July 15, 1969 R. H. KEYES 3,455,069

BUILDING STRUCTURE

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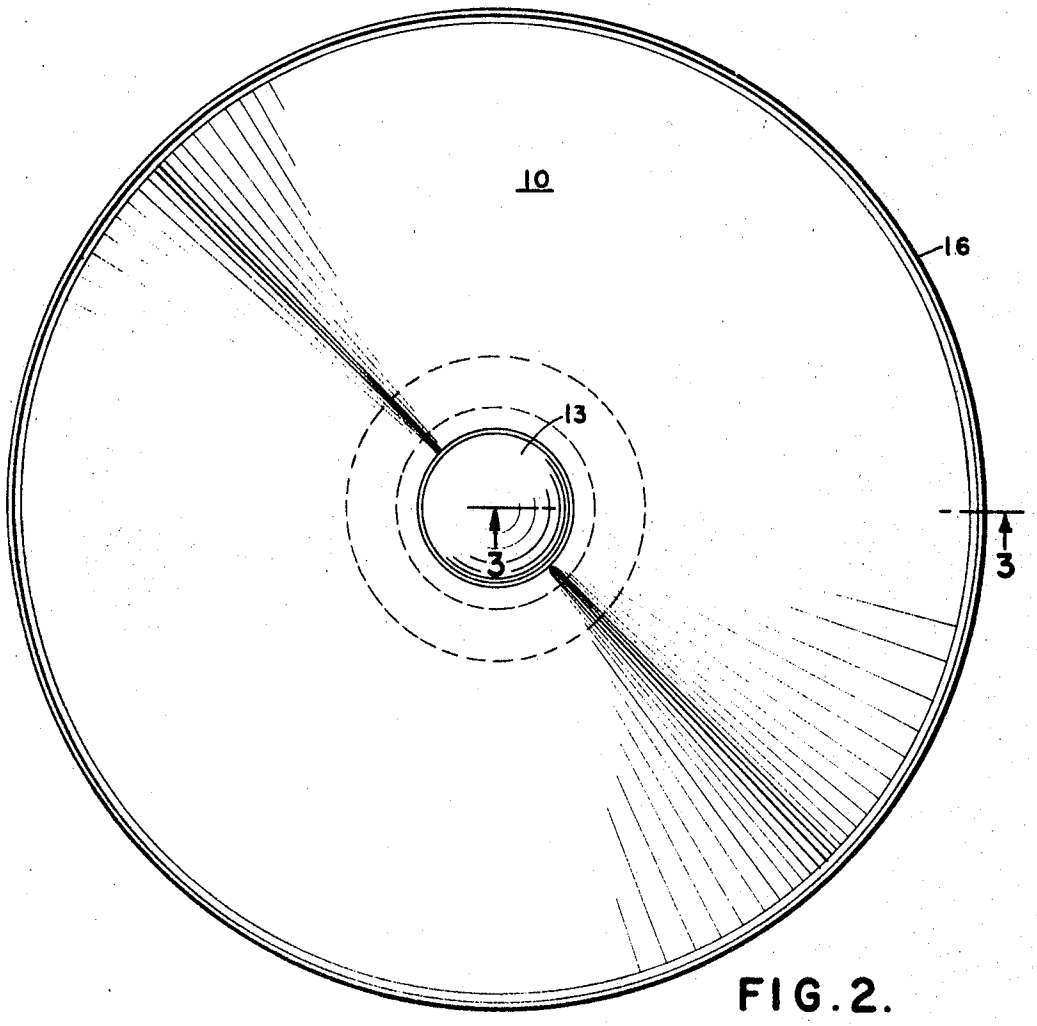


FIG. 2.

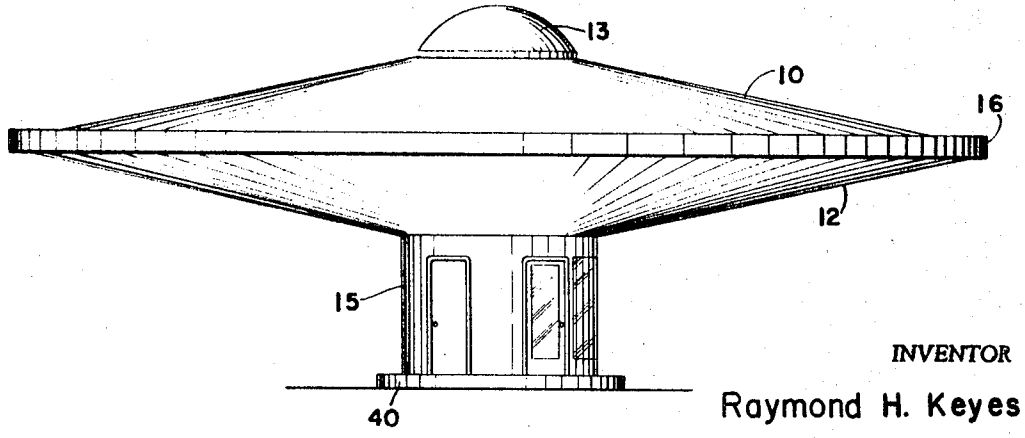


FIG. 1.

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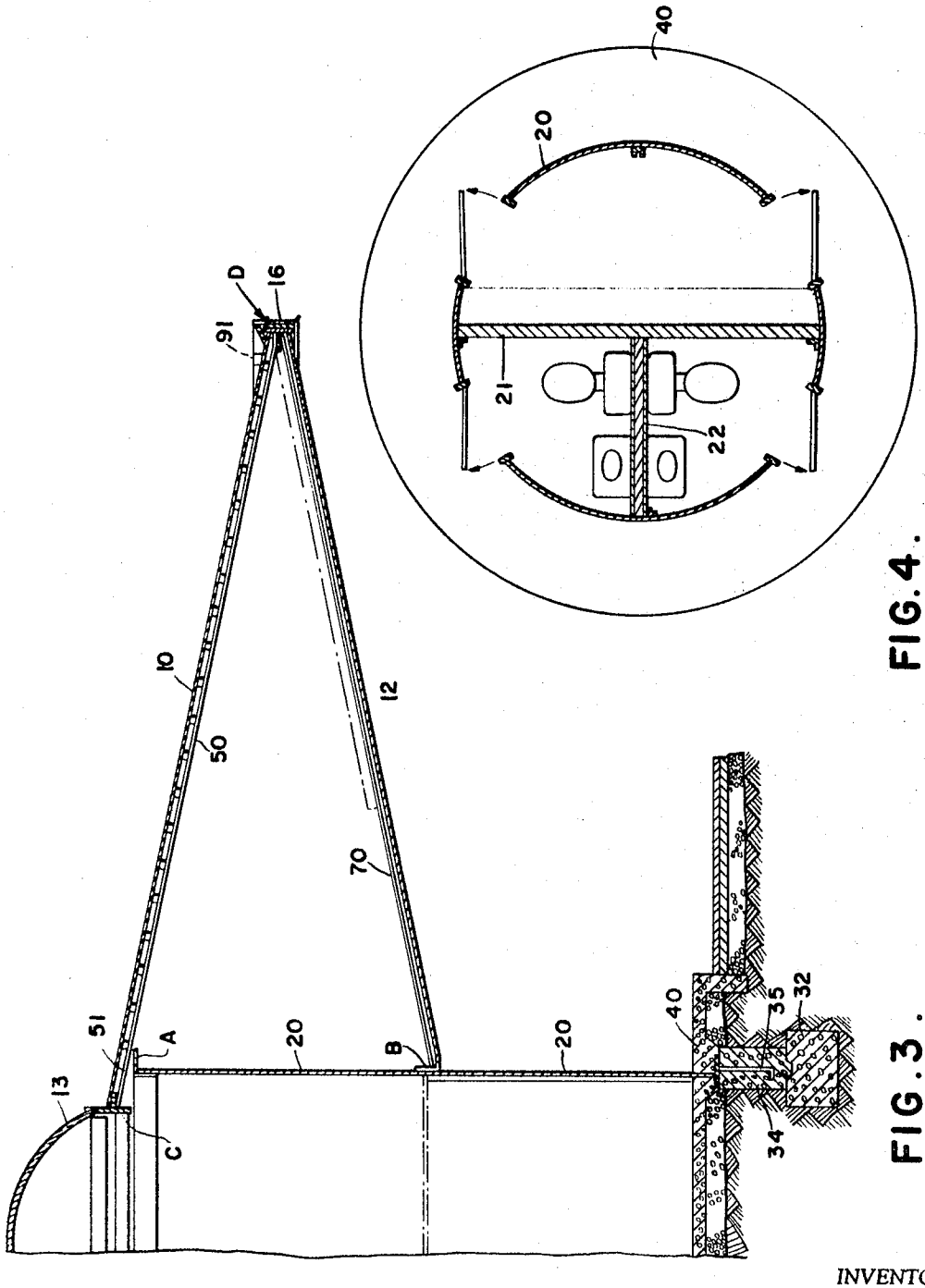


FIG. 4.

FIG. 3.

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FIG. 5.

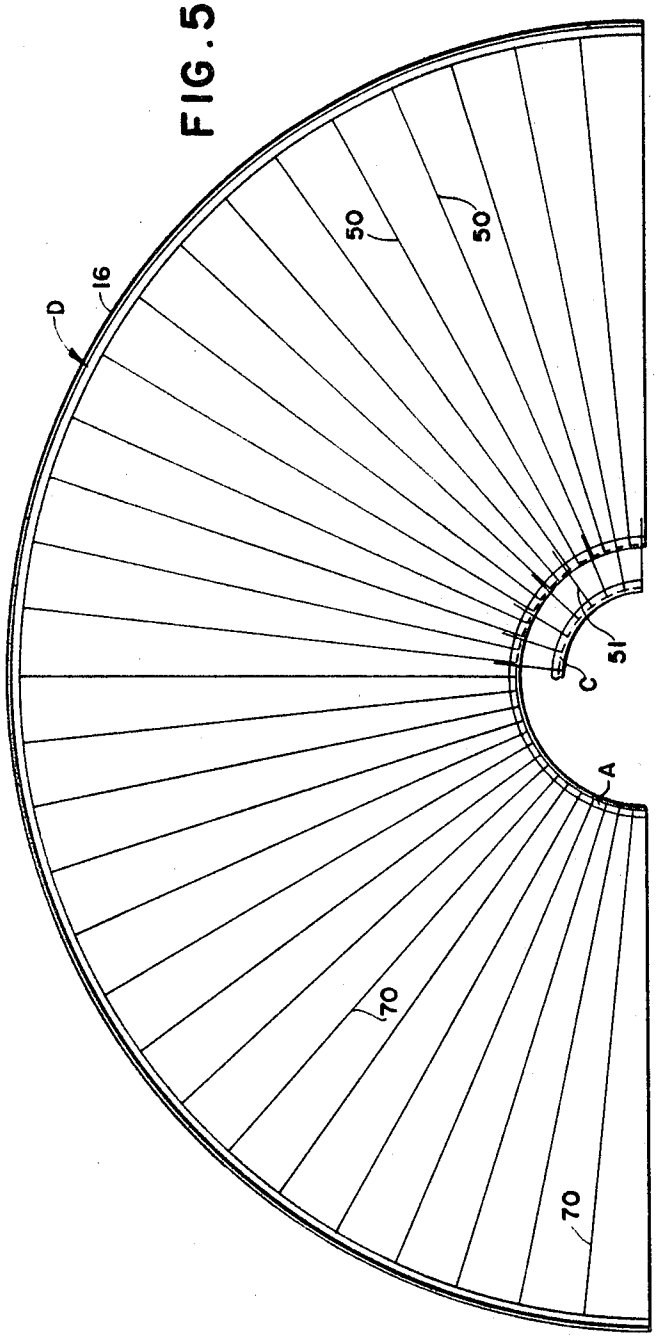


FIG. 12.

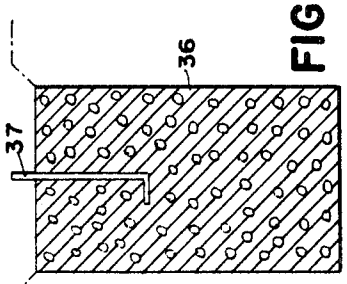


FIG. 11.

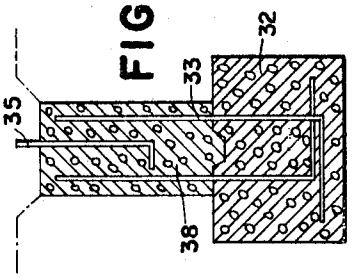
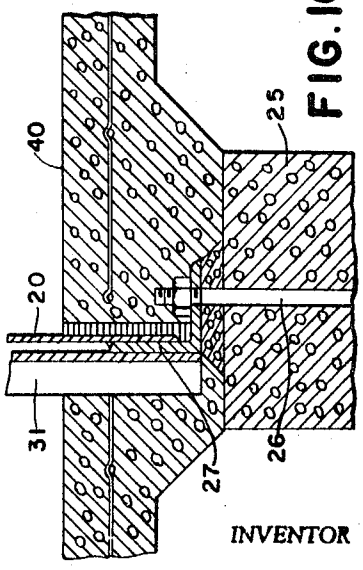


FIG. 10.



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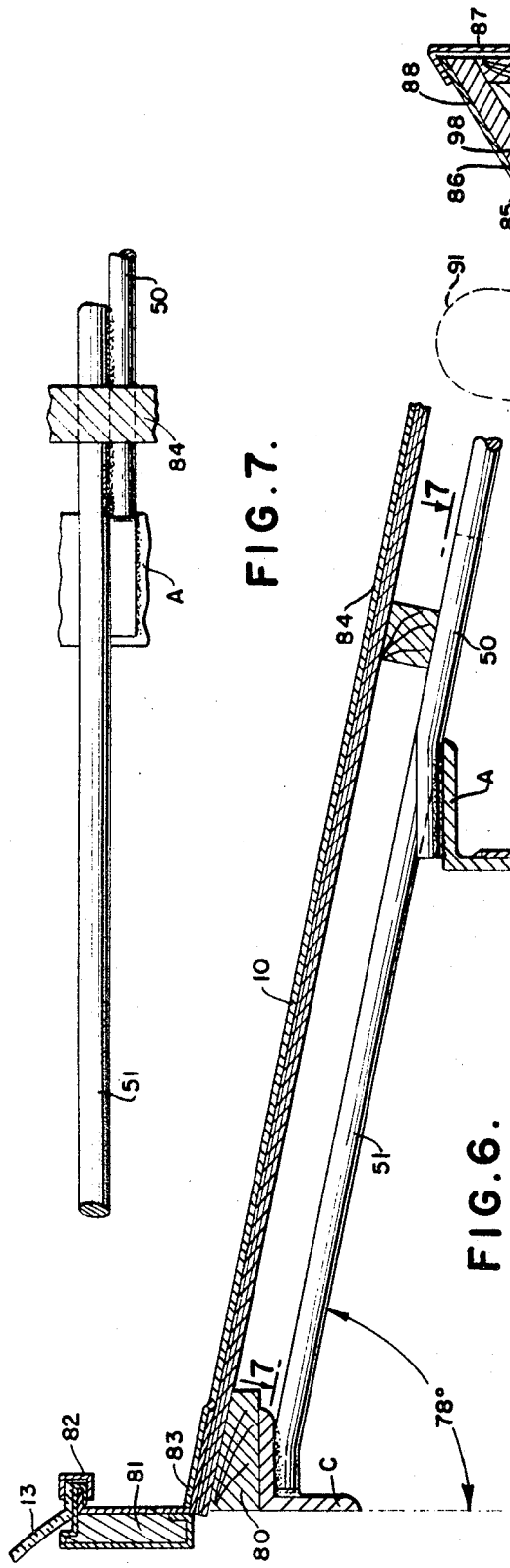


FIG. 9.

FIG. 7.

FIG. 6.

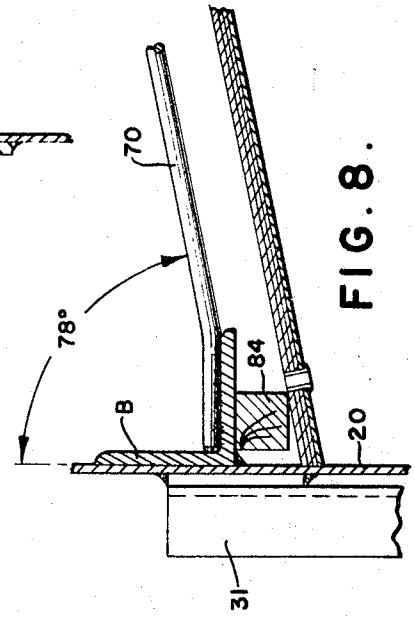


FIG. 8.

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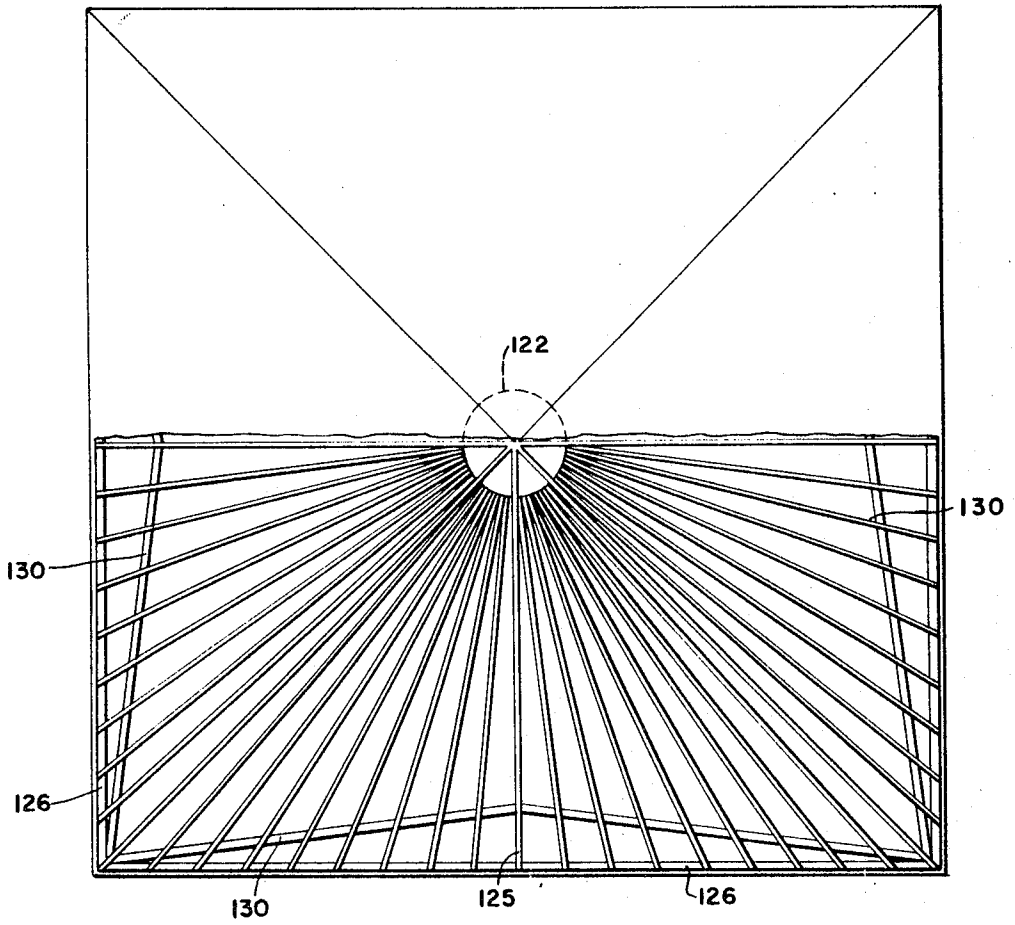


FIG. 13.

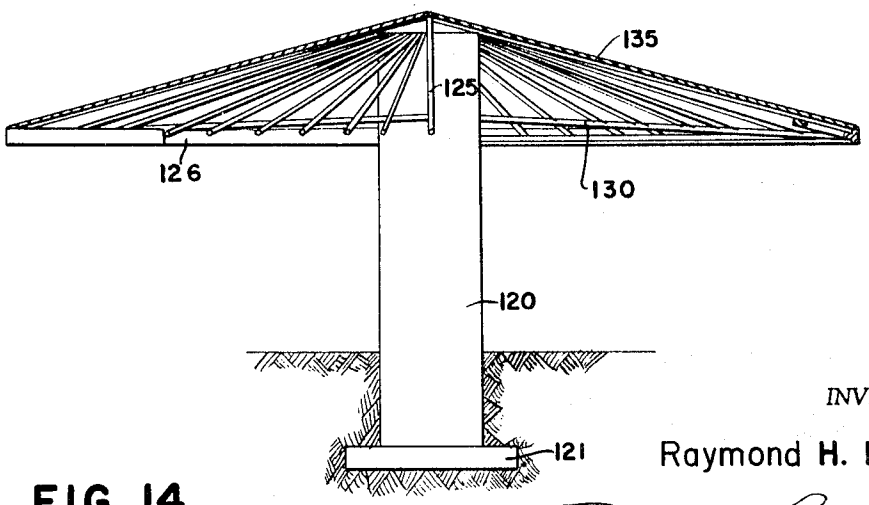


FIG. 14.

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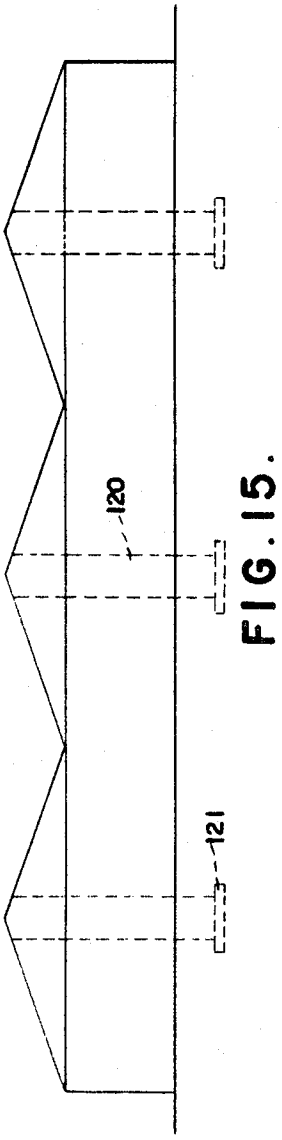


FIG. 15.

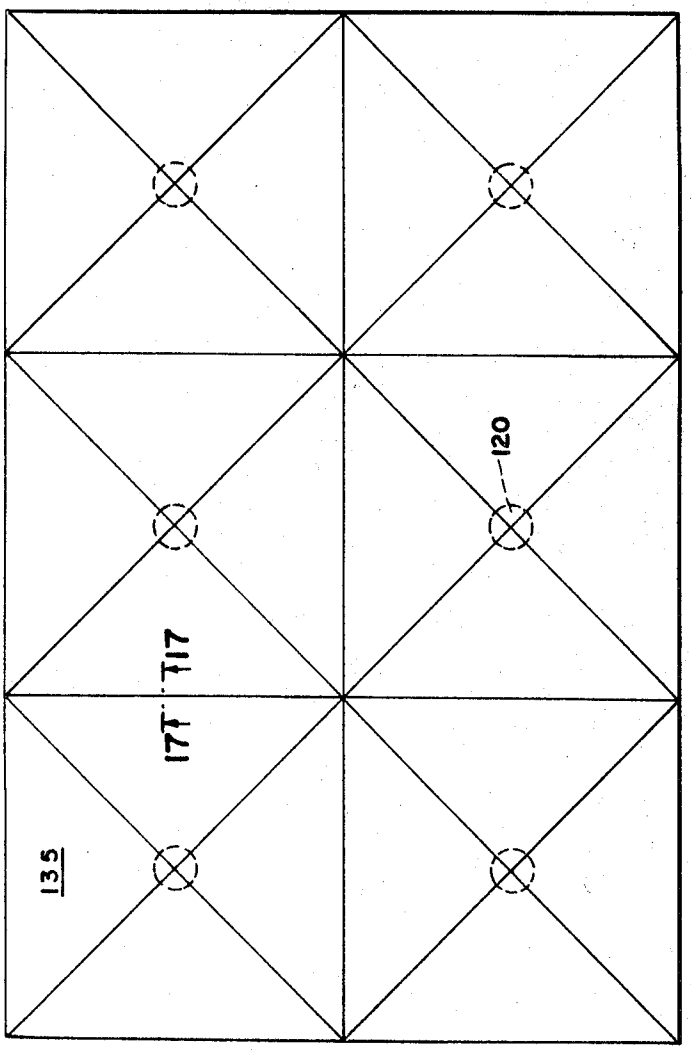


FIG. 16.

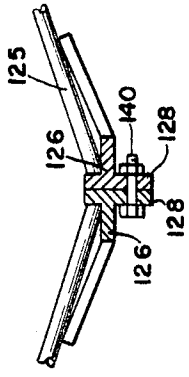


FIG. 17.

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United States Patent Office 3,455,069 Patented July 15, 1969

3,455,069

BUILDING STRUCTURE

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Filed Apr. 19, 1967, Ser. No. 631,969
Int. Cl. E04b 1/34, 7/08, 1/32
U.S. Cl. 52—73 7 Claims

ABSTRACT OF THE DISCLOSURE

A self-sustaining roof structure having an upper center tension ring, and a lower center tension ring, which rings are interconnected by means of two series of radial tension bars to an outer peripheral and surrounding compression ring, the upper series of load supporting tension bars being connected to the upper inner tension ring and the lower series of stabilizing tension bars being connected to the lower inner tension ring. These upper and lower tension rings are connected onto a vertical, cylindrical structure which is the load support of this structure.

As indicated in the foregoing abstract, this invention relates to a building structure, the novel elements of which revolve about a tension-compression system, so fabricated that the entire system is not only self-supporting with regard to its own and even additional weight, but is also self-resistant to additional roof loads as well as forces tending to twist, turn or oscillate the structure about its main central support. The arrangement further revolves about the concept of utilizing a single and center supporting element to which is affixed an upper series of tension elements as well as a lower series of tension members of similar type. All of these are radially disposed from the center support and positioned with respect to each other equally in arcs of approximately 6°. These are each interconnected with an outer peripheral or surrounding compression ring of compressible material, as steel. The tension members are placed under tension by exerting stress thereon during erection of the structure, the upper tension elements representing the main load supporting elements and the lower radial tension members representing elements resisting external and lateral or tangential forces (as a "wind load") normally tending to turn, twist or oscillate the roof structure. The presence of these lower tension elements thus eliminates any need for any ground or other engaging structure directly attached to the periphery to insure resistance to such tangential or other forces as would tend to displace the structure from its intended position.

The peripheral ring representing the outer edge or circumference of the roof structure, in contrast to the tension to which the radial members are subjected, may be considered, as indicated, a compression ring or compression member of other shape. This is because, assuming these radial elements to be disposed outwardly and separated by arcs of 6°, any two adjacent ones of same will tend to compress the peripheral ring material in the area between such arc, this of course being true throughout the entire circumference thereof. Thus, the outer ring is under compression throughout its entire periphery.

By further reference to the upper load support rods referred to in the foregoing, it is to be appreciated that with respect to each, the load supported by the inner one-half of the upper rod will be transmitted to the inner and upper tension ring and the load supported by the outer one-half of that rod will be transmitted to the outer compression ring. The vertical load transmitted to the outer ring is resolved into a diagonal load in the direction of the tension rod and will represent the tension or pull upon that rod or bar.

Similarly, the tension placed on each of the lower rods will produce a vertical component on the outer compression ring, and this will be added to the vertical components as such are determined by the roof loads, whatever that ultimately may be. Also, the vertical loads and tensions on the lower rods will appreciably add to the tension or pull on the upper rods.

The system thus, and as stated, becomes one which is entirely self-sufficient—self-supporting as to roof weight and roof loads and self-resistant to external tangential or twisting forces, such as wind force, et cetera, that would ordinarily require peripheral tie-down elements to assure that the upper roof structure does not oscillate, turn or be otherwise displaced as the result of impingement thereupon by such external pressures. Thus the system eliminates such additional components as peripheral tie-down rods or other peripheral supporting structures of any type whatsoever.

It is, accordingly, the primary object of the invention to provide a roof structure taking the advantage of the combination of peripheral compressive force and radial tension forces to produce a vector force structure resistant to roof load and to external tangential or other side components of force, the system thus representing one which is totally self-sufficient and requiring only a single, central supporting column which absorbs all of the force vectors resultant upon tension, compression and roof load or weight, and which has high resistance to tangential or other external pressures which would otherwise tilt, turn or twist the structure.

It is a further object of the invention to provide a structure of the described type wherein, because no other support therefor is required except the main central column, the exterior walls, if any, can be constructed of an infinite variety of materials; in this regard also, since the tensioned self-supporting roof does not require any exterior supporting structure about its periphery, a construction is possible where even the floor underhanging the periphery or outer circumference of the roof area may be suspended off the base or ground upon which the central support rests.

Another objective of the invention is the design of a structure of the type referred to wherein, depending upon various surface requirements, roof pitch can be increased or decreased, as desired, without affecting the self-sufficiency of the structure, the arrangement also permitting all types of roof covering to be applied to the upper and under surfaces of the two series of tension rods; in this regard, such roofing materials as concrete, aluminum, steel, resin bonded glass fibers, copper, among many other materials, may be expediently used.

A further object of the invention is the provision of such a self-supporting roof unit wherein a gutter system to void roof water is easily built into the structure, the same comprising water vents at or near the periphery, as represented by the ring element under compression, these vents leading to a point of discharge near the base column and being hidden from sight because disposed between the upper and lower tension rods, over which suitable over and under roof coverings are attached.

Another object of the invention is a provision of a self-supporting structure as herein referred to wherein the tension rods are so mounted and constructed as to be subject to variations in tension, thus permitting ease of construction, as well as attunement to the required tension in an amount to achieve the strength necessary for any amount of load which may be required or envisaged.

Another objective of the invention is the provision of a roof structure employing the tension-compression system herein described that permits the outer, peripheral compression ring or rim to be altered as to shape, i.e.,

that shape may be elliptical, circular or, as an alternate herein, rectangular or square, or many sided.

Finally, it is an object of the invention to provide a self-supporting roof structure that represents the essence of simplicity, the number of elements needed to fabricate the design being minimal, considering the size of the structure; in this regard, also, such simplicity of design results in a low cost structure viewed not only from the reduction in constructional elements but in substantial reduction in labor cost due to elimination of heavy component structural parts such as trusses, cantilevers, and other well known and usual expedients generally used in the building structure art. In this respect also, such simplicity of design renders dismantling, as well as assembly of the structure, and ease of moving intact, a comparatively simple task.

Reference will now be made to the drawings wherein a more specific description of the invention will be found, and wherein:

FIGURE 1 is a front elevation view of one embodiment of the invention wherein the central supporting column also serves the purpose of a central, partitioned room and office area;

FIGURE 2 is a top plan view of the invention as shown in FIGURE 1;

FIGURE 3 is a section view taken on the line **3—3** of FIGURE 2;

FIGURE 4 is an enlarged sectional view, in plan, of the central support member showing the manner in which the same may be partitioned to form work and room areas;

FIGURE 5 is a plan view, partially in section, of one-half of the roof area of the structure illustrating the manner of mounting and spacing of the upper and lower tension bars;

FIGURE 6 is an enlarged detail view, partially in section, showing the manner by which the series of upper tension bars are affixed to a ring affixed to the wall of the tubular support member, and alternately, in this embodiment of the invention, to an additional inner ring which provides support for the central dome;

FIGURE 7 is a detailed view taken on a line **7—7** of FIGURE 6;

FIGURE 8 is a detailed sectional view showing the manner in which the lower tension bars are affixed to the lower tension ring;

FIGURE 9 is a detailed sectional view illustrating the manner by which both upper and lower tension bars are affixed to the peripheral compression ring and, as here shown, indicating a means by which tension in each of the series of bars may be regulated and adjusted, as well as the method of attaching the plywood roof and ceiling onto the rods, also the cross sectional detail of the rain gutter and downspout is illustrated;

FIGURE 10 is a detailed sectional view of one manner of constructing the foundation for the central support;

FIGURE 11 is a detailed view similar to FIGURE 10 indicating a variation in such foundation support;

FIGURE 12 is a detailed sectional view illustrating an additional variation in formation of the foundation support;

FIGURE 13 is a top plan view, partially in section, showing an alternate embodiment of the invention wherein the structure assumes a square shape;

FIGURE 14 is a front elevation view, partially in section, of the invention as illustrated in FIGURE 13;

FIGURE 15 is an elevation view, somewhat diagrammatic, showing an arrangement of several of the units of FIGURE 14 positioned together to form a composite building structure;

FIGURE 16 is a top plan view of the invention as shown in FIGURE 15; and

FIGURE 17 is an enlarged view, partly in section, of one means of connecting together the adjacent edges of the structures shown in FIGURES 13, 14, 15 and 16.

Referring more particularly to these figures, the external appearance of the structure of this embodiment of the invention takes the form of that shown in FIGURE 1. This structure, with respect to both roof and central column, is of circular configuration. Both upper and lower roof components, here indicated at **10** and **12** respectively, are angled toward each other, from base outwardly, and to an equal extent, terminating in the outer circumferential ring element **16**, these numerals **10**, **12** and **16**, of course representing the exterior skin covering of each of such elements. A hemi-spherical skylight is shown at **13**, this being fabricated of such material as glass, clear plastic or other obviously suitable synthetic materials, and supported in a manner as hereinafter described.

The entire roof structure is supported by the central column **15** which, in this embodiment of the invention is of relatively substantial diameter in order to provide work and office space within such column and, as more particularly depicted in FIGURE 4, this central and circular column as here shown, is partitioned, as at **21** and **22**, to form a work and office space area on the one side, and additional spaces such as restrooms on the other.

It is preferred that the structure be mounted upon a concrete base, as indicated at **40**, and that such base be, in turn, secured to imbedded foundation supports of the type herein represented in FIGURES 10, 11 and 12.

Referring to FIGURE 10, anchor bolts **26** are embedded in the buried concrete under-base **25**. These, at the threaded ends thereof, are secured to an angle iron **27** to which the outer wall **20** of the central column is affixed in any usual manner, as by welding. Alternatively, the under and buried foundation **32**, as shown in FIGURE 11, may offer support for like angled anchor bolts **33**, such as there shown, the upper extremities of these being, in turn, anchored in an additional, circular concrete form **34**, the latter, if desired, having a groove-tenon interconnection **38** for accurate and permanent emplacement upon the base foundation **32**. The upper portion of this support again provides means for affixing thereto the upwardly extending anchor bolt **35** which can be suitably secured to the wall **20** of the circular support element in the manner shown in FIGURE 10.

The simplest foundation arrangement is found in FIGURE 12 where the buried portion thereof, again of concrete, is indicated at **36** and the L-shaped anchor bolt **37** embedded therein, again for attachment to wall **20** of the central column, also as in the manner shown in FIGURE 10.

The basic supporting elements for this roof structure are the upper and lower tension rods or bars, connected at their inner ends to the central support and at their outer ends to an appropriate peripheral and compression ring of sufficient strength to withstand the involved forces of tension and compression when the system is placed under tension in its final form.

The upper rods indicated at **50** are radially extended, as stated, from the central column. They are attached thereto through an L-ring A to which they are affixed as by welding or bolting. This L-ring A, positioned at the upper end of the circular frame or tubular element **20** is, in turn, bolted, or as indicated, welded to the element **20**.

The lower tension rods or bars, designated by the numeral **70**, are similarly affixed to a lower L-ring B, as indicated in FIGURE 8. This second L-ring B is similarly welded or otherwise affixed to the external surface of the central column **20**. Additional optional support for element B is found in the stanchion **31**, positioned in the base **40** and welded to the wall **20** on the opposite side thereof (FIGURES 8 and 10).

Each of such rod elements **50** and **70** are secured at their outer extremities to an outer ring, generally indicated at D, which, in cross section, is of a T or other structural design shape formation in order to provide it with a form of the simplest design but capable of withstanding the tensional and compressive forces to which

that element is subjected when the system is placed under tension.

In the preferred form of the invention the over-all diameter of the roof structure is about 50 feet and it has been found, with relationship to that size, that the upper rod elements **50**, which are self-sufficient in supporting the roof load, should be of steel and preferably of a diameter of about ¾ inch, whereas, since the lower rod elements **70** do not primarily contribute to roof support but are merely present as an "hold down" means to prevent torsional, sidewise, or other undesired movement of the structure due to exterior forces. Hence, such are smaller and, as here contemplated in this embodiment of the invention, are of ⅝ inch diameter.

Both upper tension elements **50** and lower tension bars **70**, as indicated, are affixed to the ring member D simply by passing them through an appropriate bore or aperture in the member D (see FIGURE 9). As here shown, elements **50** are passed through a bore above the radial element **100** and the bars **70** are positioned through an aperture below that dividing member **100**. Each of the outer ends of such tension elements may be threaded, as indicated in FIGURE 9, for the reception of suitable nuts **52** and **72**, the latter being adapted to be taken up against an intermediate shim or gasket, as indicated in **54** and **74**, the latter being provided with an outer bevelled or angled surface such as to permit them to bear flush against the inner surface of these nuts **52** and **72**. By means of such nuts the amount of tension, once the tension elements or bars are welded at their opposite ends to the respective L-rings A and B and as above described, can be readily adjusted and increased to that extent required by appropriate engineering calculations to place the system under the required tension, with the peripheral ring D thus subjected to such compression as to render the system self-sustaining, both with regard to roof load as well as torsional, lateral or other external forces impinging thereagainst.

Viewing FIGURE 5, it is seen that, with respect to both series of tension elements, **50** and **70** respectively, the same are radially disposed at angles of about 6° to each other, this in the preferred embodiment of the invention. Also, in the interest of equating or balancing the force vectors which exist between the upper and lower tension elements, as well as in the outer ring or peripheral element D, the lower rod elements are juxtaposed directly beneath the upper tension bars **50**, and are equal in number. Being disposed radially, and again with respect to this embodiment of the invention at a preferred adjacency of 6° arcs, it can thus be appreciated that there are a series of 60 tension elements in each bank, i.e., both in the upper as well as lower array.

Although it is to be understood that the upper tension rods may extend outwardly laterally or parallel to the supporting surface, in the instant embodiment of the invention where the lower rods provide the additional function of resistance to external side pressures, these two series or sets of tension rods are angled toward each other, proceeding outwardly from the central column. In the form of the invention which is herein specifically disclosed, the upper and lower series of tension bars, together with the vertical wall or face of the central column, form an isosceles triangle. Both lower and upper rods have an internal angle, with respect to the column surface, of 78° with the corresponding angle at their point of juncture at the peripheral compression ring being 24°. As otherwise indicated herein, the slope of the roof **10** may be varied and, of course, this may dictate a corresponding variance as to the upward angularity (from column surface outwardly) of the lower tension rods.

Referring to FIGURE 6, it is seen that provision has been made for the support of the referred to skylight **13**. This is done by extending the length of the upper rods or tension bars **50** inwardly the required distance. As shown in this figure, and also in FIGURE 7, the upper bars **50** are extended an appreciable distance inwardly by welding an extension **51** thereto. Since the latter is merely for support of the dome **13**, these extensions are not required upon each tension bar **50** as a necessary adjunct to the tension-compression system, but as here exemplified, are disposed only upon alternate ones of them, and as may be appreciated from viewing FIGURE 5. Hence, there is a total of 30 elements **51**, all extending inwardly a substantial distance with regard to the main supporting wall **20**. Each of these terminate in a third L-ring C, to which they are each respectively welded or otherwise affixed, the latter directly supporting the roof cap or center skylight **13**.

In the erection of the structure those components which have thus far been described are assembled prior to completion of the unit by addition of the outer skin coverings, et cetera. The peripheral T-ring D is first supported, by jack screws or other equivalent means, at a distance above the ground approximating that representing its final position. Upper tension bars **50** and lower rod elements **70** are then placed in position with their inner ends against the respective L-rings A and B, and also threaded through the appropriate apertures in the T-ring D at the opposite extremities thereof. The two series of tension rods are then welded or bolted to the tension rings A and B which have previously been positioned as shown and welded to the wall **20** of the central support. Tension is then placed upon each series of tension bars (upper and lower) by taking up on the respective nuts **52** and **72** to that extent where the entire system is placed under sufficient tension-compression to become self-sustaining, not only with regard to its own weight as a roof structure, but self-sustaining as to any additional roof loads which may be contemplated, and as well, as to any possible external side forces (as wind forces, et cetera), as may be visualized.

Once erected this basic frame structure is fitted with the other necessary accouterments for commercial use. The transparent dome **13** is, as stated, directly supported upon the extended rods **51** to which the inner ring C is attached. The latter is provided with a circular "nailer" **80**, preferably wooden piece, which is attached to the roof composition or exterior wall **10**. An additional peripheral member **81**, suitably enclosed in some form of weather proofing material and as indicated in FIGURE 6, rests upon the member **80** and may be secured over the upper composite **10** utilizing flashing **83**, as is customary in such cases. This spacer **81**, provided with a suitable upper and outward extending flange, is thereby locked together with a corresponding extending flange of the skylight **13** by means of the circular U-gasket or clamp means **82**.

Other nailers, consisting of wood elements extending around the central member and directly affixed in any suitable fashion to the upper surface of the rods **50**, likewise support the upper roof composite **10**, such being indicated at **84**. Similar spreaders or wooden members **84** are likewise affixed to the outer surfaces of the lower rods **70** and as shown in FIGURES 8 and 9, and these in turn provide the base upon which the under-roofing material **12** can be attached.

The peripheral compression ring D, having the cross sectional shape of a T, and disposed as shown in cross section in FIGURE 9, thus presents a vertical rim **98** to which the wood nailer **85** may be fastened in any suitable manner, these being appropriately bevelled and providing support for the outer rim covering **16**, already referred to, upper covering material **88** supported on piece **86**, and, of course, any necessary type of metal flashing as indicated at **87** (FIGURE 9).

In the construction herein referred to in this preferred embodiment of the invention, the roof is shown as inclined from the center column downwardly toward the periphery, although under the tension-compression system which is herein described, the roof, as hereinbefore men-

tioned, may extend outwardly at various angles depending on the design. At any rate, as shown here, this downward slant of the circular roof structure permits ready drainage toward the periphery or toward the compression member D with the collection of water accumulating in the V configuration formed between the upper covering **10** and the piece **88**, thus forming a trough. The water may be drained from that point by one or more suitable apertures **90** penetrating the upper roof element **10** to which are affixed some form of screen **91** (FIGURE 9) as is usual in this regard. A drain line **95** held in place as by flanges **93** is positioned in between the upper and lower tension rods and decline downwardly from the periphery of the structure toward the center column. These drain lines can be provided with outlets at any convenient point in, near or adjacent to the center column.

Although in large part this description of the invention is directed to constructions where the circular type of structure is utilized, the same principles may be effectively employed with respect to a rectangular, square or many sided roof configuration, and as illustrated in FIGURES 13 to 17 herein.

Here the center column **120** is supported upon an underground base **121**. A tension ring element **122** surrounds the upper edge of this column and to this ring is attached a series of tension rods **125**, all of which are evenly spaced and fixed to a peripheral element **126** formed in the shape of a square. With equal stress or tension placed upon each of the opposing tension rods **125** the same forces of tension-compression will be exerted, the peripheral element **126** again being under stress as a compression member. In order that sufficient tension can be exerted under these circumstances upon the element **126** and the required compression in that element induced thereby, each side is provided with a truss bar **130** which extends throughout the length of that side and is connected to an adjoining bar positioned along each adjacent side. The usual roof covering is provided, as at **135**.

When units are fabricated as per the structures shown in FIGURES 13 and 14, the straight edge of each side may be connected to a similar straight edge of a like unit; such is illustrated in FIGURES 15 and 16. In order to facilitate this operation the external compression member **126** may, again, be in the form of a T element or other structural shape having one vertical side **128**. As illustrated in FIGURE 17, the tension bars are each connected to this compression member in any suitable manner, as by welding. Each of the flanges **128** of this compression member may be apertured at suitable intervals; in this regard the apertures in this circumferential tension member are spaced the same distance in each unit, so that, when placed adjacent as shown in FIGURE 17, such bores coincide. When the matching sides of two units are thus placed together so that the tension member **126** of each faces its counterpart in the adjacent member, a suitable bolt **140** placed through the matching apertures, will securely affix the side edges of such adjacent units together.

Thus, as shown in FIGURES 15 and 16, any number of units can be juxtapositioned so that an infinite variety of shapes will result, each of the units requiring only its own individual support column **120**.

From the foregoing, the self-sustaining characteristic of this tension-compression system can be understood when it is considered that the summation of the force vectors produced by the tension rods at right angles to any line drawn through the center line of the circle defined by the compression ring will determine the pressure on that outer compression ring. The amount of this force or pressure in the outer ring determines the required cross sectional area of steel to withstand these forces. Such forces are equal at any cross sectional point in the outer compression ring.

The length of the described tension rods does not change the involved force in those rods, but only the angle of the rods to the vertical and central support will change such force. The upper tension ring is designed to resist the summation of all the forces produced, whereas the lower tension ring is designed to resist only the tension and the load only in the lower tension rods. Of course the central support column is so designed as to resist any involved wind load as well as any involved dead load.

With regard to this central column, all the involved forces are equal in all directions and are transmitted into this central support. The size of the column can be varied to meet the requirements of the building so long as the size is sufficient to carry the structural loads. Since, as indicated, the column must support the wind and dead loads of the biulding, it must extend into the ground a sufficient distance, or be otherwise firmly implanted in the ground, to achieve this objective. The overhang, or radial distance outwardly of the roof structure from the central column, is only limited by need and the availability of structural materials to carry the loads of the roof structure.

The basic concept or idea of this tension-compression system is that the tension rods directly opposite each other (i.e. opposed 180°) must exert the same pull or force, thereby cancelling each other out. The problem then reduces itself to merely the provision of mechanical connections which are of such strength to withstand these opposite forces, thus to transmit such forces into a downward reaction into the support column.

I claim:

1. In a tensional-compressional roof structure system adapted to be self and load supporting from a single central column, an upright member, a first upper tension ring on affixed to said member, a second tension ring on said member below said first tension ring, a compression element exterior to said upright member and surrounding said member, a first series of radially disposed tension bars connecting said first tension ring and said compression element, a plurality of tension bars of said first series being extended inwardly toward the center of said column to provide support for a centrally disposed skylight means, and a second series of radially disposed tension bars connecting said second tension ring and said compression element, said first series of tension bars being under sufficient tension to resist the summation of all force vectors consequent upon tension, compression and roof load, said second series of tension bars being under sufficient tension to resist the load in said lower rods and external variable forces on said system.

2. The invention as defined in claim **1** wherein said compression element is circular in configuration and said first and second series converge towards each other outwardly at an angle of about 24°.

3. The invention as defined in claim **1** wherein said first and second series of tension bars at the point of attachment to said column are disposed at inner angles to each other of about 78°.

4. The invention as defined in claim **1** wherein the system is placed under such tension-compression that the load supported by the inner one-half of each of said first series of tension bars is transmitted to said first tension ring, and the load supported by the outer one-half of each of said first series of tension bars is transmitted to said compression element.

5. The invention as defined in claim **1** wherein said upper and lower series of tension bars are so positioned with respect to the side wall of said central column as to form an isosceles triangle therewith.

6. In a tensional-compressional roof structure adapted to be self and load supporting from a single central column, an upright ground supported member, a four-sided compression member, a series of tension elements interconnecting said column and said compression member in radial fashion, a truss between adjacent corners of each of said sides of said compression member, said tension elements directly opposite each other being under tension of equal amount, said tension elements being under sufficient tension and said compression member being under

sufficient compression to resist a load equivalent to the total of all roof loads upon said roof structure.

7. The invention as defined in claim 6 wherein a plurality of said roof structures are affixed together at two adjacent sides of said four-sided compression members.

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