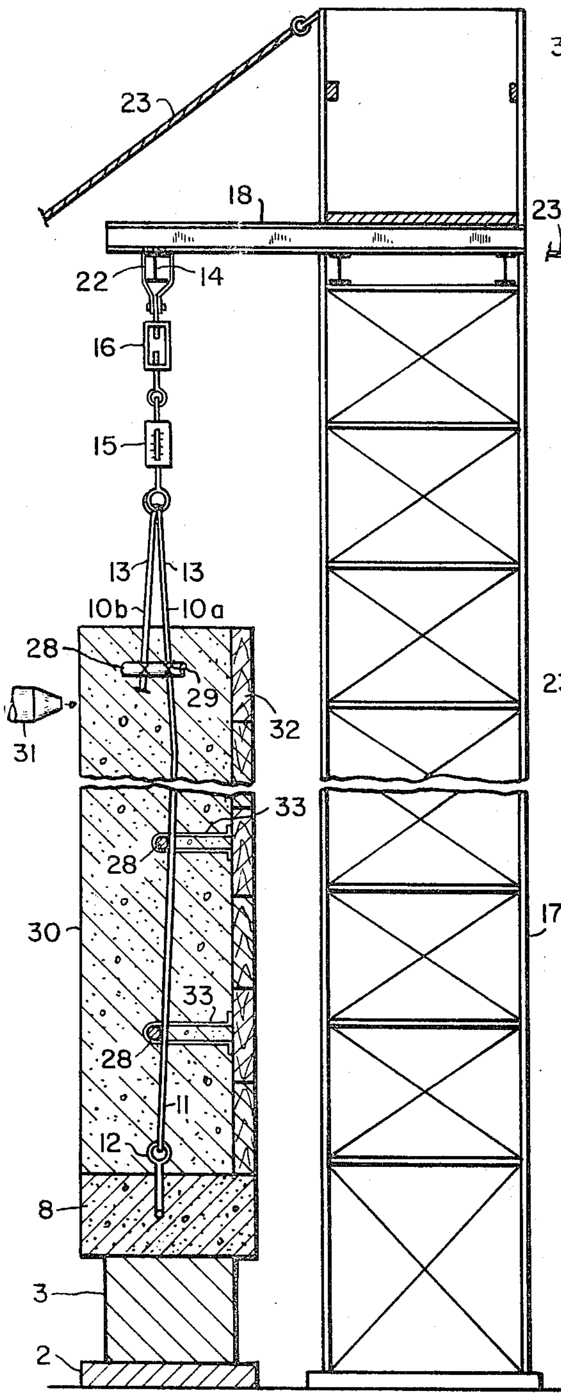

Fig. 5

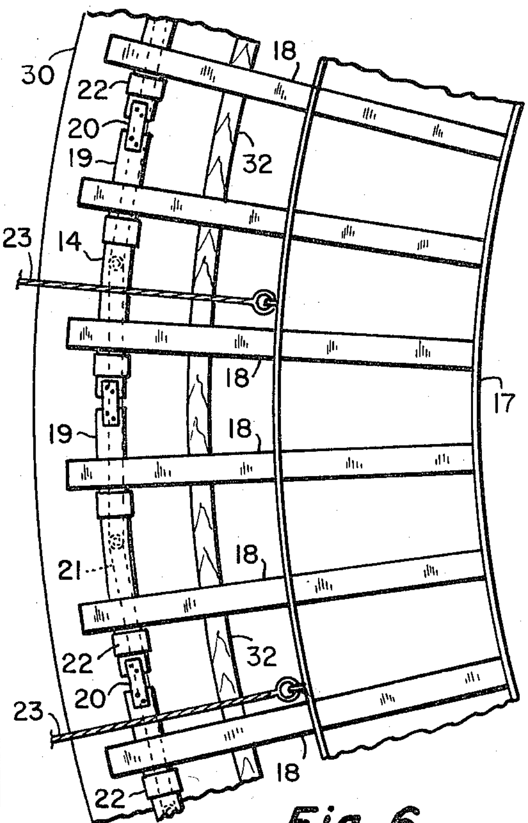

Fig. 6

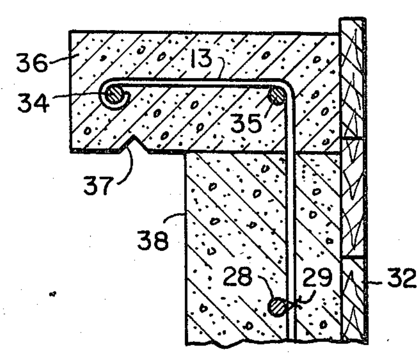

Fig. 7

INVENTOR.
John M. Sweeney
BY Webb, Mackey & Burden
HIS ATTORNEYS

United States Patent Office

3,304,351

Patented Feb. 14, 1967

1

3,304,351

METHOD OF CONSTRUCTING A HYPERBOLIC CONCRETE SHELL FOR A WATER-COOLING TOWER

John M. Sweeney, 131 Sylvania Drive, Pittsburgh, Pa. 15236

Filed Dec. 17, 1962, Ser. No. 245,260
11 Claims. (Cl. 264—32)

This invention relates to a water-cooling tower, and particularly, to a hyperbolic shell which forms an integral part of the tower and which rises from an open grillwork base of the tower. In addition to the shell and the base, the tower includes a water distribution system having cooling grids over which the water to be cooled is sprayed or flowed. This distribution system is adjacent the top of the base and has therebeneath a pond for catching the falling water and returning it to a circulating water system of a steam electric generating station. Condensers which are an integral part of the circulating water systems require cooled circulating water for their operation.

These water cooling towers may be 340 feet high and higher and 260 feet in diameter and greater at their base. Their hyperbolic shell rises from the open grillwork base which extends 30 to 40 feet above ground level. Atop this grillwork base is a ring beam upon which the hyperbolic shell is constructed.

Heretofore, some hyperbolic shells have been built by erecting forms for pouring concrete or cement which forms required use of instruments and measurements for their construction. In combination with these forms, steel reinforcing rods are joined section to section by wire, nails, bar bolsters, etc., and are supported by the forms used for pouring the cement. Erection of these steel reinforcing rods progresses step by step as the building of the shell rises from the ring beam. Consequently, costs of fabrication of such shells have been very high due to many man-hours of work required for erecting the forms and putting together the reinforcing rods to form the steel reinforcement.

My invention provides a method for constructing the hyperbolic shell of the water-cooling tower which not only effects substantial savings in man-hours for erection of the forms for the cement or concrete and for fabrication of the steel reinforcing rods into a network, but also employs a substantially smaller amount of reinforcing rods. The method comprises the steps of building the shell with a restricted neck portion between its top and bottom and from an open grillwork base by forming a substantially hyperbolic shaped network of a plurality of tension cables through affixing the lower end of each cable to the top of the grillwork base and connecting the upper end thereof to a means supported adjacent the top of the tower to be built. Then, a first portion of the cables is arranged so that each cable of the first portion extends diagonally upward from its lower end towards the means in a right-hand direction and is substantially tangent to the neck portion. The first portion cables are spaced apart from one another and disposed substantially around the top of the base and around the means. Also, there is arranged a second portion of the cables so that each cable of the second portion extends diagonally upward from its lower end towards the means in a left-hand direction and is substantially tangent to the neck portion. The second portion cables are also spaced apart from one another and disposed substantially around the top of the base and around the means. Next, each cable is subjected to a given amount of tension which takes out a substantial amount of sag in each cable but is less than that which overloads the means and sufficient to reduce distortion of the shape of the network to a given amount. Following this, the network is embedded in a cement-like material from the

2

top of the base to substantially the top of the cables. During this embedding tension is maintained in the cables substantially at the given amount by decreasing and increasing tension in the cables as the embedding progresses from the bottom of the network to the top thereof.

Preferably, tensioning of the cables to the given amount and maintaining the tension in the cables at substantially the given amount is carried out by subjecting pairs of the cables to the tension or to reductions and increases in tension wherein each pair consists of one cable of one portion and its diametrically opposite counterpart cable of the same portion.

Additionally, tension rings are applied to the network at spaced apart locations and disposed in substantially horizontal planes.

My invention in the hyperbolic shell for the water-cooling tower with the open grillwork base from which rises the shell comprises a network of a plurality of tension cables whose lower ends are affixed to the top of the base and whose upper ends are disposed at the top of the shell. A first portion of these cables extends diagonally upward from their lower ends towards the top of the shell in a right-hand direction and the second portion of the cables extends diagonally upward from their lower ends towards the top of the shell in a left-hand direction. The cables of the first and second portions are so arranged in their respective diagonal extensions that they form a restricted neck portion of the network between the top and bottom thereof and are substantially tangent to the neck portion to the neck portion to define the hyperbolic shape of the shell. The cables of the two portions are disposed substantially around the top of the base and around the top of the shell. This network is embedded in a cement-like material from the bottom to the top thereof while the cables are subjected to a substantially given amount of tension which takes out a substantial amount of sag in each cable and is sufficient to reduce distortion of the shape of the network to an acceptable amount. Mounted around the network is a plurality of tension rings at spaced apart intervals and positioned in substantially horizontal planes. At the top of the shell is a projecting lip which runs around the top thereof and is formed of the cement-like material which has embedded therein the upper ends of the cables.

In the accompanying drawings, I have shown a preferred embodiment of my invention in which:

FIGURE 1 is an elevation view of a water-cooling tower whose hyperbolic shell is built in accordance with my invention;

FIGURE 2 is a schematic view showing disposition of the tension cables which form a network of cables and which are an integral part of the shell of FIGURE 1;

FIGURE 3 is an enlarged fragmentary view of one tension ring and some tension cables which form a part of the network of FIGURE 2;

FIGURE 4 is a plan view of the network of FIGURE 2;

FIGURE 5 is an elevation view of scaffolding which supports a top ring to which is connected the tension cables of FIGURE 2 and of forms for receiving the cement-like material used to build the shell;

FIGURE 6 is a partial plan view of the scaffolding of and the top ring of FIGURE 5; and

FIGURE 7 is a fragmentary section view of an outwardly projecting lip of the top of the shell.

Referring to FIGURE 1, the water-cooling tower **1** there shown has an open grillwork base **2** formed by upwardly extending struts **3** and a hyperbolic shaped shell **4** which rises from the top of the base **2** and has a restricted neck portion **5** between its top **6** and bottom **7**. The grillwork base rests upon the ground and carries at its top a ring beam **8** which is the base of the shell (FIG.

5). Within the grillwork base **2** and the lower part of the shell **4** is a water distribution system (not shown) with cooling grids over which the water to be cooled is flowed. Beneath the grids is a pond which collects the water falling through the grids and returns the cooled water to a water circulating system (not shown) of a steam electric generation station or plant (also not shown).

Construction of the shell **4** commences with erection of a network **9** of a plurality of single length tension cables **10** which are so arranged that they form the hyperbolic shape. In mathematical terms, one example of the shell is a hyperboloid of one sheet whose mathematical formula is

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}-\frac{z^2}{c^2}=1.$$

One characteristic of a hyperboloid of one sheet is that on its surface two straight lines which lie wholly on the surface may be drawn through any point of the surface. The network stands upon the ring beam **8** and has the restricted neck portion **5** between its top **6** and bottom **7** and, as shown in FIGURE 2, the neck portion **5** is closer to the top **6** than to the bottom **7**.

One example of a shell built in accordance with my method has a base diameter of 224.9 feet, a top diameter of 148.8 feet, and a neck portion diameter of 144.0 feet, and a height of 280 feet with a distance between the neck portion and the top being 50 feet and the distance between the neck portion and the base of the shell being 230 feet. Each of the tension cabes of this 280 foot shell is about 300 feet long.

As shown in FIGURES 2 and 5, each cable has its lower end part **11** affixed to an anchor bolt **12** supported by the ring beam **8** and its upper end part **13** supported by a top ring **14** through a tension scale **15** and a turnbuckle **16** or any other suitable tensioning device disposed in tandem. Preferably, each cable is one single length between its upper and lower ends but may be at least two lengths joined together end to end and able to withstand the tension placed thereon as described hereinafter. These tension cables have a smaller cross sectional diameter than reinforcing rod. For example, in one tower, each tension cable is about 3/16 inches in cross sectional diameter; whereas, reinforcing rod hereinbefore used is 3/8 inches in cross sectional diameter. While FIGURE 5 shows one tension scale and one turnbuckle joined to the upper ends of two cables **10*a*** and **10*b***, of course, a single cable could be joined to one tension scale and one turnbuckle combination.

A scaffolding **17** (FIGURE 5) within the network amounts a plurality of beam **18** adjacent its upper end and these beams, in turn, carry the top ring **14** which is formed from a plurality of arcuate beam sections **19** arranged end to end upon the underside of the beams **18**. Channel plates **20** and support arms **21** connect the channel sections together. A hanger or strap **22** supports each turnbuckle and its tension scale in their tandem arrangement so that the scale indicates the amount of tension in the cable or cables attached to its lower end and operation of the turnbuckle permits increasing and/or decreasing the amount of tension in each cable or two cables joined thereto. As shown in FIGURES 5 and 6 guy wires **23** assist to support the scaffolding **17** in its vertical position.

The network of the tension cables comprises a first portion and a second portion in which each of the cables of the first portion designated **10*x*** is so arranged that it extends diagonally upward from its lower end towards the top ring in a right-hand direction and is substantially tangent to the neck portion **5**. The cables of the first portion are spaced apart from one another and disposed substantially around the top of the base and around the top ring with the spacing between successive cables at the ring beam for the 280 foot high shell being 12 inches and the spacing of the upper ends of the cables around the top ring between successive ones being 7.9 inches. Correspondingly, each of the cables of the second portion designated **10*y*** in so arranged that it extends diagonally upward from its lower end towards the top ring in a left-hand direction and is also substantially tangent to the neck portion **5**. These cables of the second portion are likewise spaced apart from one another and disposed substantially around the ring beam and around the top ring in the same manner as the cables of the first portion. As shown in FIGURE 2, at each anchor bolt there is attached thereto the lower end of a first portion cable **10*x*** and the lower end of a second portion cable **10*y***.

Regarding the 280 foot shell and its network **9** of tension cables, for example, any cable such as cable **10*c*** has a position in the network determined by the location of its points of connection to the ring beam and to the top ring as a result of a rotation of either the top ring or the ring beam through an arc of about 60° 47′ about the common axis **24** (FIGURE 4) of the ring beam **8** and the top ring **14** from line A, in the case of rotation of the top ring while the ring beam is stationary, where a given point **25** on the top ring is in the same vertical plane as a corresponding point **26** on the ring beam to line B to which the point **25** on the top ring has been rotated and which represents the connection of the upper end of the cable to the top ring. Point **27** on the restricted neck portion **5** represents the point of tangency of the tension cable **10*c*** to this neck portion.

Each cable is subjected to a given amount of tension to reduce sag therein by operation of its turnbuckle and by use of the tension scale to indicate the amount of tension applied by the turnbuckle. Since sag in the cables produces distortion in the shape of the network, reduction in the amount of sag in the cables lowers the amount of distortion in the shape of the network. The amount of tension employed does not remove all of the sag in the cable and is sufficient to reduce distortion of the shape of the network to an acceptable amount but is less than that which overloads the top ring. For example, the force used to tension the 300 foot cables of the 280 foot shell is about 100 pounds. Such a tension in each cable removes most of the sag and leaves a sag in the amount of 10 inches in 300 feet, where the 10 inches is the distance between a straight line drawn between the two points of connection of the cable to the top ring and the ring beam and a second line parallel to the first line and tangent to the arc formed by the sag in the curve at the point of greatest curvature of the arc which corresponds to the point of greatest sag. Amounts of sag in the tension cables similarly measured range from about 8 inches to about 14 inches and such a range of amounts of sag effects satisfactory results and reduces distortion of the shape of the networks to acceptable amounts without overloading the top ring. If the amount of sag in the cables in lowered to about 2″–4″, then the top ring is overloaded.

When subjecting the cables to tension, it is preferable to tension a pair of cables at substantially the same time with the pairs consisting of one cable of one portion and its diametrically opposite counterpart cable of the same portion (FIGURE 4), for example, cable **10*c*** and cable **10*d*** of the first portion cables **10*x***. So tensioning the cables in these pairs avoids distortion of the shape of the network and also reduces overstressing of parts of the network.

At spaced apart intervals up the height of a network is a plurality of tension rings **28** tied to the outside of the network by wire **29**, as shown in FIGURE 3, and disposed in substantially parallel, horizontal planes. The ends of the rings overlap so that each completely embraces the network and cooperates to maintain it in its hyperbolic shape. On the 280 foot shell, the rings are 3/8 inches in cross sectional diameter and are spaced about 12 inches apart.

After completion of erection of a network with mounting of the tension rings thereon and after each of the cables has been tensioned its given amount, the network is then embedded in a cement-like material **30** by blowing a mixture of cement, sand and water from a gun **31** (FIGURE 5) through the network against a form **32** disposed inside the network and spaced apart from its interior surface. This form rises from the ring beam **8** and is partially supported by same, is substantially parallel to the interior surface of the network from its bottom to substantially its top and is supported from the network by clips and bands **33** which engage the tension rings **28**. The form is built upwardly towards the top of the network as the embedding progresses to form the hyperbolic shell. The thickness of the cement-like material blown against the form is about 3–4 inches for the 280 foot shell but can, of course, be thicker if desired. When the embedding has been completed, it completely encompasses the network **9**.

Embedding of the network is also effected by erecting forms which straddle it and are on both the inside and outside thereof and substantially parallel thereto. Then, the cement-like material is poured into the form instead of blowing it as building of the shell progresses from the bottom of the network to the top to embed it therein and form the hyperbolic shell.

When the network has been embedded to a short distance from the top thereof, then the upper ends of the cables **10** are either cut or released from the scales and the upper end portion **13** of each is then bent and wrapped around to substantially concentrically located rods **34** and **35**. These rods run around the top of the network and are disposed in substantially a horizontal plane with rod **34** located on the outside of the network as shown in FIGURE 7. Then an outwardly projecting lip **36** is fabricated at the top of the shell by pouring or blowing the cement-like material to completely embed the upper ends of the cables therein. The underside of this lip has a small notch **37** which extends completely therearound to avoid rain and snow draining in under the lip and against the exterior side wall **38** of the shell to cause erosion of the cement-like material at the intersection of the lip and the upper part of the shell wall.

While the lip **36** has been shown as outwardly projecting, it can extend inwardly or both outwardly and inwardly.

As embedding of the network rises from the ring beam towards the top ring, tension in the cables increases from the given amount and is reduced to the given amount by operation of the turnbuckles. In this way, overloading the top ring and distortion of shape of the network is avoided. In addition to the embedding, changes in ambient temperature affect tension in the cables with warmer temperatures decreasing the tension and cooler temperatures increasing the tension. Also, winds, particularly high winds, affect the amount of tension in the cables. Accordingly, the tension therein is increased or decreased to the given amount by operation of the turnbuckles, thereby effecting compensation for the changes in tension from the given amount due to changes in temperature and the winds.

In order to prevent distortion of the network and/or subjection thereof to excessive stresses, increasing or decreasing the tension in the cables to the given amount is carried out in pairs of cables wherein each pair consists of one cable of the first portion and its diametrically opposite counterpart cable of the second portion.

My invention provides important advantages which materially reduce the cost of the hyperbolic shell through use of less material and requirement for substantially less labor. Since 3/16 inch tension cables are used instead of 3/8 inch reinforcing rods, the 280 foot shell saves 64 tons in weight of the reinforcement material.

Practice of my method effects overall savings in the costs of building the shell in amounts from 25% to 35% and, in some cases, an ability to build a shell 20% larger and at a saving of 20% over those previously constructed. Also, my method permits erection of the shell in greatly less time than that heretofore required.

While I have shown and described a preferred embodiment of my invention, it may be otherwise embodied within the scope of the appended claims.

I claim:

1. In a method of constructing a water-cooling tower of substantially hyperbolic shape, said tower having an open grillwork base from which rises a hyperbolic shell having a restricted neck portion between its top and bottom, the invention comprising, firstly building said shell by forming a substantially hyperbolic shaped network of a plurality of tension cables through affixing the lower end of each said cable to substantially the top of said grillwork base and connecting the upper end thereof to means supported adjacent the top of said tower, arranging a first portion of said cables so that each cable of said first portion extends diagonally upwardly from its lower end towards said means in a right-hand direction and is substantially tangent to said neck portion, said first portion cables being spaced apart from one another and disposed substantially around the top of said base and around said means, arranging a second portion of said cables so that each cable of said second portion extends diagonally upwardly from its lower end towards said means in a left-hand direction and is substantially tangent to said neck portion, said second portion cables being spaced apart from one another and disposed substantially around the top of said base and around said means, secondly subjecting each cable to a given amount of tension which takes out a substantial amount of sag in each cable but leaves more than four inches of sag in each said cable and is less than that which overloads said means and is sufficient to reduce distortion of the shape of said network to a given amount, thirdly erecting a form which is parallel to said network, fourthly utilizing said form in embedding said network in cementlike material from said top of said base to substantially said top of said cables to produce said hyperbolic shell with the restricted neck portion between its top and bottom, during said embedding maintaining tension in said cables substantially at said given amount by decreasing and increasing tension in said cables as said embedding progresses from the bottom of said network to the top thereof.

2. The invention of claim **1** characterized by carrying out said tensioning of said cables by subjecting pairs of said cables to said tension, each pair consisting of one cable of one portion and its diametrically opposite counterpart cable of said same portion.

3. The invention of claim **2** characterized by blowing a cement-like material through said network and against said form in an amount sufficient to substantially completely embed said network in said cement-like material from the bottom to the top thereof.

4. The invention of claim **2** characterized by directing a stream of cement-like material through said network and against said form in an amount sufficient to substantially completely embed said network in said cement-like material from the bottom to the top thereof.

5. The invention of claim **2** characterized by carrying out said maintaining said tension at substantially said given amount by reducing and increasing tension in pairs of cables to said given amount, each of said pairs consisting of one cable of one portion and its diametrically opposite counterpart cable of said same portion.

6. The invention of claim **5** characterized by applying tension rings to said network at spaced apart locations and disposed substantially in horizontal planes.

7. The invention of claim **5** characterized by blowing a cement-like material through said network and against said form in an amount sufficient to substantially completely embed said network in said cement-like material from the bottom to the top thereof.

8. The invention of claim 5 characterized by directing a stream of cement-like material through said network and against said form in an amount sufficient to substantially completely embed said network in said cement-like material from the bottom to the top thereof.

9. The invention of claim 1 characterized by applying tension rings to said network at spaced apart locations and disposed substantially in horizontal planes.

10. The invention of claim 1 characterized by blowing a cement-like material through said network and against said form in an amount sufficient to substantially completely embed said network in said cement-like material from the bottom to the top thereof.

11. The invention of claim 1 characterized by directing a stream of cement-like material through said network and against said form in an amount sufficient to substantially completely embed said network in said cement-like material from the bottom to the top thereof.

References Cited by the Examiner

UNITED STATES PATENTS

2,561,581	7/1951	Macerata	264—32
2,597,084	5/1952	Huddleston	264—32
2,544,828	3/1957	Dobell	50—129
2,932,964	4/1960	Dobell	50—129
3,111,965	11/1963	Hodge	264—228 X

FOREIGN PATENTS

600,954	7/1960	Canada.
329,715	5/1930	Great Britain.
492,540	9/1938	Great Britain.
797,414	7/1958	Great Britain.

FRANK L. ABBOTT, *Primary Examiner.*

HENRY C. SUTHERLAND, *Examiner.*

L. R. RADANOVIC, A. C. PERHAM, *Assistant Examiners.*