Dec. 7, 1965 A. E. MILLER 3,221,464

TETRAHELICAL STRUCTURE

Filed March 17, 1961 4 Sheets-Sheet 1

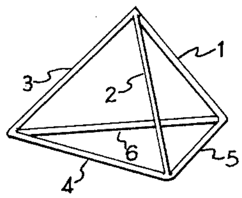

FIG. 1.

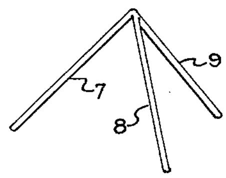

FIG. 2.

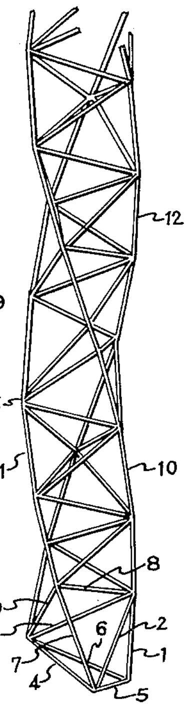

FIG. 3.

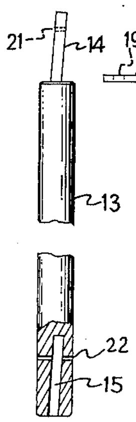

FIG. 4

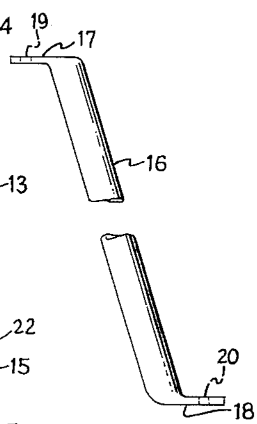

FIG. 5.

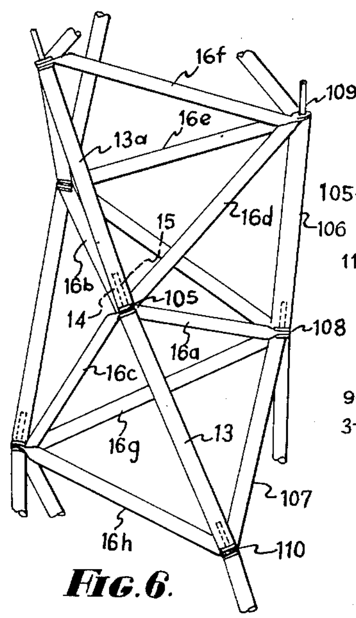

FIG. 6.

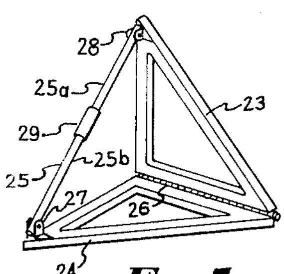

FIG. 7.

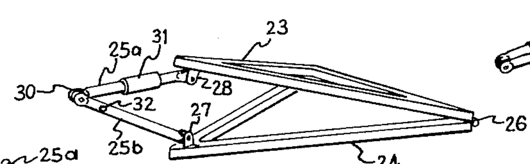

FIG. 8.

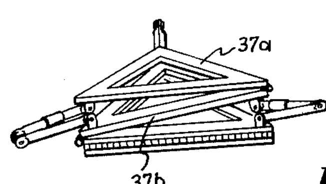

FIG. 9.

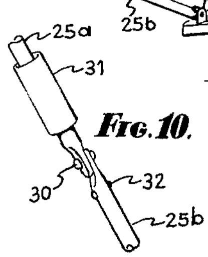

FIG. 10.

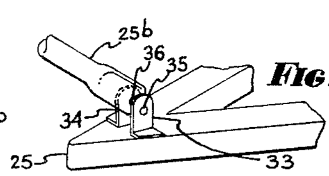

FIG. 11.

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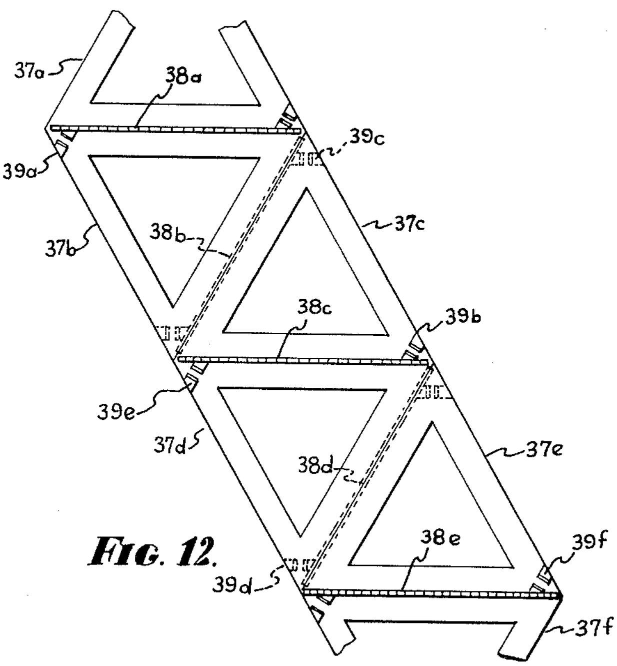

FIG. 12.

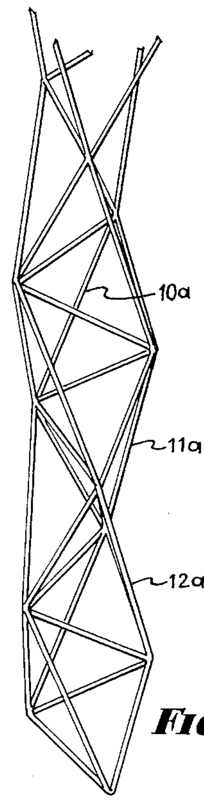

FIG. 13.

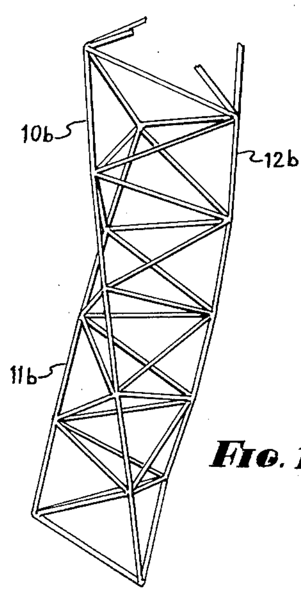

FIG. 14.

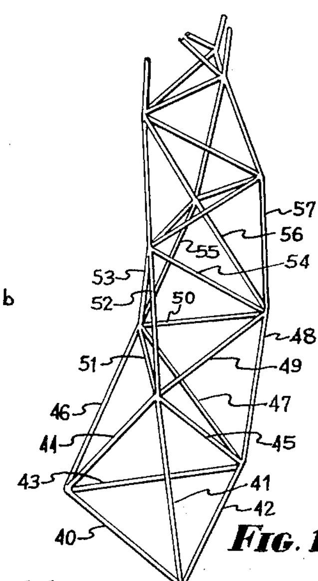

FIG. 15.

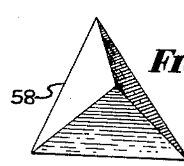

FIG. 16.

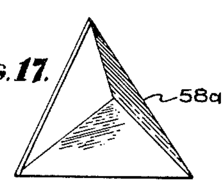

FIG. 17.

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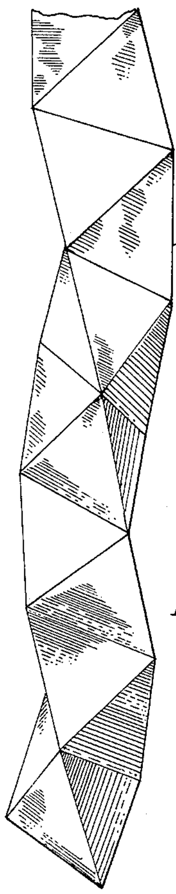

FIG. 18.

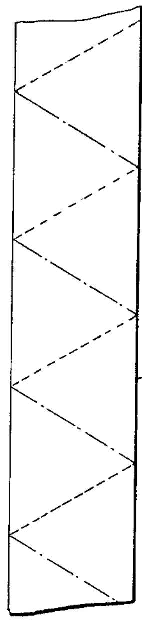

FIG 19.

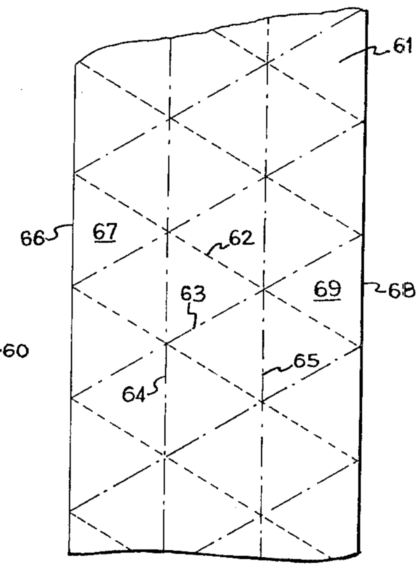

FIG. 21.

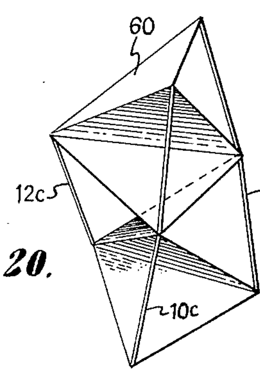

FIG. 20.

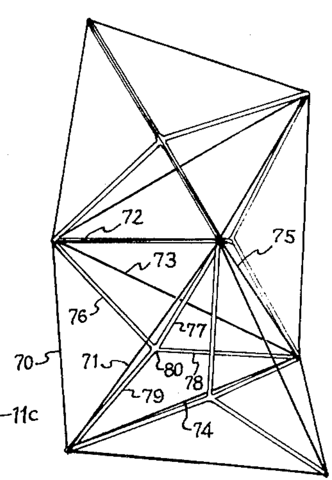

FIG 22.

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TETRAHELICAL STRUCTURE

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4 Sheets-Sheet 4

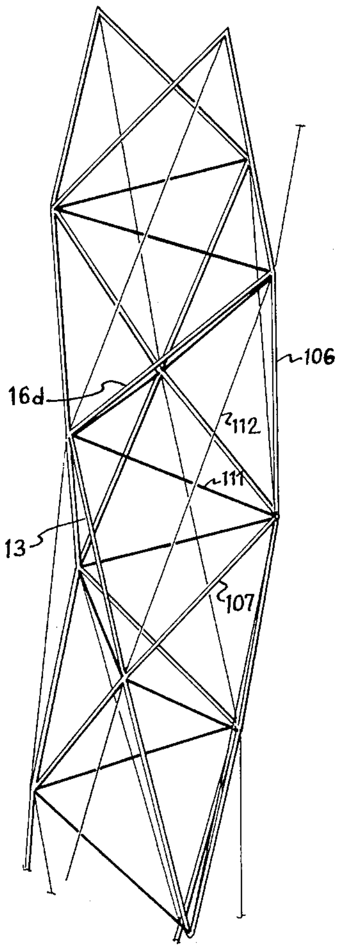

FIG. 23.

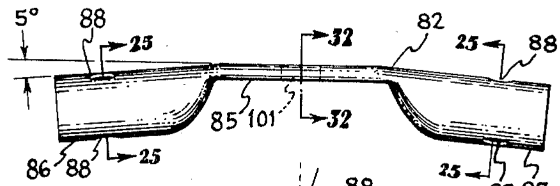

FIG. 24.

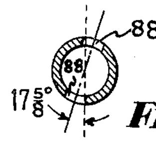

FIG. 25.

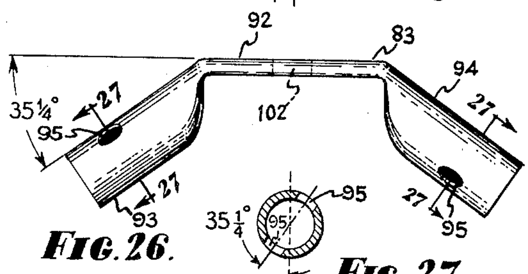

FIG. 26.

FIG. 27

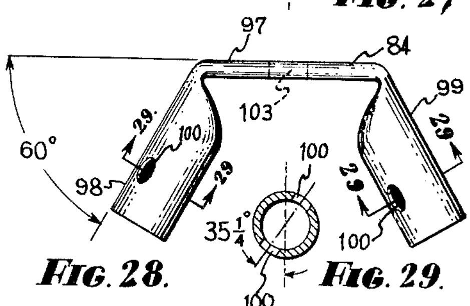

FIG. 28.

FIG. 29.

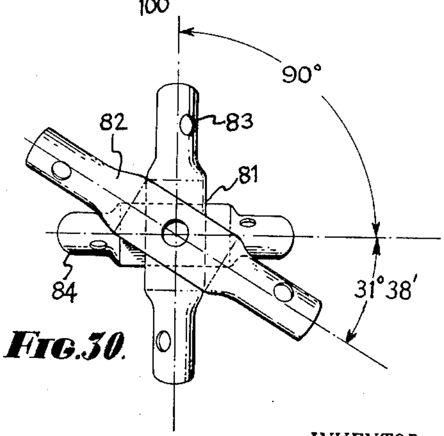

FIG. 30.

FIG. 32.

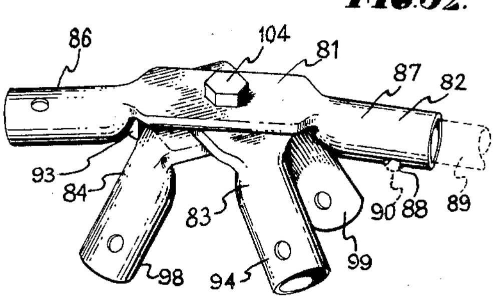

FIG. 31.

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United States Patent Office

3,221,464

Patented Dec. 7, 1965

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3,221,464
TETRAHELICAL STRUCTURE

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Filed Mar. 17, 1961, Ser. No. 96,544
12 Claims. (Cl. 52—655)

The invention relates to structures such as columns, masts, guy-wire towers, pedestal towers, derrick booms, scaffolding, outer space orbiting structures, architectural supports and other linear structural devices.

It is an object of this invention to provide improved structures of the general class set forth above which operate upon a new principle, and which attain maximum strength and rigidity with a lesser total quantity of the material used in their construction, since in the regular tetrahelical structure all surfaces are defined by equilateral triangles, the strongest and simplest of bracing units.

Heretofore, in the art, structures of the general class set forth above have been erected with required bracing added, i.e., the structures have been built and then braced. It is an object of the invention to provide improved structures wherein the bracing is integral with the structural concept and no additional bracing is required.

It is an object of the invention to provide improved structures which are inexpensive to manufacture and easily fabricated.

It is an object of this invention to provide improved structures which can be easily and quickly assembled.

It is an object of this invention to provide improved structures which may be easily transported and, in one embodiment, may be assembled at the place of manufacture and collapsed into a closely packed unit for ease in shipment. When it is desired to make use of these structures they may be easily and quickly expanded to their full dimension by springs, controlled explosives, or other simple devices.

It is an object of the invention to provide improved structures that are susceptible of permanent form and construction such as being site welded and/or riveted.

These and other objects of the invention which will be set forth hereafter or which will be apparent to those skilled in the art upon reading these specifications, are accomplished by that structure and arrangement of parts of which an exemplary embodiment will now be described. Reference is made to the accompanying drawings wherein:

FIGURE 1 is a perspective view of a tetrahedron made up of struts of equal length.

FIGURE 2 is a perspective view of a tripod made up of struts of equal length.

FIGURE 3 is a perspective view of a tetrahelical structure of the invention.

FIGURE 4 illustrates one kind of strut used in the structure of FIGURE 3.

FIGURE 5 illustrates another kind of strut used in the structure of FIGURE 3.

FIGURE 6 illustrates the manner in which the struts of FIGURES 4 and 5 are joined to form the structure of FIGURE 3.

FIGURE 7 is a perspective view showing a tetrahedron collapsible form.

FIGURE 8 is a perspective of a tetrahedron in partially collapsed condition.

FIGURE 9 shows the result of collapsing all of the tetrahedra in a structure of this invention.

FIGURES 10 and 11 are partial perspective views showing forms of hinging members which may be used.

FIGURE 12 is a partial plan view showing a plurality of hollow triangular panel members hinged together and adapted to be formed into a structure of this invention by the use of hinged struts after the manner shown in FIGURES 7 and 8.

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FIGURES 13 and 14 illustrate the results of lengthening or shortening certain struts.

FIG. 15 illustrates the result of a progressive shortening of the struts in the structure.

FIGURE 16 shows a solid tetrahedral form.

FIGURE 17 shows a hollow tetrahedral form.

FIGURE 18 shows the result of joining together the tetrahedral forms of FIGURES 16 or 17.

FIGURE 19 shows a sheet of material prepared for bending.

FIGURE 20 shows a structure made from bent sheet material and struts.

FIGURE 21 shows a sheet of material prepared for bending in such fashion as to form all exterior faces of a structure of this invention, and

FIGURE 22 shows a modified structure in which a bracing within the tetrahedra sustains compressive forces.

FIGURE 23 illustrates the results of eliminating certain struts and substituting tension wires in the structure of FIGURES 3 and 6.

FIGURE 24 is an elevational view of a sub-assembly of a hub member.

FIGURE 25 is a sectional view along the section lines 25—25 of FIGURE 24.

FIGURE 26 is an elevational view of a second sub-assembly of a hub member.

FIGURE 27 is a sectional view along the section lines 27—27 of FIGURE 26.

FIGURE 28 is an elevational view of a third sub-assembly of a hub member.

FIGURE 29 is a sectional view along the section lines 29—29 of FIGURE 28.

FIGURE 30 is an elevational view of a hub member showing the angular relationship of the three sub-assemblies.

FIGURE 31 is a perspective view of an assembled hub member.

FIGURE 32 is a sectional view through the section line 32—32 of FIGURE 24.

The invention is based on the principle that a tetrahedron made up of four equilateral triangles is the strongest basic three-dimensional structural form. The improved structures of this invention may be considered as made up of a series of such tetrahedra joined together in such fashion as to result in a linear arrangement. Each tetrahedron may be a separate structural unit with a plurality of these tetrahedra joined to form the improved structure of this invention. This can be accomplished using struts, solid or hollow tetrahedra, or combinations of plates and struts. If, however, in an exemplary embodiment, the individual tetrahedra are made of struts, when such tetrahedra are joined together the result would be a structure in which some of the struts are double, while some are single. Therefore, in such an exemplary embodiment, it would generally be more convenient and economical to form the compound structure from a base tetrahedron composed of six struts to which are added a series of three-strut structures (hereafter referred to as "tripods") so that a face, defined by three struts of the base tetrahedron, becomes the base of the next tetrahedron (this next tetrahedron, therefore, consisting of the said three struts of the base tetrahedron and a tripod) and so on.

When a tetrahedron and a series of tripods are joined in the manner hereinafter set forth, a structure is obtained in which certain side elements of successive tetrahedra follow helical lines, so that the entire structure can be encompassed within a real or imaginary cylinder. Moreover, if the structure is viewed from the end it will be found to have a central passageway capable of receiving a real or imaginary cylinder extending from end to end of the structure.

The various embodiments of this structure, although easily fabricated of fairly light material such as aluminum, wire, wood, etc. domonstrate unusual and unexpected properties of strength and rigidity and a more even distribution of forces such as tension and compression as a result of the helical configuration.

Since the structure has a natural helical formation, no single element of the lines of forces can be carried directly to the round in a long-column action. Any helical line by definition rotates around the structure, and this will distribute the forces through all of the members.

FIGURE 1 shows a basic tetrahedron made up of six struts bearing the index numerals 1 to 6 inclusive. As set forth above, another similar tetrahedron may be attached to any face of the structure of FIGURE 1. In FIGURE 2 there is shown a tripod consisting of struts 7, 8 and 9 fastened together at one end. All of the struts of FIGURES 1 and 2 are of equal length. If the free ends of struts 7, 8 and 9 of the tripod are joined to vertices of the struts forming any one of the four faces of the tetrahedron of FIGURE 1, a prismatic figure will be formed having six outer faces, i.e. a hexahedron. If now another tripod is added an eightsided figure will be obtained. Further tripods may be added, but now care should be taken to add them in such fashion that the resulting figure is extended in length in a single direction.

FIGURE 3 illustrates the result of the progressive addition of tripod elements to a basic tetrahedron in the manner described. The struts of the building units of FIGURES 1 and 2, which have been combined to form the structure of FIGURE 3, have been given like index numerals in FIGURE 3. The entire structure of FIGURE 3, which may be prolonged indefinitely within the limits of the strength of the struts, is easily recognized as consisting solely of tetrahedra formed by adding tripods to a base tetrahedron. Successive outer strut elements of the structure, made up of certain strut elements of the individual tetrahedra, form helical lines generally indicated at 10, 11 and 12.

These three helical lines define the lines of forces of this natural helical formation, and as earlier indicated, these prevent any long column action since each line is alternately in tension and compression throughout its length. Thus none of these three helical lines is in compression or tension throughout its length under live load conditions (i.e. when external forces are applied to the structure from the side).

For the sake of an exemplary showing herein, let it be supposed that the struts are made of metal tubing or metal rod stock. The structure of FIGURE 3 could be made by welding the struts together at their points of juncture. At each such point six strut ends must be joined. In most embodiments of the structure, demountability is desired, and this involves the problem of providing a means whereby six strut ends may be separably fastened together, with two of the struts forming a part of one of the three helical lines previously discussed. One way of doing this is illustrated in FIGURES 4, 5 and 6.

Two types of struts are employed. The strut 13 of FIGURE 4 has at one end a reduced diameter tongue 14 and at the other a hole 15 to accept the tongue of another similar strut. Struts of the type illustrated at 13 in FIGURE 4 will form the helical lines 10, 11 and 12 of FIGURE 3, and since in these lines the struts are almost but not quite in three dimensional linear alignment, it will be noted that in FIGURE 4 both the tongue 14 and the hole 15 are at a slight angle to the axis of the strut.

The other type of strut is shown at 16 in FIGURE 5. This strut has flattened and angularly related end portions, 17 and 18. These portions are perforated at 19 and 20 to accept the tongues 14 of strut elements of the type shown in FIGURE 4. The angularity of the elements 17 and 18 to the axis of the strut 16 of FIGURE 5 is substantially 120°.

It will be clear from FIGURE 6 how each joint of the

structure may be formed by placing an angularly related end portion of four struts *16a* to *16d* over a tongue 14 of a strut 13. Then a strut *13a* is engaged with the strut 13 by passing the tongue 14 into the hole 15. The structure may be fastened together at the joint just described by passing a cotter pin (not shown) through a perforation 21 in the tongue 14 and a perforation 22 in the end of the strut *13a* containing the hole 15. Other modes of locking the joint may be employed, as well as other modes of forming the joint itself.

Another means of separably fastening six strut ends together to construct a tower of the type shown in FIGURE 3 is illustrated in FIGURES 24 through 32. Briefly, this method contemplates the use of struts of equal length, made of any suitable material such as metal tubing or metal rod stock, and a hub member comprising six angularly related socket members, each of which receive and rigidly retain a strut end. An exemplary embodiment of such a hub member is illustrated in FIGURE 31. The hub generally indicated at 81 is made up of three sub-assemblies 82, 83 and 84 which are made of metal tubing, a central portion of which is flattened to form two socket members with a flat central portion therebetween (see FIGURES 24, 26, 28 and 32).

The sub-assembly 82 is illustrated in FIGURE 24 showing a flat central portion 85 and two socket portions 86 and 87. The sockets 86 and 87 are angled downwardly 5° from the plane of the flat central portion. The sockets contain perforations 88 the axes of which, as shown in FIGURE 25, form an angle of 17⅝° with the perpendicular. When strut ends are located in the sockets, they may be held therein by means of bolts, pins or rivets through the perforations 88 and corresponding holes in the strut ends. This is illustrated in FIGURE 31 wherein a strut is indicated at 89 in the socket member 87 and a pin 90 is indicated in the perforation 88.

A second sub-assembly 83 is illustrated in FIGURE 26 with a central flattened portion 92 and socket portions 93 and 94. The socket portions 93 and 94 are angled downwardly 35¼° from the plane of the central portion 92. The socket portions contain perforations 95 the axes of which form an angle of 35¼° with the perpendicular (see FIGURE 27).

The third sub-assembly 84 is illustrated in FIGURE 28 with a central flattened portion 97 and socket portions 98 and 99. The socket portions 98 and 99 are angled downwardly 60° from the plane of the central portion 97. The socket portions contain perforations 100 the axes of which form an angle of 35¼° with the perpendicular (see FIGURE 29).

The assembly hub member 81 is shown in FIGURES 30 and 31. The sub-assemblies may be welded together, or the flattened portions 85, 92 and 97 of the sub-assemblies may be perforated as at 101, 102 and 103 respectively (see FIGURES 24, 26 and 28) and the sub-assemblies held together by means of a rivet or bolt such as the bolt 104 in FIGURE 31. As illustrated in FIGURE 30, the sub-assemblies must be properly oriented so that the axes of sub-assemblies 83 and 84 form an angle of 90° and the axes of sub-assemblies 82 and 84 form an angle of 31°38′.

As an illustration, when the hub of FIGURE 31 is used in the assembly of a tower such as that of FIGURES 3 and 6 at all junctures of strut ends such as the one indicated at 105, the struts 13, *13a*, *16c*, *16d*, *16b* and *16a* will be retained in the sockets 87, 86, 94, 93, 98 and 99 respectively in the order named. It will be evident to one skilled in the art that the hub 81 of FIGURE 31 may be used in the assembly of the towers of FIGURES 13, 14 and 15 (hereinafter described) if proper modifications are made in the angular relationships of the parts.

The structure of FIGURE 3 may be collapsible instead of demountable, as shown in an examplary embodiment in FIGURES 7, 8 and 9. In FIGURE 7 each tetrahedron is shown as consisting of two triangular perforated plates 23 and 24 and a strut 25. The plates 23 and 24 are fastened together by a hinge 26. The strut 25 is affixed to the plates 23 and 24 by the hinging means 27 and 28. The strut 25 is also provided with a central hinge 29. The hinging means 29 is shown in FIGURE 10. The two halves 25*a* and 25*b* of the strut 25 are pivotally joined by a pin or rivet 30. When the strut halves 25*a* and 25*b* are swung to a position at which their axes coincide, a sleeve 31 slides down and rests on the abutment 32 locking the hinging means 29 and preventing the strut 25 from folding about the pin or rivet 30. The hinging means 27 and 28 are identical. The hinge 27 (FIGURE 11) consists of lugs 33 and 34 on the plate 24. A pin or rivet 35 passes through the lug 33, the perforation 36 in the strut half 25*b* and the lug 34. Thus the strut half 25*b* is pivotally mounted to the lugs 33 and 34 by means of the pin or rivet 35. Any suitable hinging means may be substituted for the hinges 26, 27 and 28. The hinge 29 may be any form of lockable or self-locking hinge as known in the art.

The hinged tetrahedra illustrated in FIGURE 7 may be made to collapse as in FIGURE 8. If as in FIGURE 12, a series of triangular plates 37*a*, 37*b*, 37*c*, 37*d*, 37*e* and 37*f* are connected together by hinges 38*a*, 38*b*, 38*c*, 38*d* and 38*e*, and the lugs 39*a* and 39*b*, 39*c* and 39*d*, 39*e* and 39*f* are connected by centrally hinged struts similar to strut 25 at FIGURE 7, a structure similar to that of FIGURE 3 will result. This structure is shown in collapsed form in FIGURE 9. The collapsed structure may be re-erected by tension applied to its ends, by the thrust of an internally positioned expanding member, such as a spring, or by controlled explosive means.

Modifications may be made in the structures of this invention. If the struts 13 making up the lines 10, 11 and 12 of the structure shown in FIGURE 3 are elongated or shortened without making any change in the strut members 16 the pitch of the helices will be changed. This is illustrated in FIGURES 13 and 14. In the first of these figures the struts making up the helical lines 10*a*, 11*a* and 12*a* have been elongated with respect to the other struts in the structure with the result that the helical lines have a greater pitch and the entire structure is elongated. In FIGURE 14 the struts making up the helical lines 10*b*, 11*b* and 12*b* have been shortened with respect to the other struts in the structure with the result that the helical lines have a lesser pitch and the entire structure is shortened.

It is possible within the limits of the invention to make a tower-like structure which will diminish in diameter from end to end. This is accomplished by progressive shortening of the struts or diminution of certain of the edge portions of faces of the tetrahedra. An example is illustrated in FIGURE 15, where the first nine struts are of equal length. These struts are marked 40 to 48 inclusive. It will be noted that the strut 48 constitutes one leg of a tripod attached to the second tetrahedron. The other legs of this tripod 49 and 50 are of shorter length than the strut 48. Similarly the struts 51, 52, 53, 54, 55, 56 and 57 are of the same length as the struts 49 and 50. The next nine struts in the figure are of still shorter length, and so on. The tapering character of the resulting structure is clearly evident in FIGURE 15.

The structures of this invention may be made from a series of solid tetrahedra such as 58 in FIGURE 16. Similarly the structures may be made from hollow tetrahedral forms such as 58*a* in FIGURE 17. Such forms may be made from sheet metal or other suitable material with the edges either constituting bends in the material, or fastened together by welding or in any other suitable way. The form of FIGURE 17 may have four solid sides, or may have one open side as shown. The tetrahedral forms of FIGURES 16 and 17 when joined together will produce an elongated structure such as that shown at 59 in FIGURE 18. This structure in configuration is like that of FIGURE 3 excepting that the sides of the tetrahedra are solid.

In the fabrication of structures from sheet metal or similar materials, a single strip of material may be used to provide adjacent sides of a plurality of tetrahedra. In FIGURE 19, there has been shown a sheet metal strip 60, designed to be bent along certain indicated lines so as to provide a series of connected panels, each panel being in the form of an equilateral triangle. Dotted lines indicate folds to be made in one direction while dot-dash lines indicate folds to be made in the opposite direction. The triangular portions will be bent to angularities of about 60° to each other. Such a folded strip may be used as shown in FIGURE 20 by connecting the free apices of adjacent triangular portions together by means of struts. The struts so employed are the ones forming the helical lines indicated in FIGURE 20 at 10*c*, 11*c* and 12*c*.

The entire tetrahedral structure may, if desired, be formed from a single piece of sheet material. This is illustrated in FIGURE 21 which shows a sheet of material 61, such as a metal sheet with indicated lines of fold. Again, dotted lines such as 62 indicate folds in one direction while dot-dash lines such as 63 indicate folds in the opposite direction. It will be noted that the sheet is characterized by two spaced longitudinal folds 64 and 65. On these longitudinal folds the sheet may be formed into a generally triangular conformation; but in doing so the sheet will be racked or twisted so that, for example, the edge 66 of the equilateral triangle 67 will be caused to coincide with and be attached to the edge 68 of the equilateral triangle 69 which does not lie directly opposite it. Folding the sheet as has been described, and attaching its edges together as by welding will give a figure which in external appearance is the same as that shown in FIGURE 18. However, since the sheet material is being used to form only the exterior faces of the tetrahedra, the figure will be hollow as hereinabove described in connection with FIGURE 3.

It does not constitute a departure from the spirit of the invention to provide internal bracing for the tetrahedra. If this internal bracing is rigid it may be caused to withstand the compressional stresses, leaving the edges of the tetrahedra to withstand the tensional stresses. In this event, the edges of the tetrahedra may be made of wire or like material.

This is shown in FIGURE 22 where a tetrahedron having edge portions 70, 71, 72, 73, 74 and 75 carries an internal structure made up of four rigid arms 76, 77, 78 and 79. These arms are rigidly attached together as at 80 at the centroid of the tetrahedron, and they extend outwardly to the apices of the tetrahedron. As indicated above the rigid structure comprising the arms 76 to 79 inclusive will withstand compressional forces, and will place the edges 70 to 75 inclusive of the tetrahedron in tension when the structure is loaded. Consequently the members 70 to 75 inclusive need be designed only to withstand tensional forces, and may be made of wire, cable and the like.

It is also within the scope of this invention to remove certain of the struts from a tower such as that of FIGURES 3 and 6 and substitute a plurality of tension wires therefor. With reference to FIGURE 3, each of the struts which are most nearly horizontal (i.e. the struts forming the helical line with the greatest pitch) such as struts 16*h*, 16*g*, 16*a*, 16*b*, 16*e* and 16*f* may be replaced by two tension wires. Each such strut will be found to lie across the center of a centrally depressed diamond shape described by surrounding struts. For example, the strut 16*a* lies across the center of the centrally depressed diamond formed by struts 13, 16*d*, 106 and 107 (FIGURE 6). The strut 16*a* may be replaced by a tension wire from the strut junction 105 to the junction 108 and a second tension wire from the junction 109 to the junction 110. A tower of this construction is illustrated in FIGURE 23 wherein a similar centrally depressed diamond has been given the same index numerals. It can be seen that there is no strut equivalent to strut 16*a* of FIGURE 3, because it has been replaced by the two tension wires **111** and **112**. Thus the tower of FIGURE 23 has one third less struts than the tower of FIGURES 3 and 6. Such a tower will be substantially one third lighter in weight and less expensive to construct. The tension members may be made of wire, wire rope, metal strip or strand or any other relatively lightweight and flexible material capable of withstanding the expected tensional stresses.

It will be noted in FIGURE 3 that the end face of the lowermost tetrahedron is not perpendicular to the axis of the structure. If the structure is to be used as a guyed tower it may be caused to rest upon the point at the bottom of the lowermost tetahedron. Otherwise, it will be within the skill of the workers of the art to add to the end face of the lowermost tetrahedron such structure as will provide a base perpendicular to the axis of the tower.

Structures of this invention are rigid and may be made to be lighter in weight than comparable structures existing prior to this invention. While structures of this invention have many uses in construction and otherwise as set forth above, they are useful also as reinforcements in cylindrical casings or castings and particularly in view of the collapsible features hereinabove described, they are also of interest in devices intended to be put into orbit, where the structures of this invention may be expanded after orbit is attained.

The invention having been described in certain exemplary embodiments, what is claimed as new and desired to be secured by Letters Patent is:

1. A structure of elongated form made up of struts joined together at their ends so that any six adjacent struts constitute the edges of a tetrahedron, there being a single succession of such tetrahedra in the direction of the length of the structure, one strut of each such tetrahedron lying in substantial axial alignment with a strut of an adjacent tetrahedron and forming a part of one of three helices passing around the surface of said structure.

2. The structure claimed in claim **1** wherein all struts are of equal length.

3. The structure claimed in claim **1** wherein the struts of adjacent tetrahedra are of progressively differing lengths.

4. The structure claimed in claim **1** wherein all struts are of equal length excepting for the said struts which form the said helices.

5. The structure claimed in claim **1** in which six struts are joined at each juncture and in which said junctures are separable.

6. The structure claimed in claim **1** in which six struts are joined at each juncture in such fashion as to be hinged with respect to each other, and in which the struts forming the said helices are provided with hinges at their median portions.

7. The structure claimed in claim **1** in which a strut which sustains tensional stresses upon endwise compression of the structure is eliminated, the four adjacent struts forming a substantially diamond shaped figure, and flexible tension sustaining members respectively connecting opposite apices of said diamond shaped figure.

8. The structure claimed in claim **1** in which at the points of juncture of the struts members are provided presenting sockets in sufficient number and so angularly related as to receive detachably the ends of struts meeting at said juncture.

9. The structure claimed in claim **8** in which said members comprise sections of tubing flattened in their central portions and fastened together thereat, the unflattened end portions of said sections constituting said sockets and disposed at angularities with respect to their respective flattened portions to correspond with the angularities of the meeting struts.

10. A structure of linear, helical, elongated form consisting of a number of elements fastened together to form a plurality of tetrahedra, two of the faces of each tetrahedron being unitary structures hinged together along meeting edges, and having apices opposite said edges, said apices being connected by collapsible struts.

11. A structure of linear, helical, elongated form consisting of a number of elements fastened together to form a plurality of tetrahedra, one face of each tetrahedron being a part of a single integral sheet of material.

12. A structure of linear, helical, elongated form consisting of a number of elements fastened together to form a plurality of tetrahedra, all external faces of the said structure being parts of an integral sheet of material.

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