

Aug. 26, 1969

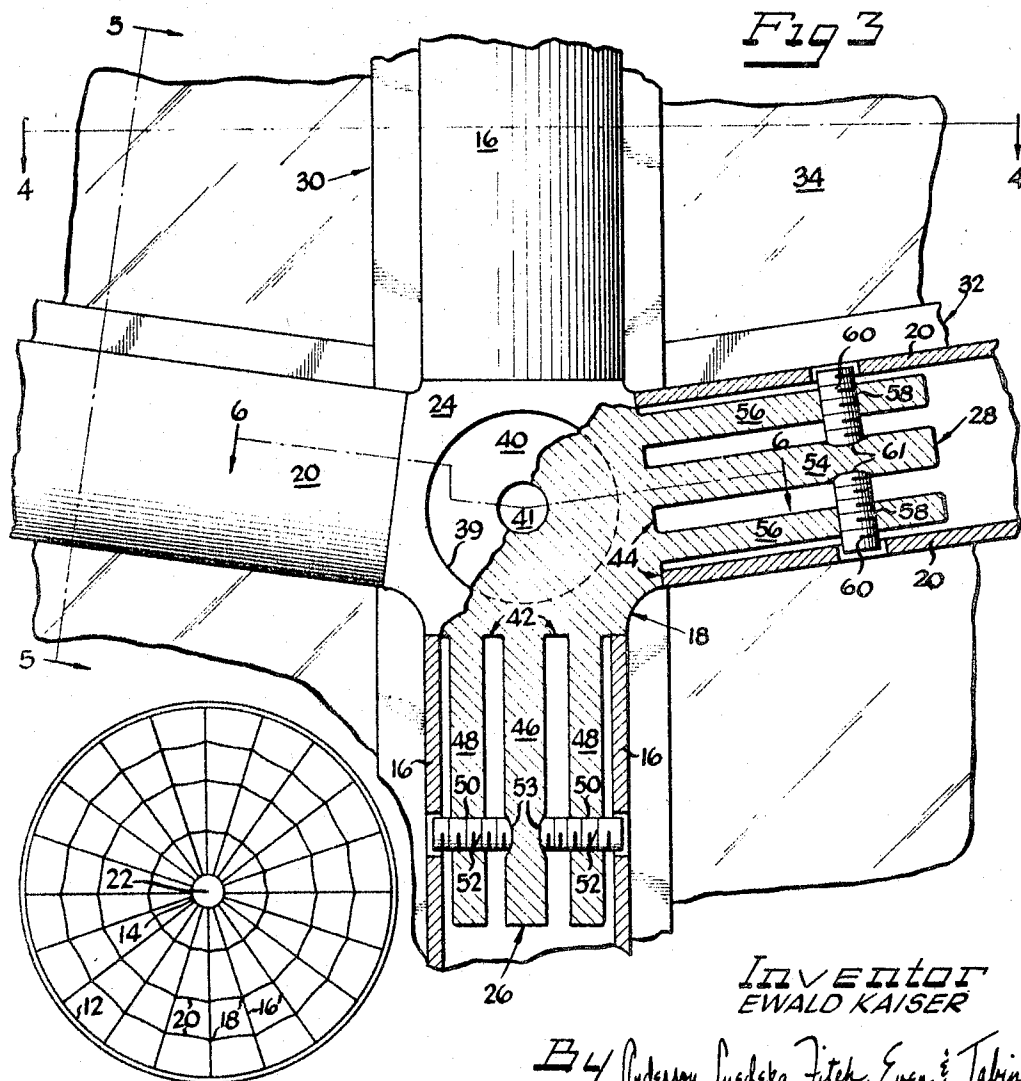
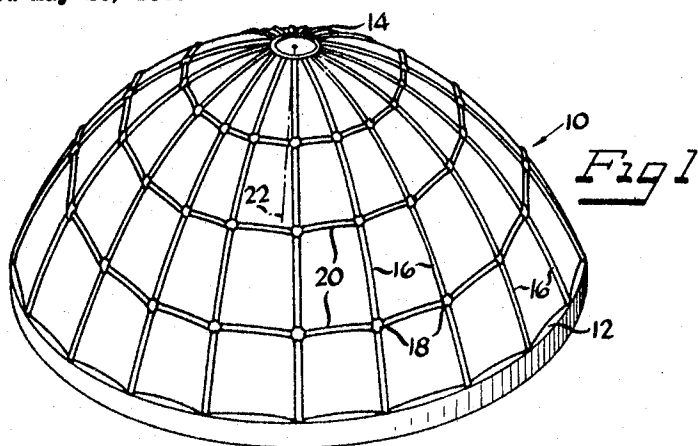
E. KAISER

3,462,893

DOMES WITH CONNECTED FRAME MEMBERS AND FRAME CONNECTING MEMBER

Filed May 20, 1965

2 Sheets-Sheet 1



Inventor
EWALD KAISER

B4 Anderson, Lurdeska, Fitch, Even & Tablin
Attys

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E. KAISER

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DOME WITH CONNECTED FRAME MEMBERS AND FRAME CONNECTING MEMBER

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2 Sheets-Sheet 2

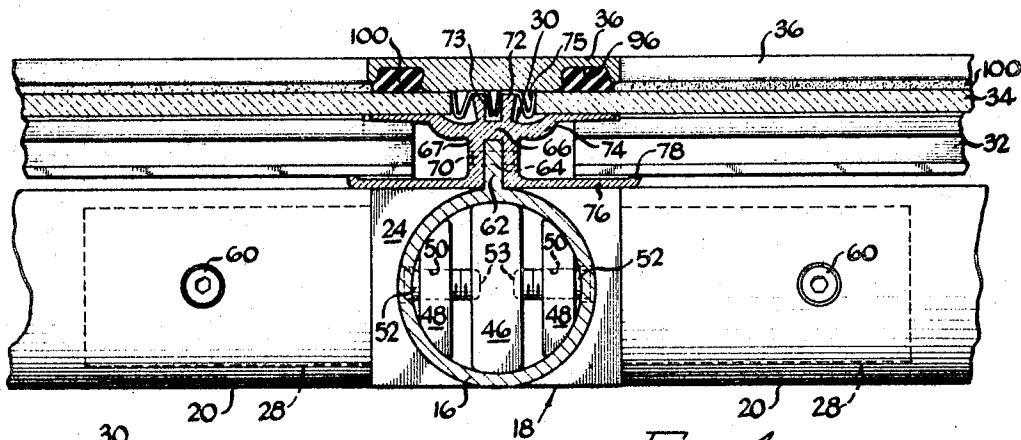


Fig 4

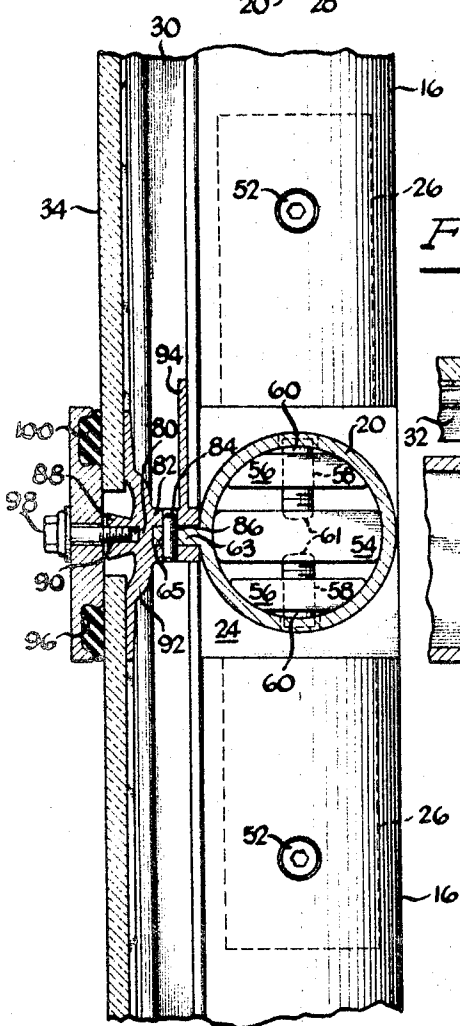


Fig 5

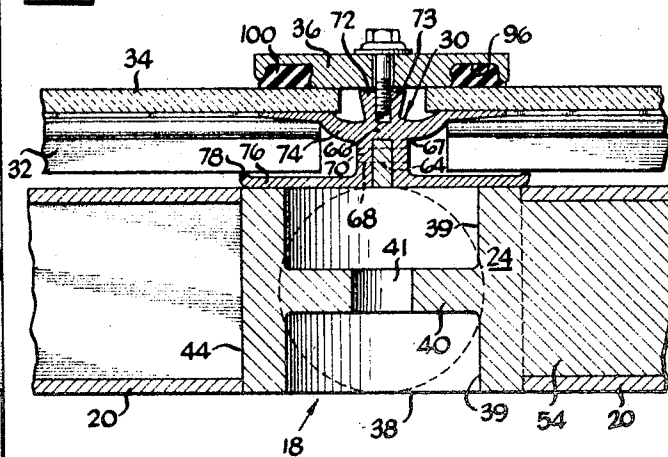


Fig 6

INVENTOR
EWALD KAISER

By *Anderson, Lundeke, Fitch, Evers & Tablin*
Att'y's

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3,462,893

DOME WITH CONNECTED FRAME MEMBERS AND FRAME CONNECTING MEMBER

Ewald Kaiser, Chicago, Ill., assignor to Ickes-Braun Glasshouses, Inc., Chicago, Ill., a corporation of Illinois
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Int. Cl. E04b 7/10

U.S. Cl. 52—80

7 Claims

ABSTRACT OF THE DISCLOSURE

A building structure is disclosed having the form of a surface of revolution which includes meridian frame members located on selected meridian curves of the surface, ring frame members located on geodesic lines of the surface and each extending between the intersections of two of the selected meridian curves and a plane perpendicular to the surface's axis, and connecting members at such intersections joining the meridian and ring members. The frame members have hollow ends and the connecting members include portions adapted to be moved into the hollow ends of the frame members and engage them.

This invention relates generally to building structures and, more particularly, to building structures in the form of domes and to improved structural elements adapted for use in domes. As used herein and in the art, the term "dome" includes all structures in the general form of a surface of revolution.

There is a growing use of modern dome structures to enclose spaces for a variety of applications. Such structures are especially suitable for enclosing large areas without the necessity for providing internal columns or bracing, a feature which may be desirable in swimming pool or tennis court enclosures, solariums, green houses, and the like. Moreover, such structures possess aesthetic features which do not appear in conventional structures of rectilinear form.

It is desirable in the construction of domes that building units of as few sizes and shapes as possible be utilized so as to simplify the fabrication of components and the erection of the completed domes.

Accordingly, it is an important object of the present invention to provide a dome structure in which the number of structural members of different sizes and shapes may be minimized and the fabrication of such members may be simplified.

Further objects of the invention are to provide a strong, light weight building structure which may be quickly and easily assembled from prefabricated framework members and panels; to provide an improved means for disposing of condensation on the inner surface of a dome structure which is subjected to different temperatures at its inner and outer surfaces; and to provide a standardized, adjustable connecting device for securing various framework members to each other in a dome structure, which connecting device may also find general utility in the fabrication of structures of more conventional design.

Other objects and advantages of the invention will become apparent from the following description when considered in conjunction with the accompanying drawings in which:

FIGURE 1 is a partially diagrammatic and partially broken away perspective view of a structure showing various features of the invention;

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

FIGURE 3 is an enlarged detailed view, partially in section, of an intersection of structural members taken in

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a plane perpendicular to a line which is normal to the surface of the structure shown in FIGURE 1;

FIGURE 4 is a sectional view taken along line 4—4 of FIGURE 3;

FIGURE 5 is a sectional view taken along line 5—5 of FIGURE 3;

FIGURE 6 is a sectional view taken along line 6—6 of FIGURE 3.

As shown in the accompanying drawings, the present invention includes a framework which is designated generally by the reference numeral 10 and comprises a tension ring 12, a compression ring 14, meridian members 16, connecting members 18, and ring members 20. The geometrical relationships of the elements of the framework 10 which contribute to achieving the objects of the invention are defined by reference to a surface of revolution having an axis of revolution 22 about which a plane curve is revolved to generate the surface. As shown in the drawings and described herein the surface of revolution is a hemisphere generated by revolving a quadrant of a circle about a vertical axis, but it will be understood that the invention is equally applicable to other surfaces of revolution such as paraboloids or ellipsoids and that the axis of revolution need not be vertical.

The meridian members 16 are all positioned on meridian curves of the surface of revolution and extend between the horizontal tension ring 12, located at the base of the structure, and the horizontal compression ring 14, located at the peak of the structure. A meridian curve is defined as the curve formed by the intersection of a surface of revolution and a plane passing through the axis of revolution. The planes defining the meridian curves on which the meridian members 16 are positioned preferably are so chosen that all the dihedral angles formed by adjacent planes are equal so that in the case of the hemisphere shown in the drawings, adjacent meridian members 16 define equal sectors of the hemisphere. It will be apparent from the above description that the meridian members are located on geodesic lines of the surface of revolution and, in the case of the illustrated hemisphere, on great circles of the sphere.

The positions of the connecting members 19 are defined by the intersections with the meridian members 16 of a plurality of planes perpendicular to the axis of revolution 22. The intersections of these planes with the hemisphere shown in the drawings define horizontal parallels of the hemisphere which are small circles of the sphere but are not geodesic lines.

The ring members 20 are positioned on the surface of revolution, or hemisphere as illustrated, and extend between adjacent connecting members which are located in the same horizontal plane. They do not, however, lie on the parallels of the hemisphere but rather, like the meridian members 16, lie on geodesic lines of the surface of revolution or great circles of the illustrated hemisphere. In the case of the illustrated hemisphere, each of these geodesic lines on which a ring member is positioned is defined by the intersection of the surface of the hemisphere and a plane defined by the positions of two adjacent connecting members located on the same horizontal parallel and the center of the hemisphere. Thus, adjacent ring members form an angle with each other, referred to herein as the "connecting angle," which is somewhat less than 180° due to the fact that they lie on different intersecting geodesic lines.

One result of this geometric relationship between the various members of the framework is that all the meridian members 16 and ring members 20 may be identically curved to the radius of the hemisphere when they are fabricated, thus simplifying the manufacture of these

members. Other similar advantages in connection with other elements of the dome structure will become apparent as such other elements are described in detail.

Referring now to FIGURES 3 through 6, various aspects of the detailed structure of the illustrated dome may be seen. Generally the illustrated connecting member 18 comprises a central hub 24 with two meridian arm sets 26, to each of which is attached a tubular meridian member 16, and two ring arm sets 28 to each of which is attached a tubular ring member 20. A meridian cap 30 is suitably attached to and overlies the meridian members and connecting member while ring caps 32 are attached to and overlie the ring members. The outer covering surface of the structure is formed by panels 34 of a suitable material such as Plexiglas, manufactured by Rohm and Hass Company of Philadelphia, Pa., which are attached to and overlie the ring caps and meridian caps and are secured in position by clamping bars 36.

More specifically, each connecting member 18 is preferably formed of a single aluminum casting which includes the central hub 24, two meridian arm sets 26 and two ring arm sets 28. The hub 24 is generally in the form of an annulus with a central aperture 38 extending along a line normal to the surface of revolution. The aperture 38 is defined by cylindrical side walls 39 which, as shown, extend inwardly from both ends of the annulus and terminate centrally thereof in an inwardly projecting shelf 40 surrounding a hole 41. The hole and shelf may be utilized to facilitate the attachment of dependent objects such as lighting fixtures or, if desired, the shelf may extend entirely across the aperture thus eliminating the hole. The surfaces of the annulus at the ends of the aperture 38 are substantially flat so that the hub may be snugly fitted to the overlying meridian cap in a manner that will be described hereinafter.

The outer surface of the annular hub includes two meridian shoulders 42 in the form of flat, circular surfaces which are parallel to each other and to the line normal to the surface of revolution passing through the aperture 38 and from which project the meridian arm sets 26. The outer surface of the annular hub further includes two ring shoulders 44 in the form of flat circular surfaces which are parallel to the line normal to the surface of revolution passing through the aperture 38 and from which project the ring arm sets 28. The ring shoulders are not parallel to each other as are the meridian shoulders, however, but rather form an acute angle with each other due to the fact that the ring arm sets of each member and ring members attached to the same connecting member lie on segments of different intersecting geodesic lines of the surface of revolution.

Projecting outwardly from the two meridian shoulders 42 and substantially perpendicular thereto are the meridian arm sets 26. Each meridian arm set includes a central arm 46 and two side arms 48. The longitudinal surfaces of the arms and suitably curved to afford a sliding fit with the internal dimension of the corresponding meridian member 16. Each of the side meridian arms is provided with a transverse threaded hole 50 adjacent to its outer end which is generally tangent to the surface of revolution and in which is inserted a set screw 52 which may be adjusted to bear against a recess 53 in the central meridian arm 46 to force the side arm away from the central arm and cause a tight fit of the arm against the inner surface of the meridian member.

Similarly, extending outwardly from the substantially perpendicular to the ring shoulders 44 are the ring arm sets 28 each of which include a central arm 54 and two side arms 56. The longitudinal surfaces of these ring arms are suitably curved to afford a sliding fit with the inside surface of the corresponding ring members. Each of the side arms 56 is also provided with a transverse threaded hole 58 adjacent to its outer end which is generally tangent to the surface of revolution and into which is inserted a set screw 60 which may be adjusted to bear

against a recess 61 in the central ring arm 54 thus forcing the side arm 56 away from the central arm 54 and causing a tight fit of the arm against the inner surface of the ring member.

It has been heretofore noted that adjacent ring members 20 of the dome framework 10 form an angle with each other which is somewhat less than 180° due to the fact that they lie on different intersecting geodesic lines and that this angle is referred to herein as the connecting angle. This particular geometrical arrangement possesses special advantages in simplifying the fabrication of ring and meridian members, as well as the ring caps, meridian caps and clamping bars to be hereinafter described in detail, namely, that all such members must be curved in only one direction about one axis and in the case of the illustrated hemisphere with only one radius of curvature. This geometrical relationship, however, also requires the connecting angle formed by adjacent ring members to be different for each ring of the dome. In practice, it has been found that the variation in this angle may be held to a minimum amount within any particular dome by the use of a sufficient number of meridians. For example, in a hemispherical dome having the following parameters the difference in the connecting angles will be 9°27'36" between the top and bottom rings of the dome, excluding the tension ring and the compression ring where ordinarily no connecting members are used.

Diameter of hemisphere	33'8"
Number meridians	20
Dihedral angle between the planes defining adjacent meridian curves	18°
Number of rings having connecting members	3
Height of connecting members above plane of tension rings:	
On bottom ring	5'11¾"
On middle ring	11'25½"
On top ring	15'7/8"
Connecting angle:	
On bottom ring	173°43'28"
On middle ring	168°15'15"
On top ring	164°15'15"

Due to the unique design, described above, of the ring arm sets, the two set screws 60 in any arm set may be tightened to different extents so that the angle which ring arm sets 26 of the same connecting member forms with each other, and hence the connecting angle which adjacent ring members form with each other, may be varied. In practice, it has been found that a single casting design may be used for all of the connecting members in a single dome and the variation in the connecting angle on different rings may be achieved by adjustment of the set screws 60 in the ring arm sets.

The illustrated meridian members 16 and ring members 20 which are attached to the connecting members are each similar hollow tubes having circular cross sections and preferably formed of aluminum in accordance with the curvature of the surface of revolution. The tubes have internal and external diameters such that they fit slidably over the meridian arms and ring arms respectively, and abut the meridian shoulders and ring shoulders respectively. The members 16 and 20 are provided with holes adjacent to their ends and in such a position that they may be aligned with the threaded holes 50 and 58 in the side meridian arms 48 and side ring arms 56 respectively so that the set screws 52 and 60 may be adjusted after the members are inserted over their respective arm sets. The members 16 and 20 are each further provided with respective longitudinal ribs 62 and 63 which project outwardly from the respective member, which are positioned on the surface of the member which is adjacent the outside of the dome and which have transverse holes 64 and 65 to facilitate attachment of the meridian caps 30 and ring caps 32 as will be hereinafter described.

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As may be seen most clearly in FIGURES 4 and 6, each meridian cap 30 which overlies and is attached to meridian members and connecting members and which supports the panels 34 in spaced relation to the meridian members is preferably a curved elongated aluminum extrusion having a central body 66. The central body is provided with downwardly extending legs 67 which are of such size and shape as to fit snugly over the rib 62 of the associated meridian member 16. The legs are provided with transverse holes 68 which are congruent with and disposed adjacent the holes 64 in the ribs. Pins 70 extend through the holes 68 in the legs and holes 64 in the ribs, thereby securely fastening the meridian cap 30 to the meridian member 16. The central body 66 is also provided with an upwardly extending head 72 having a continuous longitudinally extending recess 73 in its upper surface. The longitudinal surfaces of the recess 73 are provided with a plurality of parallel grooves which function as threads for screws utilized in the attachment of the clamping bars 36 as will be hereinafter described.

Furthermore, the central body 66 of the meridian cap 30 is provided with two arms 74 which project outwardly from the central body and are generally perpendicular to the head 72 and legs 67. The arms 74 in general have a flat lower surface and a flat upper surface on which the panels 34 rest and to which they are attached in a manner to be hereinafter described; however, as shown, small depressions in the upper and lower surfaces of each arm are provided adjacent the head. These depressions which extend longitudinally on the meridian cap 30 provide channels for draining off any water which might leak into the spaces between the panels 34, meridian cap 30 and clamping bars 36. These spaces are each also occupied by flat springs 75 having three arms as shown. One arm of each spring is inserted in the recess 73 and the remaining arms exert force on the head and the edge of the panels 34. A plurality of the springs 75 are disposed along the longitudinal dimension of the meridian caps thereby minimizing relative motion of the panels and meridian cap caused by changes in ambient temperature.

The meridian cap 30 is further provided with two lower surfaces or feet 76, each of which projects from the lower end of the legs 67 transverse to the longitudinal dimension of the cap and is generally parallel to the arms 74. The feet 76 are somewhat wider in cross section than the corresponding portion of the arms 74 and have at their extremities a ridge 78 extending longitudinally along the meridian. The feet thus may serve as internal channels or gutters along which condensation which collects on the inner surface of the dome due to temperature differences between the inner and outer surface may flow downward along meridians to the bottom of the dome.

The ring cap 32 which is seen most clearly in FIGURE 5 is similar in form to the meridian cap 30 in that it has a central body 80, legs 82 having transverse holes 84 disposed adjacent the holes 65 in the ribs 63 of the ring member 20 and through which pins 86 are inserted to fasten the ring cap to the associated ring member. Moreover, the central body 80 of the ring cap 32 is provided with a head 88 which is similar in form to the head of the central body 66 of the meridian cap and has a longitudinal recess 90 with longitudinal grooves to facilitate attachment of the clamping bars. Furthermore, the central body 80 is provided with arms 92 which are similar in form to the arms 74 and on which the panels 34 rest. The spaces between the panels 34, ring cap 32, and clamping bar 36 are also occupied by a plurality of flat springs 75 which help to stabilize the relative positions of these elements during changes in ambient temperature.

The ring cap 32, however, as shown has only one foot 94 which is located on the upper side of the ring but which is otherwise identical in form with a foot 76 of a meridian cap 30 except that it does not have a similar ridge at its extremity. Furthermore, the foot 94 is spaced from the lower end of its leg 82 so that it is positioned

above and mates with the foot 94 of the associated meridian cap 30. In addition, the ends of the arms 92 of each ring cap are suitably machined so as to lie below and mate with the lower surface of the arms 74 of the associated ring cap and so that the extremities of the ring caps do not touch the legs 67 of the associated meridian member. The foot 94 of the ring cap 32 and its leg 82 thus form an internal channel or gutter along which condensation on the inner surface of the dome may flow to the gutters formed by the feet 76 of the meridian cap 30 and thence downward in these gutters past successive rings of the dome. This flow is facilitated by the fact that the ring caps, being positioned on great circles, have their highest elevation midway between connecting members and their lowest elevations where they meet the meridian caps.

It will be apparent that the extrusions from which the ring caps and meridian caps 30 are formed must be curved to conform with the shape of the underlying ring members 20 and meridian members 16. Impressing this curvature on the caps is greatly simplified by the use of geodesic lines for both the ring members and meridian members. The caps need only to be curved about a single axis when such lines are used. Furthermore, in the illustrated dome which is in the form of a hemisphere, fabrication is further simplified because all ring caps 32 and meridian caps 30 may be formed with the same radius of curvature.

The panels 34, which are also curved to fit the surface of revolution on which the dome is based, cover the three dimensional polygons defined by intersecting rings and meridians. Each of the panels 34 as shown rests upon the flat upper surface of the arms 74 of two ring caps 32 and upon the flat upper surface of the arms 92 of two meridian caps 30. Adjacent panels, however, do not touch the heads 72 and 88 of the respective caps and a space is thereby allowed for purposes to be described hereinafter. The panels are secured to the upper faces of the caps by clamping bars 36 in the form of generally flat extruded pieces which like the other framework members are curved to the radius of curvature of the hemisphere. Two longitudinally extending recesses 96 are provided on each side of the lower face of each clamping bar. The clamping bars 36 rest upon adjacent panels when they are placed on the caps. Clamping screws 98 extend through suitably spaced holes in the clamping bars, into the recesses 73 and 90 in the heads of the ring caps and meridian caps, thereby securing the clamping bars and panels to the caps. Since the recesses are threaded along their entire length the clamping screws 98 may be located at any desired position on the ring caps and meridian caps. The space defined by the recesses 96 in the clamping bars and the panels 34 is filled with a suitable sealing material 100, vulcanized butyl sealing tape having been found to be satisfactory for this purpose. The volume defined by the heads, clamping bars, panels and arms provides a drainage channel for any moisture which might seep through the sealed joint.

It will be seen that this invention provides a dome structure in which many of the elements are interchangeable and for which the fabrication of elements is simplified. Furthermore, the invention provides a means of easily disposing of internal condensation on a dome structure and a simple, adjustable and interchangeable connecting element for building structure which is especially suitable for dome structures but could also be utilized in other types of building structures.

Various changes and modifications may be made in the above described building structure without departing from the invention. For example, various surfaces of revolution could be used to define the geometry of the structure or a plurality of various geometrical forms could be combined in one structure. Furthermore, different materials could be used for the various elements of the structure and the connecting member could be used in structures other than domes, all of which variations

would fall within the spirit and scope of the present invention, various features of which are set forth in the accompanying claims.

What is claimed is:

1. In a building structure substantially in the form of a surface of revolution having an axis of revolution, said structure including a tension ring, a compression ring, a plurality of meridian members disposed on meridian curves of the surface extending between said tension ring and said compression ring, each of said meridian members having its ends in the form of a hollow tube, the improvement comprising a plurality of connecting members joining adjacent members on the same meridian curve and disposed at the intersections of said meridian curves with a plurality of parallel planes, each of said planes being perpendicular to the axis of revolution of the surface, and a plurality of ring members connected between adjacent connecting members whose position is defined by the same parallel plane, each of said ring members being disposed on a geodesic line of the surface of revolution and each of said ring members having its ends in the form of a hollow tube, each of said connecting members comprising a central hub, a plurality of meridian arm sets extending into the hollow ends of the meridian members which said connecting member joins together and a plurality of ring arm sets extending into the hollow ends of the ring members to which said connecting member is connected, each of said meridian arm sets being adjustable between a first configuration such that said meridian arm set has a sliding fit with said meridian member and a second configuration such that said meridian arm set has a tight fit with said meridian member, each of said ring arm sets including a central arm, two side arms and means for selectively varying the distances between the outer ends of the side arms and the central arm so that the arm set may be adjusted into a tight fit with the ring member and so that the angle between ring arm sets of the same connecting member may be varied.

2. In a building structure substantially in the form of revolution having an axis of revolution, said structure including a tension ring, a compression ring, a plurality of meridian members disposed on meridian curves of the surface extending between said tension ring and said compression ring, the improvement comprising a plurality of connecting members joining adjacent meridian members on the same meridian curve and disposed at the intersections of said meridian curves with a plurality of parallel planes, each of said planes being perpendicular to the axis of revolution of the surface, a plurality of ring members connected between adjacent connecting members whose position is defined by the same parallel plane, each of said ring members being disposed on a geodesic line of the surface of revolution, and a plurality of cap members attached to and overlying said meridian members, connecting members and ring members, each of said cap members being disposed on geodesic lines of the surface of revolution and having an upper surface to which is attached a cover for the building structure, a spacing member within the structure and a lower surface within the structure spaced from said upper surface by said spacing member, so that said lower surface and said spacing member comprise a channel for the generally downward flow of liquid on the inside of the structure.

3. For use in a structural framework wherein a plurality of tubular members having hollow end portions are employed, a connecting member for the tubular members comprising a central hub, a plurality of arm sets extending outwardly from said hub, and adapted for sliding movement into the hollow end portions, each of said arm sets including a central arm and two side arms, and means for adjusting the distances between said arms at their outer ends so that the angles between arm sets may be varied and so that the arm sets may be adjusted into a tight fit with the hollow end portions.

4. A connecting member in accordance with claim 3 wherein said means for adjusting comprises two separate adjustment means each engaging said central arm and one of said side arms adjacent the outer ends of said arms and adapted independently of one another to vary the distance between the outer end of said one side arm and the outer end of said central arm.

5. A building structure substantially in the form of a surface of revolution having an axis of revolution, said structure including a tension ring, a compression ring, a plurality of elongated frame members having hollow end portions and a plurality of connecting members joining said frame members to one another, said connecting members being positioned at the intersections of selected meridian curves of said surfaces of revolution with at least one plane perpendicular to the axis of revolution of said surface, said frame members including meridian members extending between adjacent connecting members on each of said selected meridian curves of the surface of revolution between said tension ring and said compression ring and ring members each extending between two connecting members positioned on adjacent ones of said selected meridian curves and on the same plane perpendicular to the axis, said ring members being on geodesic lines of said surface of revolution, and said connecting members having portions adapted for movement into and engagement with associated hollow end portions of said frame members.

6. A building structure substantially in the form of a surface of revolution having an axis of revolution, said structure including a tension ring, a compression ring, a plurality of elongated frame members having hollow end portions and a plurality of connecting members joining said frame members to one another, said connecting members being positioned at the intersections of selected meridian curves of said surface of revolution with at least one plane perpendicular to the axis of revolution of said surface, said frame members including meridian members extending between adjacent connecting members on each of said selected meridian curves of the surface of revolution between said tension ring and said compression ring and ring members each extending between two connecting members positioned on adjacent ones of said selected meridian curves and on the same plane perpendicular to the axis, said ring members being on geodesic lines of said surface of revolution, and each of said connecting members including a hub, a plurality of outwardly extending arm sets with transverse dimensions suitable for sliding movement into associated hollow end portions of said frame members, said arm sets including a central arm and two side arms and two separate adjustment means each engaging said central arm and one of said arms adjacent the outer ends of said arms and adapted independently of one another to vary the distance between the outer end of said one side arm and the outer end of said central arm.

7. A building structure substantially in the form of a surface of revolution having an axis of revolution, said structure including a tension ring, a compression ring, a plurality of elongated frame members having hollow end portions and a plurality of connecting members joining said frame members to one another, said connecting members being positioned at the intersections of selected meridian curves of said surface of revolution with at least one plane perpendicular to the axis of revolution of said surface, said frame members including meridian members extending between adjacent connecting members on each of said selected meridian curves of the surface of revolution between said tension ring and said compression ring and ring members each extending between two connecting members positioned on adjacent ones of said selected meridian curves and on the same plane perpendicular to the axis, said ring members being on geodesic lines of said surface of revolution, and each of said connecting members including a hub, a plu-

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ality of outwardly extending arm sets with transverse dimensions suitable for sliding movement into associated hollow end portions of said frame members, and means for moving a portion of the outer end of each of said arm sets transversely relative to the remainder of said arm set without moving said remainder so as to vary the angle said arm sets make with one another.

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JOHN E. MURTAGH, Primary Examiner

U.S. Cl. X.R.

52—665, 698; 287—2, 54, 124, 127

**UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION**

Patent No. 3,462,893

August 26, 1969

Ewald Kaiser

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 56, "and" should read -- are --; line 66, "the" should read -- and --. Column 4, line 9, "thta" should read -- that --; line 44, "sets", second occurrence, should read -- set --; line 46, "forms" should read -- form --; line 75, "20" should read -- 30 --. Column 6, line 17, before "and" insert -- 32 --. Column 7, line 40, before "revolution", first occurrence, insert -- a surface of --. Column 8, line 15, "surfaces" should read -- surface --; line 53, before "arms", first occurrence, insert -- side --.

Signed and sealed this 5th day of May 1970.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

WILLIAM E. SCHUYLER, JR.

Commissioner of Patents