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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : E04B 1/19

A1

(11) International Publication Number: WO 99/41466

(43) International Publication Date: 19 August 1999 (19.08.99)

(21) International Application Number: PCT/GB99/00437

(22) International Filing Date: 11 February 1999 (11.02.99)

(30) Priority Data:
9802975.4 13 February 1998 (13.02.98) GB

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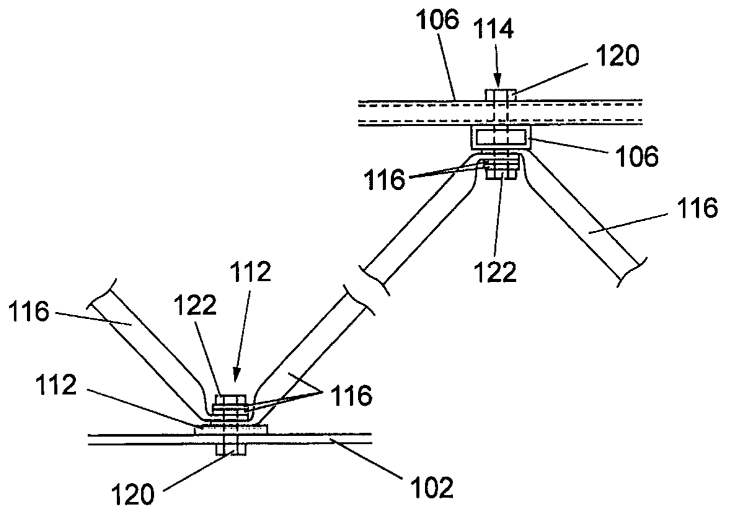
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: STRUCTURAL SYSTEMS



(57) Abstract

A space truss system comprising at least two planar grids (106, 102), the grids (106, 102) being substantially parallel and adjacent grids (106, 102) being connected by at least one diagonal strut (116). The grids (106, 102) are connected at the intersection of their respective cross members (nodes) (112, 114) and each connection is secured by a single connector (120) which is passed through a hole in the node (112, 114) (not shown), the hole being substantially perpendicular to the plane of the grid (106, 102). The diagonal strut (116) is connected to the connector (120) by means of a connecting section on the strut (116) formed by part of the strut (116), the connecting section being shaped and angled to be parallel to the planar grid (102, 106) whilst the diagonal strut (116) is connected to the planar grid (102, 106). In one embodiment, the strut (116) has a connecting section formed at each end. In an alternative embodiment, the strut (116) is V-shaped and has a connection section being formed at its centre by flattening portions of the tubular members.

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STRUCTURAL SYSTEMS

This invention relates to structural systems, and relates more particularly but not exclusively to structural systems in the form of space truss systems.

A wide-area flat roof supported on walls or columns at or adjacent to the edges or corners of the roof may be based upon a structure known as a space truss, which is a form of space frame having an overall shape approximately that of a thick slab. Such a space truss generally comprises two horizontal square grids of mutually joined orthogonal members, the grids being mutually parallel and vertically separated by a distance of between a half and one times the edge dimension of a square, with the nodes (junctures of the orthogonal members forming the respective grids) in each grid being mutually horizontally displaced by about half the edge dimension of a square in each direction parallel to the edges of the grid squares, and with each node in each grid being joined to all of the horizontally adjacent nodes in the other grid by respective struts which are diagonal with respect to both horizontal axes parallel to the edges of the grid squares and also with respect to the vertical axis normal to these horizontal axes. A continuous water-tight covering over the upper surface of such a space truss structurally completes the basic construction of the roof.

Various forms of such a space truss have been proposed, in which the members are metal tubes or channels, (or combinations of these) mutually joined in various ways such as bolting, welding, or by the use of special jointing members. Proposed forms of space truss have been subjected to testing and found to suffer from various disadvantages, such as a need for precise dimensioning of components, a need for precise assembly of components, a need for on-site welding at height, and/or excessive complexity and cost. In some proposed space truss systems, even relatively minor imperfections in components, assembly, or installation impart a susceptibility to catastrophic failure of the space truss.

Ideally, a space truss will have components which are easy to make and need not be dimensionally precise, a minimum number of different types of component, a structure which can be prefabricated or assembled on site at choice and without the need for highly skilled craftspersons, a structure in which components need not be precisely dimensioned or precisely aligned, but still give a structure which is safe, reliable, and performs to design specifications, the components and their method of assembling being economical and preferably low cost, and the finished space truss being aesthetically pleasing. If the grid members (which have considerable length in the assembled space truss) can be subdivided and the parts joined by simple but reliable demountable joints, then the space truss becomes suited for temporary installation without difficulties in handling and storing excessively lengthy components.

According to a first aspect of the present invention there is provided a space truss system comprising at least two planar grids, said grids being substantially parallel and adjacent grids being connected at the intersection of their cross members by means of at least one diagonal strut, each connection being secured by a single connector, said connector being passed through a hole in the intersection of the cross members substantially perpendicular to the plane of the grid, said at least one diagonal strut being connected to said planar grid through said connector by means of a connecting section formed by part of the strut, said connecting section being shaped and angled to be parallel to the planar grid whilst the diagonal strut is connected to the planar grid.

Preferably, the strut has connecting sections located at each end.

Optionally, the strut has a single connection section located substantially in the middle of its length. The connection section forming the apex of the V shape.
Preferably, the planar grids are connected by connecting arms of adjacent diagonal struts along the same axis.
Use of a V-shaped strut simplifies joint design by reducing the number of struts connected to each connector. Preferably the arms of the strut form an angle of less than 180°.
Preferably the adjacent arms of adjacent diagonal supports are connected by means of a splice. The use of a V-shaped strut decreases the number of connections made using a single connector. Therefore, the distance from the joint to the outmost connection is decreased and the amount of eccentricity at the joint decreased because the connections are closer to the centre of the joint.

Preferably, the connecting section of the strut is flat.

The steps of flattening and bending are preferably undertaken in a manner which avoids kinking or localised bending of the tube, conveniently by applying the lateral compression to the tube end by means of a pair of jaws, at least the jaw on the inside of the bend having a curved lead-in to its compression face such as to avoid a low-radius bend being imparted to the tube.

Preferably, the connector consists of a screw threaded bolt and a matching screw threaded nut or a stud and matching nuts.

Preferably, the nut is lockable.

Preferably, the diagonal strut is a substantially circular tube constructed of mild steel.

Preferably, the planar grids are arranged horizontally in pairs such that, in use, grid members of the lower grid are subject to a tensile force and grid members of the upper grid are subject to a compressive force.

Preferably, the adjacent grids are respectively formed of flat strips of mild steel and hollow rectangular sections of mild steel.

With the intersecting grid members arranged to have their broad faces in mutual contact, a stabilising effect is produced by way of resistance to torsion which would distort the truss and degrade its performance if not counteracted; at the same time, the vertical extent of the structure at each node through which the respective single fastener has to pass is kept to a minimum and eccentricity of strut loading is also minimised.

The flat strips of the lower grid members may be spliced together from lengths less than the requisite length by locating ends of lesser lengths of strip in end-to-end and longitudinally coaxial relationship and clamping these ends between fishplates which are preferably secured to each strip end by means of a single bolt or other through fastener having a diameter equal to or less than the diameter of the node fastener.

Preferably, the intersection of the cross members of one grid are horizontally displaced such that they are located substantially over the centre of the space between the grid cross members of an adjacent grid.

Optionally, adjacent grids are displaced by substantially half a grid pitch.

The space truss system according to the first aspect of the present invention may be adapted to facilitate temporary installation of a truss, wherein it is preferable that the truss components are of a relatively short length so as to be easily handled and stored (in comparison to the relative difficulty of handling and storing full-length components, e.g. full truss-width grid members). To this end, the lower grid may be modified by sub-dividing the grid members into units each having a length slightly shorter than the inter-node distance and with a hole adjacent to each end, and providing a connecting plate at each node, the connecting plate having a central hole for the fastening of the struts and four peripheral holes symmetrically disposed around the central hole, the peripheral holes being for the attachment (one to each hole) of the perforated ends of the lower grid units, conveniently by a respective nut and bolt. Thereby the lower grid can be built up as before, with a single hole at each node for the single-fastener attachment of the diagonal struts, but the lower grid is now composed of relatively short components (comparable to the strut length) which can thereby be relatively easily handled and stored, so facilitating installation, use, and subsequent non-destructive dismantling of a space truss for subsequent re-use.

Correspondingly, the upper grid can be similarly modified by sub-dividing the grid members into units each having a length about equal to the inter-node distance. However, it is preferred that the upper grid members be so sub-divided that the upper unit ends are about mid-way between the nodes of the upper grid. Where the upper grid members are formed of RHS as an economic way of providing resistance to longitudinal compressive loading, the preferred means of splicing the upper grid units is to circumlocate abutting unit ends with a short length of rectangular "U" channel, preferably aligned with the channel base against the undersides of the grid units. The preferred means of securing the upper grid units via the channel length is by passing one or more fasteners (e.g. bolt(s) with respective nut(s)) through each unit end and the circumlocated channel, preferably through both opposite legs of the "U". Where such upper grid units intersect at the nodes, their attachment to each other and to the conjoining struts is exactly as if the upper grid members were undivided, ie the mutual attachment is by a single fastener.

The lower and upper grids may be mutually vertically separated by a distance of between one quarter of the lesser dimension of a grid rectangle and the greater dimension of a grid rectangle.

The mutual spacings of adjacent ones of the grid members in the one array of grid members in each of the lower and upper grids may be substantially equal to the mutual spacing of adjacent ones of the grid members in the other array of grid members in each of the lower and upper grids such that each of the lower and upper grids is a square grid.

Foregoing references to "horizontal" and to "vertical" assume that the space truss is in a typical alignment with its major faces (the lower and upper grids) substantially horizontal, but the space truss system according to the present invention can equally be utilised with these faces in a non-horizontal alignment (e.g. as a foundation for an artificial recreational slope), or even with the major faces vertical (e.g. as a wall, screen, or hoarding) and references to "horizontal" and to "vertical" should accordingly be construed in a relative and non-literal manner.

Furthermore, while the foregoing space truss can be considered as a two-layer space truss (ie a truss having a lower grid and an upper grid), the principles of the invention can be extended to triple-layered trusses (ie trusses having lower, upper, and intermediate grids), and possibly to trusses having more than three layers (which are normally but not necessarily mutually substantially parallel). The principles of the invention can also be extended to space trusses which lie in two or more intersecting planes, eg a roof and a wall formed as an integral structure, or area coverings in the form of faceted domes or canopies.

According to a second aspect of the present invention there is provided a method of fabricating a diagonal strut for a space truss system according to the first aspect of the present invention, said method comprising the steps of providing a piece of tubing of a suitable material and not shorter than the length required to fabricate a finished strut, cutting or otherwise reducing said piece of tubing to the length required to fabricate a finished strut if the piece is not initially of said length, laterally compressing each end of the length of tubing until both ends are substantially flat, bending each flattened end of the length of tubing substantially to a predetermined angle with respect to the longitudinal axis of the length of tubing and such that the bent and flattened ends lie in substantially parallel planes, the predetermined angle being that appropriate to the space truss system in which the finished truss is to be used, and forming a respective through hole in each flattened end for the passage therethrough of respective single fastener in use of the strut.

According to a third aspect of the present invention there is provided a kit of parts for constructing a space truss system according to the first aspect of the present invention, said kit of parts comprising a plurality of lower grid members, a plurality of upper grid members, a plurality of struts for diagonally joining nodes in lower and upper grids when assembled, and a plurality of fasteners, each strut being formed of a tube of appropriate length having both of its ends flattened and each flattened end bent into a plane which is at an appropriate angle to the longitudinal axis of the strut, each flattened end being provided with a through hole for the reception of one of said fasteners.

Said struts are preferable formed by the method according to the second aspect of the present invention.

In the case where said space truss system is adapted to facilitate temporary installation, said lower grid members are preferably constituted by a plurality of lower grid units each slightly shorter than the inter-node distance and with a hole adjacent to each end, together with a plurality of connecting plates each having a central hole for the fastening of the struts and four peripheral holes symmetrically disposed around the central hole for the attachment of the perforated ends of the lower grid units, said kit of parts further comprising a plurality of fasteners for the attachment of the lower grid units to the connecting plates. Correspondingly, the upper grid members are preferably constituted by a plurality of upper grid units each having a length about equal to the inter-node distance and having a through hole at about its mid-length to accommodate the single fastener for securing the grid members and struts at that node. When the upper grid members are so sub-divided, the kit of parts will further include a plurality of splicing means to splice together the adjacent ends of adjacent upper grid units in the assembled space truss, each such splicing means preferably comprising, in the case where the upper grid units are lengths of RHS, a short length of rectangular "U" channel, together with fastener means to fasten the channel to adjacent ends of the upper grid units.

Thus in its broadest sense, the present invention consists of a space truss system having first and second grids having struts extending between them and connected thereto at nodes, wherein a node has struts overlying one another and secured to the grid by single fastening means.

Embodiments of the invention will now be described by way of example, with reference to the accompanying drawings wherein:-

Figures 1A and 1B are respectively plan and elevation views of a double-layered space truss in accordance with the invention;
Figure 2 shows constructional details, to a much enlarged scale, of the space truss of Figure 1;
Figure 3 shows a modification of part of the Figure 2 arrangement;
Figure 4 shows a detail of the fabrication of a diagonal strut forming part of the space truss of Figure 1;
Figure 5 shows the fabricated diagonal strut undergoing longitudinal compression;
Figure 6 shows an optional constructional detail, to a much enlarged scale, of the space truss of Figure 1;
Figure 7 graphically illustrates load versus strain during a test to destruction of the truss of Figure 1, together with comparative results for the same test applied to a prior art truss;
Figure 8 schematically depicts a modification of the space truss of Figure 1 such as to facilitate temporary installation of the truss;
Figures 9A, 9B and 9C are respectively the elevation, plan and cross-section, to an enlarged scale, of detail A in Figure 8;

Figures 10A and 10B are respectively the elevation and plan, to an enlarged scale, of detail B in Figure 8;

Figure 11 graphically illustrates load versus strain during a test of the arrangement of Figures 9A to 9C, together with comparative results for the same test applied to variants;

Figure 12 shows a variant of the constructional detail of Figure 6;

Figures 13A, 13B, 13C and 13D are respectively a plan view, an end elevation, a side elevation, and a much enlarged detail of 13C, of part of a modified form of space truss incorporating the variant of Figure 12;

Figures 14A, 14B, 14C and 14D are respectively a plan view, an end elevation, a side elevation, and an enlarged detail of Figure 14C, of part of an alternatively modified form of space truss;

Figure 15 is a perspective view of a connection device for connecting timber plates to a space truss;

Figure 16 is a perspective view of an alternative form of splicing member suitable for use in a truss joint similar to that shown in Figures 9A-C;

Figures 17A, 17B and 17C are respectively the elevation, plan and cross-section of a truss joint employing the splicing member of Figure 16;

Figure 18 schematically depicts details of a truss extending in two general planes which are mutually orthogonal, the details being shown in the region of the transition between these two planes;

Figures 19 and 20 correspond to Figure 18, wherein the two planes are at mutual angles of 60° and 120°, respectively;

Figure 21 shows a space truss in accordance with the invention in which the diagonal member is

V shaped; and

Figure 22 shows a splice for joining together adjacent top members.

Referring first to Figures 1A and 1B, these show the layout of a typical corner-supported square-on-square double-layer space truss 100 with bottom tension members 102, forming a lower grid 104, and top compression members 106 forming an upper grid 108, with diagonal struts 110 joining the lower grid 104 to the upper grid 108. As is usual, both grids 104 and 108 are square grids, with regular pitching (mutual spacing) of the grid members 102, 106. Moreover, the grid nodes 112 in the lower grid 104 (ie the intersections of the orthogonally arranged grid members 102) are precisely under the mid-points of the squares of the upper grid 108. Conversely the grid nodes 114 in the upper grid 108 (ie the intersections of the orthogonally arranged grid members 106) are precisely over the mid-points of the squares of the lower grid 104.

Each of the nodes 112 in the lower grid 104 is joined to each of the horizontally adjacent nodes 114 in the upper grid 108 by means of a diagonal strut 116.

Further details of the grid members 102 and 106, and of the struts 116, will be given below, with particular reference to Figure 2.

The truss 100 is supported at a desired height by means of columns 118 (schematically depicted in Figures 1A and 1B) which connect with the outer corners of the lower grid 104.

Referring now to Figure 2, the lower grid members 102 are each in the form of a flat steel strip, and the upper grid members 106 are each formed of steel RHS (Rectangular Hollow Section). Each of the diagonal struts 116 is formed of a steel tube having its ends flattened and bent in a manner subsequently to be detailed. At the lower nodes 112 and at the upper nodes 114 where the lower grid members 102 mutually intersect and the upper grid members 106 mutually intersect respectively, and where each of the grids 104 and 108 intersect with the flattened ends of the diagonal struts 116, through holes are formed to accommodate a single bolt 120 at each of the nodes 112, 114. Each bolt 120, in conjunction with a respective nut 122, services to fasten the truss components conjoining at that node.

Figure 3 shows a modification of the truss structure at the corners of the lower grid 104, where the usual bolt 120 and nut 112 (see Figure 2) are replaced by a stud 124 and two nuts 126 to attach the corner node 111 to the truss support 118 via an interposed spacer 128.

Figure 4 shows a preferred method of fabricating a diagonal strut 116 from stock CHS (Circular Hollow Section or hollow steel tubing). The steel tubing is cut to a suitable length, and one end of the cut tube is placed between a lower jaw 130 and an upper jaw 132 which are then forced together to flatten the tube end. Without opening the jaws 130 and 132 or removing the flattened end from the jaws 130 and 132, the tube is bent upwards by any suitable means (eg manipulation) until it forms a suitable angle with the flattened end (see below). With most gauges and diameters of tubing, heating is not necessary before bending. Since it is believed to be desirable to avoid inducing kinking or localised buckling of the tube at or near the bend, the relevant edge 134 of the upper jaw 132 is suitably curved to avoid producing a small radius on the inside of the bend. A bolt-accommodating hole is formed in the flattened end, eg by drilling or punching through pilot holes (not shown) in the jaws 130, 132 before they are opened, or by suitably forming the hole after the jaws 130, 132 are separated to release the tube, preferably in a jig to ensure accurate location and spacing of the end holes.

The above procedure is then repeated at the other end of the tube, care being taken to rotationally align the tube before the jaws 130, 132 are closed to flatten the other end, such that the second flattened and bent end lies in a plane parallel to the plane of the first flattened and bent end (see Figures 2 and 5).

The result of the procedure described above with reference to Figure 4 is a fully formed strut 116, as shown in Figure 5 (to a lesser scale) where the finished strut 116 is shown bolted at each end to the testpiece connectors 136 of a testing machine (the rest of which is not shown). Compression testing (as depicted in Figure 5) has shown that the strut 116 is capable of sustaining an axial compression load which is significantly larger than the calculated value for a pin-ended member. This indicates that the particular form of the ends of the strut 116 provides more tangible flexural stiffness (in contrast to pin-jointed struts).

The space truss 100 could be assembled from suitable numbers of its standard components 102, 106, 116, 120, and 122, assembly taking place at ground level (on preferably level ground) or at height (in situ on the support columns 118), each option having its own merits. When assembled on the ground, the lower grid members are laid down first, and then connected at each node 112 to the requisite member of diagonal struts 116, using a single bolt 120 (and co-operating nut 122) at each node. Next, the upper grid members 106 are fastened in place and connected to the diagonal struts 116, again with a single bolt 120 (and co-operating nut 122) at each node 114. All of the nuts 122 are initially kept loose on their respective bolts 120 until all of the truss components are in place, and finally the fasteners 120, 122 are tightened in any order. This assembly procedure largely eliminates the effects of "lack of fit", ie dimensional disparities in components. On the other hand, particularly if assembly space is unavailable, the truss components could be assembled in situ (at height), commencing from the tops of the support columns 118. In the latter case, "lack of fit" might have some effects on the finished truss in dependence on the accuracy of manufacture of the truss components.

In any event, it is preferred to make all of the struts 116 with nominally identical lengths, and then to assemble them (normally with four to a node) such that a given strut which is lowermost in the stack at its lower end is also lowermost in the stack at its upper end, and correspondingly for the other three strut ends at each node. Strut ends which do not lie flat in trial assembly can be manually bent to correct alignment.

Where necessary or desirable, the lower grid members 102 can be spliced as shown in Figure 6, wherein the ends of adjoining lower grid members 102 are mutually aligned and mutually secured by being clamped between a pair of fishplates 138 secured by bolts 140 and nuts 142. (An alternative splicing procedure will subsequently be described with reference to Figure 12).

A full-scale model of the space truss 100 was built and tested to failure. The solid-line graph in Figure 7 shows the central deflection of the test truss under loading to failure. The truss experienced an initial stage of linear behaviour during which no instance of yielding or buckling could be detected in any of the truss components. When the first instance of component yielding occurred, a reduction in truss stiffness resulted. With more components yielding, truss stiffness gradually degraded until a nearly plastic stage of behaviour was reached. The test truss manifested a substantial ductility not present in prior art truss systems. The test was terminated by a fracture in a severely elongated lower grid member 102 on the edge of the lower grid 104. During the test, several upper grid members 106 deformed laterally, indicating the start of a buckling mode. However, this did not progress into a complete buckling of the relevant components as adjacent parallel grid members helped to relieve the overloaded grid members and protect them against further deterioration. Slight component joint (node) rotations could be seen near the supports 118 just before overall failure of the test truss. No noticeable joint rotations were recorded before the final stage of behaviour.

From considerations of design details of the truss (see especially Figure 2) there are two principal factors affecting the behaviour of the truss under load:

1 The simplicity of the node joints results in a slight joint eccentricity. Longitudinal axes of

the truss components do not all meet at one point as in some prior art truss systems. This might lead to some joint rotation at upper grid nodes.

2 The continuity of grid members through the nodes adds flexural stiffness to the truss joints, more than the stiffness achieved in prior art truss systems comprising components that are substantially pin-jointed. The tests carried out showed that the flexural stiffness in the joints of the truss according to the present invention increased joint stability, component buckling strength, and truss resistance to brittle collapse.

The results obtained from testing the truss model are indicated in Figure 7 which graphically illustrates load versus strain during a test to destruction of the truss of Figure 1, together with comparative results for the same test applied to a prior art truss. The dashed-line denoted by letter B in Figure 7 illustrates the performance of one prior art truss system. The negative slope of the load/strain curve beyond peak load-withstand indicates a runaway failure mode. In contrast, the solid line which gives the performance of the present invention, gives clear warning of impending failure compared to the catastrophic failure of the prior art. These results indicated that the effects of grid member continuity outweighed those of joint eccentricity. The truss of the present invention had high flexural stiffness at its joints and hence had more stable joints which enhanced the ability of the truss to distribute loads away from fully loaded areas and significantly increased truss ductility. For a space truss with the illustrated proportions to give about 50 millimetres of central deflection as is apparent in the results given in Figure 7 for the present invention, and to fail by tension fracture after excessive yielding of a lower grid member is quite uncommon. No similar behaviour was experienced with prior art truss systems as described in published literature.

The above-described embodiment 100 of the space truss of the present invention which involves grid members 102 and 106 that are long (edge to edge of the lower and upper grids 104 and 108) and continuous (or effectively continuous, even if the lower grid members 102 are spliced as in Figure 6) is especially suitable for permanent installation. However, the invention can easily be modified to suit temporary structures which may be characterised by dimensions that differ from installation to installation. A practicable truss system for temporary structures should be re-usable and adaptable, preferably involving identical short components that can be easily and efficiently assembled, dismantled, transported and stored.

Referring now to Figure 8, this shows part of a truss system 200 in accordance with the invention and having the same basic principles as the truss 100, but with modifications thereof to suit repeated temporary installation. The principal modifications consist of forming the lower grid from lower grid units 202 each having a length slightly less than the distance between adjacent lower grid nodes 212, and of forming the upper grid members from upper grid units 206 each having a length about equal to the distance between adjacent upper grid nodes 214.

Figures 9A, 9B and 9C shown in elevation, plan, and section respectively and to an enlarged scale, details of one of the upper grid unit splices (circled "A" in Figure 8). The splice consists of a short length 250 of rectangular "U" channel having dimensions that enable it to fit snugly around the adjacent ends of two upper grid units 206, the channel length 250 in particular having an interface dimension with a maximum tolerance on the RHS width of 1 millimetre. The splice is completed by a lateral bolt 252 through each of the adjacent grid unit ends, secured in each case by a respective nut 254. (An alternative form of splice will subsequently be described with reference to Figures 16 and 17).

Tests were carried on a specimen of the joint described with reference to Figure 9 (a "two-bolt splice"), on a similar joint with two bolts per grid unit end (not shown; a "four-bolt splice"), and on a unitary member unit without splices. Compressive load/strain graphs for these three specimens are shown in Figure 11. Very little difference was observed to exist between the three cases, but the two-bolt splice (ie the Figure 9 joint) was marginally superior.

Figures 10A and 10B respectively illustrate the elevation and plan, to an enlarged scale, of details of one of the lower grid nodes 212 (circled "B" in Figure 8). The node comprises a square junction plate 260 having four symmetrically disposed holes for the attachment by respective bolts 262 and nuts 264 of perforated ends of the lower grid units 202 conjoining at that node. A lower grid of the truss 200 (equivalent to the lower grid 104) is built up to the required size from an appropriate number of the lower grid units 202, junction plates 260, and fasteners 262, 264. Each junction plate 260 has a central hole for fastening the end of conjoining struts 216 by means of a respective single bolt 220 and nut 222, ie the same single-fastener system as in the truss 100.

In the truss system 200, the diagonal struts 216 are substantially identical to the struts 116 of the truss system 100, since these truss components are already of a size to be handled easily.

Advantages of the present invention include the following features:

1 The simplicity of the truss joints considerably reduces cost as there is no requirement for skilled labour or for sophisticated machinery.

2 Continuity of grid members across the truss joints results in more ductile behaviour of the truss under load, and hence a better distribution of forces between the truss components.

3 The dimensional tolerances inherently allowed by the present invention diminish difficulties with "lack-of-fit" in comparison to prior art truss systems.

4 The truss system is easily adapted for temporary installation and differing overall sizes without loss of the preceding advantages, and with minimal extra cost.

The invention is not limited to the structural details described above. For example, the lower grid splice of Figure 6 could be substituted by the splice arrangement shown in Figure 12 wherein the lower grid members 102 have their ends mutually overlapping and mutually directly secured by the bolts 140 and nuts 142.

(Compared to the Figure 6 arrangement, the grid members in the Figure 12 arrangement will be suitably lengthened so as to overlap adjacent grid members without significantly changing the grid pitch of the truss). Whereas in Figure 6 all lower grid members 102 extending in a given direction were coplanar, in the Figure 12 arrangement lower grid members 102 extending in a given direction are alternately above and below a nominal plane coinciding with the mutually contacting faces at a splice. This alternative "up" and "down" staggering of adjacent lower grid members 102 requires an arrangement which is schematically depicted in Figure 13A, and non-schematically illustrated in Figures 13B and 13C, with a much enlarged fragmentary detail of Figure 13C being shown in Figure 13D. Although the lower grid members 102 in the Figure 12 splice arrangement require to be somewhat longer than in the Figure 6 arrangement, the Figure 12 arrangement has the advantage of eliminating the need for the fishplates 138 of the Figure 6 arrangement.

The length of an individual one of the lower grid members 102 is dependent, in part, on easy handling. In suitable circumstances, for example if the grid nodes 112 are close together, a lower grid member 102 may be both short enough for easy handling but long enough to extend completely across a square of the lower grid and into each of the adjacent squares such that splices are required only every second square. This arrangement is schematically depicted in Figure 14A, non-schematically illustrated in Figures 14B and 14C, with an enlarged fragmentary detail of Figure 14C being shown in Figure 14D. The arrangement of Figures 14A-14D employs the same splice arrangement as used in Figures 13A-13D, ie the Figure 12 splice arrangement, but only about half as many splices are required.

A space truss 100 in accordance with the invention may serve as a foundation for timber decking usable (for example) as a floor. An accessory 300 which is illustrated in Figure 15 facilitates the connection of timber plates (not shown) to the truss 100 (not illustrated in Figure 15). The accessory 300 is generally in the form of a wide-flanged channel, conveniently fabricated by cold-forming thin metal sheet. Holes 302 in the flanges of the accessory 300 allow fasteners (not shown) to attach the accessory 300 to timber plates, while a single central hole 304 in the bottom of the channel allows the accessory 300 to be attached to the truss 100 by means of the single bolt 120 at a given one of the upper nodes 114. As many accessories 300 would be employed with a truss 100 as were necessary in given circumstances, up to one accessory 300 for each of the upper nodes 114. The accessory 300 can be secured to an upper node 114 in either one of two different ways:-

1 The accessory 300 can be inserted between the upper and lower members 106 forming the upper grid 108 (see Figure 2). For this mode of installation, the depth of the central channel of the accessory 300 should be at least equal to the depth of the upper member 106, and the internal width of the central channel should not be less than but preferably close to the external width of the upper member 106.

2 The accessory 300 can alternatively be located on top of the upper member 106. For this mode of installation, neighbouring accessories 300 across the upper face of the truss 100 are preferably mutually aligned at 90° so as to prevent any lateral movement of the timber plates relative to

the members 106 forming the upper grid 108.

The accessory 300 (when employed in suitable numbers and at suitable locations on the truss 100) ensures that the top timber plates can work compositely with the truss 100 rather than merely serving as flooring or a cosmetic covering, thus allowing some reduction in the top chord cross-sectional area for a given strength of the truss.

A space truss 100 in accordance with the invention can be utilised to support a layer of wet concrete cast in-situ to form a top layer of slabs. Flat decking plates are placed between the upper and lower members 106 forming the upper grid 108 (see Figure 2), with holes drilled through the decking plates at each node 114 to accommodate the respective bolt 120. Whilst sitting on the lower ones of the members 106 and being connected to the truss 100 at the upper nodes 114 (by means of the respective bolts 120), these decking plates work as membranes to support the weight of wet concrete. For moderate panel widths and concrete slab thickness, the plates may be thin and not require stiffening. However, stiffeners (which may, for example, be lengths of cold-formed angle) can be spot-welded to the underside of the decking plates for extra stiffness and reduced sagging.

The upper grid splice previously described with reference to Figures 9A-C employed a short length 250 of rectangular "U" channel. However, such material may have a flange thickness which varies over a range sufficient to make it unsuitable for providing an efficient connection or splice between the adjacent upper members 206. It has been found that a much reduced variability in thickness is obtainable by forming a channel 350 (Figure 16) from rectangular hollow section ("RHS") having one face removed. The RHS from which the channel 350 is formed is selected to fit around the upper grid units 206 with only a moderate tolerance, typically less than 1 millimetre. A joint made using the channel 350 in place of the channel 250 is illustrated in Figures 17A-17C (which may be compared with equivalent Figures 9A-9C).

Figure 18 schematically illustrates a space truss 400 which is a form of the invention enabling the truss to extend in two intersecting planes (at a mutual angle of 90° as shown in Figure 18). The truss 400 comprises a right-angled inner member 402 and a right-angled outer member 406 at the corner (intersection of the two planes). The remainder of the truss 400 can be of any suitable form, and may, for example, be composed of the components utilised in the truss 100. It is preferred that the truss 400 have two diagonal struts 116 mutually connecting the members 402 and 406 at points which are close to their corners. The members 402 and 406 may be fabricated by welding together suitable lengths of straight stock. Figure 18 is schematic and depicts only principal components of the truss 400.

Bi-planar trusses in accordance with the invention need not be restricted to the 90° form shown in Figure 18; Figure 19 shows a space truss 500 wherein the two planes intersect at 60°, and Figure 20 shows a space truss 600 where in the two planes intersect at 120°. Other angles are possible within the scope of the invention. At the corners of the trusses 500 and 600, up to eight diagonal struts can be mutually connected at one node and to the two grid members also intersecting at that node; such a joint can be handled in the same way as any other joint, ie assembled and secured by a single bolt.

The principles described with reference to Figures 18, 19 and 20 can be extended to more than two intersecting planes, for example to form dome-like structures, a platform with walls and a roof, canopies of varying degrees of complexity, and other permanent or temporary structures for which space trusses are suitable.

Figure 21 shows a further preferred embodiment of a space truss system 700 according to the present invention. As can be seen from Figure 21, the diagonal strut in this embodiment is V-shaped. The truss comprises a top member 702 and a bottom member 704. Perpendicular to the top member 702 and in the same plane is a further top member 708, together they form the top node 728. Similarly, a perpendicular bottom member 722 is in place and along with member 704 forms the bottom node 730. Bolt 706 is used to join together top members 702 and 708 to diagonal strut 712. This is done by drilling holes (not shown) in top members 702 and 708 and connecting them to diagonal strut 712 at the top node 728. As can be appreciated from Figure 21, the diagonal strut 712 is V shaped and contains a flattened section located approximately at the centre of its length. The diagonal strut 712 is bent at points located to each side of the flattened section to give its characteristic V shape defined by the flat middle section 726 and arms 720 and 724. The angle between the arms is normally 90° and is always less than 180°. Similarly, bolt 710 is used to join together bottom members 704 and 722 to diagonal strut 714. As is apparent from the diagram, the arms of diagonal strut 712 and diagonal strut 714 are angled so as to meet at a point on the axis between the top node 728 and the bottom node 730. The arm 720 of the

diagonal strut 712 attached to the top node 728 and the arm 718 of the diagonal strut 714 attached to the bottom node 730 are joined together by means of splice tube 716 to form a supporting connection from the bottom node 730 to the top node 728. The splice tube 716 in use is slotted over the outside of the arms 718 and 720 of the diagonal struts. As is apparent from the diagram, the holes in the arms of the diagonal struts 718 and 720 are arranged to match up with those bored in the splice tube 716 thus allowing secure connection of the splice tube 716 to the arms 718 and 720 by means of a bolt or similar connection.
In use, a space truss will also have diagonal supports perpendicular to those shown in Figure 21. The flat section 732 of such a diagonal support arm connected to the bottom grid intersection is indicated on Figure 21. It is apparent when comparing Figures 2 and 21 that the use of a V-shaped diagonal support simplifies the joint assembly. The joint assembly disclosed in Figure 2 has four flattened sections attached to each grid intersection. Along with the perpendicular members of both top and bottom members this means that 6 seperate elements are connected through by a single bolt. In the embodiment of figure 21, only four elements are attached through a single bolt. Therefore, because there are two fewer connections at each joint, the distance from the joint to the outmost connection is less than in the embodiment described in figure 2. Therefore the amount of eccentricity at the joint is less than in the figure 2 embodiment. In addition, the use of a splice as in Figure 21 has, in itself, some constructional advantages since it can be used to further enhance the compression strength of the diagonal member.

Figure 22 shows an alternative splice arrangement 800 for joining together the top-most members of a space truss system where decking sheets are to be placed above the top-most member. The diagram shows adjacent top-most members of a space truss system 806 and 808 along with two side angle splices 802 and 804. In use, the truss members 806 and 808 are placed together and sandwiched between side angle splices 802 and 804. The angles are connected to the truss members 806 and 808 in an eccentric fashion i.e. so that each connection from a splice to the truss members 806 and 808 is off-set from the centre line of the join. The high stiffness of the splices is used to counteract the effect of the eccentricity.

In cases where the above embodiment of the present invention is constructed from a kit of parts, assembly of the present invention from the kit can be speeded up by using short cylinders of plastic or card board in order to pre-assemble the diagonal members. This allows the diagonal members to be assembled before being joined to the upper and lower grid intersections.

While certain modifications and variations have been described above, the invention is not restricted thereto, and other modifications and variations can be adopted without departing from the scope of the invention.

Claims

1. A space truss system comprising at least two planar grids, said grids being substantially parallel and adjacent grids being connected at the intersection of their cross members (nodes) by means of at least one diagonal strut, each connection being secured by a single connector, said connector being passed through a hole in the intersection of the cross members substantially perpendicular to the plane of the grid, said at least one diagonal strut being connected to said planar grid through said connector by means of a connecting section formed by part of the strut, said connecting section being shaped and angled to be parallel to the planar grid whilst the diagonal strut is connected to the planar grid.

2. A space truss system as in claim 1 in which the strut has connecting sections located at each end.

3. A space truss system as in claim 1 in which the strut has a single connection section located substantially in the middle of its length.

4. A space truss system as in claim 3 in which the strut is V shaped, the connection section forming the apex of the V shape.

5. A space truss system as in claim 3 or claim 4 in which adjacent planar grids are connected by connecting adjacent arms of adjacent diagonal struts along the same axis.

6. A space truss system as in any of claims 3 to 5 in which the arms of the strut form an angle of less than

180°.

7. A space truss system as in claims 3 to 6 in which adjacent arms of adjacent diagonal supports are connected by means of a splice.

8. A space truss system as in any of the preceding claims in which the connecting section of the strut is flat.

9. A space truss system as in any of the preceding claims in which the connector consists of a screw threaded bolt and a matching screw threaded nut or a stud and matching nuts.

10. A space truss system as in claim 7 in which the nut is lockable.

11. A space truss system as in any of the preceding claims in which the diagonal strut is a substantially circular tube constructed of mild steel.

12. A space truss system as in any of the preceding claims in which the planar grids are arranged horizontally in pairs such that, in use, grid members of the lower grid are subject to a tensile force and grid members of the upper grid are subject to a compressive force.

13. A space truss system as in any of the preceding claims in which the grid cross members of said horizontally arranged paired grids are each subdivided into units, each unit having a length equal to or slightly less than the distance equal to that of an integral number of inter-node lengths.

14. A space truss system as in any of the preceding claims in which the lower grid of the horizontally arranged grid pair has a unit length of less than the inter node length.

15. A space truss system as in any of the preceding claims in which the grids are substantially rectangular.

16. A space truss system as in any of the preceding claims in which adjacent grids are mutually vertically separated by a distance of between the size of one quarter of the lesser dimension of the grid rectangle and the size of the greater dimension of the grid rectangle.

17. A space truss system as in any of the preceding claims in which adjacent grids are respectively formed of flat strips of mild steel and hollow rectangular sections of mild steel.

18. A space truss system as in any of the preceding claims in which the intersection of the cross members of one grid are horizontally displaced such that they are located substantially over the centre of the space between the grid cross members of an adjacent grid.

19. A space truss system as in any of the preceding claims in which adjacent grids are displaced by substantially half a grid pitch.

20. A method of fabricating a diagonal strut for a space truss system according to the first aspect of the present invention, said method comprising the steps of providing a piece of tubing of a suitable material and not shorter than the length required to fabricate a

finished strut, cutting or otherwise reducing said piece of tubing to the length required to fabricate a finished strut if the piece is not initially of said length, laterally compressing each end of the length of tubing until both ends are substantially flat, bending each flattened end of the length of tubing substantially to a predetermined angle with respect to the longitudinal axis of the length of tubing and such that the bent and flattened ends lie in substantially parallel planes, the predetermined angle being that appropriate to the space truss system in which the finished truss is to be used, and forming a respective through hole in each flattened end for the passage therethrough of respective single fastener in use of the strut.

21. A kit of parts for constructing a space truss system according to the first aspect of the present invention, said kit of parts comprising a plurality of lower grid members, a plurality of upper grid members, a plurality of struts for diagonally joining nodes in lower and upper grids when assembled, and a plurality of fasteners, each strut being formed of a tube of appropriate length having both of its ends flattened and each flattened end bent into a plane which is at an appropriate angle to the longitudinal axis of the strut, each flattened end being provided with a through hole for the reception of one of said fasteners.

22. A space truss system as hereinbefore described with reference to the accompanying drawings.

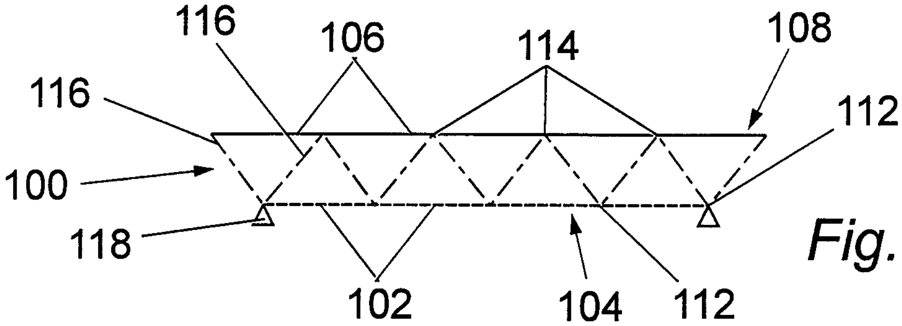

Fig. 1B

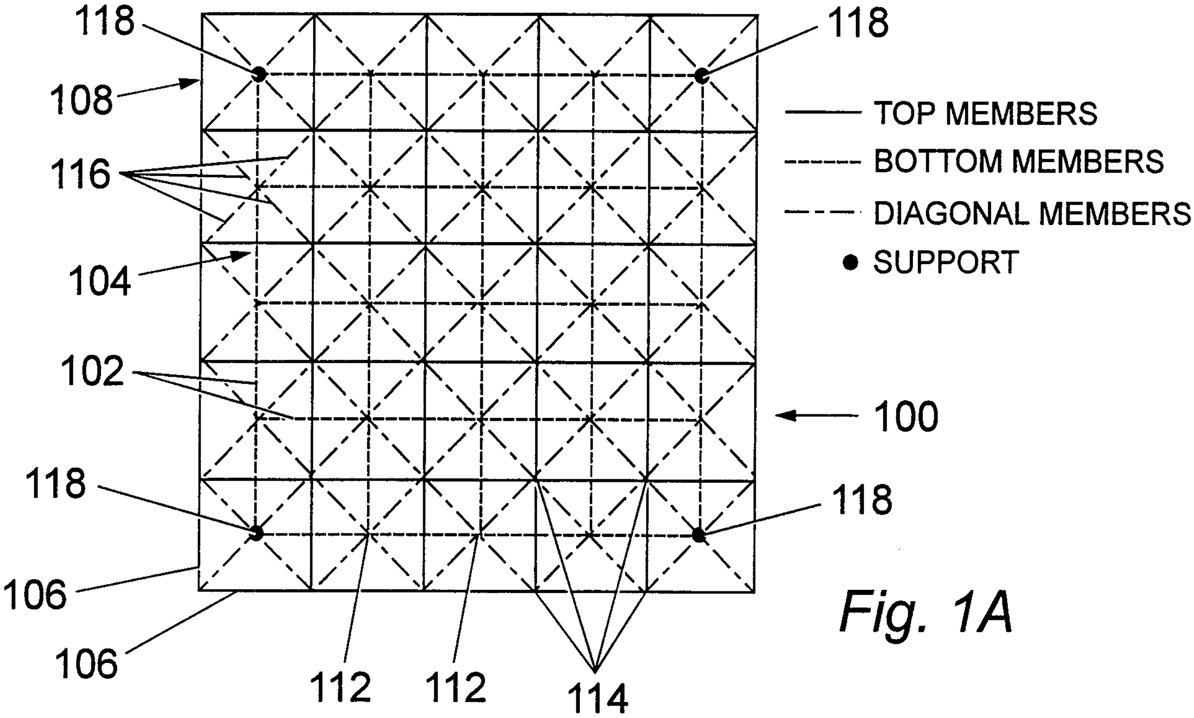

Fig. 1A

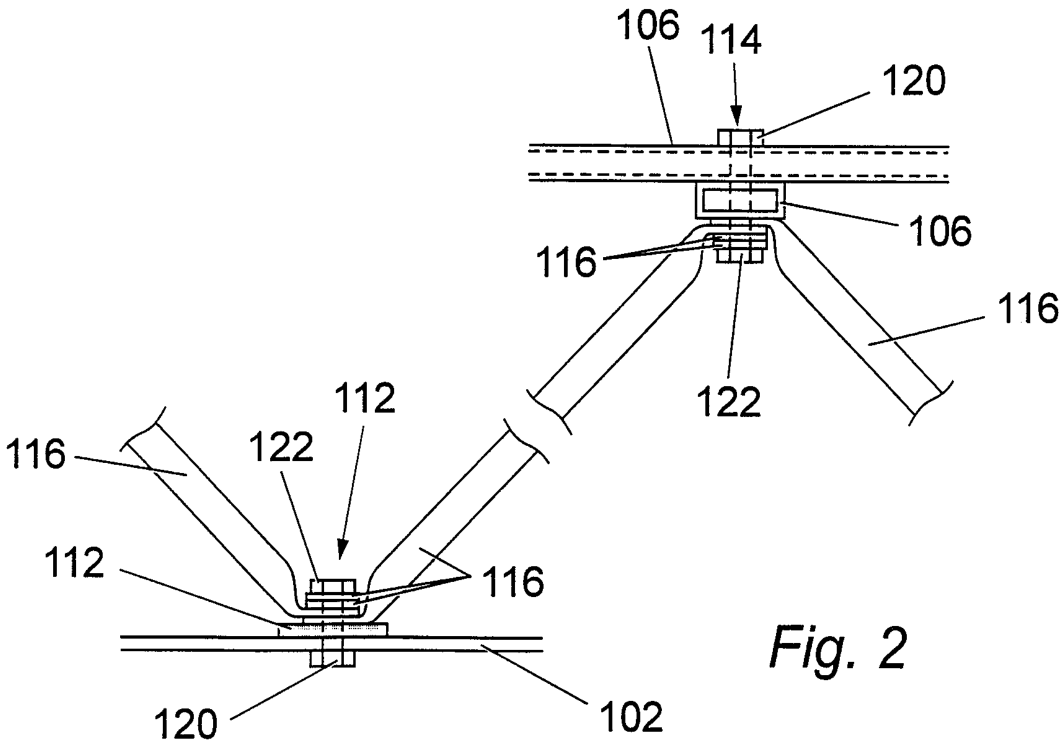

Fig. 2

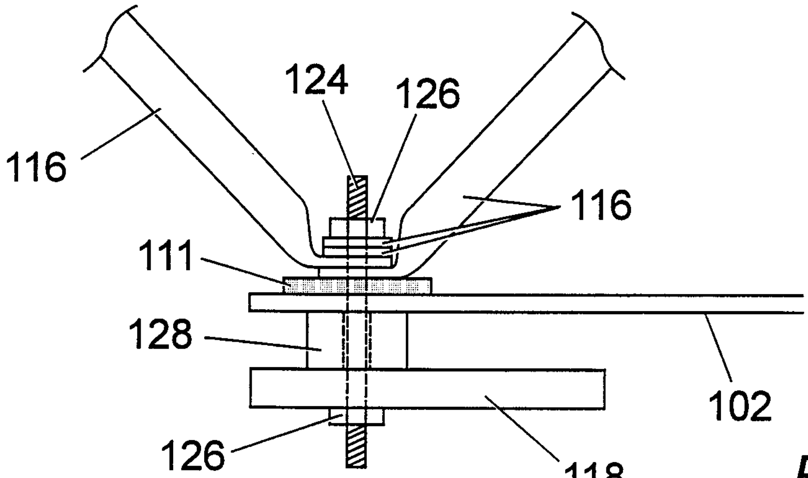

Fig. 3

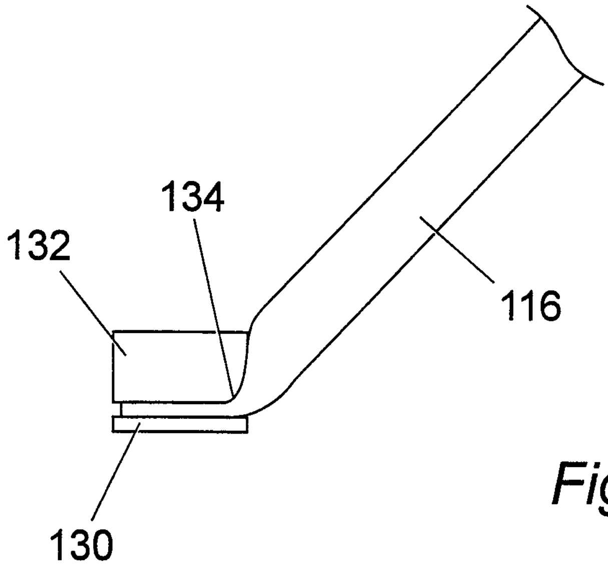

Fig. 4

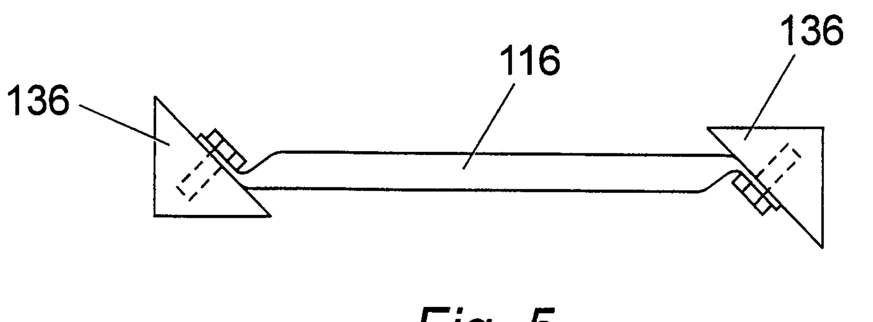

Fig. 5

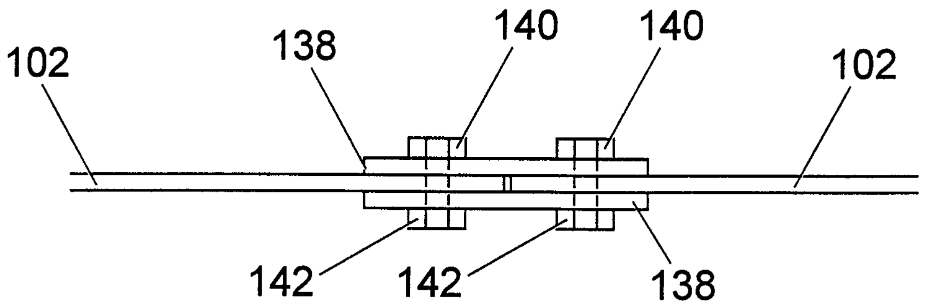

Fig. 6

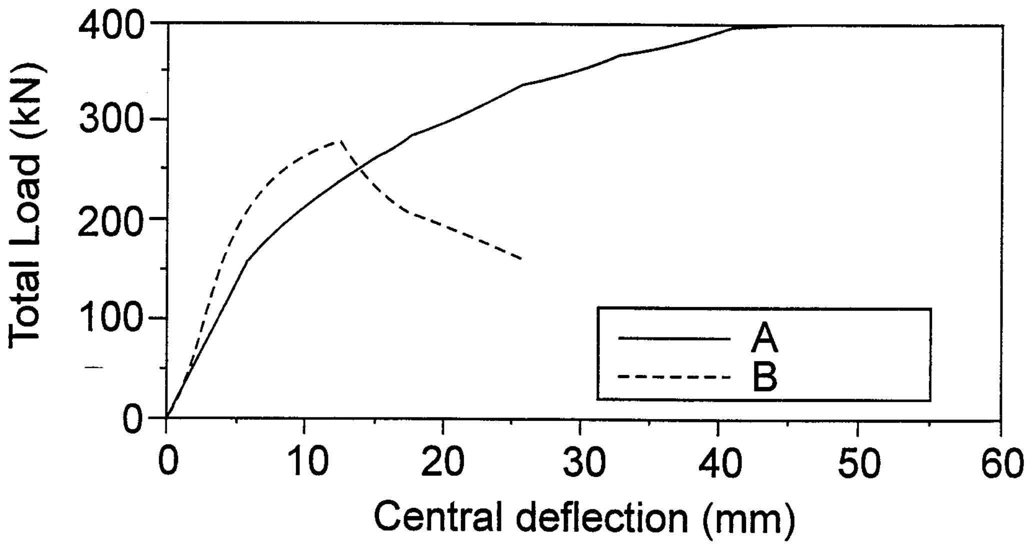

Fig. 7

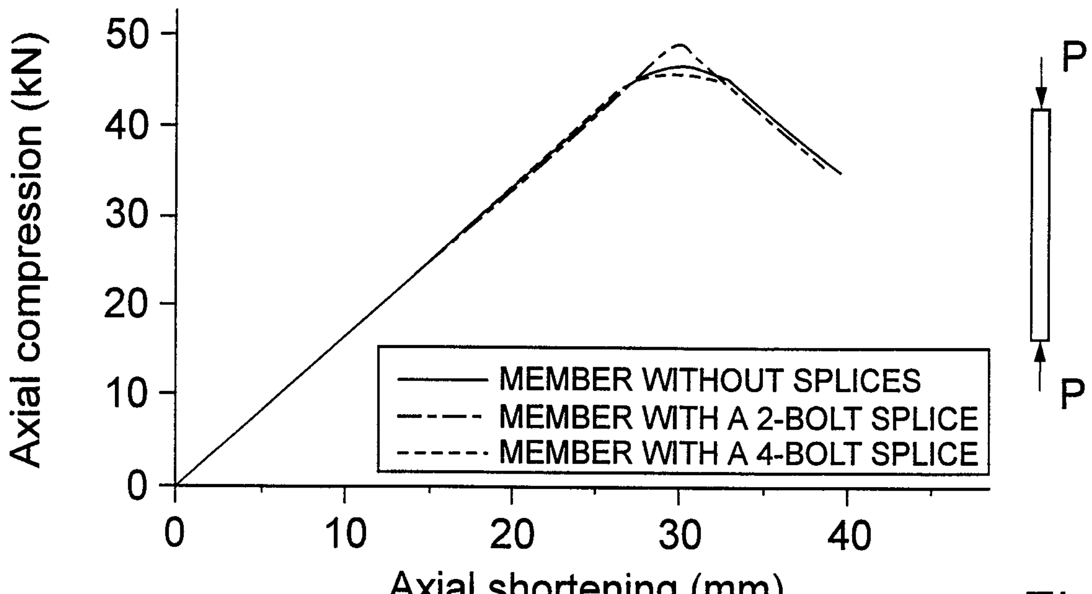

Fig. 11

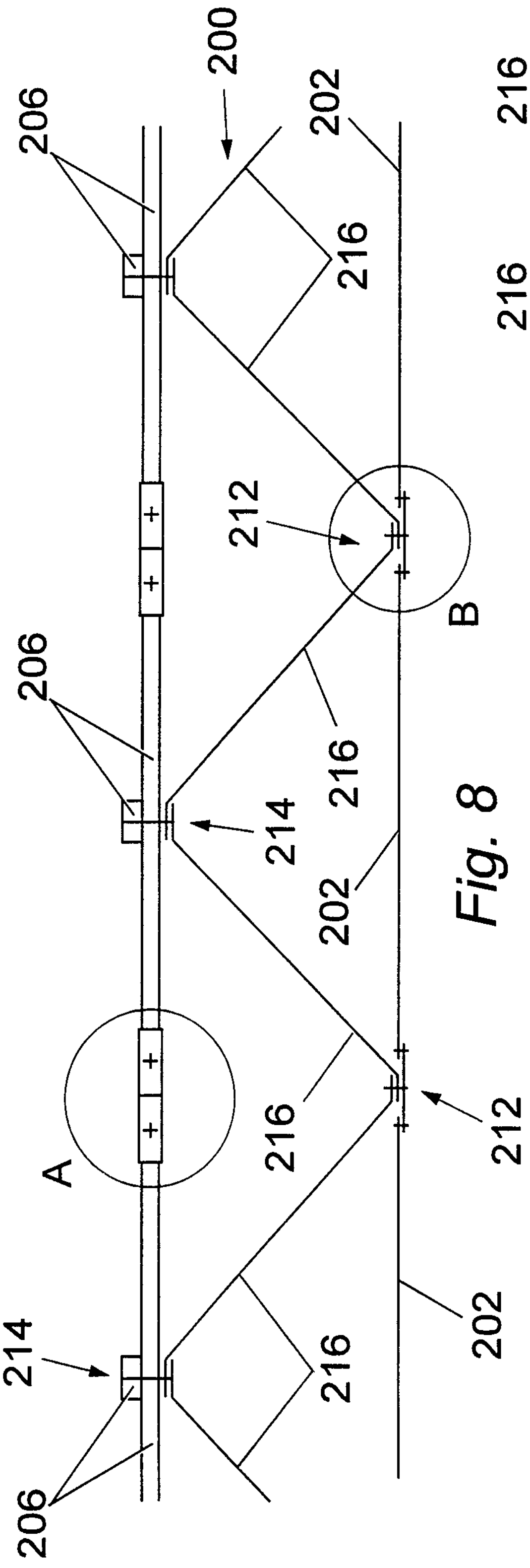

Fig. 8

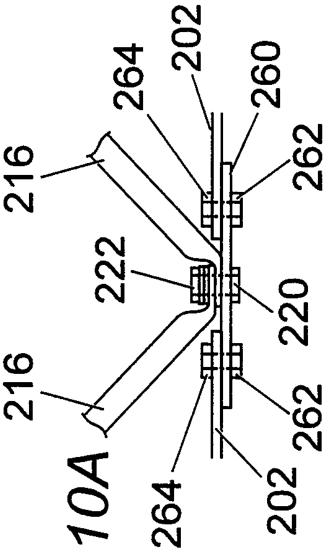

Fig. 10A

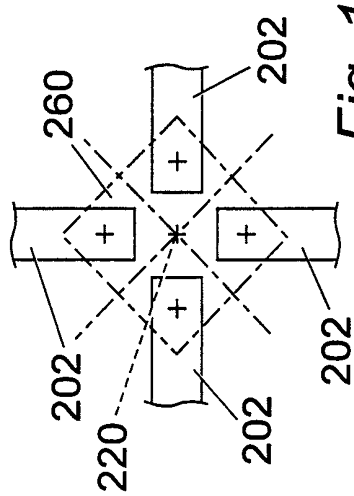

Fig. 10B

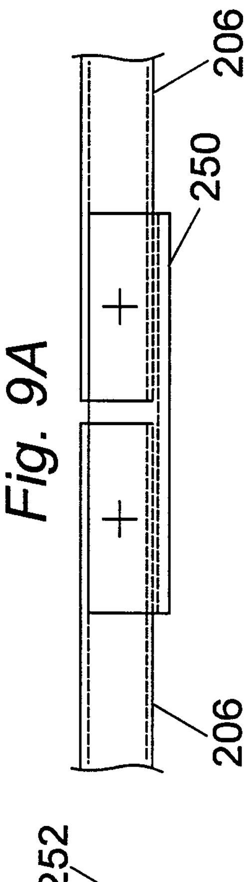

Fig. 9A

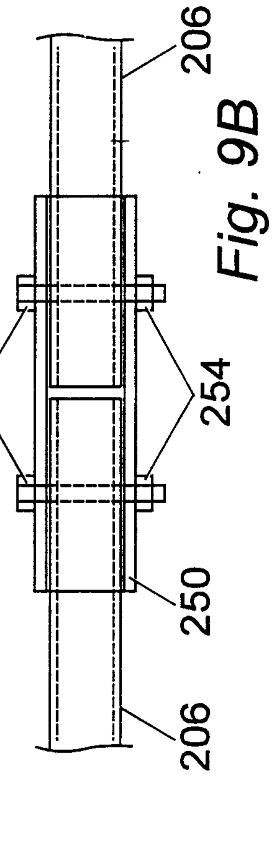

Fig. 9B

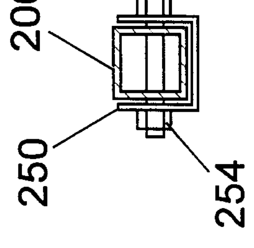

Fig. 9C

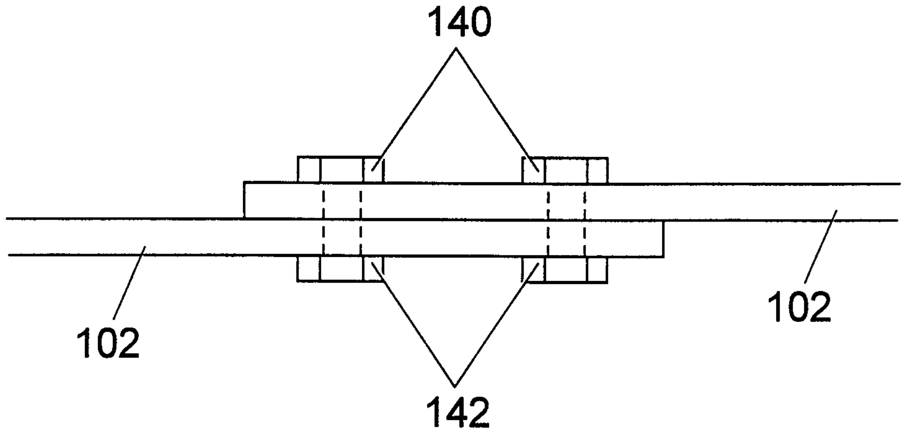

Fig. 12

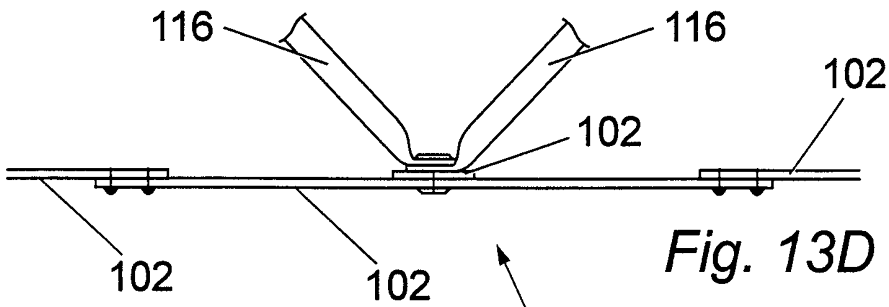

Fig. 13D

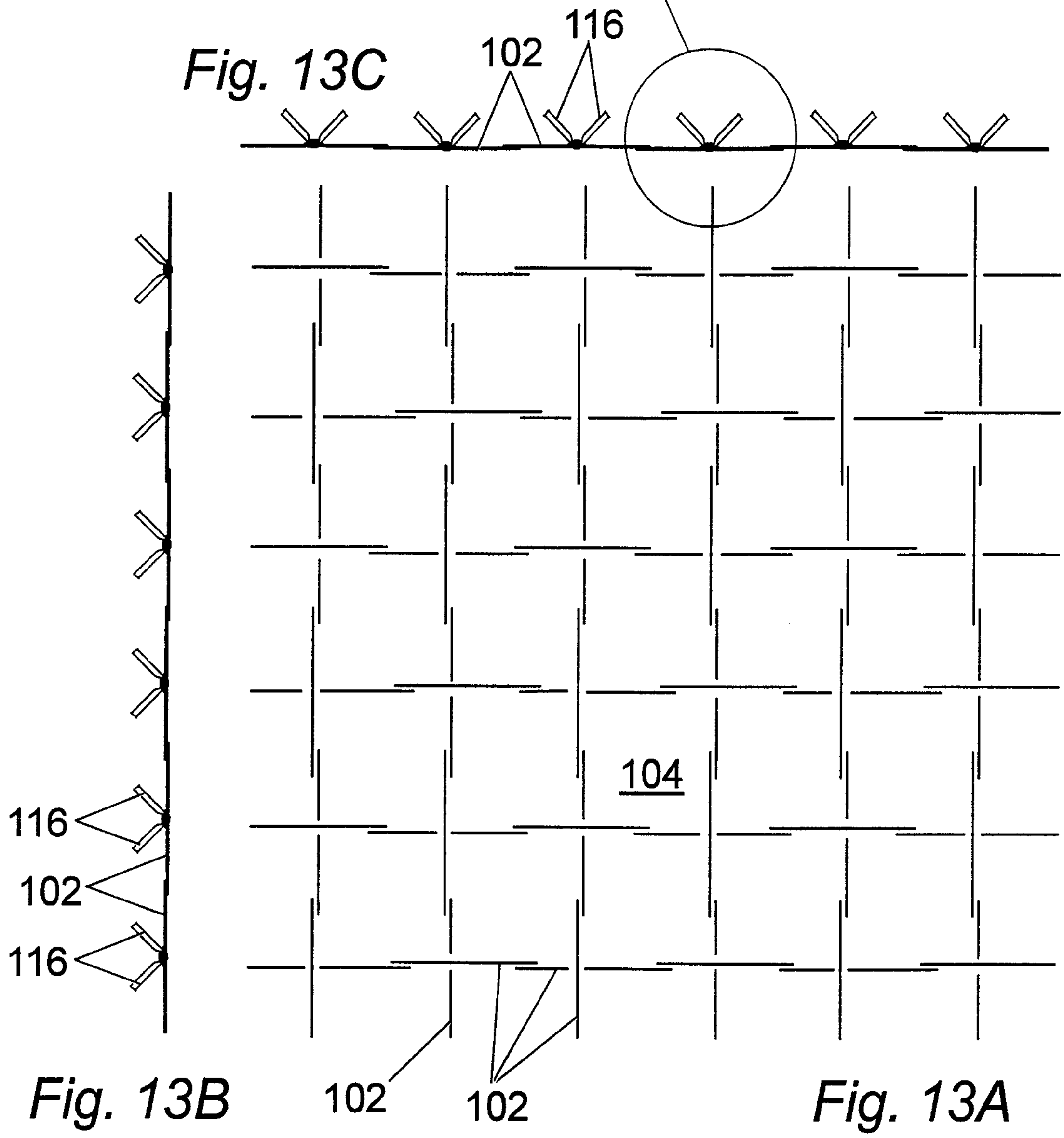

Fig. 13C

Fig. 13B

Fig. 13A

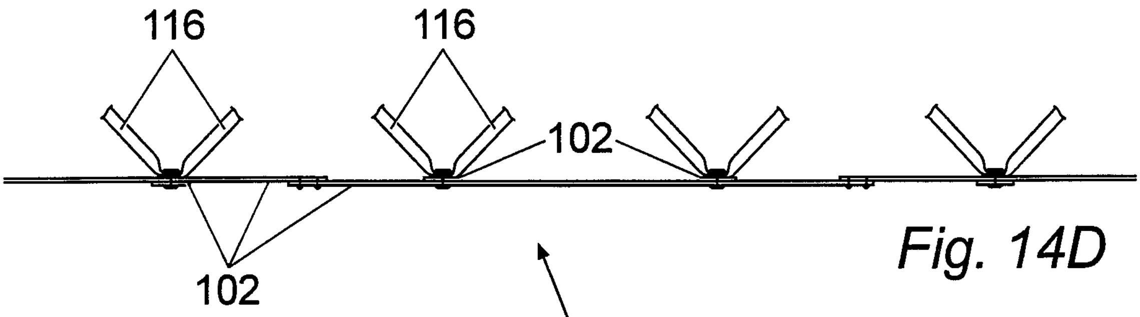

Fig. 14D

Fig. 14C

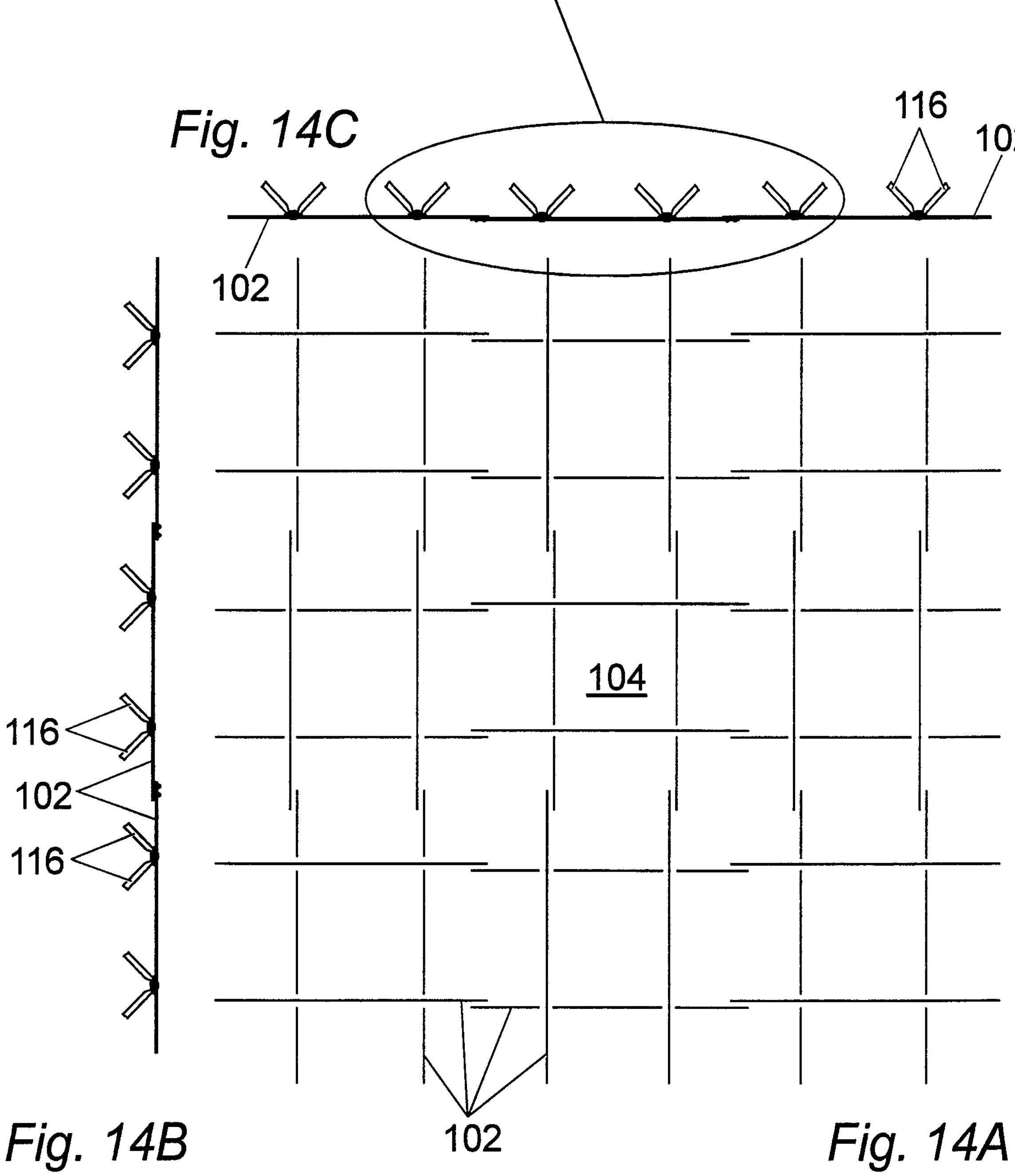

Fig. 14B

Fig. 14A

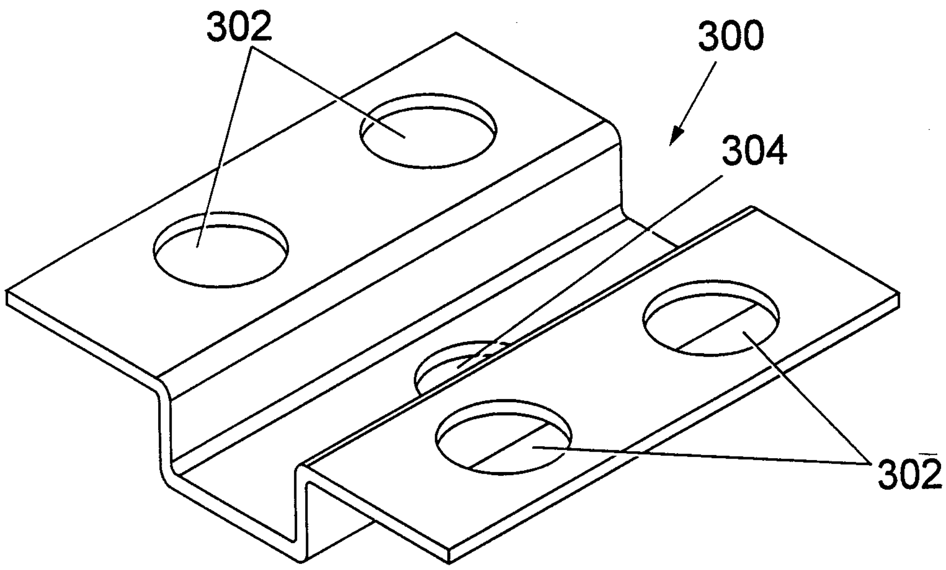

Fig. 15

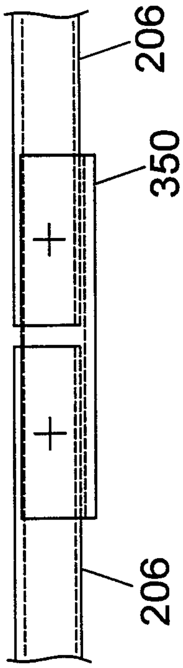

Fig. 17A

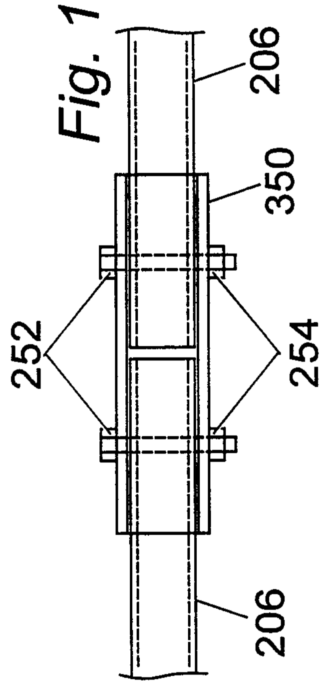

Fig. 17B

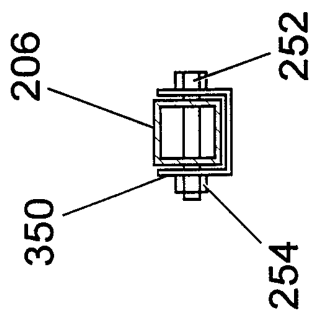

Fig. 17C

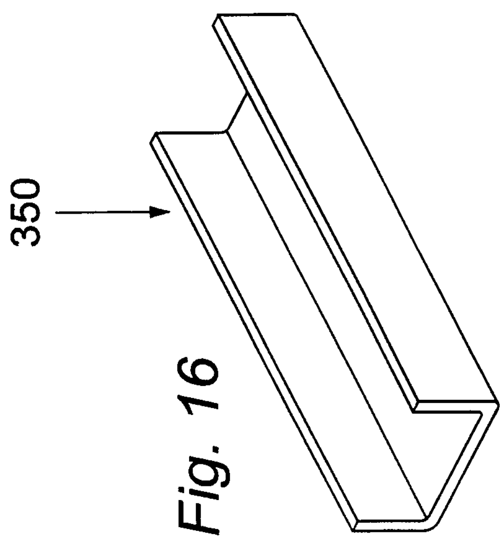

Fig. 16

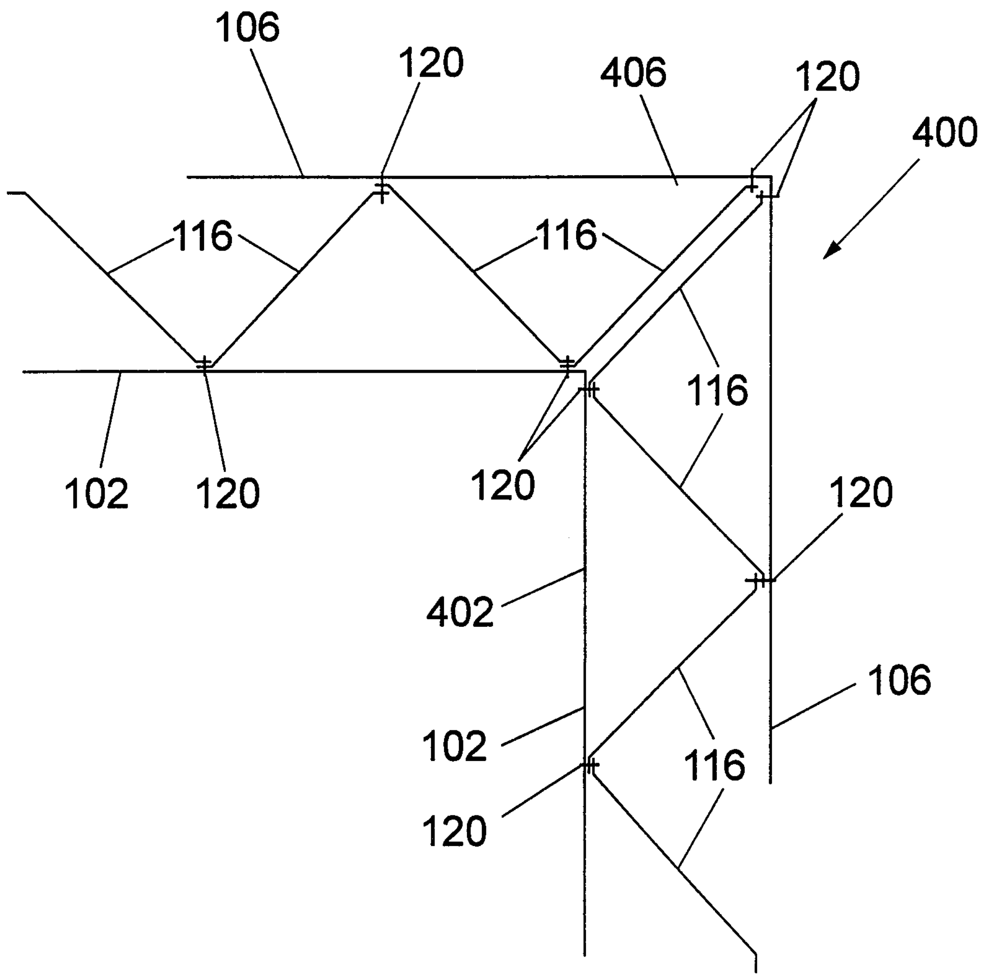
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Fig. 18

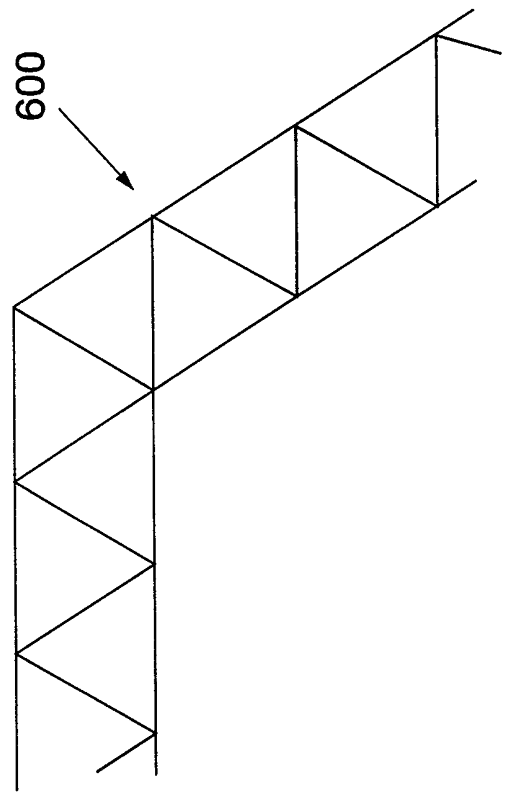

Fig. 20

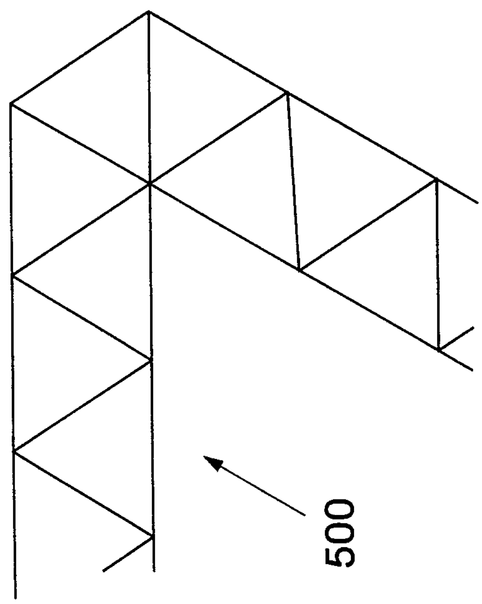

Fig. 19

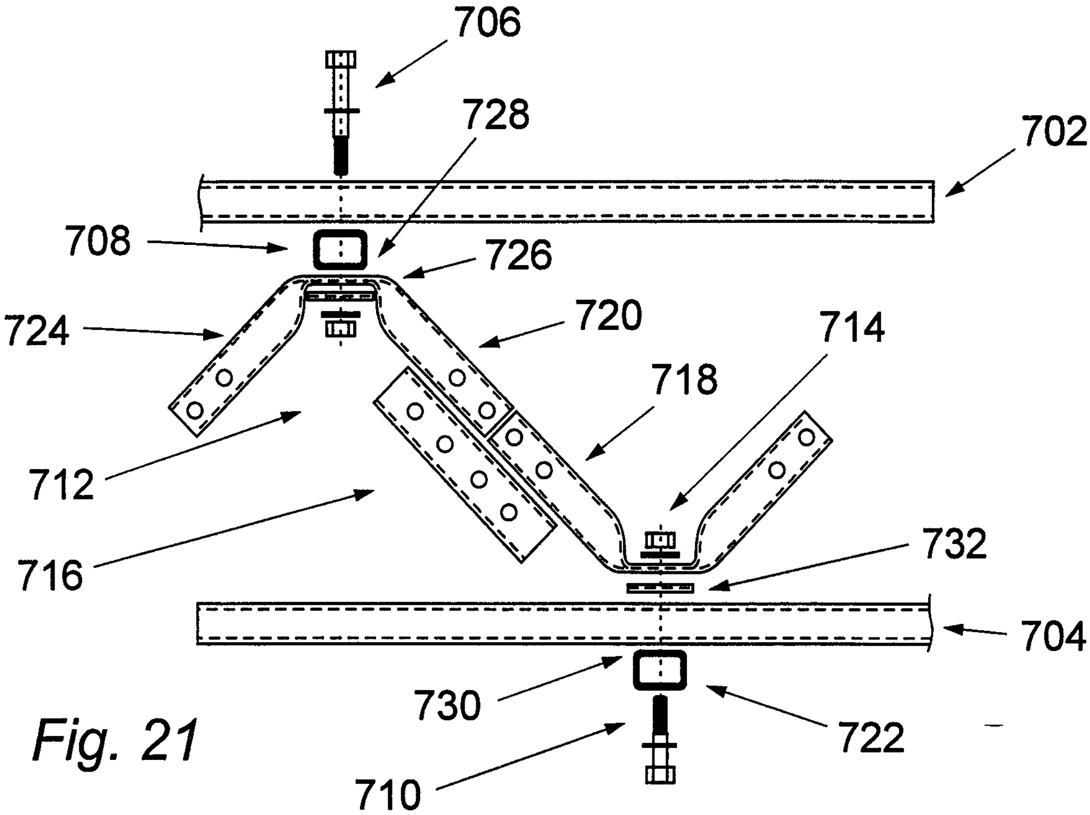
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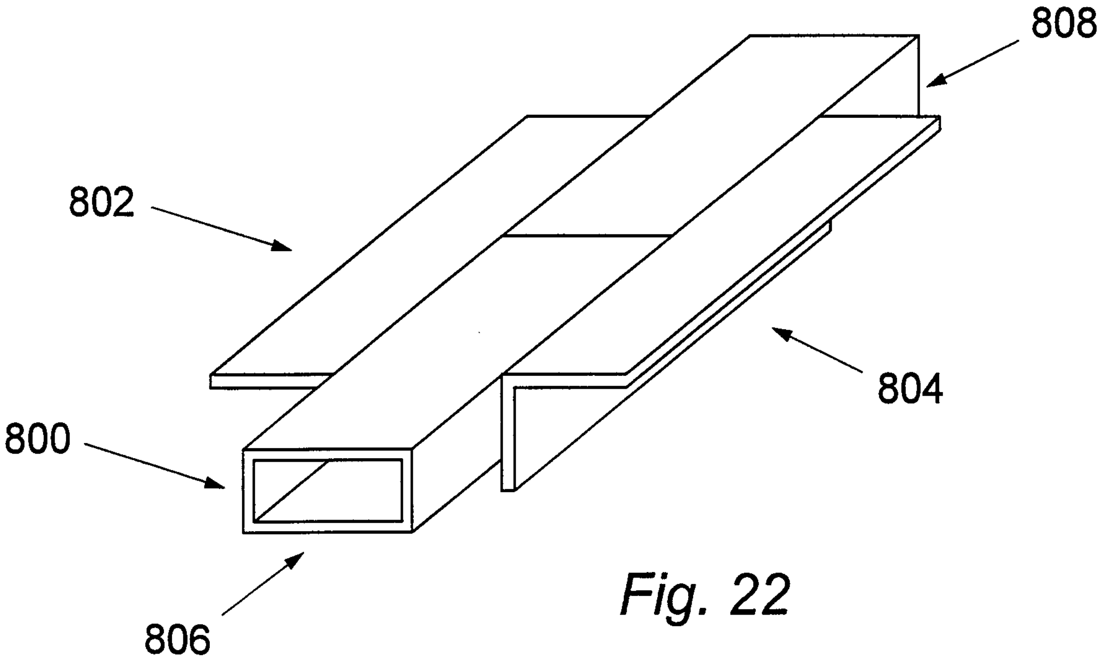
Fig. 21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806

Fig. 22

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 99/00437

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E04B1/19

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 E04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 88 08 039 U (MYLAEUS) 19 January 1989 see page 4, line 19 - page 5, line 24 see page 7, line 5 - page 11, line 23; figures 1-4 ---	1,2, 8-13,15, 16,18-21
X	DE 39 02 342 A (STEINER JUERG) 26 July 1990 see the whole document ---	1,2, 8-10,12, 13,16, 20,21

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 April 1999	17/05/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Porwoll, H

1

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	DE 27 05 480 A (KOENNYUEIPARI SZERELOE ES EPIT) 23 March 1978	1,2, 8-10,12, 15,16, 18,19
A	see page 10, line 15 - page 12, line 24 see page 14, line 11 - page 15, line 8; figures	13,17,21
X	FR 1 417 350 A (VALLOUREC SA) 4 February 1966	1,8-12, 15
Y	see the whole document	3,4,6
A		13,20
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