(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 161 878 B1**

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification: **08.08.90**

(51) Int. Cl.^{5}: **E 04 B 7/14**

(21) Application number: **85303148.2**

(22) Date of filing: **02.05.85**

(54) Roof structure.

(30) Priority: **09.05.84 US 608424**

(43) Date of publication of application:
21.11.85 Bulletin 85/47

(45) Publication of the grant of the patent:
08.08.90 Bulletin 90/32

(84) Designated Contracting States:
AT BE CH DE FR GB IT LI LU NL SE

(56) References cited:
DE-B-1 256 863
FR-A-1 056 325
FR-A-1 446 326
FR-A-2 153 032
FR-A-2 207 228
US-A-3 807 421

(73) Proprietor: **Geiger, David H.**
Kirby Lane
Rye New York 10580 (US)

(72) Inventor: **Geiger, David H.**
Kirby Lane
Rye New York 10580 (US)

(74) Representative: **Taylor, Derek George et al**
Mathisen, Macara & Co. The Coach House 6-8
Swakeleys Road
Ickenham Uxbridge UB10 8BZ (GB)

EP 0 161 878 B1

Courier Press, Leamington Spa, England.

Description

The present invention relates to a roof structure constructed of tension members and compression members and suitable for spanning delineated areas of various size for providing a protective roof thereover for stadiums, arenas and the like.

In recent years, dome and roof structures have been constructed of light weight membranes in order to achieve lower cost and to improve their performance. These structures have been constructed of either synclastic surfaces held-up and stiffened by air pressure or anticlastic surfaces formed by ridged arches, masts, and/or cables against which the membrane has been pre-stressed. The synclastic surface may have a low aspect ratio, that is, the ratio of surface area to delineated plan area. The resulting low aspect ratio has an important advantage for permanent membrane roofs, such as low profile air structures, since the membrane cost is as much as 70% of the roof cost, the balance being cables, clamps, and compression ring. However, the disadvantage of the air structure has been its dependence on mechanical systems for keeping the roof up and the resulting requirement for providing air tight buildings, snow melting systems, emergency generators, revolving doors, and the like. On the other hand, the anticlastic surface has a very high aspect ratio resulting in higher roof costs per unit of delineated plan area. For example, those anticlastic surfaces employing masts and cables have high aspect ratios in order to provide sufficiently low membrane stress, while those utilizing arches have high aspect ratios due to design considerations such as arch buckling.

In addition to the foregoing problems encountered with regard to the use of light weight membranes consisting of either synclastic or anticlastic surfaces, there has been a problem with roof insulation. Previous attempts to incorporate insulation in air supported roofs have required the installation of snow melting systems separate and apart from the interior heating system so as to prevent condensation of moisture on the upper covering membrane thereby impairing the insulation value of the insulation. In addition, it has been necessary to pressurize the insulation space to pressures higher than the interior pressure of the enclosed delineated area in order to prevent the collapse of the insulation. Further difficulties are often encountered in erecting structures constructed of continuous flexible elements such as cables with discontinuous stiff elements such as compression struts as they generally do not have the required stiffness except in their complete assembled condition.

DE—B—1256863 discloses a roof support structure in which stress cables span radially from a circular outer compression ring to an interior tension ring of much smaller diameter. Two intermediate tension rings are arranged between these rings. Cables are run from the outer ring to the lower edge of the first intermediate ring, from the outer ring over the upper edge of the first intermediate ring to the lower edge of the second intermediate ring and over the upper edges of both intermediate rings to the interior ring.

There is therefore a need for a tension structural system, such as a cable truss dome, which is suitable for spanning large areas where the tension elements support a light weight membrane, which provides a low aspect ratio eliminating the need for supporting air pressure, and which can be erected easily.

The invention provides a roof structure for spanning a delineated area, said structure comprising support members radially spanning said delineated area for supporting a roof thereon, and extending between support means extending around the perimeter of the delineated area and an inner tension ring, the support members comprising tension members and compression members characterised in that the compression members comprise a plurality of separate compression members arranged between the support means and the inner tension ring in at least two radially spaced arrangements, the separate compression members in each arrangement being in angularly spaced relationship, the tension members including an upper chord extending between said support means and an upper end of an associated separate compression member, a diagonal chord extending between said support means and a base of an associated separate compression member, the roof structure further including flexible tension members extending between the bases of the separate compression members.

According to a further aspect, the invention provides a method of erectig a roof structure comprising tension members and compression members for spanning a delineated area, said method comprising the steps of spanning said delineated area with said tension members, arranging a plurality of said compression members in a circle and providing at least one further circle of separate compression members spaced radially from said first mentioned circle, attaching one end of said compression members to said tension members at a predetermined location, attaching the other end of said compression members to said tension members to form diagonal chords therefrom, attaching each said other end of said compression members of said circle to said other end of the next adjacent compression member of the further circle with said further flexible tension members and tensioning said tension members spanning said delineated area and said further tension members to form said roof structure.

The roof structure preferably comprises a flexible membrane as the roof, held down on the support members by means for tensioning means such as valley cables extending between adjacent support means. This has the advantage of resisting wind-induced uplift forces which sometimes exceed the deadweight of the roof structure.

In order that the invention may be better understood, the preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying diagrammatic drawings, wherein:—

Fig. 1 is a top plan view showing a roof structure according to a first embodiment of the invention, constructed of a cable truss dome including a plurality of radially-arranged arched support members and a plurality of concentric tension rings, and including valley cables radially disposed between adjacent arched support members;

Fig. 2 is a partial side elevation of one of the arched support members of Figure 1, constructed of a plurality of tension members in the form of cables to provide upper tension chords and diagonal tension chords, and compression members in the form of vertical struts arranged between the upper chords and diagonal chords;

Fig. 3 is a partial top plan view of a tension ring at the centre of the structure of Figure 1, having a plurality of arched support members attached thereto and extending radially outward therefrom along with the adjacent valley cables;

Fig. 4 is a partial side elevation of the tension ring of Fig. 3;

Fig. 5 is a partial side elevation of the top of a compression member in the form of a strut and attached to adjacent upper tension chords by means of a hanger;

Fig. 6 is a partial front elevation of the compression member and hanger used during construction as shown in Fig. 5;

Fig. 7 is a top plan view in cross-section of the compression member as shown in Fig. 5 and further showing a platform supported by a plurality of tension rings at the bottom of the compression member;

Fig. 8 is a partial side elevation of the bottom of the compression member and platform as shown in Fig. 7;

Figs. 9 to 15 are illustrations showing the erection sequence for the roof structure of Figures 1 to 8;

Fig. 16 is a partial side elevation of a cable truss in accordance with a second embodiment of the present invention, constructed of tension members and compression members, wherein the tension members form both upper and lower tension chords, and diagonal chords extending therebetween; and

Fig. 17 is a partial side elevation of the compression members shown in Fig. 16 connected between the upper and lower tension chords by a bracket.

Referring now to the drawings wherein like reference numerals represent like elements, Fig. 1 is a plan view of a roof structure 100 in the form of a cable truss dome. The cable truss dome 100 forms an undulating supporting surface and is constructed of a plurality of arched support members 102 arranged radially to a delineated area thereby to form a dome covering a space such as a stadium or arena. As shown in Fig. 2, the support members 102 are constructed of a plurality of stranded cables 104 constituting a single, compound tension member and a plurality of rigid struts 106 forming compression members. The cables 104 are attached to a continuous compression ring 108 which is arranged to circumscribe the delineated area to be covered. The compression ring 108 acts as a foundation to the roof structure, and consists of several chords joined end-to-end. Alternatively, the cables 104 may be secured to a plurality of individual anchorage blocks (not shown) buried in the ground at locations spaced around the perimeter of the delineated area. As shown in Fig. 1, the compression ring 108 can be constructed as a portion of the perimeter wall defining the stadium or arena to be covered. The cables 104 extend radially from the compression ring 108 overyling a portion of the delineated area. Some cables 104 have their other inner ends secured to a central tension ring 110; others have their inner ends secured to the top or bottom of struts 106, as shown in greater detail in Figs. 3 and 4.

Cables 104 extending from the compresion ring 108 to the central tension ring 110 form upper tension chords 112 or ridge cables of the support members 102. On the other hand, a number of these cables 104 initiating from the compression ring 108 diverge from the upper chords and constitute diagonal tension chord 114 extending downwardly at an angle from successive predetermined locations along the support members 102. As best shown in Fig. 2, a plurality of cables 104 are secured to the compression ring 108 and extend radially towards the tension ring 110. At a first outermost, predetermined location, a number (one or more) of cables 104 are peeled away from the remaining cables and are arranged extending downwardly from those remaining cables forming the upper tension chord 112, to provide a first diagonal tension chord 114. Similarly, at the next successive predetermined location, a number of cables 104 are again peeled away from the remaining cables 104 and extend at an angle downwardly from those remaining cables forming the next upper chord 112 to provide the next diagonal chord 114. The upper chords 112 and underlying diagonal chords 114 form two adjacent sides of a triangle. Struts 106 are connected between the upper chord 112 and diagonal chords 114 to complete the third side of each triangle by means of the structure shown in Figs. 5 through 8, to be described hereinafter. These triangles are arranged in a substantially vertical orientation lying within a common plane. Each support member 102 comprises a discrete series of such triangles each connected to one or two neighbouring triangles only at respective vertices, so tha the triangles do not share common sides. In this manner, the strut 106 of one triangle has its upper end attached to the cables 104 at the intersection of the upper chord 112 and diagonal chord 114 of an adjacent triangle nearer the centre of the structure. Thus, the number of cables 106 forming successive upper chords 112 successively decreases towards the centre of the structure, as a corresponding number of these cables are peeled away to provide the diagonal chords 114. The number of cables 104 contained within each diagonal chord 114 is preferably the same, although it may vary.

To complete the support members 102, and maintain the diagonal chords in tension, a pluraty of concentric tension rings 116 each constructed of stranded cables 118 are secured to the lower ends of corresponding struts 106 of adjacent support members 102 as best shown in Figs. 7 and 8.

Overlying the support members 102 is a flexible membrane 120 serving as a roof over the delineated area. The membrane 120 may be formed of a woven synthetic fabric, although it is contemplated that other materials such as canvas or thin metallic formed membranes may also be utilized. The membrane 120 is constructed to be weather resistant and preferably of a non-combustible composition. Coated fabrics may be employed for the membrane 120 such as Teflon (Registered Trade Mark) coated glass fibre, silicon-coated glass fibre, silicon-coated polyester, and the like. In addition, the membrane 120 can be translucent to allow light into the enclosed volume, and may be adapted to provide good acoustic properties. A plurality of valley chords 122 are positioned between adjacent support members 102 and extend between the compression ring 108 and tension ring 110. The flexible membrane 120 is maintained under tension by prestressing the valley cables 122, for example, as disclosed in U.S. Patent No. 3,807,421. That portion of the flexible membrane 120 extending in V-shaped cross-section between adjacent support members 102 can be in the form of rectangles, trapezoids, triangles, wedge shapes, and the like. In this regard, the flexible membrane 120 can be constructed of a plurality of triangular shaped panels radiating outwardly from the central tension ring 110 such that the joints between adjacent panels can be continuously heat-sealed or adhered in place during field installation so that there are no joints intersecting with those of adjacent panels.

Turning now to Figs. 5 and 6, each strut 106 is attached to the cables 104 at a predetermined location by means of a hanger 124. The upper end of the hanger 124 is provided with a pivotable U-shaped bracket 126 through which the cables 104 extend. To secure the bracket 126 to the cables 104, a number of cables may be terminated and secured to the hanger by means of a fixture 128. As previously noted, a number of cables 104 extend through the U-shaped bracket 126 and are displaced at an angle downwards to provide the diagonal chords 114. In addition, supplemental diagonal chords 114' may be employed by securing same between the hanger 124 and the lower end of an adjacent strut 106 as shown. Bracing between adjacent support members 102 is not required due to the fact that the cables 104 forming the upper chords 112 and diagonal chords 114 are under tension. However, trussing or cross-bracing between adjacent support members 102 can be provided for the purpose of load redistribution and facilitating the erection of the cable truss 100. In this regard, the trussing or bracing can be achieved by providing cross-bracing in the form of diagonal cables 130 secured between corresponding struts 106 of adjacent support members 102, In particular, the diagonal cables 130 are secured at one end to the hangers 124 and attached at their other ends to the lower ends of corresponding struts 106, as shown in Figs. 7 and 8. Although the diagonal cables 130 are shown seven in number, it is expected that only two or three such diagonal cables would be required. To facilitate load redistribution, these diagonal cables are clamped at their crossing point.

The cables 104 continuing through the hangers 124 within a support member 102 are secured to the central tension ring 110 in the manner shown in Figs. 3 and 4. In addition, the valley cables 122 are also secured to the central tension ring 110 between adjacent cables 104. Thus, the support members 102 have one end attached to the tension ring 110 and extend radially outward therefrom, while having their other ends attached to the compression ring 108. The lower ends of the struts 106 are provided with a support 132 arranged generally transverse to the strut and extending outwardly along the direction of the support members 102. The support 132 is adapted for securing the cables 118 of the individual concentric tension rings 116 thereto. A platform 134 is disposed overlying the cables 118 to provide a catwalk for maintenance and installation personnel. The platform 134 overlies the concentric tension rings 116 between adjacent struts 106, and a safety handrail 136 is provided on either side of the platform.

As thus far described, the cable truss dome 100 incorporates a structural system that uses trusses that have their upper chords 112 made of tension members comprising a plurality of prestressed cables 104. The cables 104 are anchored to the compression ring 108 or buried anchorage blocks (not shown). The diagonal chords 114 are discontinuous from one another, are attached to the nested, concentric tension rings 116. As the cable truss dome 100 is a tension dome and dome buckling is not a problem, the rise of the dome can be made as shallow as possible consistent with water drainage and the functions required of the enclosed space. Thus the aspect ratio, i.e., the ratio of dome surface area to delineated plan area, can be made a minimum. The anticlastic membrane surface can be prestressed by the valley cables 122 that pull the flexible membrane 120 down against the upper chords 112 of each of the support members 102. With the upper chords 112, diagonal chords 114, and tension rings 116 constructed of cables prestressed to a perimeter restraining system, i.e. the compression ring 108, these elements can be combined with rigid elements such as beams or trusses in such a manner so as to impart additional stiffness to these elements without introducing compression forces.

The uniqueness of the cable truss dome 100 is demonstrated by the fact that it is not triangulated. The rigidity of a triangular structure is not required of the cables truss dome 100 as structural roof membranes, i.e., architectural fabrics, permit the membrane to act as both a deck and a weathering membrane. This membrane, if properly shaped and prestressed, can accommodate the large displacements of a structural system that is not triangulated. Thus, non-linear large displacement structural analysis is possible using digital computers. In addition, the cable truss dome 100 can be formed with either circular or non-circular plan configurations based on skewed symmetric principles, for example as in U.S. Patent No. 3,841,038. As previously noted, the prestressed flexible membrane 120 covering the cable truss dome 100 has shallow undulations permitting the aspect ratio to be a minimum thus allowing maximum economy in the flexible membrane.

This economy is further enhanced by the use of individual multi-stranded cables 104 which permit maximum efficiency in the use of material in the upper chords 112 and diagonal chords 114. This efficiency is achieved in that the number of individual cables 104 required in successive upper chords 112 decreases from the perimeter to the centre of the structure. This amount of decrease in the numbers of individual cables 104 between adjacent chords can be of the same order of magnitude as the number of cables required in the individual diagonal chords 114. Consequently, the number of connections required of the cables 104 is minimized. Further, the use of a plurality of cables 118 in the construction of each of the tension rings 116 allows the resulting structure to function as the support for a catwalk as previously described.

The use of the cable truss dome 100 is a practical consideration because of the efficiency with which the cable end forces can be resisted through the use of skewed symmetric compression rings or anchorage blocks. Given the flexibility of the cable truss dome 100, and the fact that it is not triangulated, such facts are advantageous because the cable truss dome can be largely assembled on the ground or in a hanging position. With or without the flexible membrane 120, and then hoisted into position using simple cable tensioning devices that are used to put the final tension into the cables 104, as described below.

The method for erection of the cable truss dome 100 will now be described with reference to Figs. 9 through 15. The erection of the cable truss dome 100 uses the natural propensity for cables to drape in a concave upward position between anchor points under gravity. The tension ring 110 is supported on a scaffolding 138 or alternatively may be positioned on the ground and hoisted in place by jacking of the ridge cables. A bundle of cables 104, including the upper chords 112 and diagonal chords 114 for the support members 102, are positioned radially about the delineated area to be covered. The perimeter ends of the cables 104 are secured to the compression rings 108 while the other ends of those cables providing the upper chords 112 are secured to the tension ring 110. Those cables 104 providing the diagonal chords 114 are allowed to drape downwardly from the remaining cables at successive locations corresponding to the positions for the struts 106 along each support member 102. The lengths of some of the diagonal chords 114 are greater than required in the erected cable truss dome 100, in order to facilitate the erection, as described below.

The struts 106, having attached hangers 124 and supports 132, are positioned on the ground, scaffolding and/or stadium seating as shown in Fig. 9. The struts 106 are securely set so that their plan position relative to each other is maintained during the attachment of the concentric tension rings 116. The cables 118 are spun overlying the supports 132 of corresponding 106 to provide the plurality of concentric tension rings 116. The tension rings 116 are slightly tensioned as they are attached to the supports 132 of each of the struts 106. The struts 106 having attached hangers 124, supports 132 and tension rings 116, are lifted vertically upward and secured to those cables 104 forming the upper chords 112. Alternatively, the hangers 124 may be attached to the cables 104 first and the struts 106 can be attached later to the hangers during final erection of the cable truss dome 100. The attachment of the hangers 124, to the cables 104 is achieved by pivotally attaching the U-shaped bracket 126 over the cables 104 to the upper end of the hangers 124, and securing the cables thereto by means of the fixture 128. The cables 104 providing the diagonal chords 114 are inserted through the lower ends of the struts 106. This procedure is repeated for all concentric rings formed by corresponding struts 106 and the tension rings 116. After the struts 106 have been set securely, cables 104 may then be arranged spanning the delineated area by successively attaching them to the top of one strut and then to the bottom of an adjacent strut, so as to form the diagonal chords 114 therebetween. This alternative method allows the cable truss dome 100 to be easily assembled and erected from a ground level position.

Engaging the free ends of the diagonal chords 114 at the outermost struts 106, these diagonal chords are then jacked by shortening their length through the struts so that the cables 104 forming the upper chords 112 and the diagonal chords 114 are placed under tension, which then lifts the outer portion of the support members 102 upwardly as shown in the sequence between Figs. 10 and 12. The jacking of the diagonal chords 114 is repeated for each of the concentric rings formed by the corresponding struts 106 and tension members 116 so as to place all cables 104 within the cable truss dome 100 in tension thereby causing the cable truss dome to invert as shown between the erection sequence of Figs. 11 through 14. The diagonal chords 114 are then secured to the struts 106, to complete the structure of the cable truss dome 100 is covered with the flexible membrane 120 and prestressed by tensioning the valley cables 122 or tensioning the diagonals 114.

As thus far described, the interior tension rings 116 are spun at grade level or on a support structure such as stadium seating and lifted with the struts 106 for attaching same to the cables 104 providing the upper chords 112. The cables 104 forming the upper chords 112 are in an inverted position and are subsequently made to assume a concave downward position by simultaneous shortening of the diagonal chords 114, one concentric ring at a time, so as to cause the support members 102 to reverse their curvature one ring at a time. Alternatively, it is contemplated that the flexible membrane 120 may be attached to the cables 104 and valley cables 122 for inflating the roof structure using mechanical blowers. The upward movement of the flexible membrane 120 by means of mechanical blowers causes the reversing of the curvature of the support members 102 and brings the struts 106 approximately into their final positions, at which the diagonal chords 114 are then attached. Using hydraulic jacks, the struts 106 are then brought into their final position in which the support members 102 assume a concave downward position, at which time the internal pressure created by the mechanical blowers is no longer required to hold the cable truss dome 100 up. By performing the erection sequence at grade level, or as close to ground as possible, such a sequence is greatly facilitated.

Turning now to Figs. 16 and 17, there is shown half of a cable truss 140 in accordance with the second embodiment of the present invention. The cable truss 140 is constructed of a plurality of tension members 142 arranged to span the delineated area, to be covered with, for example, a flexible membrane 120 of the type illustrated in Fig. 1. The tension members 142 are constructed of stranded cables of the type described and illustrated with respect to the previous embodiment, and are anchored in the same way to buried blocks or to a compression ring 108. The tension members 142 each overlie a portion of the delineated area and have their other ends secured to a central tension ring 144 in the manner to be described, or, in the case of a linear truss, secured to the other side. In addition to the tension members 142, the cable truss 140 also includes a plurality of rigid struts 146, which may be of varying length, and which form compression members similar in function to the struts 106 as shown in Fig. 2.

The tension members 142 are arranged in the cable truss 140 to form upper chords 148, diagonal chords 150 and lower chords 152. As shown, the number of cables within the upper chords 148 decreases from the compression ring 108 to the tension ring 144, while the number of cables within the lower chords 152 increases from the compression ring to the tension ring. By way of an example, a plurality of continuous tension members 142 are secured to the top of a first strut 146, thereby forming an upper chord 148 between the compression ring 108 and first strut 146. A tension member 142 is attached to the bottom end of an adjacent second strut 146′ to form a diagonal chord 150 therebetween. The tension member 142 forming the diagonal chord 150 is then attached to the bottom end of the remaining strut 146″ and has its free end attached to the lower end of the tension ring 144. The remainder of the tension members 142 attached to the top of the fist strut 14, are secured to the top end of the adjacent second strut 146′ to form an upper chord 148. The number of cables in the upper chord 148 running between the adjacent first and second struts 146, 146′ is less than the number of cables in the upper chord running between the compression ring 108 and first strut 146. Likewise, a tension member 142 connected to the top of the second strut 146′ is attached to the lower end of the adjacent third strut 146″ to form diagonal chord 150, and ultimately to the lower end of the tension ring 144 to form a lower chord 152. The remaining tension members 142 attached to the upper end of the second strut 146′ are attached to the uppper end of the adjacent third strut 146″ in the previous manner described.

Thus the number of cables within the upper chords 148 between successive struts 146 146′, 146″ decreases in number, while the number of cables within the tension members 142 forming the lower chords 152 increases between successive struts. In other words, the tension members 142 extend continuously from the compression ring 108 to the tension ring 144 in the form of an upper chord 148, a diagonal chord 150 and a lower chord 152. In turn, the struts 146, 146′, 146″ are secured between the upper chords 148 and lower chords 152 to maintain the tension members 142 under tension upon application of a load.

As shown in Fig. 17, the struts 146 are secured to the tension members 142 by means of saddle-type brackets 154, 154′. As shown, the upper and lower brackets 154, 154′ are secured to the ends of the strut 146. The upper bracket 154 is provided with a pair of spaced ears 156 between which the tension members 142 are retained. The lower bracket 154′ is in turn provided with a U-shaped retainer plate 158 to sandwich the tension members 142 therebetween, which tension members are also confined between spaced bushes 160. In this manner, the struts 146 are attached between the tension member 142, so as to maintain the tension members under tension during an applied load.

The method for erection of the cable truss 140 will now be described briefly: it is similar to the method of erection of the cable truss dome 100 previously described with reference to Figs. 9—15. A bundle of tension members 142 is arranged overlying the delineated area between the compression ring 108 and tension ring 144. A plurality of struts 146 are attached to the tension members 142 at intermediate locations between the compression ring 108 and tension ring 144, so that the tension members are divided into upper chords 148, diagonal chords 150 and lower chords 152, as shown in Fig. 16. The tension members 142 and struts 146 may be assembled on the ground or using a scaffolding 138 in the manner previously described. The cable truss 140 is erected by tensioning the tension members 142 by engaging their free ends at their location at the compression ring 108. The tension members 142 are respectively tensioned by shortening their length between the compression ring 108 and tension ring 144, so that the tension members forming the upper chords 148, diagonal chords 150 and lower chords 152 are placed under tension, which then lifts the outer portion of the cable truss 140 upwardly. By successively tensioning those tension members 142 which form the next adjacent inward diagonal chord 150, all tension members within the cable truss 140 are placed under tension, thereby causing the cable truss to be raised into its tensioned self-supporting position, as shown in Fig. 16. Additionally, cross-bracing 130 may be provided between adjacent corresponding struts 146. The cable truss 140 can then be covered with a flexible member 120 which may be pre-stressed by the tensioning of valley cables 122 attached between the tension ring 144 and compression ring 108.

Claims

1. A roof structure (100) for spanning a delineated area, said structure comprising support members (102; 142) radially spanning said delineated area for supporting a roof (120) thereon, and extending between support means (108) extending around the perimeter of the delineated area and an innner tension ring (110), the support members comprising tension members (104; 142) and compression members (106; 146) characterised in that the compression members comprise a plurality of separate compression members (106; 146) arranged between the support means (108) and the inner tension ring (110) in at least two radially spaced arrangements, the separate compression members in each arrangement being in angularly spaced relationship, the tension members including an upper chord (112; 148) extending between said support means and an upper end of an associated separate compression member (106; 146), a diagonal chord (114; 150) extending between said support means and a base of an associated separate compression member (106; 146), the roof structure further including flexible tension members (116; 152) extending between the bases of the separate compression members (106; 146).

2. A roof structure according to claim 1 characterised in that said plurality of separate compression members (106; 146) are arranged in a circle, there being provided at least one further circle of separate compression members (106; 146) spaced radially from said first mentioned circle, each compression member (106; 146) of said further circle being connected at an upper end thereof to said tension members (104), a diagonal tension chord (114; 150) interconnecting the lower end of each compression member (106; 146) of said further circle and the upper end of a compression member belonging to a circle next adjacent thereto; said lower end also being connected to further flexible tension members (116; 152) extending between said lower end and the lower ends of the next adjacent compression members (106; 146) of the further circle to maintain the diagonal tension chords under tension; whereby, upon assembly in use, each compression member (106; 146) forms, with its associated upper tension chord and diagonal tension chord, a triangle.

3. A roof structure according to claim 1 or claim 2 characterised in that said flexible tension members (116), comprise a plurality of cables arranged in a bundle.

4. A roof structure according to any one of claims 1 to 3 characterised in that said tension members (104; 142) extend radially outward from said tension ring (110) spanning said delineated area.

5. A roof structure according to any preceding claim characterised in that a roof (120) in the form of a flexible membrane overlies said support members.

6. A roof structure according to claim 5, characterised in that tensioning means (122) extend between adjacent tension members (104) for tensioning said flexible membrane (120).

7. A roof structure according to claim 5 or claim 6 characterised in that said flexible membrane (120) comprises a plurality of adjacent wedge shaped panels radiating outwardly from said tension ring (110) area.

8. A roof structure according to any preceding claim, characterised in that said support means comprises a compression member (108) forming a closed loop circumscribing said delineated area to which said tension members (104) are attached.

9. A roof structure according to claim 2, characterised in that said tension members (104) comprise an upper chord (112; 148) for each circle of compression members (106; 146), the number of said upper chords decreasing from the perimeter of said delineated area to a central portion thereof, at each position at which a diagonal chord (114; 150) extracts therefrom.

10. A roof structure according to claim 9, characterised in that said flexible tension members (152) are formed by a number of cables the number of said cables forming said lower tension members (152) increasing in a direction from the perimeter of said delineated area to a central portion thereof at each position at which a diagonal chord adjoins the lower tension members.

11. A roof structure according to claim 3 or any claim dependent on claim 3, characterised in that the number of said cables within said diagonal chords remains the same from the perimeter of said delineated area to a central portion thereof.

12. A roof structure according to any one of claims 11 to 13 characterised in that at a plurality of junctions of a diagonal chord (114; 150) with an upper chord (106; 146), the number of cables in the upper chord to one side of said junction is not less than the sum of the number of cables in the diagonal chord and in the upper chord to the other side of the said junction.

13. A roof structure according to claim 1, characterised in that said further flexible tension members comprise concentric tension rings (116) each connected to the lower end of a respective compression member (108) of each support member (102) of an angularly spaced arrangement of said support members (102).

14. A roof structure according to any of claims 1 to 13 characterised in that at least some of said upper chords, diagonal chords, and further flexible tension members comprise a common cable.

15. A roof structure according to any one of claims 1 to 3 further characterised by a platform (134) secured to said tension rings.

16. A roof structure according to any preceding claim characterised by bracing means (130) extending between corresponding compression members of adjacent support members.

17. A roof structure according to claim 13, characterised in that said further flexible tension members comprise a plurality of concentric cables.

18. A method of erecting a roof structure according to claim 2, said method being characterised by the steps of spanning said delineated area with said tension members (104; 142), attaching one end of each of said compression members (106; 146) to said tension members (104) at different points thereon, attaching the other end of each of said compression members to said tension members at another point thereon to form said diagonal chords (114; 150) therefrom, attaching each of said other ends of said compression members (106; 146) of a said circle to said other ends of the next adjacent compression member (106; 146) of the further circle with said further flexible tension members and tensioning said tension members spanning said delineated area and said further tension members to form said roof structure.

19. A method according to claim 18, characterised by tensioning said tension members (104) by the step of shortening the length of said diagonal chords (114; 150).

20. A method according to claim 18 characterised by attaching a flexible membrane (120) to said tension members (104), and inflating said flexible membrane to tension said tension members.

Patentansprüche

1. Eine Dachkonstruktion (100) zum überspannen einer vorgegebenen Fläche, wobei die Konstruktion Trägerglieder (102; 142) umfaßt, die die vorgegebene Fläche zum Tragen eines Daches (120) darauf radial überspannen und sich zwischen einer Trägereinrichtung (108), die sich um den Umfang der vorgegebenen Fläche erstreckt, und einem inneren Spannring (110) erstrecken, wobei die Trägerglieder Spannglieder (104, 142) und Stützglieder (106, 146) umfassen, dadurch gekennzeichnet, daß die Stützglieder eine Vielzahl von separaten Stützgliedern (106, 146) umfassen, die zwischen der Trägereinrichtung (108) und dem inneren Spannring (110) in wenigstens zwei radial beabstandeten Anordnungen angeordnet sind, wobei die separaten Stützglieder in jeder Anordnungen im Winkel zueinander versetzt angeordnet sind, die Spannglieder eine obere Sehne (112; 148), die sich zwischen der Trägereinrichtung und einem oberen Ende eines zugehörigen separaten Stützgliedes (106; 146) erstreckt, une eine diagonale Sehne (114; 150) die sich zwischen der Trägereinrichtung und einem Basisteil eines zugehörigen separaten Stützgliedes (106; 146) erstreckt, enthält, und die Dachkonstruktion weiterhin flexible Spannglieder (116; 152) enthält, die sich zwischen den Basisteilen der separaten Stützglieder (106, 146) erstrecken.

2. Dachkonstruktion nach Anspruch 1, dadurch gekennzeichnet, daß die Vielzahl von separaten Stützgliedern (106; 146) auf einem Kreis angeordnet sind, wobei wenigstens ein weiterer Kreis von separaten Stützgliedern (106; 146), die radial zu dem zuerst erwähnten Kreis beabstandet sind, vorgesehen ist, jedes Stützglied (106; 146) von dem weiteren Kreis en einem oberen Ende mit den Spanngliedern (104) verbunden ist, eine diagonale Spannsehne (114; 150) das untere Ende von jedem Stützglied (106; 146) von dem weiteren Kreis und das obere Ende von einem Stützglied, das zu einem nächsten angrenzenden Kreis gehört, miteinander verbindet; wobei das untere Ende auch mit weiteren flexiblen Spanngliedern (116; 152) verbunden ist, die sich zwischen dem unteren Ende und den unteren Enden der nächsten angrenzenden Stützglieder (106; 146) des weiteren Kreises erstrecken, um die diagonalen Spannsehnen unter Spannung zu halten; wodurch in der verwendeten Konstruktion jedes Stützglied mit seiner zugehörigen oberen Spannsehne und diagonalen Spannsehne ein Dreieck bildet.

3. Dachkonstruktion nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß die flexiblen Spannglieder (116) eine Vielzahl von Kabeln umfassen, die in einem Bündel angeordnet sind.

4. Dachkonstruktion nach wenigstens einem der Ansprüche 1 bis 3, dadurch gekennzeichnet, daß die Spannglieder (104; 142) sich von dem Spannring (110) unter überspannung der vorgegebenen Fläche radial nach außen erstrecken.

5. Dachkonstruktion nach wenigstens einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß über den Trägergliedern ein Dach in der Form einer flexiblen Membran liegt.

6. Dachkonstruktion nach Anspruch 5, dadurch gekennzeichnet, daß sich zwischen angrenzen-

den Spanngliedern (104) Spanneinrichtungen (122) zum Spannen der flexiblen Membran (120) erstreckt.

7. Dachkonstruktion nach Anspruch 5 oder 6, dadurch gekennzeichnet, daß die flexible Membran (120) eine Vielzahl von aneinandergrenzenden keilförmigen Tafeln umfaßt, die sich von dem Bereich des Spannrings (110) radial nach außen erstrecken.

8. Dachkonstruktion nach wenigstens einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Trägereinrichtung ein Stützteil (108) umfaßt, das eine geschlossene, die vorliegende Fläche umschreibende Schlaufe, an welcher die Spannglieder (104) befestigt sind, bildet.

9. Dachkonstruktion nach Anspruch 2, dadurch gekennzeichnet, daß die Spannglieder (104) eine obere Sehne (112; 148) für jeden Kreis von Stützgliedern (106; 146) umfassen, wobei die Anzahl der oberen Sehnen vom Umfang der vorgegebenen Fläche zu einem zentralen Teil hin an jeder Position, an der eine diagonale Sehne (114; 150) davon abzweigt, abnimmt.

10. Dachkonstruktion nach Anspruch 9, dadurch gekennzeichnet, daß die flexiblen Spannglieder (152) durch eine Anzahl von Kabel gebildet sind, wobei die Anzahl der Kabel, die die unteren Spannglieder (152) bilden, in einer Richtung von Umfang der vorgegebenen Fläche zu einem zentralen Teil hin an jeder Position, an welcher sich eine diagonale Sehne an die unteren Spannglieder anschließt, zunimmt.

11. Dachkonstruktion nach Anspruch 3 oder wenigstens einem der sich auf den Anspruch 3 beziehenden Ansprüche, dadurch gekennzeichnet, daß die Anzahl der Kabel innerhalb der diagonalen Sehnen vom Umfang der vorgegebenen Fläche zu ihrem Zentralteil hin gleich bleibt.

12. Dachkonstruktion nach wenigstens einem der Ansprüche 11 bis 13, dadurch gekennzeichnet, daß eine Vielzahl von Verbindungen von einer diagonalen Sehne (114; 150) mit einer oberen Sehne (106; 146) vorgesehen ist, wobei die Anzahl der Kable in der oberen Sehne zu einer Seite der Verbindung nicht geringer als die Summe der Anzahlen der Kabel in der diagonalen Sehne und in der oberen Sehne zu der anderen Seite der Verbindung ist.

13. Dachkonstruktion nach Anspruch 1, dadurch gekennzeichnet, daß die weiteren flexiblen Spannglieder konzentrische Spannring (116), die jeweils mit dem unteren Ende eines jeweiligen Stützgliedes (108) von jedem Trägerglied (102) einer im Winkel versetzt vorgesehenen Anordnung der Trägerglieder (102) verbunden ist.

14. Dachkonstruktion nach wenigstens einem der Ansprüche 1 bis 13, dadurch gekennzeichnet, daß wenigstens einige der oberen Sehnen, diagonalen Sehnen und der weiteren flexiblen Spannglieder ein gemeinsames Kabel umfassen.

15. Dachkonstruktion nach wenigstens einem der Ansprüche 1 bis 3, gekennzeichnet durch eine an den Spannringen befestigte Plattform (134).

16. Dachkonstruktion nach wenigstens einem der vorhergenenden Ansprüche, gekennzeichnet durch eine Befestigungseinrichtung (130), die sich zwischen entsprechenden Stützgliedern von aneinandergrenzenden Trägergliedern erstreckt.

17. Dachkonstruktion nach Anspruch 13, dadurch gekennzeichnet, daß die weiteren flexiblen Spannglieder eine Vielzahl von konzentrischen Kabeln umfassen.

18. Verfahren zur Errichtung einer Dachkonstruktion nach Anspruch 2, gekennzeichnet durch die Verfahrensschritte: überspannen der vorgegebenen Fläche mit den Spanngliedern (104; 142), Verbinden eines Endes von jedem der Stützglieder (106; 146) mit den Spanngliedern (104) un unterschiedlichen Punkten der Spannglieder, Verbinden des anderen Endes von jedem der Stützglieder mit den Spanngliedern an einem anderen Punkt, um dadurch die diagonalen Sehnen (114; 150) zu bilden, Verbinden jedes der anderen Enden der Stützglieder (106; 146) von einem gennanten Kreis and dem anderen Ende von dem nächsten angrenzenden Stützglied (106; 146) des weiteren Kreises mit den weiteren flexiblen Spanngliedern und Spannen der die vorgegebene Fläche überspannenden Spannglieder und der weiteren Spannglieder, um die Dachkonstruktion zu bilden.

19. Verfahren nach Anspruch 13, gekennzeichnet durch Spannen der Spannglieder (104) durch Verkürzen der Länge der diagonalen Sehnen (114; 150).

20. Verfahren nach Anspruch 18, gekennzeichnet durch Befestigen einer flexiblen Membran (120) an den Spanngliedern (104) und Aufblähen der flexiblen Membran, um die Spannglieder zu spannen.

Revendications

1. Structure de toit (100) destinée à recouvrir une zone délimitée, la structure comprenant, des organes de support (102; 142) disposée radialement sur toute la zone délimitée afin qu'ils supportent un toit (120) et disposés entre un dispositif de support (108) placé autour de la périphérie de la zone délimitée et un anneau interne de tension (110), les organes de support comprenant des organes (104; 142) travaillant à la traction et les organes (106; 146) travaillant à la compression, caractérisé en ce que les organes travaillant à la compression comprennent plusieurs organes séparés (106; 146) travaillant à la compression, placés entre le dispositif de support (108) et l'anneau interne de tension (110) sous forme d'au moins deux ensembles placés radialement, les organes séparés travaillant à la compression de chaque ensemble étant distants angulairement, les organes travaillant à la compression comprenant un élément supérieur (112; 148) placé entre le dispositif de support et l'extrémité supérieure d'un organe séparé associé (106; 146) travaillant à la compression, un élément diagonal (114; 150) étant disposé entre le dispositif de support et la base d'un organe séparé associé (106; 146) travaillant à la compression, la structure du toit

comprenant en outre des organes souples (116; 152) travaillant à la traction et placés entre les bases des organes séparés (106; 146) travaillant à la compression.

2. Structure de toit selon la revendication 1, caractérisé en ce que les organes séparés (106; 146) travaillant à la compression sont disposés en cercle, et au moins un cercle supplémentaire d'organes séparés (106; 146) travaillant à la compression sont espacés radialement par rapport au premier cercle, chaque organe (106; 146) travaillant à la compression du cercle supplémentaire étant raccordé, à une extrémité supérieure, aux organes (104) travaillant à la traction, un élément diagonal (114; 150) travaillant à la traction reliant l'extrémité inférieure de chaque organe (106; 146) travaillant à la compression du cercle supplémentaire à l'extrémité supérieure d'un organe travaillant à la compression appartenant à un cercle immédiatement adjacent, l'extrémité inférieure étant aussi connectée à des organes souples supplémentaires (116; 152) travaillant à la traction et disposés entre l'extrémité inférieure et les extrémités inférieures des organes adjacents suivants (106; 146) travaillant à la compression et appartenant au cercle supplémentaire afin que les éléments diagonaux soient maintenus sous tension, si bien que, après montage et pendant l'utilisation, chaque organe (106; 146) travaillant à la compression forme un triangle avec l'élément supérieure associé et l'élément diagonal associé travaillant à la traction.

3. Structure de toit selon la revendication 1 ou 2, caractérisée en ce que les organes souples (116) travaillant à la traction comprennent plusieurs câbles disposés sous forme d'un groupe.

4. Structure de toit selon l'une quelconque des revendications 1 à 3, caractérisée en ce que les organes (104; 142) travaillant à la traction sont disposés radialement vers l'extérieure de l'anneau de tension (110) afin qu'ils recouvrent la zone délimitée.

5. Structure de toit selon l'une quelconque des revendications précédentes, caractérisé en ce qu'un toit (120) sous forme d'une membrane souple recouvre les organes de support.

6. Structure de toit selon la revendication 5, caractérisée en ce qu'un dispositif de mise sous tension (122) est disposé entre les organes adjacents (104) travaillant à la traction afin qu'ils mettent la membrane souple (120) sous tension.

7. Structure de toit la revendication 5 ou 6, caractérisée en ce que la membrane souple (120) comporte plusieurs panneaux adjacents en forme de coin dirigés radialement vers l'extérieur depuis la région de l'anneau de tension (110).

8. Structure de toit selon l'une quelconque des revendications précedentes, caractérisée en ce que le dispositif de support comprend un organe (108) travaillant à la compression, formant une boucle fermée entourant la zone dèlimitée et à laquelle sont fixés les organes (104) travaillant à la traction.

9. Structure de toit selon la revendication 2, caractérisée en cen que les organes (104) travaillant à la traction comprennent un élément supérieur (112; 148) pour chaque cercle d'organes (106; 146) travaillant à la compression, le nombre d'éléments supérieurs diminuant de la périphérie de la zone délimitée vers sa partie centrale, à chaque emplacement auquel un élément diagonal (114; 150) en est séparé.

10. Structure de toit selon la revendication 9, caractérisée en ce que les organes souples (152) travaillant à la traction sont formés par un certain nombre de câbles, le nombre formant les organes inférieures (152) travaillant à la traction augmentant de la périphérie de la zone délimitée vers sa partie centrale à chaque emplacement auquel un élément diagonal se reccorde aux organes inférieurs travaillant à la traction.

11. Structure de toit selon la revendication 3 et toute revendication dépendant de la revendication 3, caractérisée en ce que nombre de câbles des éléments diagonaux reste le même de la périphérie de la zone délimitée jusqu'à sa partie centrale.

12. Structure de toit selon l'une quelconque des revendications 11 à 13, caractérisée en ce que à plusieurs jonctions d'un élément diagonal (114; 150) et d'un élément supérieur (106; 146), le nombre de câbles de l'élément supérieur placés d'un côté de la jonction n'est pas inférieur à la somme du nombre de câbles de l'élément diagonal et de l'élément supérieur placé de l'autre côté de la jonction.

13. Structure de toit selon la revendication 1, caractérisée en ce que les organes souples supplémentaires travaillant à la traction sont des anneaux concentriques de tension (116) raccordés chacun à l'extrémité inférieure d'un organe respectif (108) de compression de chaque organe de support (102) d'un ensemble d'organes de support (102) qui sont espacés angulairement.

14. Structure de toit selon l'une quelconque des revendications 1 à 13, caractérisée en ce que certains au moins des éléments supérieurs, des élément diagonaux et des organes souples supplémentaires travaillant à la traction forment un câble commun.

15. Structure de toit selon l'une quelconque des revendications 1 à 3, caractérisée en outre par une plateforme (134) fixée aux anneaux de tension.

16. Structure de toit selon l'une quelconque des revendications précédentes, caractérisée par des dispositifs d'entretoises (130) placés entre des organes, correspondants travaillant à la compression d'organes adjacents de support.

17. Structure de toit selon la revendication 13, caractérisée en ce que les organes souples supplémentaires travaillant à la traction comprennent plusieurs câbles concentriques.

18. Procédé de montage d'une structure de toit selon la revendication 2, le procédé étant caractérisé par les étapes suivantes: le recouvrement de la zone délimitée par les organes (104; 142) travaillant à la traction, la fixation d'une première extrémité de chacun des organes (106; 146) travaillant à la compression aux organes (104) travaillant à la traction en différents point de ceux-ci,

la fixation de l'autre extrémité de chacun des organes travaillant à la compression aux organes travaillant à la traction en un autre point de ceux-ci afin que les éléments diagonaux (114; 150) soient formés, la fixation de chacune des autres extrémités des organes travaillant à la compression (106; 146) d'un cercle à l'autre extrémité de l'organe immédiatement adjacent (106; 146) travaillant à la compression du cercle supplémentaire aux organes souples supplémentaires travaillant à la traction, et la mise sous tension des organes travaillant à la traction placés sur la zone délimitée et des organes supplémentaires travaillant à la traction afin que la structure du toit soit formée.

19. Procédé selon la revendication 18, caractérisé en ce qu'il comprend la mise sous tension des organes (104) travaillant à la traction par raccourcissement de la longeur des éléments diagonaux (114; 150).

20. Procédé selon la revendication 18, caractérisé par la fixation d'une membrane souple (20) aux organes (104) travaillant à la traction, et le gonflage de la membrane souple afin que les organes travaillant à la traction soient mis sous tension.

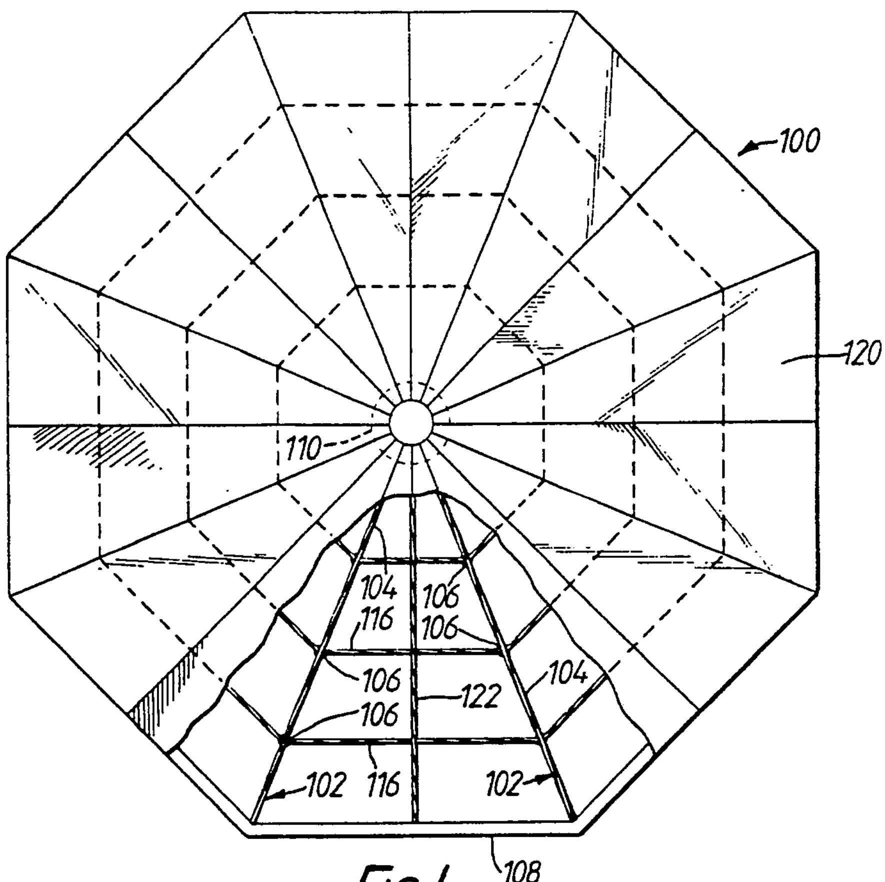
100
120
110
104
106
116
106
106
122
104
106
102
116
102
108

FIG.1.

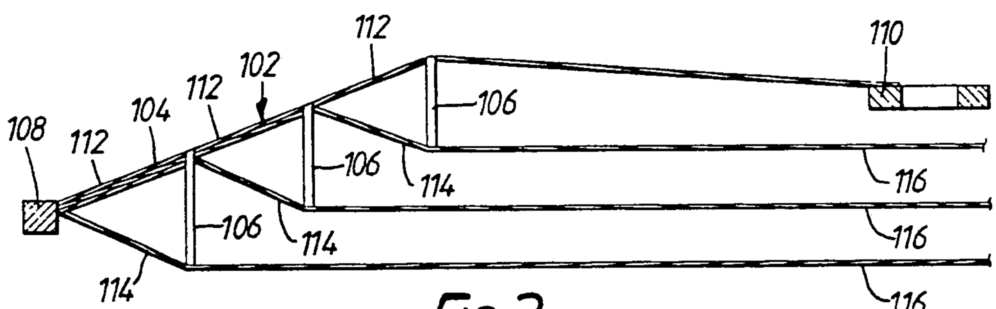
112
110
102
112
106
108
112
104
106
114
116
106
114
116
114
116

FIG.2.

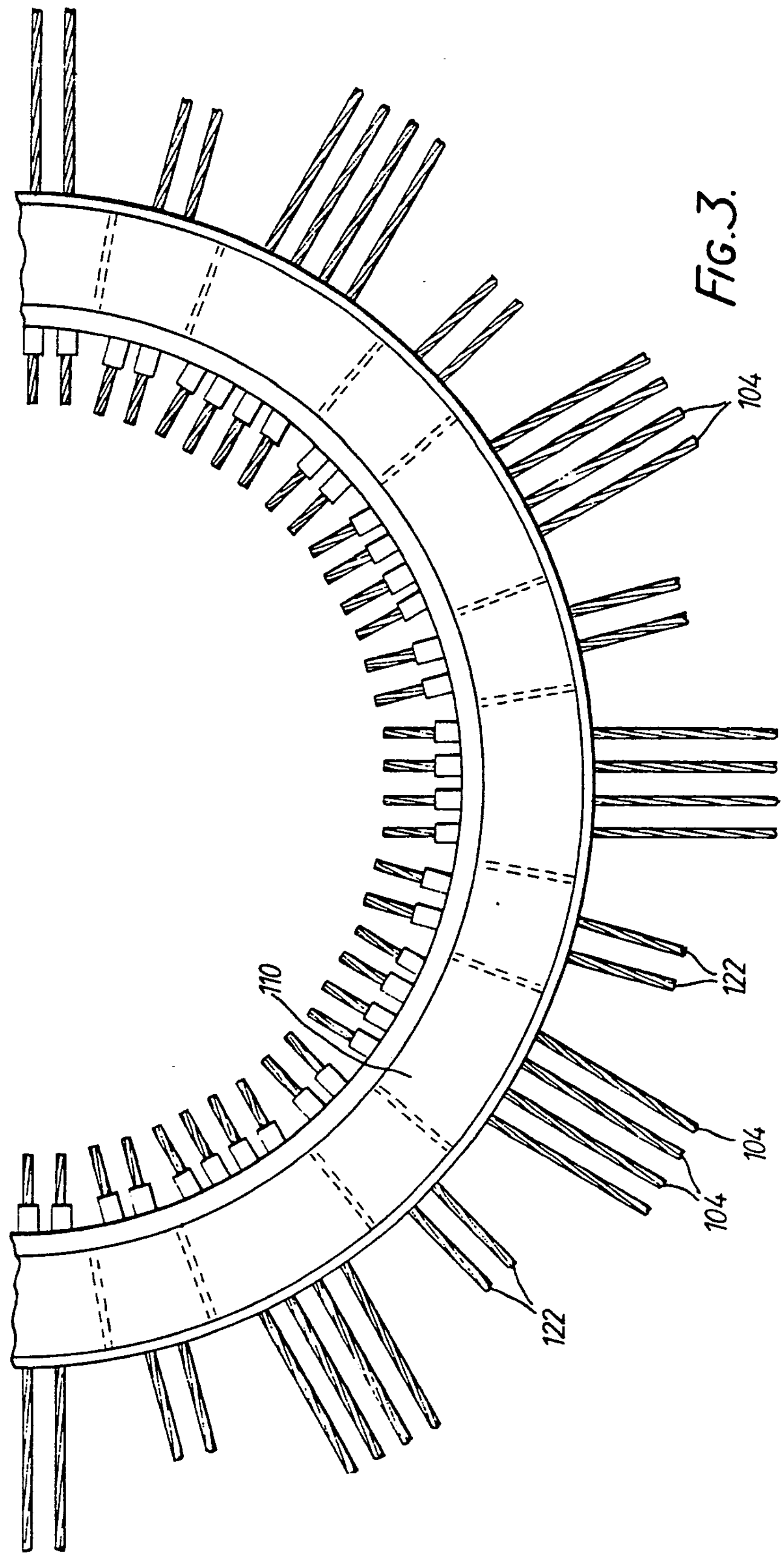

FIG.3.

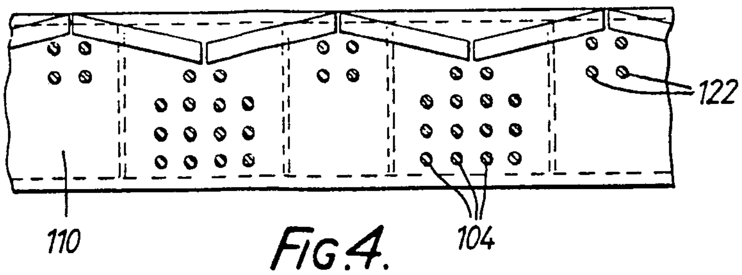

FIG.4.

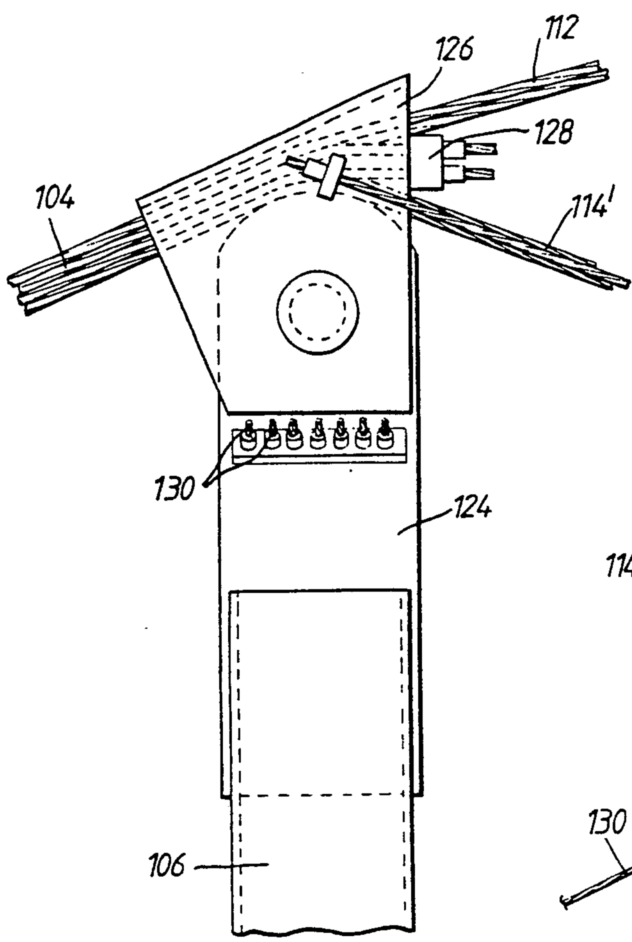

FIG.5.

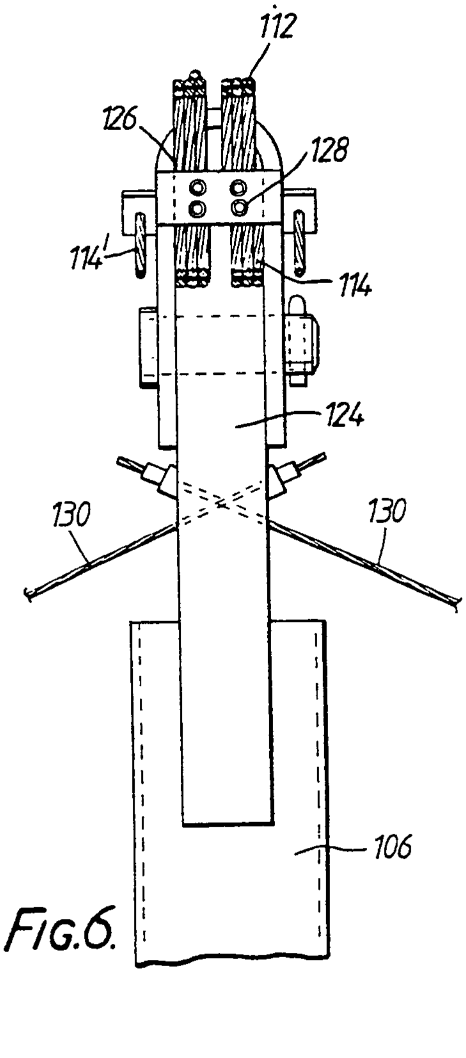

FIG.6.

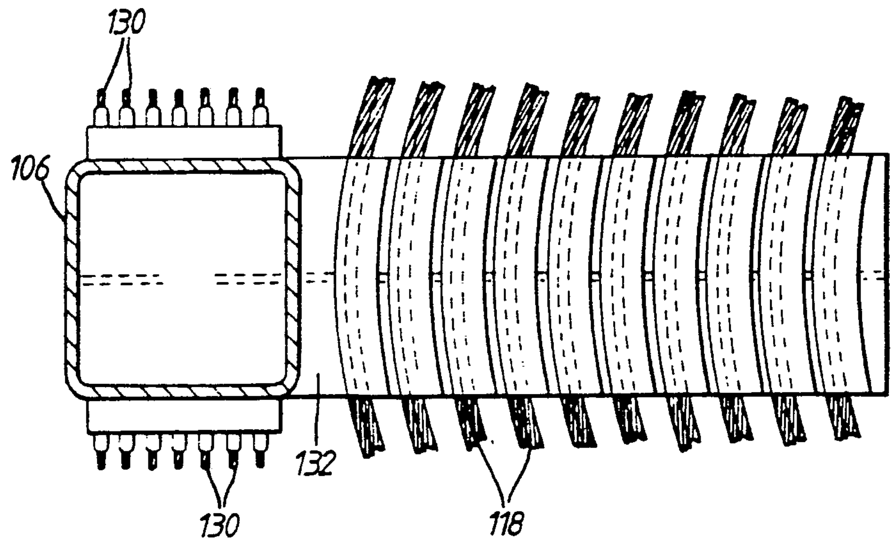

FIG.7.

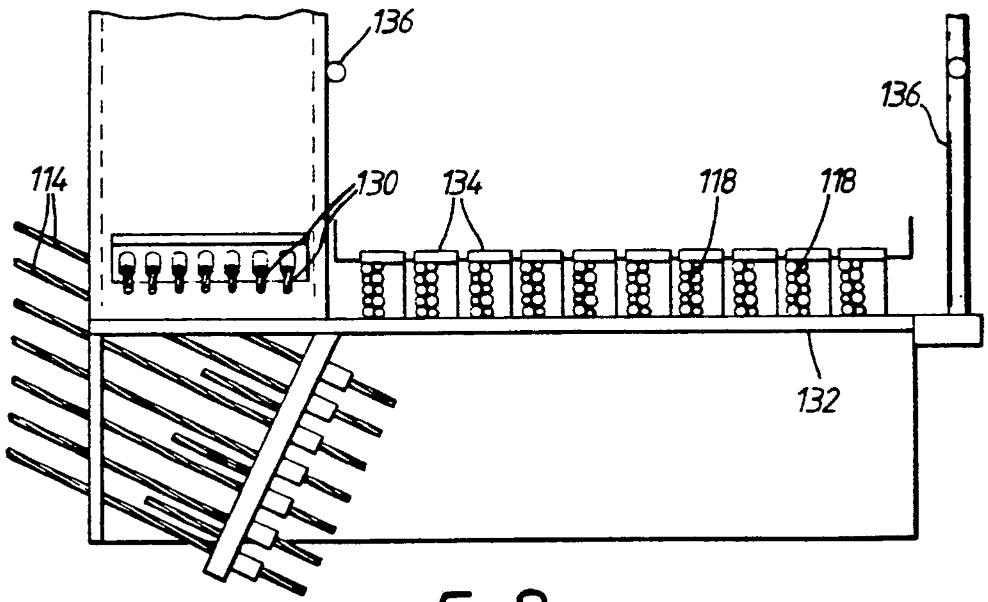

FIG.8.

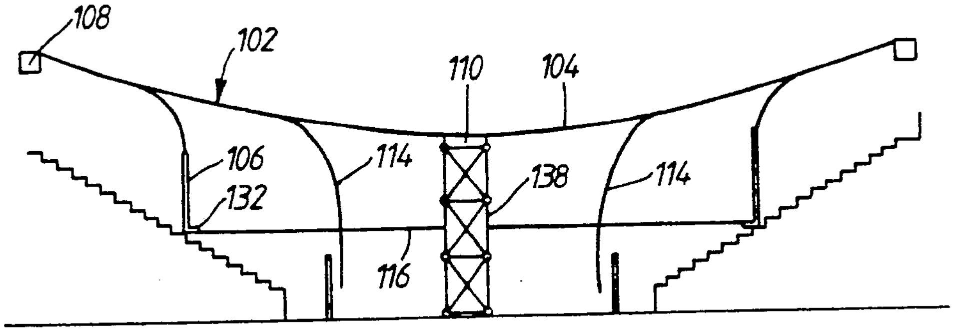

FIG.9.

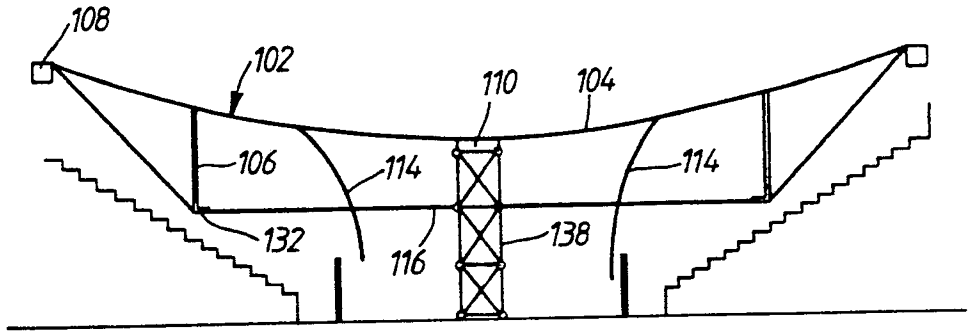

FIG.10.

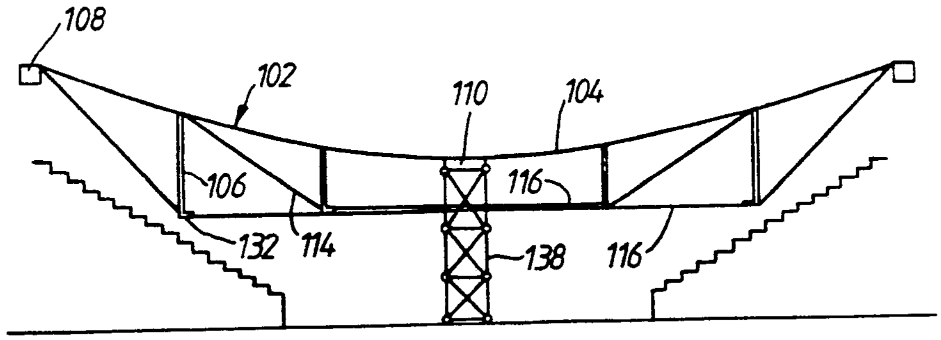

FIG.11.

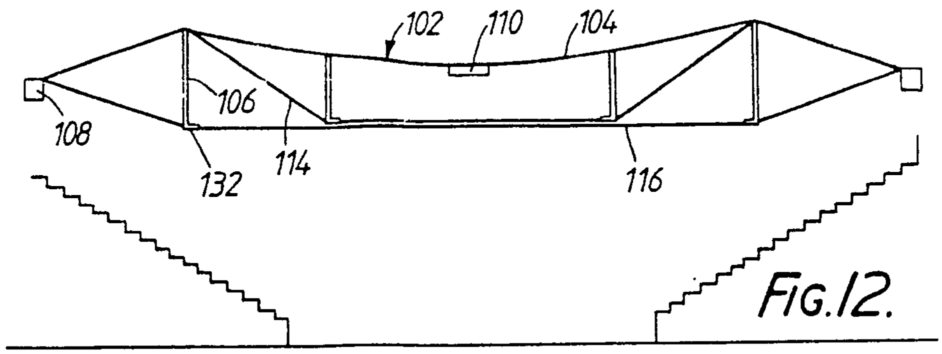

FIG. 12.

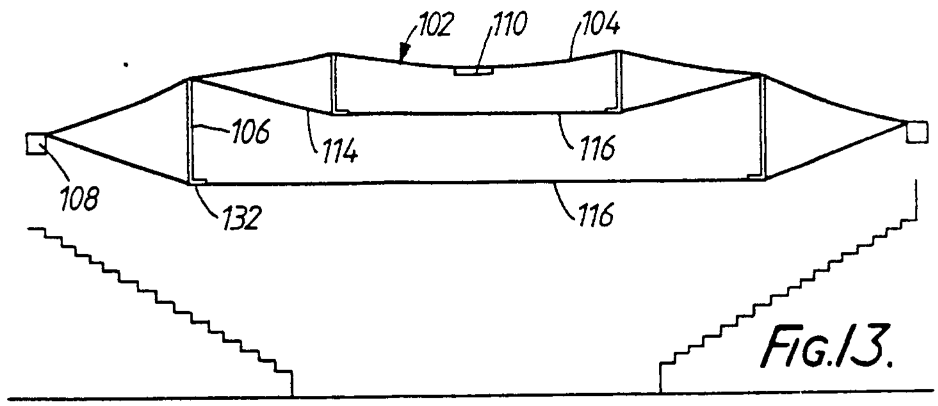

FIG. 13.

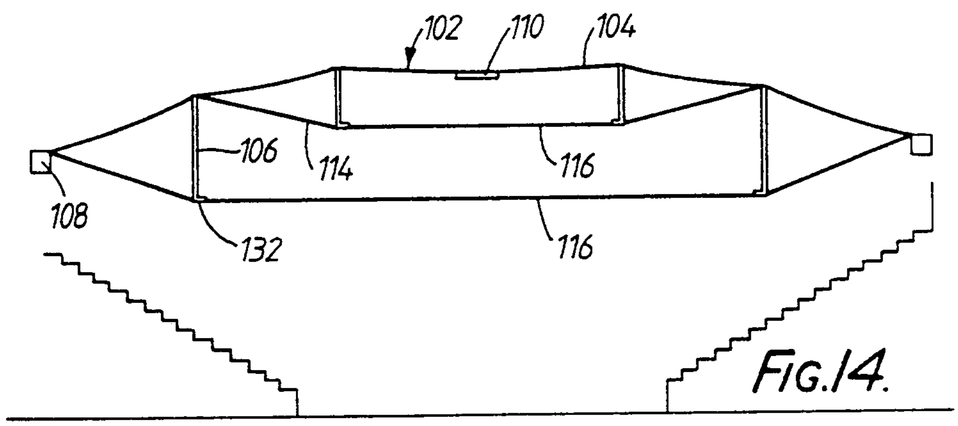

FIG. 14.

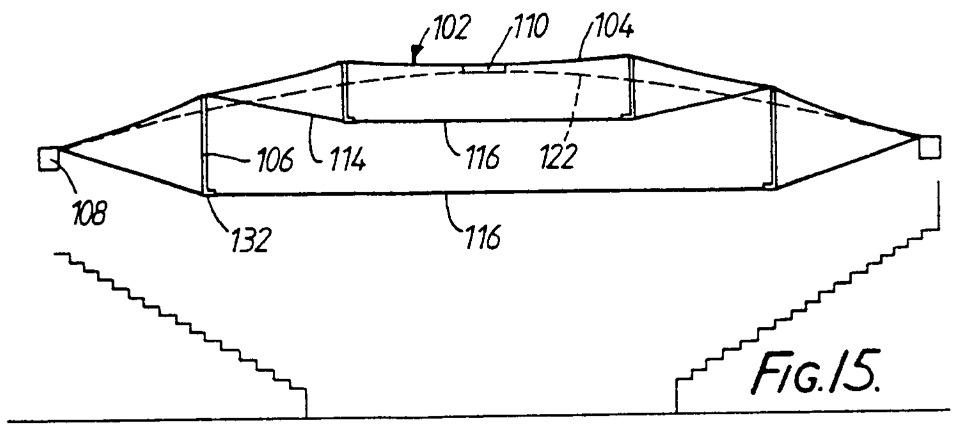

FIG. 15.

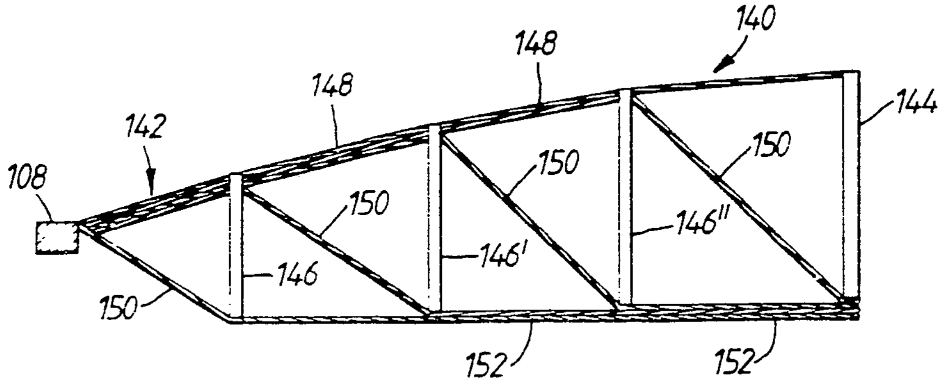
140
148
148
142
144
108
150
150
150
150
146
146'
146''
150
152
152

FIG.16.

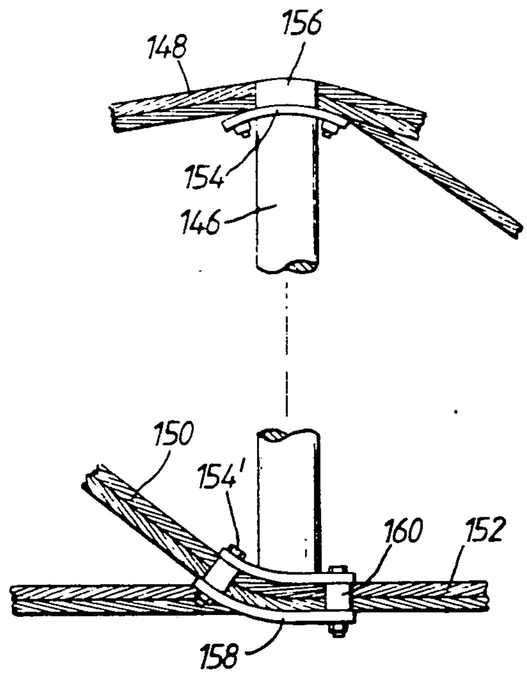
156
148
154
146
150
154'
160
152
158

FIG.17.