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⑳ **Modular space frame and modular units therefor.**

㉑ A modular space frame is disclosed which is made up of planar units. Each unit has an upper chord 7 attached via a post 9 to a tie bar interconnection member which may be a boss 10 or a lower chord 31. One unit has two other units connected one across each end of its upper chord and two further units connected by their ends to radiate from the chord at its mid-point where the post is attached. The tie bar interconnection members are connected by tie bars which extend in a grid similar to that of the chords but disposed in register below the chords.

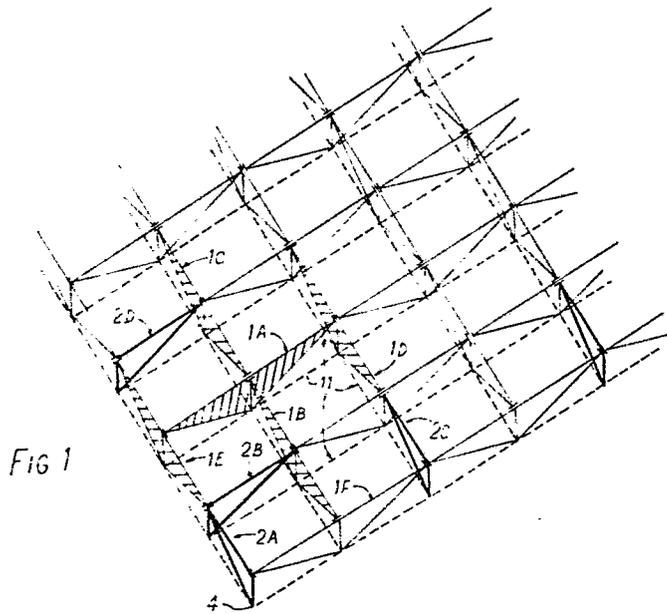


FIG 1

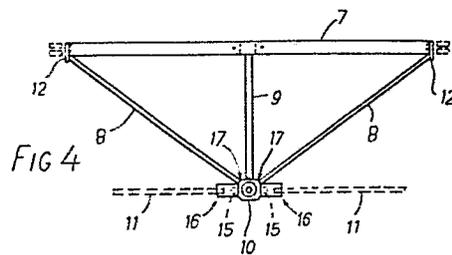


FIG 4

"MODULAR SPACE FRAME and MODULAR UNITS THEREFOR"

The present invention relates to a modular space frame, that is to say a three dimensional structure, such as is suitable for use in the building industry, constructed of modular units.

A prior space frame constructed of modular units is described in my Patent Specification No. 1,464,777. This frame is based on the use of a modular pyramid unit comprising three or more struts extending from an apex. Generally the struts are inter-connected at their ends remote from the apex by a planar polygonal frame. The space frame is constructed by joining together a plurality of pyramid units along the sides of their polygonal frames so that the polygonal frames form a deck. The pyramid units are so arranged that all the struts extend to the under-side of the deck. The space frame is completed by inter-connecting the apices of the pyramids with tie bars.

Such a space frame suffers from two disadvantages. Firstly the modular pyramid units are three dimensional units which renders their transport from factory to site awkward and inefficient. This limits the size of the pyramid units and makes the structure uneconomical. Secondly the apices are positioned centrally with respect to their polygonal frames. Consequently the sides of the base frames and the tie bars are not in register above each other but constitute offset grids. This can restrict the size and positioning of apertures extending through the space frame, such as skylights, where the space frame is being used



to support a roof.

I have now realised that a space frame may be constructed from vertically disposed planar modular units, thereby overcoming the above noted disadvantages.

5 Typically the modular units will be in an arrangement wherein a) their so called "deck edges" form a square grid deck with tie bars forming a second grid below and in register the grid formed by the deck edges;

b) each unit is connected to two other units extending

10 laterally from its mid-point, one on each side; and

c) each unit is connected to two further units, one extending across each end thereof.

Addition of the next four units extending laterally from the mid-points of the other units defines

15 four squares of the grid - the sides of the squares being half the length of the units. Of course, the units need not all be of the same length, thus a rectangular grid may be made up of units of one length oriented in one direction and units of another length oriented at right

20 angles. Further, the units need not be arranged at right angles; the units may be arranged into rhombic or parrallelogram grid space frames. Such a space frame may be referred to as a "planar modular unit quadilateral space frame".

25 According to one aspect of the invention there is provided a planar modular unit for a quadrilateral space frame comprising an elongate deck-edge chord,

a post attached perpendicularly at one end thereof to the said chord, a tie bar interconnection member attached to the other end of the said post, at least one brace attachedly extending from an end of the  
5 said chord remote from the said post to the other end of the said post or to the said tie bar interconnection member, end connection means at the said one end or both ends of the said chord and side connection means on the said chord adjacent the said  
10 one end of the said post, the said side connection means and the said end connection means being complementary whereby one or two other such units can be connected via its or their end connection means to the said chord on one or both sides  
15 thereof respectively, the said tie bar interconnection member being adapted for interconnection by tie bars with the tie bar interconnection members of such other unit or units and of any other such unit connected to the said end connection means,  
20 such tie bars extending in register with the said chord and the chords of such other units connected to the said chord.

The planar modular unit may be a half unit, having its post attached to its chord at one end of the  
25 chord and having a single brace, for use at the end of a space frame comprised mainly of main frame units of twice the length of the half frame units. Such a main frame unit has its post attached to its chord at the mid-point of the chord and has a pair of braces,  
30 one extending from one end of the chord to the other

end of the post or the tie bar interconnection member and the other extending from the other end of the chord to the other end of the post or the tie bar interconnection member.

5           In place of the main frame units, extended frame units may be employed. Such a unit has its elongate tie bar interconnection member in the form of an elongate second chord arranged parallel to its deck-edge chord, has its post attached to the deck-  
10 edge chord and the second chord intermediate their respective ends, has a pair of braces, one extending from one end of the deck-edge chord to the corresponding end of the second chord and the other extending from the other end of the deck-edge chord to the other  
15 end of the second chord and has further braces triangulating the unit between the ends of the second chord and one of the ends of the post.

The extended frame units may be double frame units. Such a unit has its deck-edge chord substantially twice the length of its second chord, has its  
20 post attached to the two chords at their mid-points and has two further braces, one extending from one end of the second chord to the mid-point of the deck-edge chord and the other extending from the other end  
25 of the second chord to the mid-point of the deck-edge chord. Double frame units may be used in conjunction with main frame units, in which case they are twice the length of the main frame units.

According to another aspect of the invention  
30 there is provided a planar modular unit quadrilateral space frame comprised of a plurality of main frame units or ~~extended frame units~~ and a plurality of

tie bars, the units being arranged in a space frame with their deck-edge chords forming a regular-quadrilateral grid deck and their tie bar interconnection members all on one side of the deck where they are interconnected by the tie bars, the arrangement including at least one unit connected by its end connection means to two other units via their side connection means and by its side connection means to two further units via their end connection means and the tie bar interconnection member of the said at least one unit being connected to the tie bar interconnection members of the other and the further units by tie bars forming a regular-quadrilateral grid in register with that of the deck-edge chords. The said at least one, two other and two further units are referred to hereinafter as the "basic five" units.

A space frame having the basic five and a number more units alone has an irregular end. The frame can be given a regular end by use of half frame units.

In such a space frame, an end is defined by a plurality of aligned main frame, double frame or other extended frame units which are connected to the rest of the frame on one side via their side connection means; one half frame unit is connected between each adjacent pair of the said units forming the end of the frame via the end connection means of the said units and the side connection means of the half frame unit, the end connection means of each half frame member being connected to the side connection means of

a unit identical to the said end units in a line adjacent the end of the frame.

At a corner between to two adjoining ends of the space frame, the corner is formed between an end one  
5 of the said end units of one end of the frame and a half frame unit forming the end of the said end units of the other end of the frame, the said half frame unit being connected by its side connection means to the said end one of the said end units and by its end connection means to the end connection means of the adjacent  
10 end unit of the other end of the frame with a half frame unit extending to the adjacent line of units connected therebetween.

In general, in a space frame certain members  
15 are more highly loaded than others. If a member becomes critically loaded, that is loaded to a load at which it fails, and it is in compression, the member can be expected to fail in a brittle manner. Then the member will cease to be effective in bearing any load in the  
20 space frame. The total load previously borne by the failed member will be redistributed to other members. This can result in further compression loaded members becoming critically loaded and failing brittly whereupon the entire space frame may collapse.

25 If a tension loaded member becomes critically loaded, the member can be expected to fail in a plastic manner. Then the member will continue to be load bearing whilst undergoing appreciable elongation. During this elongation, that proportion of the failed member's  
30 load bearing capacity which it can no longer carry will be redistributed to other members. This redistributed

load is only a small proportion of the failed member's total load bearing capacity and should not result in further members becoming critically loaded and failing, thus collapse of the entire space frame should be avoided.

5 A planar modular unit according to the invention preferably includes a load limiting device in the deck-edge chord for limiting the compression load therein to a value below the member's critical compression load, the load limiting device being such as to fail plastically at this value of load.

10 Preferably the load limiting device comprises an externally screw-threaded plug threadedly engaged in an internally screw-threaded socket, one of the plug-and-socket being attached to the chord and the other to the end connection means with the screw thread of the plug-and-socket being axially aligned with the direction of compression load application to the chord from the end connection means, the screw thread being plastically deformable for load limiting by thread shear.

15 It is envisaged that the thread shear may occur in the plug or the socket or both. This can be controlled by the relative hardness of the plug and the socket and the tooth form adopted. Whilst the plug could be attached to the chord or the socket could be in an extension of the chord, it is preferred that the socket be attached inside the end of the chord. This is particularly convenient where the chord is hollow.

20  
30 Preferably the plug is attached to an abutment plate which constitutes the end connection means and

bears against the side connection means of another unit to receive the compression load. Normally a gap will be provided between the abutment plate and the socket. The gap diminishes as the thread shears.

5 Ultimately if the redistribution of load is insufficient to relieve the load on the chord to below the predetermined value, the abutment plate will come into contact with the socket at the end of the chord giving solid abutment with the chord.

10 A soft sealing washer is preferably provided between the abutment plate and the socket.

The planar modular unit quadrilateral space frame of the invention may include frame units having load limiting devices at the ends of their chords. However,  
15 a space frame made up of such frame units need not include any with load limiting devices if the chords are unlikely to be critically loaded. In a more heavily loaded space frame the devices need only be included in the most heavily loaded frame units,  
20 i.e. the central frame units of a peripherally supported space frame.

To help understanding of the invention various specific embodiments thereof will not be described with reference to the accompanying drawings in which:

25 Figure 1 is a perspective diagrammatic view of a portion of a planar modular unit quadrilateral space frame of the invention:

Figure 2 is a diagrammatic plan view of the space frame of Figure 1;

Figure 3 is a diagrammatic cross-section on the line III-III of Figure 2;

Figure 4 is a side view of a main frame unit of the invention in its installed orientation;

5 Figure 5 is a similar view to Figure 4 of a half frame unit;

Figure 6 is a scrap view of a typical tie bar interconnection member of a frame unit;

10 Figure 7 is a scrap side view showing connection details of the chords of three main frame units;

Figure 8 is a plan view of the details of Figure 7;

15 Figure 9 is a perspective diagrammatic view of a portion of planar modular unit quadrilateral space frame constructed with main frame units and double frame units;

Figure 10 is a view similar to the Figure 9 of a space frame constructed with double frame units;

20 Figure 11 is a plan cross-sectional view of a load limiting device at the end of a chord of a modular frame unit;

Figure 12 is a cross-section on the line X-X of Figure 11; and

25 Figure 13 is a view similar to Figure 11 of another load limiting device.

The space frame portion shown in Figure 1 is the bottom left hand portion of Figure 2. Main frame units 1 shown in Figure 1 include five basic units 1a,

lb, lc ld, le which are shown cross-hatched for clarity. Half frame units 2 are shown in Figure 1 in bold lines whilst the other main frame units are merely shown in out-line. The support column 3 at the  
5 bottom left hand corner 4 of Figure 2 is omitted from Figure 1.

The first main frame unit la of the basic five units has two other main frame units lb, lc connected to it and extending at right angles from it on either  
10 side at its mid-point, details of the connection between the units are explained below. Two further main frame units ld, le extend at right angles across either end of the first main frame unit la which is connected to the further units at their mid-points.  
15 Another main frame unit lf is connected across the end of unit lb opposite from unit la. Units le and lf extend in the left hand and bottom (in Figure 2) ends of the space frame. Half frame unit 2a extends from the end of the unit lf at the corner 4 to the  
20 unit le, whilst a second half frame unit 2b extends in from the junction of units 2a and le to the mid-point of unit lb. Similarly half frame units 2c, 2d extend in from the ends of the space frame at the ends of the units le, lf remote from the corner 4. The  
25 space frame can be seen to be completed by more main frame units connected in like manner with half frame units as appropriate at the ends.

From Figure 3, each of the main frame units can be seen to consist of an upper, deck-edge, chord 7.  
30 Such chords are the edges of the units which form the

deck of the space frame in a square grid - the sides of the squares being one half the length of the chords. In the space frame of Figure 2, which is supported peripherally by the eight support columns 3 the chords, being upper-most, are in compression. Each main frame has a pair of equal length braces 8 extending down to an apex from the ends of the chord. A post 9 extends down from the mid-point of the chord also to the apex. At the apex, a tie bar interconnection boss 10 is provided from which four tie bars 11 radiate to the bosses of adjacent frame units. Two tie bars radiate in line with the chord of the first unit in question one in one direction and one in the other. The other two tie bars radiate in line with the other two units connected to the mid-point of the first unit. Thus the tie bars form a square grid in line with that formed by the chords as may be seen in Figure 1 where the tie bars are shown as chain dotted lines; that is to say the grid formed by the chords and the grids formed by the tie bars are in register.

Figure 4 shows one main frame unit in greater detail. The chord 7 is of square section steel tube having plates 12 welded across its ends; these plates constitute end connection means. Each plate extends laterally on either side of the chord to accommodate bolt holes through which connection bolts 13 can connect the unit to the next two units as shown in Figures 7 and 8, with the plate abutting against the side of the first of these midway along its length. At this position each main frame unit is provided with welded

in sleeves 14 for reinforcement where the bolts 13 pass through, the sleeves constitute side connection means.

Below and between the sleeves, the solid steel post 9 is welded to the chord 7. To the foot of the post is welded the boss 10, which as shown is a boss or junction similar to that described and claimed in my Patent No. 1,464, 777. The boss has four studs 15 to which the tie bars are connected by connectors 16.

Two of the studs radiate oppositely from the boss in line with the chord and two radiate oppositely at right angles to the chord. Immediately above the first two studs, oblique flats 17 are provided on the boss. The two opposite solid steel diagonal braces 8 are welded to the flats 17 and extend diagonally up to the ends of the chord where they are welded to its underside in corners formed by lower extensions of the abutment plates 12.

Figure 5 shows one half frame unit which is identical to the main frame unit of Figure 4 save that a) its chord terminates at one end adjacent the upper end of the post, this end being plated with a plate similar to plates 10, b) it has only one diagonal brace, and c) it may have only three studs.

Figure 6 shows one manner of providing support for a frame unit via a plate 18 welded by cruciform fillets 19 underneath the boss 10.

Figures 9 and 10 show space frames utilizing alternative extended frame units 30. As shown these are double the length of the main frame units and as such are known as double frame units. Even longer

frame units could be used with additional triangulation  
braces. Such longer frame units could have posts even-  
ly spaced along their length to produce a space frame  
having a grid size less than half the length of the units  
5 or a single post to provide a space frame similar to that  
shown in Figure 10. The double frames have an elongate  
tie bar interconnection member in the form of a rectan-  
gular tubular steel lower chord 31. At the lower end  
of the post the lower chord has screwed studs welded in  
10 and extending **through laterally** for connection of the  
laterally extending tie bars. At the end of the lower  
chord further screwed studs are welded for connection  
of axially extending tie bars.

Main frame units are used in conjunction with  
15 double frame units in the Figure 9 space frame to pro-  
duce a rectangular grid. The main frame units extend  
in one direction in the grid whilst double frame units  
extend in the other. In Figure 10, double frame units  
extend in both directions. This figure clearly shows  
20 an advantage of double frame units, namely that at any  
post tie bar connection is simplified with only two tie  
bars 11 requiring connection.

The load limiting device shown in Figures 11 and  
12 has a screw-threaded plug 20 welded to an abutment  
25 plate 12. The plug is screwed into a threaded socket  
21 received in the end of the chord 7 where it is weld-  
ed in position via a flange 22. A plug 23 at the inner  
end of the socket seals the chord. A soft washer 24  
seals the device.

30 In Figures 1 and 2, X marks the position of  
load limiting devices at the ends of various chords in

the most highly loaded frame units. These units are those at the centre of the space frame. Due to build up of tolerances it is possible for one of the chords having a load limiting device to be carrying substantially more compression load than others. Should this chord become critically loaded its load limiting device will yield plastically by thread shear redistributing load to other frame units. Subsequently the frame unit having the failed device should be replaced to bring the space frame back to design strength.

As shown those chords equipped have load limiting devices at both ends. Alternatively the devices could be provided at one end only.

Figure 13 shows an alternative load limiting device wherein a proving ring 25 is provided between a diaphragm plate 26 in the chord and a boss 27 on the plug 20. Once the thread has deformed plastically, the boss loads the proving ring to enable the device to carry a total load in excess of the plastic deformation load. A buffer 28 of soft material between the ring and the boss loads the ring progressively. The buffer may be of expanded polystyrene or foam rubber for instance.

The invention is not intended to be restricted to the details of the above described embodiment. In particular diagonal members may be fitted between selected upper chord connections to stabilize the assembled frame. Further, other sections than rectangular steel tubes for the chords and solid steel bars for the posts and braces may be used. For instance, where appropriate rolled steel sections may be used. Also, for main frame units and half frame units, the tie bar interconnecting solid boss 10 may be replaced by a fabricated arrangement.

CLAIMS

1. A planar modular unit for a quadrilateral space frame comprising an elongate deck-edge chord, a post attached perpendicularly at one end thereof to the said chord, a tie bar interconnection member attached to the other end of the said post, at least one brace attachedly extending from an end of the said chord remote from the said post to the other end of the said post or to the said tie bar interconnection member, end connection means at the said one end or both ends of the said chord and side connection means on the said chord adjacent the said one end of the said post, the said side connection means and the said end connection means being complementary whereby one or two other such units can be connected via its or their end connection means to the said chord on one or both sides thereof respectively, the said tie bar interconnection member being adapted for interconnection by tie bars with the tie bar interconnection members of such other unit or units and of any other such unit connected to the said end connection means, such tie bars extending in register with the said chord and the chords of such other units connected to the said chord.

2. A planar modular unit as claimed in Claim 1 wherein the unit is a half frame unit having its post attached to its chord at one end of the chord and having a single brace.

3. A planar modular unit as claimed in Claim 1 wherein the unit is a main frame unit having its post attached to its chord at the mid-point of the chord and having a pair of braces, one extending from one end of the chord to the other end of the post or the tie bar interconnection member and the other extending from the other end of the chord to the other end of the post or the tie bar interconnection member.

4. A planar modular unit as claimed in Claim 1 wherein the unit is an extended frame unit having its elongate tie bar interconnection member in the form of an elongate second chord arranged parallel to its deck-edge chord and the second chord intermediate their respective ends, having a pair of braces, one extending from one end of the deck-edge chord to the corresponding end of the second chord and the other extending from the other end of the deck-edge chord to the other end of the second chord and having further braces triangulating the unit between the ends of the second chord and one of the ends of the post.

5. A planar modular unit as claimed in Claim 2 or Claim 3 wherein the tie bar interconnection member comprises a solid steel boss to which the post and the brace or braces are welded and screwed studs welded to the boss for screwed connection to the tie bars.

6. A planar modular unit as claimed in Claim 4 wherein the tie bar interconnection member comprises a rectangular section steel tube constituting the second chord, to which the post, the braces and further braces are welded, a screwed stud welded to each end of the second chord and a screwed stud extending laterally through the second chord adjacent the post.

7. A planar modular unit as claimed in any preceding claim, including a load limiting device in the deck-edge chord for limiting the compression load therein to a value below the member's critical compression load, the load limiting device being such as to fail plastically at this value of load.

8. A planar modular unit as claimed in Claim 7 wherein the load limiting device comprises an externally screw-threaded plug threadedly engaged in an internally screw-threaded socket, one of the plug-and-socket being attached to the chord and an end thereof and the other to the end connection means with the screw thread of the plug-and-socket being axially aligned with the direction of compression load application to the chord from the end connection means, the screw thread being plastically deformable for load limiting by thread shear.

9. A planar modular unit as claimed in Claim 8 wherein the chord is hollow and the load limiting plug-and-socket are arranged in the end of the chord with the socket attached to the chord, and the end connection means includes an abutment plate attached to the outer end of the plug with a gap between the plate and the end of the chord, the arrangement being such that the gap diminishes and ultimately the plate comes into solid abutment with the chord upon complete plastic deformation of the load limiting device.

10. A planar modular unit as claimed in Claim 8 or Claim 9 wherein the load limiting device includes a spring arranged to be compressed when the screw thread has plastically deformed to a certain extent.

11. A planar modular unit as claimed in Claim 10 wherein the spring is a proving ring arranged to be loaded by the plug when it has deflected to the certain extent.

12. A planar modular unit as claimed in Claim 11 including a buffer interposed between the plug and the proving ring.

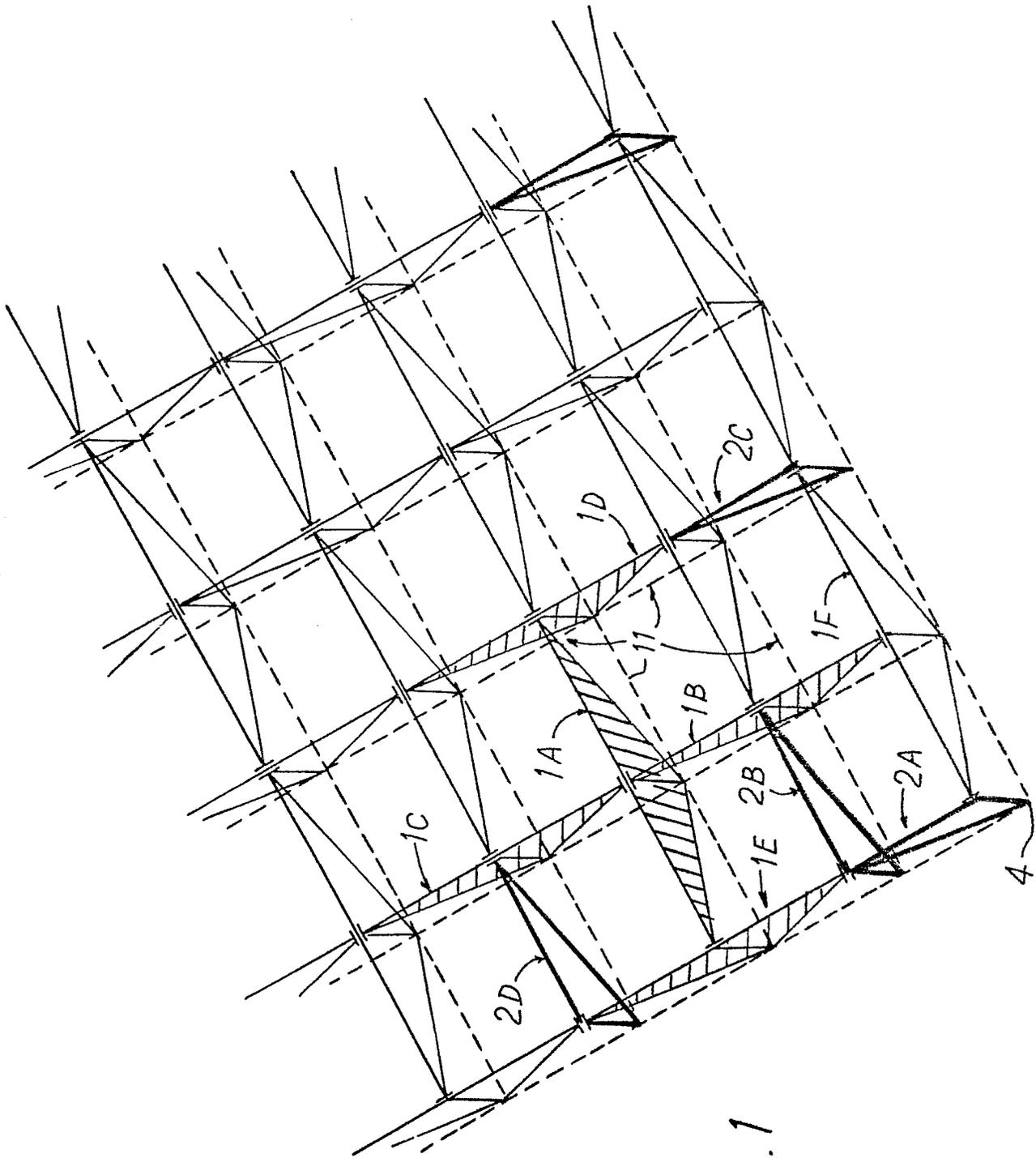


FIG. 1

FIG. 2

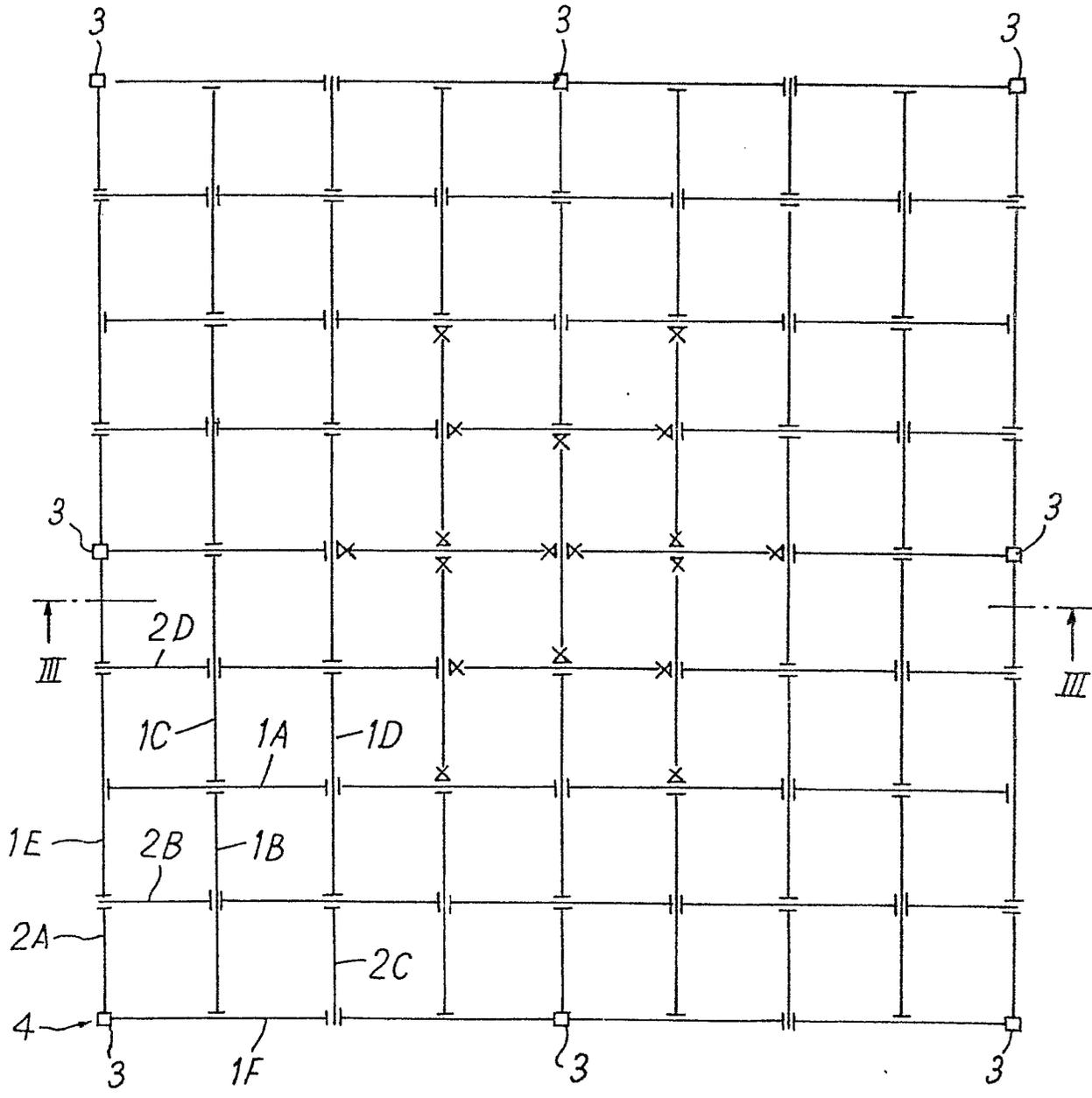
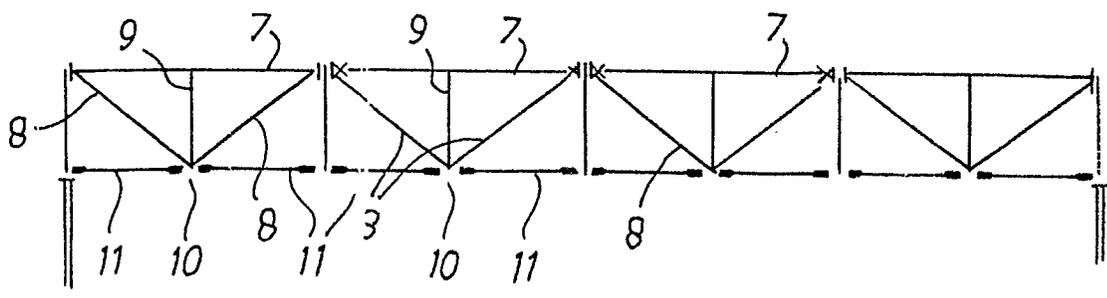


FIG. 3



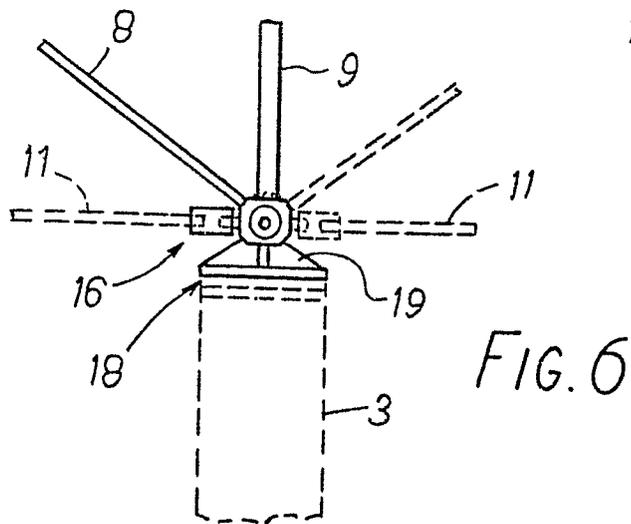
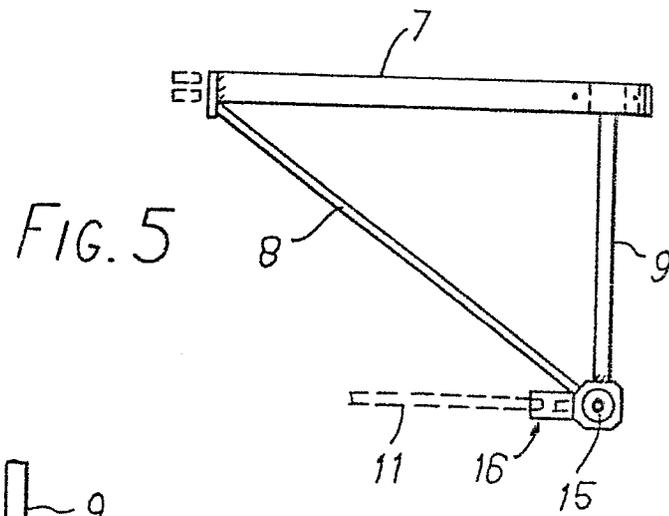
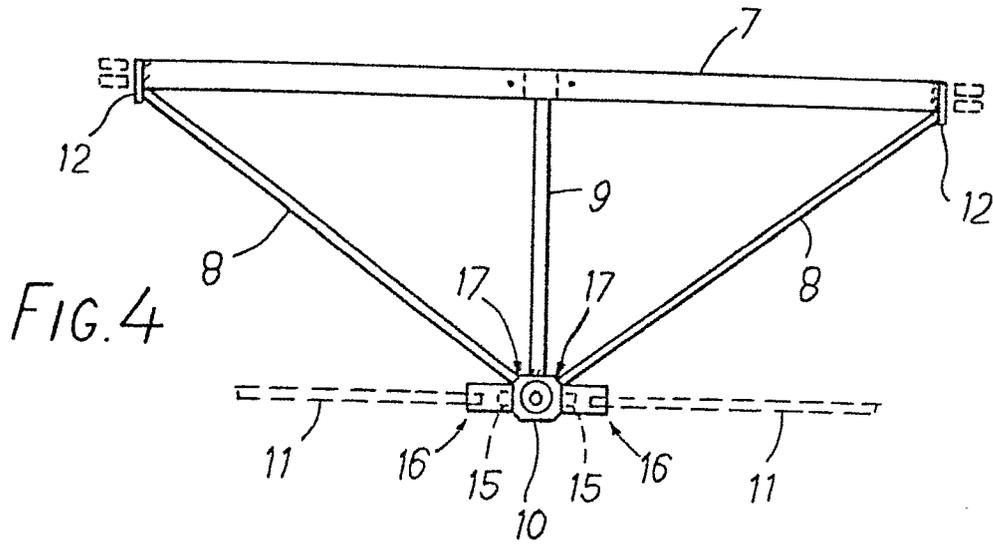


FIG. 7

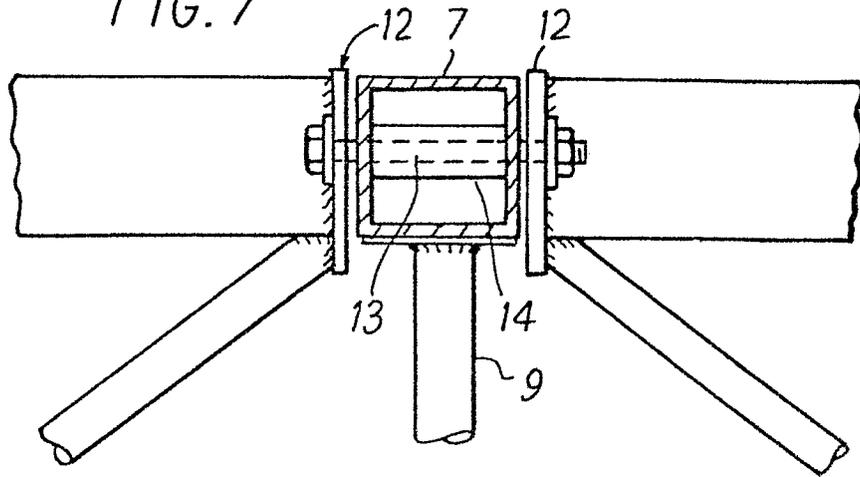


FIG. 8

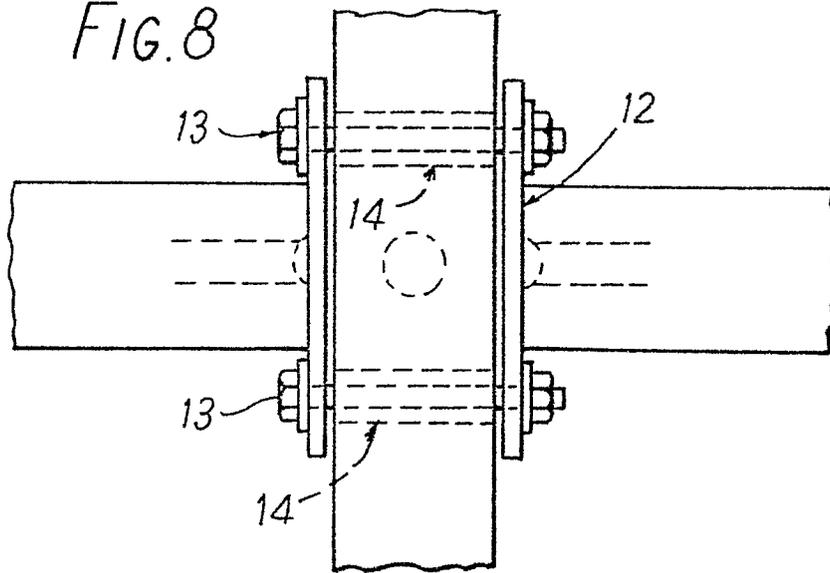


FIG. 11

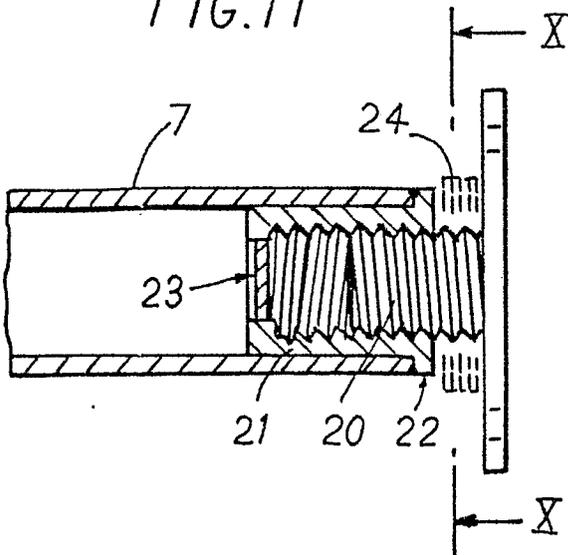


FIG. 12

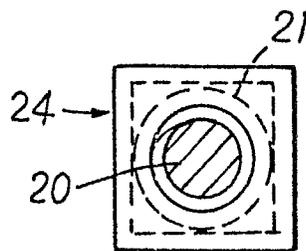


FIG. 9

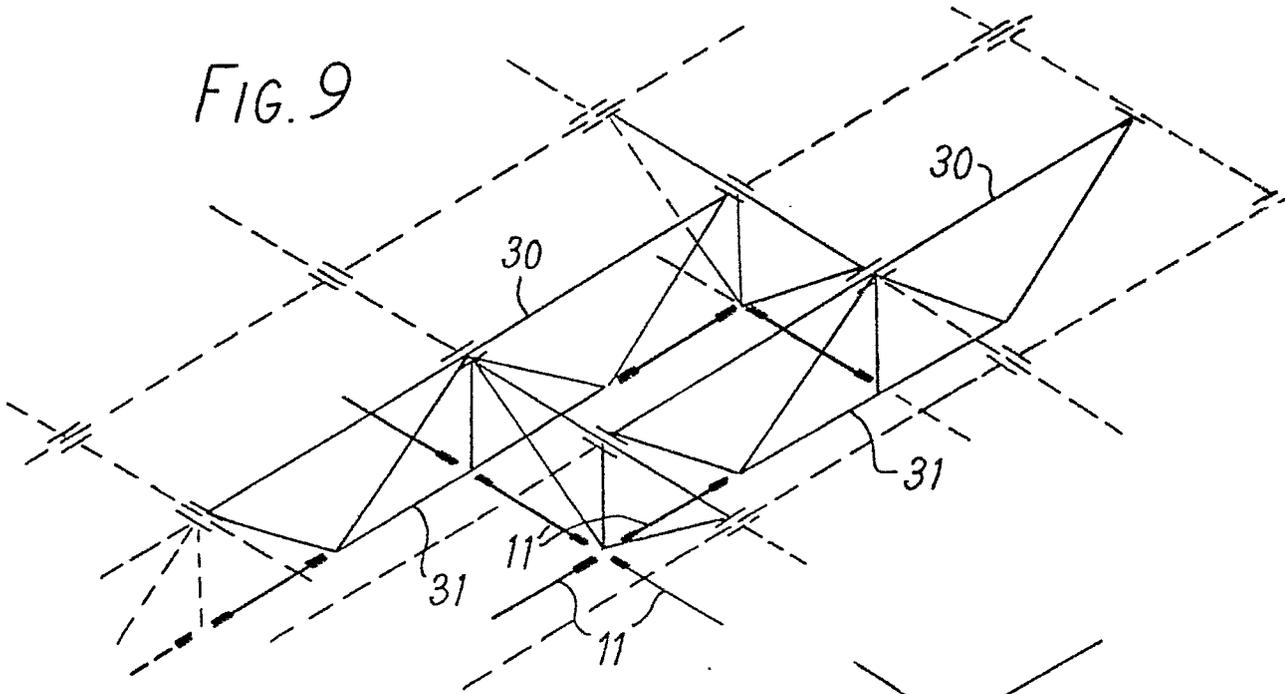


FIG. 10

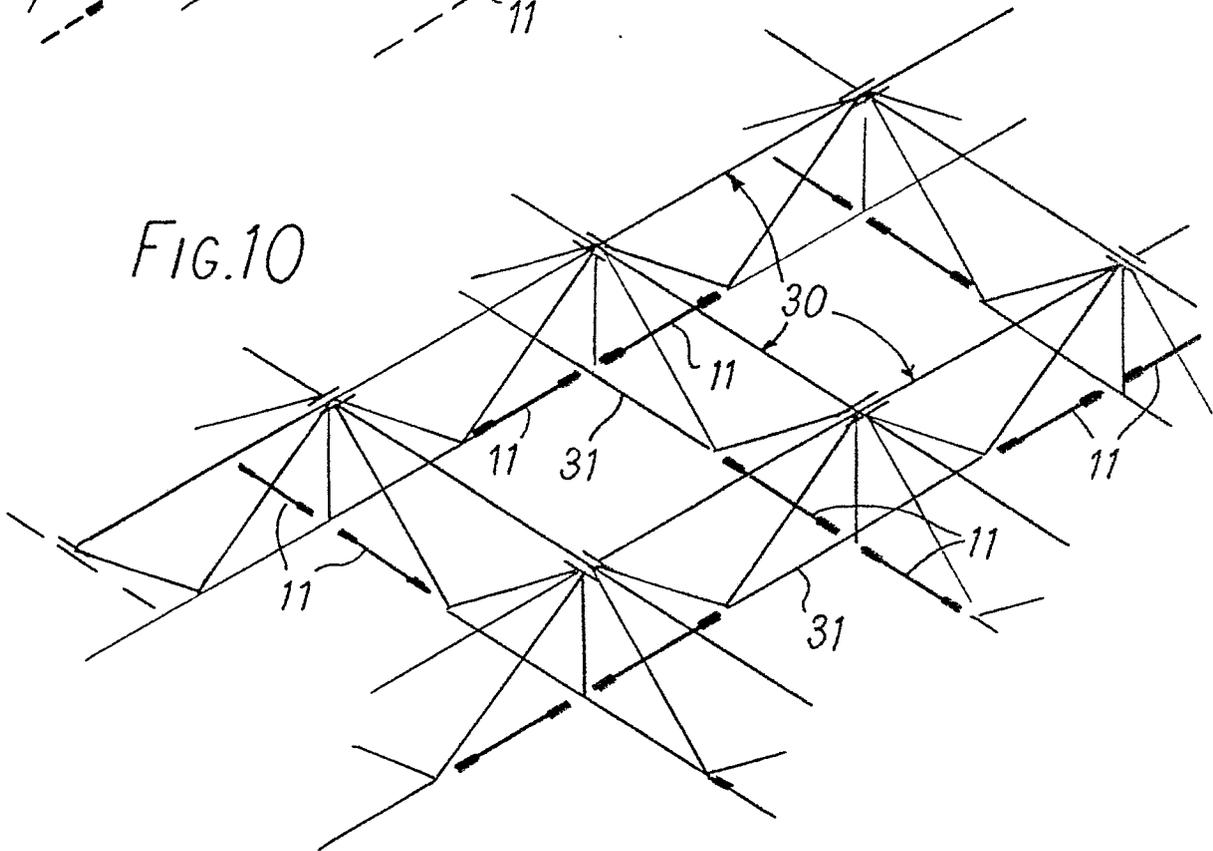
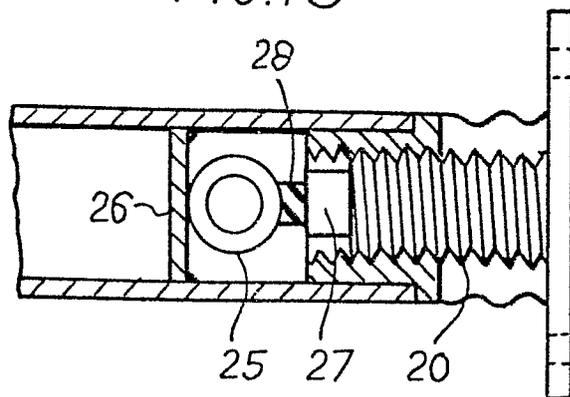


FIG. 13





European Patent  
Office

EUROPEAN SEARCH REPORT

0067251

Application number

EP 81 30 2532

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	<p><u>BE - A - 824 419</u> (BHAGAT)</p> <p>* Page 2, paragraphs 1,2,3; page 9, paragraph 2 to page 10, paragraph 2; page 13, paragraph 4; figures 3,8 *</p> <p>--</p> <p><u>GB - A - 770 167</u> (BOLTON)</p> <p>* Page 1, lines 10-17; page 3, line 66 to page 4, line 32; figure 11 *</p> <p>--</p> <p><u>US - A - 3 477 189</u> (MERSON)</p> <p>* Column 1, lines 25-29; column 3, lines 17-61; figures 2,3 *</p> <p>--</p> <p><u>US - A - 2 744 590</u> (BUTTS)</p> <p>* Column 1, lines 15-21; column 3, line 70 to column 4, line 5; figure 5 *</p> <p>-----</p>	<p>1,3</p> <p>1,5</p> <p>1</p> <p>1</p>	<p>E 04 B 1/19</p> <p>TECHNICAL FIELDS SEARCHED (Int. Cl.)</p> <p>E 04 B</p> <p>CATEGORY OF CITED DOCUMENTS</p> <p>X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons</p> <p>&amp;: member of the same patent family. corresponding document</p>
<p><i>A</i> The present search report has been drawn up for all claims</p>			
Place of search	Date of completion of the search	Examiner	
The Hague	18-11-1981	CAVALERI	

