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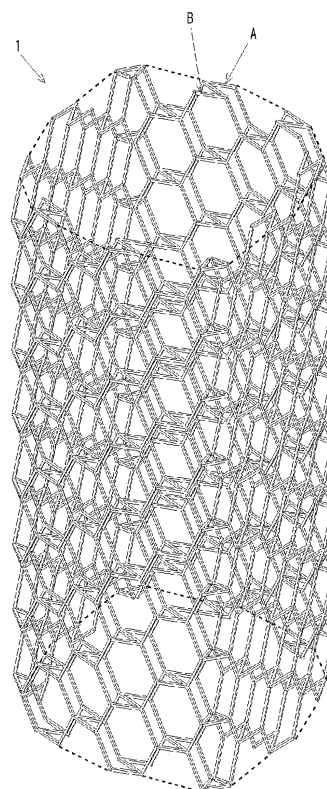
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(54) **THREE-DIMENSIONAL TUBE BUILDING STRUCTURE**

(57) The present invention ensures high structural stability and high earthquake resistance and, at the same time, achieve a high degree of freedom in design than is available with the architectural structure based on the tubular frame of the prior art.

Disclosed is a three-dimensional tubular architectural structure constituted by forming a three-dimensional tubular frame from a main frame by erecting a plurality of single-layer structural modules having honeycomb structure of first rigid joint in multiple layer configuration, disposing two sides each on the left- and right-hand sides of the hexagonal structural unit with an angle from the plane which includes the top and bottom sides, disposing adjacent two layers of the hexagonal structural unit to oppose each other and connecting the hexagonal structural units by means of inter-layer tie beams, forming a second hexagonal structural unit from beams corresponding to the top and bottom sides of one of two layers of adjacent single-layer structural modules, the inclined columns disposed on the left and right sides and the inter-layer tie beam, and forming a honeycomb structure of second rigid joint from the second hexagonal structural units.

[Fig.1]



## Description

### BACKGROUND OF THE INVENTION

#### Field of the Invention

**[0001]** The present invention relates to an architectural structure, and particularly to a three-dimensional tubular architectural structure comprising a tubular frame having 3-dimensional structure.

#### Description of the Related Art

**[0002]** In the prior art it has been common to design a high-rise or super high-rise architectural structure based on pure rigid frame consisting of columns and beams combined in a 3-dimensional grid, which has such a drawback that the existence of a beam in every span poses restrictions on the design of the internal space. In contrast, a tubular frame formed from columns disposed in succession along the perimeter of the building and beams which connect the columns enables it to secure an interior space free of columns and beams and therefore provides an advantage of high degree of freedom in design. An additional advantage is pointed out in that the entire building undergoes tube-like deformation which results in improved resistance against seismic vibration and wind force.

**[0003]** Japanese Unexamined Patent Publication (Kokai) No. 2002-317565 discloses a so-called double-tube structure, which includes a common use zone formed at the center and a residential zone formed along the periphery, the double-tube structure comprising an outer tubular frame having ordinary rigid frame structure of rectangular grid formed from outer circumferential columns and intervening outer circumferential beams disposed along the perimeter of the residential zone, and an inner tubular frame having ordinary rigid frame structure formed from inner circumferential columns and intervening inner circumferential beams disposed along the perimeter of the common use zone.

**[0004]** Japanese Unexamined Patent Publication (Kokai) No. 2004-251056 also discloses a double-tube structure comprising an outer frame and inner frame of ordinary rigid frame structure.

**[0005]** Japanese Unexamined Patent Publication (Kokai) No. 7-197535 discloses a structure having an outer tubular frame having crossing braces disposed in a grid of ordinary rigid frame structure formed from vertical columns and horizontal beams, wherein the outer tubular frame has a slab-like diaphragm disposed inside thereof, to ensure strength and rigidity comparable to those of the conventional pure rigid frame structure.

**[0006]** Meanwhile a honeycomb structure constituted by connecting hexagonal cells has been known as a rugged structure, and has been used in various sections of architectural structures and as building members (Japa-

nese Unexamined Patent Publication (Kokai) No. 9-4130 and Japanese Unexamined Patent Publication (Kokai) No. 10-18431). As an application of the honeycomb structure to tubular frame, such a structure is known as hexagonal cells are connected in a horizontal plane to form a honeycomb structure and a plurality of the honeycomb structures are combined via straight vertical columns to form a multi-story structure, as disclosed in Japanese Unexamined Patent Publication (Kokai) No. 9-60301.

**[0007]** "Resurrection from Ground Zero: New York WTC Competition" Susanne Stephens, translated by Yuko Shimoyama shows a structure constituted from curved external surface layer consisting of honeycomb members made of steel, supported by columns disposed inside. The steel honeycomb members constituting the external surface layer, however, are not formed by connecting hexagonal cells of the same shape in a uniform configuration, and the line segments that constitute the cell are not ordinary linear members (column, beam, etc.).

**[0008]** Japanese Unexamined Patent Publication (Kokai) No. 7-3890 describes a single-layer dome frame formed by connecting units of plane of structure having hexagonal shape in beehive-like configuration. The hexagonal cell is provided with a clustered column disposed vertically at the center thereof, with the top and bottom ends of the clustered column being tied to the vertices of the cell by means of tensioner members, so that the tension can be controlled by adjusting the length of the tensioner member.

**[0009]** Basic structure of the conventional tubular frame is an ordinary rigid frame structure formed by connecting rectangular cells constituted from vertical columns and horizontal beams. An outer tube frame alone is often insufficient for ensuring structural stability and earthquake resistance, especially in a high-rise or super high-rise building. Thus in most cases it has been inevitable to provide structural constraint such as increasing the number of columns disposed per unit distance of the outer tube frame and/or the inner tube frame, providing the inner tube frame, connecting the outer tube frame and the inner tube frame with flat slabs or specific beams, adding a sub-frame within the outer tube frame, connecting a plurality of outer tube frames. For example, the technologies disclosed in Japanese Unexamined Patent Publication (Kokai) No. 2002-317565 and Japanese Unexamined Patent Publication (Kokai) No. 2004-251056 make it inevitable to employ at least a double-tube frame structure. The technology disclosed in Japanese Unexamined Patent Publication (Kokai) No. 7-197535 makes it inevitable to provide horizontal slab-like diaphragms disposed inside.

**[0010]** However, even when a tubular frame is formed in a double- or multiple-frame structure, axial directions of columns and beams are limited to specific directions as long the basic structure remains the ordinary rigid frame structure constituted from vertical columns and horizontal beams. As a result, the structural members

may be subjected to bending stress of significant intensity depending on the direction in which external load is applied. Accordingly, the higher the building becomes, the larger the cross section of the columns and/or beams must be in order to maintain sufficient strength of the structure, which poses a restriction on the design.

**[0011]** In most of the applications of honeycomb structure to tubular frame, slabs of honeycomb structure disposed horizontally are placed one over another via vertical columns as shown in Japanese Unexamined Patent Publication (Kokai) No. 9-60301, and at least the vertical load is borne by the vertical columns similarly to the case of the ordinary rigid frame structure. The beehive-like structure described in Japanese Unexamined Patent Publication (Kokai) No. 9-60301 is aimed at forming a single-layer dome frame, and is not intended to form a tubular frame applicable to high-rise or super high-rise architectural structure.

**[0012]** The structure described in "Resurrection from Ground Zero: New York WTC Competition" Susanne Stephens, translated by Yuko Shimoyama, published on December 1, 2004 by Exknowledge Co., Ltd; p137 has steel members of honeycomb structure provided in the external surface layer, but the external surface layer does not bear the entire load and requires a load-bearing column disposed inside.

#### SUMMARY OF THE INVENTION

**[0013]** In view of the problems described above, an object of the present invention is to provide an architectural structure based on a tubular frame having a novel basic structure entirely different from that of the conventional tubular frame. The present invention aims at ensuring higher structural stability and higher earthquake resistance with the tubular frame only, than are available with the prior art technologies, especially in high-rise and super high-rise buildings, and achieving a higher degree of freedom in the design of architectural structures than possible with the conventional tubular frame.

**[0014]** The present invention which achieves the above-mentioned object has the following constitutions:

(1) A three-dimensional tubular architectural structure according to claim 1 is an architectural structure formed from a three-dimensional tubular frame based on a main frame constituted by erecting a plurality of single-layer structural modules with a spacing from each other, the single-layer structural module being formed by rigidly connecting hexagonal structural units with each side thereof being shared by adjacent hexagonal structural units into honeycomb configuration, wherein structural members corresponding to the sides of the hexagonal structural unit comprise two inclined columns disposed on the left and two inclined columns disposed on the right of the hexagon which are inclined from the vertical direction in op-

posite directions from each other and are connected with each other, and beams corresponding to the top and bottom sides disposed in the horizontal direction, the two sides on the left and the two sides on the right are disposed with an angle from the plane defined by the top and bottom sides,

adjacent two layers of the single-layer structural module of the main frame are connected together by a plurality of inter-layer tie beams, while each of the hexagonal structural units in one of the single-layer structural modules and corresponding one of the hexagonal structural units in the other single-layer structural module are disposed so as to oppose each other, and

in plan view of the main frame, a second hexagonal structural unit is formed from beams corresponding to the top side or the bottom side of two adjacent single-layer structural modules, the two inclined columns disposed on the left and the two inclined columns disposed on the right and the inter-layer tie beams connecting the two layers, and the second hexagonal structural unit is rigidly connected to the adjacent second hexagonal structural units;

(2) A three-dimensional tubular architectural structure according to claim 1 is characterized in that, in plan view of the main frame, the inter-layer tie beams are located on the diagonal of a rectangle which comprises top sides of the two hexagonal structural units that oppose each other as opposing sides of the rectangle, and on the diagonal of a rectangle which comprises the bottom sides as opposing sides of the rectangle;

(3) A three-dimensional tubular architectural structure according to claim 3 is the three-dimensional tubular architectural structure of claim 1 or 2 wherein the plurality of single-layer structural modules are two single-layer structural modules;

(4) A three-dimensional tubular architectural structure according to claim 4 is the three-dimensional tubular architectural structure of any one of claims 1 to 3 wherein, in case a slab is provided inside of the single-layer structural module disposed at the innermost position among the plurality of single-layer structural modules, edges of the slab are used as structural members instead of the top or bottom beam of the hexagonal structural units of the single-layer structural module disposed at the innermost position.

(5) A three-dimensional tubular architectural structure according to claim 5 is the three-dimensional tubular architectural structure of any one of claims 1 to 4 wherein, at corners of the three-dimensional tubular architectural structure which has substantially rectangular shape in plan view, at least the single-layer structural module disposed at the outermost position among the plurality of single-layer structural modules and the single-layer structural module located inside of and adjacent to the former are con-

nected by inter-layer tie beams which form the equal sides of an isosceles triangle in plan view;

(6) A three-dimensional tubular architectural structure according to claim 6 is the three-dimensional tubular architectural structure of any one of claims 1 to 5 wherein the main frame includes sections which have different numbers of the single-layer structural modules;

(7) A three-dimensional tubular architectural structure according to claim 7 is the three-dimensional tubular architectural structure of any one of claims 1 to 6 wherein the three-dimensional tubular architectural structure partially includes a section formed from one layer of the single-layer structural module;

(8) A three-dimensional tubular architectural structure according to claim 8 is the three-dimensional tubular architectural structure of one of claims 1 to 7 wherein a plurality of slabs are provided, as the main frame, at the same intervals as the height of the hexagonal structural unit; and

(9) A three-dimensional tubular architectural structure according to claim 9 is the three-dimensional tubular architectural structure of any one of claims 1 to 7 wherein a plurality of slabs are provided, as the main frame, at intervals one half as large as the height of the hexagonal structural unit.

(A) The three-dimensional tubular architectural structure of the present invention is constituted from a main frame formed by erecting a plurality of single-layer structural modules with a predetermined spacing from each other, the single-layer structural module being formed by rigidly connecting hexagonal structural units with each other in honeycomb configuration, the main frame being used to a tubular frame. Although the tubular frame of the present invention having such a constitution is thick and three dimensional, the plurality of single-layer structural modules as a whole should be regarded as a shell of tube. With this regard, it is essentially different from the conventional double-tube frame, for example the one disclosed in Japanese Unexamined Patent Publication (Kokai) No. 2004-251056, wherein a space for residential zone or the like is secured between the external frame and the internal frame. The present invention is also different, in that the circumference of the tubular frame is formed in honeycomb structure, from the hexagonal structural units constituted from honeycomb structures, each disposed within the horizontal plane, are placed one over another via vertical columns, as described in Japanese Unexamined Patent Publication (Kokai) No. 9-60301.

The constitution of the present invention described above makes it possible to build a very strong tubular frame, since the single-layer

structural module being formed by rigidly connecting hexagonal structural units with each other in honeycomb configuration is a strong structure itself, and the single-layer structural modules disposed in multi-layer configuration are connected with each other by the inter-layer tie beams. The effects of the present invention will now be described in detail.

The tubular frame of the present invention, constituted from the single-layer structural modules each being formed by rigidly connecting hexagonal structural units with each other in honeycomb configuration, has a constitution entirely different from that of the tubular frame having ordinary rigid frame structure of the prior art, in that the beams and the inter-layer tie beams do not continue straight within the horizontal plane, and that the columns are constituted from the inclined columns which are connected in zigzag configuration.

The present invention is further characterized in that the two inclined columns disposed on the left and the two inclined columns disposed on the right of the hexagonal structural unit of the single-layer structural module are disposed with an angle from the plane defined by the top and bottom sides, and adjacent two layers of the single-layer structural module of the main frame are connected together by a plurality of inter-layer tie beams. In this constitution, in plan view of the main frame, a second hexagonal structural unit is formed from a beam corresponding to the top side or the bottom side of one of two adjacent hexagonal structural units, either the two inclined columns disposed on the left or the two inclined columns disposed on the right and the inter-layer tie beams connecting the two layers. Moreover, the second hexagonal structural unit is rigidly connected with the adjacent hexagonal structural unit so as to form honeycomb structure in plan view. The second honeycomb structure formed from the second hexagonal structural units in this manner is a three-dimensional structure having ups and downs in the vertical direction due to the inclined columns which can be recognized as hexagonal in plan view, unlike the honeycomb structure which extends in the horizontal plane as that described in Japanese Unexamined Patent Publication (Kokai) No. 9-60301.

In the three-dimensional tubular architectural structure of the present invention, in addition to the honeycomb structure which is formed by first rigid joints and extends along the circumference of the tube in each of the single-layer structural modules, the three-dimensional second honeycomb structure is formed by the second rigid joints extending in substantially horizontal direc-

tion via the inter-layer tie beams which connect the adjacent single-layer structural modules. Furthermore, the first honeycomb structures are disposed in multiple layers in the radial direction of the tube, as the plurality of single-layer structural modules are disposed. On the other hand, the second honeycomb structures are disposed in multiple layers in the direction of height of the tube. As a result, the three-dimensional honeycomb structure disposed in three-dimensional configuration throughout the tubular frame of the three-dimensional tubular architectural structure is realized.

The three-dimensional honeycomb structure resembles the crystal structure of diamond. Diamond is the hardest among natural minerals, stable and hard to break, despite a low packing index of the crystal structure. This is because diamond has a three-dimensional structure constituted from hexagonal cells as the unit. The three-dimensional tubular architectural structure of tubular frame of the present invention is likened to the crystal structure of diamond of which interatomic bonds are replaced with columns and beams, and is therefore considered to have high intrinsic strength.

As described above, the three-dimensional tubular architectural structure of the present invention forms the tubular frame of which entire configuration has the three-dimensional honeycomb structure, and therefore achieves high bearing capacity for external loads applied in any direction.

Since the honeycomb structure is supported in the vertical direction solely by inclined columns which are connected in zigzag configuration, the structure not only bears the sustained loads applied in the vertical direction but also effectively bears temporary loads applied in horizontal and other directions. The inclined columns of the present invention play the roles of columns and braces at the same time. Moreover, stress generated by an external load in the joint of a column and a beam becomes less than that generated in tubular frame having the ordinary rigid frame structure. This is because a part of bending stress is converted into axial load of the structural members (inclined columns and beams) and is transferred through the structure. Ordinary reinforced concrete members have high bearing capacity against compressive force, and therefore advantageous in bearing axial force.

The tubular frame having the three-dimensional honeycomb structure has such a geometrical configuration as the stress generated by an external load applied in any given direction can be readily converted into axial forces of the inclined

column and the beam. Moreover, since the tubular frame having the three-dimensional honeycomb structure has such a geometrical configuration as the external load can be readily transmitted continuously throughout the frame, the stress is converted into axial force in the course so that the load can be distributed in a dissipative manner. As a result, stress generated by bending moment can be mitigated. This is because the three-dimensional honeycomb structure constituted from a plurality of the single-layer structural modules disposed in multiple layer configuration of the present invention has a larger number of inclined columns and beams disposed in more diversified axial directions and in well-balanced distribution, than in the case of the two-dimensional honeycomb structure consisting of only one layer of single-layer structural module.

As described above, the tubular frame in the three-dimensional tubular architectural structure of the present invention has higher structural stability and higher earthquake resistance than the tubular frame having the ordinary rigid frame structure and a tubular frame constituted from only one layer of single-layer structural module, and therefore enables it to use members smaller in cross section than those of such conventional tubular frames and allows higher degree of freedom of planning. As a result, a horizontal load which causes the same magnitude of deformation can be borne by using columns and beams of smaller cross sections than in the case of the tubular frame having the ordinary rigid frame structure and a tubular frame constituted from only one layer of single-layer structural module.

Also, the tubular frame in the three-dimensional tubular architectural structure of the present invention is constituted by erecting the single-layer structural modules in multiple layer configuration connected with each other, and therefore has higher standalone capability than in the case of erecting only a single layer of single-layer structural module. As a result, the degree of freedom in the design of the shape and arrangement of slabs increases due to lower dependency on the strength of the slabs.

The three-dimensional tubular architectural structure of the present invention, as the main frame of high-rise and super high-rise buildings, ensures structural stability, earthquake resistance and wind resistance of the entire building solely by means of the tubular frame.

Since the single-layer structural module is basically constituted from a larger number of hexagonal structural units of the same configuration at least within each module, all columns and

beams can be reduced to one or few varieties of size and shape, and therefore the construction work can be made easier, construction period can be made shorter and the cost can be reduced.

The hexagonal structural unit can be made in pre-stressed concrete unit, which again makes it possible to make the construction work easier, reduce the construction period and reduce the cost.

Use of the honeycomb structure constituted from the hexagonal structural units contributes also to aesthetic quality of the building exterior. (B) In one preferred embodiment of the three-dimensional tubular architectural structure of the present invention, in plan view of the main frame, the inter-layer tie beams are located on the diagonal of a rectangle which comprises top sides of the two hexagonal structural units which oppose each other as opposing sides of the rectangle, and on the diagonal of a rectangle which comprises the bottom sides of the two hexagonal structural units as opposing sides of the rectangle. This constitution achieves a strong structure since the beams are rigidly connected with each other in the horizontal plane. Also, because the inter-layer tie beam is disposed to be inclined from the plane of the two opposing hexagonal structural units, the inter-layer tie beam is disposed at an angle which is advantageous to serve as one side constituting the second honeycomb structure in plan view.

(C) In one preferred embodiment of the three-dimensional tubular architectural structure of the present invention, the simplest form capable of achieving the above-mentioned effects can be realized by making the multiple layers of single-layer structural module in two layers. This enables it to decrease the total weight of the structure and the construction cost.

(D) In one preferred embodiment of the three-dimensional tubular architectural structure of the present invention, in case a slab is provided as main frame inside of the single-layer structural module disposed at the innermost position among the plurality of single-layer structural modules disposed in multiple layer configuration, edges of the slab can be used as structural members instead of the beam used in the top or bottom side of the hexagonal structural unit constituting the single-layer structural module disposed at the innermost position. This enables it to decrease the number of beams.

(E) In a preferred embodiment of the three-dimensional tubular architectural structure of the present invention, at corners of the tubular architectural structure which has substantially rectangular shape in plan view, at least the single-

layer structural module disposed at the outermost position among the plurality of single-layer structural modules and the single-layer structural module located inside of and adjacent to the former are connected by the inter-layer tie beams which form the equal sides of an isosceles triangle in plan view. With this constitution, since the inter-layer tie beams are arranged more densely in the corners and are disposed in triangular arrangement wherein the external load can be easily converted to axial force, strength can be increased in the corners of the structure where the stress tends to be concentrated.

(F) In a preferred embodiment of the three-dimensional tubular architectural structure of the present invention, the main frame includes sections which include different numbers of single-layer structural modules. With this constitution, as the number of single-layer structural modules can be decreased in a section subject to less stress concentration so as to make the main frame thinner, and the number of single-layer structural module is increased in a section where significant stress concentration is expected (for example, in the vicinity of a corner) so as to make the main frame thicker in the section, optimum design of the three-dimensional tubular architectural structure is made possible. Also, the number of single-layer structural modules can be decreased to the minimum necessary, so that the total quantity of structural members and the construction cost can be reduced.

(G) In a preferred embodiment of the three-dimensional tubular architectural structure of the present invention, there is a section formed from one layer of single-layer structural module. This constitution enables optimum design of the three-dimensional tubular architectural structure as a whole, by forming a section subject to less stress concentration from one layer of single-layer structural module to make it thinner, and forming a section subject to significant stress concentration (for example, in the vicinity of a corner) from a number of single-layer structural module in multiple layer configuration. Total quantity of structural members and the construction cost can also be reduced by providing only one single-layer structural module.

(H) In one preferred embodiment of the three-dimensional tubular architectural structure of the present invention, a plurality of slabs are provided as the main frame at intervals equal to the height of the hexagonal structural unit. In another preferred embodiment, a plurality of slabs are provided as the main frame at intervals one half as large as the height of the hexagonal structural unit. With these constitutions, strength of the en-

tire three-dimensional tubular architectural structure can be increased by providing the slabs as the main frame. As a result, load on the tubular frame can be reduced so that the columns and beams of the tubular frame can be made thinner. In this way, when the tubular frame is accompanied by additional main frame element, their proportions of bearing the load can be controlled by the design, and the size of the members can be selected accordingly.

## BRIEF DESCRIPTION OF THE DRAWINGS

### [0015]

Fig. 1 is a perspective view of an example of the tubular frame in the three-dimensional tubular architectural structure of the present invention showing the exterior thereof.

Fig. 2A is a partially enlarged view of the tubular frame 1 of Fig. 1, Fig. 1(a) showing a portion around the lower end of the tubular frame, and Fig. 1(b) showing a pair of opposing hexagonal structural units among the hexagonal structural units which constitute the single-layer structural modules A, B. Fig. 2B shows the constitution of the single-layer structural module A disposed as the outermost layer of the tubular frame shown in Fig. 1, where Fig. 2B (a) is a partially enlarged front view of the single-layer structural module A, and Fig. 2B(b) is a plan view of the single-layer structural module A corresponding to the portion shown in (a).

Fig. 2C(a) is a partially enlarged plan view of the tubular frame shown in Fig. 1, Fig. 2C(b) schematically shows only a part of the second hexagonal structural unit shown in Fig. 2C(a) and Fig. 2C(c) shows a portion constituted from beams and inter-layer tie beam, extracted from the drawing of Fig. 2C (b).

Fig. 2D is a plan view of the entire tubular frame shown in Fig. 1, the tubular frame 1 having substantially rectangular cross section.

Fig. 3A(a) shows a part of an example of the single-layer structural module A, and Fig. 3A(b) shows a part of main frame formed by providing the single-layer structural module A shown in Fig. 3A(a) and the single-layer structural modules B having the same constitution in multiple-layer configuration.

Fig. 3B(a) shows a part of an example of the single-layer structural module A, and Fig. 3B(b) shows a part of main frame formed by providing the single-layer structural module A shown in Fig. 3B(a) and the single-layer structural modules B having the same constitution in multiple-layer configuration.

Fig. 3C(a) shows a part of an example of the single-layer structural module A, and Fig. 3C(b) shows a part of main frame formed by providing the single-layer structural module A shown in Fig. 3C(a) and

the single-layer structural modules B having the same constitution in multiple-layer configuration.

Fig. 3D is a plan view of an example of tubular frame having substantially circular cross section.

Fig. 4 is a perspective view of an example of the three-dimensional tubular architectural structure of the present invention showing the exterior thereof.

Fig. 5 is a perspective view of another example of the three-dimensional tubular architectural structure of the present invention showing the exterior thereof. Fig. 6(a) is a partial perspective view showing the structure of corner X of the tubular frame 1 having substantially rectangular cross section shown in the plan view of Fig. 2D, and Fig. 6(b) is a partial plan view thereof.

Fig. 7(a) is a partial perspective view showing the structure of the number of layers transition section between a section of layer S and section two layers, and Fig. 7(b) is a partial perspective view showing the structure of the number of layers transition section between the section of layer S and the section of three layers.

## DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention will now be described with reference to the accompanying drawings.

**[0016]** Fig. 1 and Fig. 2A to Fig. 2D show the basic forms of tubular frame in the three-dimensional tubular architectural structure of the present invention.

**[0017]** The tubular frame in the three-dimensional tubular architectural structure of the present invention has such a basic constitution that a plurality of single-layer structural modules having honeycomb structure are erected and connected with each other to form a main frame which is used to constitute the tubular frame structure. This constitution makes it possible to build a very strong tubular frame, since the single-layer structural module being formed by rigidly connecting the hexagonal structural units with each other in honeycomb configuration is a strong structure itself, and a plurality of the single-layer structural modules are connected with each other.

**[0018]** Fig. 1 is a perspective view of an example of the tubular frame in the three-dimensional tubular architectural structure of the present invention showing the exterior thereof. The tubular frame 1 shown in Fig. 1 is Example which has the main frame comprising two layers of single-layer structural module. Centerline of the tube extends in the vertical direction. While the tube of the Example shown in the drawing has a substantially rectangular cross section, the cross section may have a shape of other polygon, circle, oval, etc. The two layers of single-layer structural module are single-layer structural module A erected on the outside and single-layer structural module B erected inside with a predetermined space from the former. The main frame formed from these two layers constitutes the basis of the skeleton,

and provides the predominant source of structural resistance.

**[0019]** Fig. 2A is a partially enlarged view of the tubular frame 1 of Fig. 1. Fig. 2A(a) shows a portion in the vicinity of the lower end of the tubular frame 1, and Fig. 2A(b) shows a pair of opposing hexagonal structural units 10A, 10B among the hexagonal structural units which constitute the single-layer structural modules A, B.

**[0020]** As shown in Fig. 2A(a) and Fig. 2A(b), the single-layer structural module A is formed by rigidly connecting the hexagonal structural unit 10A and the adjacent hexagonal structural units with each side thereof shared by the adjacent hexagonal structural units so as to form the honeycomb structure. Similarly, the single-layer structural module B is formed by rigidly connecting the hexagonal structural unit 10B and the adjacent hexagonal structural units with each side thereof shared by the adjacent hexagonal structural units so as to form the honeycomb structure. The hexagonal structural unit 10A that constitutes the single-layer structural module A and the hexagonal structural unit 10B that constitutes the single-layer structural module B are disposed so as to oppose each other.

**[0021]** Structural members that constitute the six sides of the hexagonal structural unit 10A, one of those which form the single-layer structural module A, are beams disposed horizontally to form the bottom side 11A and the top side 12A, inclined columns disposed on the left to form the two sides 13A and 14A, and inclined columns disposed on the right to form the two sides 15A and 16A.

**[0022]** Similarly, structural members that constitute the six sides of the hexagonal structural unit 10B, one of those which form the single-layer structural module B, are beams disposed horizontally to form the bottom side 11B and the top side 12B, inclined columns disposed on the left to form the two sides 13B and 14B, and inclined columns disposed on the right to form the two sides 15B and 16B.

**[0023]** The single-layer structural module A and the single-layer structural module B are further connected with each other by a plurality of inter-layer tie beam L. The inter-layer tie beams L form rigid connection between the top sides 12A and 12B and between the bottom sides 11A and 11B of the hexagonal structural unit 10A and the hexagonal structural unit 10B which oppose each other. As shown in the drawing, the inter-layer tie beams extend obliquely, not perpendicular to the top sides and the bottom sides. That is, the inter-layer tie beam L connects the two parallel top sides 12A and 12B with joints located at ends on opposite sides thereof, and connects the two parallel bottom sides 11A and 11B with joints located at ends on opposite sides thereof.

**[0024]** The basic form of the tubular frame of the present invention may include such a constitution as more than two single-layer structural modules are disposed in multi-layer configuration, in which case a slab may be provided as the main frame inside of the single-layer structural module disposed at the innermost posi-

tion. When such a slab is provided, the beam forming the top or bottom side of the hexagonal structural unit in the innermost single-layer structural module may be replaced by an edge of the slab which is used as a structural member. This enables it to reduce the number of beams.

**[0025]** Fig. 2B shows the constitution of the single-layer structural module A disposed as an outer layer of the tubular frame 1 shown in Fig. 1. The single-layer structural module

B also has the similar constitution. Fig. 2B(a) is a partially enlarged front view of the single-layer structural module A, and Fig. 2B(b) is a plan view of the single-layer structural module A corresponding to the portion shown in Fig. 2B(a).

**[0026]** The plan views in the drawings accompanying the present specification show the basic form of the tubular frame of the present invention as viewed from above. When the tubular frame 1 is applied to an architectural structure, beam or other member of special configuration is normally disposed at the top end of the structure for the purpose of termination. The plan views show the tubular frame while omitting the configuration characteristic to the top end of the structure. This applies to all plan views attached to the present specification.

**[0027]** The single-layer structural module A is formed by rigidly connecting the hexagonal structural units in honeycomb configuration as shown in Fig. 2A. As partially shown in Fig. 2B(a), this honeycomb structure includes a row 10A1 (first row) of a plurality of hexagonal structural units connected in the vertical direction G, a row 10A2 (second row) of a plurality of hexagonal structural units connected in the vertical direction G disposed on the right-hand side of the first row adjacent thereto, and a row 10A3 (third row) of a plurality of hexagonal structural units connected in the vertical direction G disposed on the right-hand side of the second row adjacent thereto. The first row 10A1 and the second row 10A2 are disposed at staggered positions with a displacement of one half of the height  $h$  of the hexagonal structural unit. The second row 10A2 and the third row 10A3 are disposed similarly with respect to each other. The first row 10A1 and the third row 10A3 are disposed at the same height. Thus the honeycomb structure has such a configuration as the first row 10A1 and the second row 10A2 are disposed alternately along the perimeter of the tube.

**[0028]** As shown in the front view of Fig. 2B(a), the hexagonal structural unit has bilaterally symmetrical shape in two-dimensional configuration, but is not necessarily an equilateral hexagon. The two sides on the right are the lower right side 15A and the upper right side 16A which are two columns inclined in the opposite directions from the vertical direction G and are connected with each other. The lower right side 15A is inclined by an angle  $\alpha$  from the vertical direction G, and the upper right side 16A is inclined by the angle  $\alpha$  in the opposite direction from the vertical direction G. The joint between these two inclined columns protrudes outwardly from the hexagonal structural unit.

**[0029]** The lower left side 13A and the upper left side 14A which are the two sides located on the left are inclined columns connected with each other to form a mirror image of the two sides located on the right.

**[0030]** In actuality, the hexagonal structural units of the single-layer structural module A according to the present invention do not have planar configuration as can be seen from the plan view of Fig. 2B(b). In plan view of the hexagonal structural unit 10A2, for example, the inclined column of the upper left side 14A (superposed over the lower left side 13A) is disposed at an angle  $\beta_1$  from the plane which includes the top side 12A and the bottom side 11A, while the inclined column of the upper right side 16A (superposed over the lower right side 15A) is disposed at an angle  $\beta_2$  from the plane which includes the top side 12A and the bottom side 11A. In this case, the inclined column located on the left and the inclined column located on the right are located at positions opposite to each other with respect to the plane which includes the top and bottom beams. As a result, in the plan view, the row 10A2 of the hexagonal structural unit bends while descending from the upper left toward lower right position with regards to the positional relationship represented on the paper. Similarly, the row 10A1 of the hexagonal structural unit which adjoins the former to the left thereof bends while descending from the upper left toward lower right position. In contrast, the row 10A3 of the hexagonal structural unit which adjoins the former to the right thereof bends while ascending from the lower left toward upper right position with regards to the positional relationship represented on the paper.

**[0031]** In one hexagonal structural unit, the inclined column located on the left and the inclined column located on the right may also be located at positions opposite to each other or on the same side with respect to the plane which includes the top and bottom beams, in plan view. The angle  $\beta_1$  and the angle  $\beta_2$  by which the inclined column located on the left and the inclined column located on the right, respectively, are inclined from the plane which includes the top and bottom beams may be different from each other.

**[0032]** It is noted, however, that all hexagonal structural units which are connected with each other in the vertical direction and included in the same row have common planar configuration in plan view without staggering, as shown in Fig. 2B(b). The hexagonal structural units belonging to different rows (for example, the second row and the third row) may have different planar configurations.

**[0033]** The tubular frame 1 having a specified cross sectional shape can be formed by connecting the hexagonal structural units, formed by disposing the inclined column located on the left and the inclined column located on the right at predetermined angles from the plane which includes the top and bottom beams, in a predetermined arrangement. Accordingly, bending shape and arrangement of the individual hexagonal structural units are determined in accordance to the cross sectional shape of

the desired tubular frame 1.

**[0034]** Fig. 2C(a) is a partially enlarged plan view of the tubular frame 1 shown in Fig. 1. A part of the main frame constituted from the two single-layer structural modules A and B and the inter-layer tie beams which connect the two layers is shown. The drawing shows the rows 10A1 to 10A4 of the hexagonal structural units for the single-layer structural module A, and the rows 10B1 to 10B4 of the hexagonal structural units for the single-layer structural module B. Inter-layer distance  $d$  between the single-layer structural modules is maintained substantially constant throughout the tubular frame 1.

**[0035]** As shown in plan view of Fig. 2C(a), one of the features of the main frame constituting the tubular frame of the present invention is that the second hexagonal structural units 21, 22, 23... are formed as can be seen in plan view. These second hexagonal structural units 21, 22, 23... are also rigidly connected with each other so as to share the sides thereof with the adjacent second hexagonal structural units. As a result, the tubular frame 1 has the second honeycomb structure extending in substantially the horizontal direction.

**[0036]** Fig. 2C(b) schematically shows a part of the second hexagonal structural units 21 and 22 shown in Fig. 2C(a).

**[0037]** Structural members that constitute the six sides of the second hexagonal structural unit 21, for example, are the beams of either the first row 10A1 and the second row 10A2 of the single-layer structural module A or the first row 10B1 and the second row 10B2 of the single-layer structural module B, the inclined columns and the inter-layer tie beams, specifically as follows.

<Structural members for six sides of the second hexagonal structural unit 21>

**[0038]** Upper left side: Inter-layer tie beam L  
Lower left side: Beams 11A1, 12A1 of the first row 10A1 of the

single-layer structural module A

Top side: Inclined columns 15B1, 16B1 of the first row 10B1 and inclined columns 13B2, 14B2 of the second row 10B2 of the single-layer structural module B

Bottom side: Inclined columns 15A1, 16A1 of the first row 10A1 and inclined columns 13A2, 14A2 of the second row 10A2 of the single-layer structural module A

Upper right side: Beams 11B2, 12B2 of the second row of single-layer structural module B

Lower right side: Inter-layer tie beam L

**[0039]** Structural members that constitute the six sides of the second hexagonal structural unit 22, adjacent to the hexagonal structural unit 21 to the right thereof, are beams of either the second row 10A2 and the third row 10A3 of the single-layer structural module A or the second row 10B2 and the third row 10B3 of the single-layer structural module B, the inclined columns and the inter-layer tie beams, specifically as follows.

<Structural members for six sides of the second hexagonal structural unit 22>

**[0040]** Upper left side: Inter-layer tie beam L

Lower left side: Beams 11A2, 12A2 of the second row 10A2 of the

single-layer structural module A

Top side: Inclined columns 15B2, 16B2 of the second row 10B2 and inclined columns 13B3, 14B3 of the third row 10B3 of the single-layer structural module B

Bottom side: Inclined columns 15A2, 16A2 of the second row 10A2 and inclined columns 13A3, 14A3 of the third row 10A3 of the single-layer structural module A

Upper right side: Inter-layer tie beam L

Lower right side: Beams 11B3, 12B3 of the third row of the single-layer structural module B

**[0041]** As shown in Fig. 2C(b), at least the opposing inclined columns which constitute the two opposing sides of the second hexagonal structural unit are parallel to each other and have the same length in plan view.

**[0042]** Fig. 2C(c) shows a portion constituted from a pair of opposing beams and inter-layer tie beams L, extracted from the drawing of Fig. 2C(b). The inter-layer tie beams are disposed along the diagonal of a rectangle having the top sides of the two opposing hexagonal structural units as opposing sides thereof, and along the diagonal of a rectangle having the bottom sides of the two opposing hexagonal structural units as opposing sides thereof. In case the crossing diagonals making this pair are different in length, the inter-layer tie beam is preferably disposed along the shorter diagonal. In other words, this portion has the shape of letter N in italics. In a curved section of the tubular frame 1, the portion may have the shape of inverted letter N in italics. In Fig. 2C(a), for example, two portions having the shape of letter N in italics on the left and two portions having the shape of letter N in italics on the right are shaped as inverted to each other.

**[0043]** As shown in Fig. 2C(b) and Fig. 2C(c), the second honeycomb structure of the tubular frame in plan view may also be regarded as comprising inclined columns in the positions of two sides which are parallel and oppose each other and the portion having the shape of letter N in italics formed from the beams and the inter-layer tie beam, which are connected alternately.

**[0044]** In the basic form of the tubular frame of the present invention, more than two single-layer structural modules may be provided in multi-layer configuration. In this case, too, the second hexagonal structural unit is formed from the beam corresponding to the top side or bottom side of either of the two adjacent single-layer structural modules in plan view, the inclined columns corresponding to the two sides on the left or the two sides on the right, and the inter-layer tie beams connecting the two layers, while the second hexagonal structural units which are adjacent to each other are rigidly connected, with the sides thereof shared by the adjacent units so as to form the second honeycomb structure.

**[0045]** The second hexagonal structural unit may not

necessarily have bilaterally symmetrical shape in plan view as shown in Figs. 3A to 3D to be referred to later, and opposing beams may be different in length. Moreover, some joints may protrude inward. This is because the shape of the individual second hexagonal structural unit depends on the design of the cross section of the tubular frame 1. However, at least the two opposing sides constituted by inclined columns have the same length and are disposed in parallel to each other.

**[0046]** The second hexagonal structural unit also does not have planar shape as can be seen in side view, and has ups and downs in the vertical direction since the inclined columns are included as elements for the sides.

**[0047]** Fig. 2D is a plan view of the entire tubular frame 1 shown in Fig. 1. The tubular frame 1 shown has a substantially rectangular cross section. The second honeycomb structure is formed from the second hexagonal structural units 21, 22... in each side of the substantially rectangular shape. The four corners X have special structure, which will be described later with reference to Fig. 6.

**[0048]** The second honeycomb structure has multiple-layer constitution wherein the tubular frame 1 includes a plurality of layers of the second honeycomb structure from the side view. The first honeycomb structure which forms the perimeter of the single-layer structural module also has multiple-layer constitution wherein a plurality of layers of the first honeycomb structure are provided. Thus the tubular frame 1 has three-dimensional honeycomb structure constituted from the first honeycomb structure and the second honeycomb structure.

**[0049]** Fig. 3A to Fig. 3C are partial plan views showing Examples of connecting the hexagonal structural units in the single-layer structural module in various forms, and Examples of connecting in various forms in the main frame where the single-layer structural modules are provided in two layers.

**[0050]** Fig. 3A(a) shows a part of Example of the single-layer structural module A, where the rows from the first row 10A1 to the fourth row 10A4 of the hexagonal structural units are included. The rows of the hexagonal structural units are disposed so that the inclined columns for the opposite sides of the hexagon are located at positions opposite to each other with respect to the plane which includes the beams. Moreover, different rows of the hexagonal structural units are connected so as to bend in the same direction, and therefore form a line descending from the upper left toward lower right position. Fig. 3A(b) shows a part of the main frame formed by providing the single-layer structural module A having the constitution shown in Fig. 3A(a) and the single-layer structural module B of the same constitution, in multiple-layer configuration. In this case, all the portions having the shape of letter N in italics constituted from the beams and the inter-layer tie beam are disposed in the same direction. This constitution can be applied to the linear section in the cross section of the tubular frame.

**[0051]** Fig. 3B(a) shows a part of another example of the single-layer structural module A, where rows of the

hexagonal structural units from the first row 10A1 to the fourth row 10A4 are included. Each row of the hexagonal structural units is disposed so that the inclined columns located on both sides of the hexagon lie on the opposite sides of the plane which includes the beams. This constitution is different from the Example shown in Fig. 3A in that the rows of the hexagonal structural units are connected with each other so as to bend toward the opposite sides in an alternating manner, thus resulting in such an entire configuration that meanders up and down with regards to the positional relationship represented on the paper. Fig. 3B(b) shows a part of the main frame formed by providing the single-layer structural module A having the constitution

shown in Fig. 3B(a) and the single-layer structural module B of the same constitution, in multiple-layer configuration. In this case, the portions having the shape of letter N in italics constituted from the beams and the inter-layer tie beam protrude toward the opposite sides in an alternating manner. This constitution can be applied to the linear section including the meandering configuration in the cross section of the tubular frame.

**[0052]** Fig. 3C(a) shows a part of further another example of the single-layer structural module A, where rows of the hexagonal structural units from the first row 10A1 to the third row 10A3 are included. Unlike the Examples shown in Fig. 3A and Fig. 3B, each row of the hexagonal structural units is disposed so that the inclined columns located on both sides of the hexagon lie on the same side of the plane which includes the beams, thus resulting in the entire configuration forming a curve. Fig. 3C(b) shows a part of the main frame formed by providing the single-layer structural module A having the constitution shown in Fig. 3C(a) and as the single-layer structural module B having substantially the same constitution, in multiple-layer configuration. In this case, since the entire configuration forms a curve, the beams used in the single-layer structural module B located inside are made smaller than the beams used in the single-layer structural module A located outside. This constitution can be applied to the curved section in the cross section of the tubular frame.

**[0053]** Fig. 3D is a plan view of an example of the tubular frame 1 having substantially circular cross section. The second honeycomb structure is formed from the second hexagonal structural units 21, 22... uniformly along the entire circumference of the substantially circular shape in plan view.

**[0054]** The tubular frame 1 of the present invention, as described above, has the three-dimensional honeycomb structure formed from the first honeycomb structure which constitutes the single-layer structural modules and the second honeycomb structure in plan view. This geometry tends to bear external loads applied in any directions by transforming them into the axial forces of the inclined columns and beams. In addition, the tubular frame 1 having the three-dimensional honeycomb structure has such a geometry that allows external loads to transmit continuously throughout the frame, and accord-

ingly absorbs the external loads in dissipative manner in the form of axial forces. As a result, bending stress can be mitigated. This is because the three-dimensional honeycomb structure constituted from a plurality of the single-layer structural modules of the present invention has a larger number of inclined columns and beams disposed in more diversified axial directions and in well-balanced distribution, than in the case of the two-dimensional structure of one single-layer structural module only.

**[0055]** Fig. 4 is a perspective view of an example of the three-dimensional tubular architectural structure of the present invention showing the exterior thereof. The tubular frame 1 has a constitution similar to that shown in Fig. 1. The structure shown in Fig. 4 has a plurality of slabs 31a, 31b inside of the tubular frame 1. In this Example, each of the slabs 31a, 31b extends horizontally throughout the inner space of the single-layer structural module B which is disposed inside. The plurality of slabs 31a are connected to the beams 11B1 and 12B1 disposed in the top side and bottom side of the hexagonal structural unit included in the first row 10B1. The plurality of slabs 31b are connected to the beams 11B2 and 12B2 disposed in the bottom side and top side of the hexagonal structural unit included in the adjoining second row 10B2. As a result, the distance between the slab 31a and the slab 31b which adjoin each other is one half of height  $h$  of the hexagonal structural unit. When it is assumed that the distance between the slab 31a and the slab 31b corresponds to the height of two stories, four stories can be provided within the height  $h$  of one hexagonal structural unit, by using a sub-frame to separate the space into two stories.

**[0056]** Edges of the slab 31a and/or the slab 31b which provide the main frame can play the roles of the beams 11B1, 12B1 of the hexagonal structural unit of the single-layer structural module B, and therefore these beams may be omitted.

**[0057]** The edges of the slab 31a and/or the slab 31b may be disposed to protrude beyond the single-layer structural module B into the space between the single-layer structural modules A and B, or further protrude beyond the single-layer structural module A to the outside, in the area which is free of the beam of the single-layer structural module B (that is, on the center line which divides one hexagonal structural unit into two equal parts in the horizontal direction).

**[0058]** Fig. 5 is a perspective view of another example of the three-dimensional tubular architectural structure of the present invention showing the exterior thereof. The Example shown in Fig. 5 is substantially similar to the constitution shown in Fig. 4, except for such a difference that while the adjoining slabs 31a and 31b are disposed at a distance one half the height  $h$  of the hexagonal structural unit, each of the slabs 31a and 31b is partially provided inside of the single-layer structural module B which is located inside. In this case, each of the slabs 31a and 31b is designed to have surface area permitted by the structural mechanics.

**[0059]** In case the slabs are provided as the main frame as shown in Fig. 4 and Fig. 5, they may be provided at intervals of height  $h$  of the hexagonal structural unit, although not shown in the drawing. There is no restriction on setting of the height  $h$  of the hexagonal structural unit, which may be the height of four stories or two stories of the building. Thus the tubular frame having the three-dimensional honeycomb structure of the present invention has a high degree of freedom in determining the positions and distance of placing the slabs within a plane, number of stories, etc.

**[0060]** In case the height  $h$  of the hexagonal structural unit is set to accommodate four stories, the beams are disposed alternately in every two stories and therefore the main frame forms a space of two stories or four stories. As a result, the sub-frame is not required to bear the seismic load and wind load acting on the building, and can be freely connected or separated thereby allowing higher degree of freedom in designing planar and three-dimensional space.

**[0061]** Since all structural members of the tubular frame of the present invention are linear members, it is easier to secure openings.

**[0062]** The tubular frame of the present invention is a very strong structure due to the constitution of a plurality of single-layer structural module connected together, and is therefore capable of supporting the entire architectural structure without need for the slabs provided inside as the main frame. As a result, high degree of freedom is allowed in designing elevator shaft, stairway, ducting space, air-well void and the like.

**[0063]** Since honeycomb structure is basically a repetition of hexagonal structural units of the same size, it allows it to restrict the sizes and shapes of all columns and beams within few varieties. As a result, construction work can be made easier, construction period can be made shorter and the cost can be decreased.

**[0064]** The hexagonal structural unit can be made in pre-stressed concrete structure of pre-cast concrete or steel structure with predetermined shapes, which also provides the advantage that the construction work can be made easier, construction period can be made shorter and the cost can be decreased.

**[0065]** The form of the corners of the tubular frame according to the present invention and other modified forms will now be described.

**[0066]** Fig. 6(a) is a partial perspective view showing the structure of corner X of the tubular frame 1 having the substantially rectangular cross section shown in the plan view of Fig. 2D, and Fig. 6(b) is a partial plan view thereof. Disposed at the corners of the outermost single-layer structural module A is a hexagonal structural unit 40A forming equal angles ( $45^\circ$  in the example shown) with the adjacent faces on both sides (assumed to be flat surface). The hexagonal structural units 40A are connected in plurality in the vertical direction so as to form a row at the corner. The hexagonal structural unit 40A is constituted from beams corresponding to the bottom side 41

and the top side 42, inclined columns on the left side corresponding to the lower left side 43 and the upper left side 44 and inclined columns on the right side corresponding to the lower right side 45 and the upper right side 46.

**[0067]** On the other hand, disposed at one corner of the single-layer structural module B located inside are two hexagonal structural units, which are connected together at the joints 51, 52 of two inclined columns, located at the ends of the adjacent faces on both sides (assumed to be flat surface). Thus a rhombic shape is formed from four inclined columns 13B, 14B, 15B and 16B at the corner of the single-layer structural module B.

**[0068]** Furthermore, both ends of the beam 41 of the single-layer structural module A are connected to the joint 51 at the corner of the single-layer structural module B by the inter-layer tie beams 47a, 48a, respectively. Similarly, both ends of the beam 42 of the single-layer structural module A are connected to the joint 52 at the corner of the single-layer structural module B by the inter-layer tie beam 47b, 48b, respectively. As can be seen from the plan view of Fig. 6(b), the inter-layer tie beams 47a and 48a (or 47b and 48b) extending from both ends of the beam 41 (or 42) disposed at the corner of the single-layer structural module A located at the outermost position constitute the two equal sides of an equilateral triangle having the apex at the joint 51 (or 52) of the single-layer structural module B located inside.

**[0069]** The corner shown in Fig. 6 has such a structure as the inter-layer tie beams are arranged with higher density in the corner and in a triangular configuration which tends to resist the external load with axial forces of the members, so that strength can be increased in the corner where the stress is concentrated.

**[0070]** Fig. 7 shows a form of the tubular frame of the present invention in which different numbers of single-layer structural modules are provided in different sections of the structure. While the tubular frame of the present invention is basically constituted from a plurality of single-layer structural modules, it is not necessarily formed in solely two-layer structure or three-layer structure and, instead, may include sections of two-layer structure and three-layer structure coexisting. Further, a section constituted from only one layer of single-layer structural module may be included in part as long as the effects of the present invention are achieved.

**[0071]** Fig. 7(a) is a partial perspective view showing the structure of a number of layers transition section disposed between a section where only one layer of single-layer structural module is provided (section of layer S) and a section where two layers of single-layer structural module are provided (section comprising layer A and layer B). Two-layer section is shown on the left side of the drawing and layer S section is shown on the right side. The drawing shows an example of forming the layer S and layer A connected apparently continuously, wherein the layer B is provided at a position located toward the inside of layer A (toward the back of the paper) with a

spacing therefrom. In this case, another beam M directed inward is connected at a predetermined angle to the end of the beam 12A, on the side of layer S, of the hexagonal structural unit (number of layers transition section) located at the end position of layer B. The predetermined angle is determined so that the distance d between the end of beam M and the end of beam 12A becomes the distance between layer A and layer S. The hexagonal structural unit of layer B is connected to the end of the beam M.

**[0072]** Fig. 7(b) is a partial perspective view showing the structure of the number of layers transition section located between a section where only one layer of the single-layer structural module is provided (section of layer S) and a section where three layers of the single-layer structural module are provided (section comprising layer A, layer B and layer C). The three-layer section is shown on the left side of the drawing and the section of layer S is shown on the right side. The drawing shows an example of forming the layer S and layer A connected apparently continuously, wherein the layer B is provided at a position toward the inside of layer A with a spacing therefrom, and layer C is disposed at a position inward from layer B at the inter-layer distance therefrom. In this case, another beam M1 directed inward is connected at a predetermined angle to the end of the beam 12A, on the side of layer S, of the hexagonal structural unit (number of layers transition section) located at the end position of layer S. The predetermined angle is set so that the distance d1 between the end of beam M1 and the end of beam 12A becomes the distance between layer A and layer B. The hexagonal structural unit of layer B is connected to the end of the beam M1. Further another beam M2 directed inward is connected at a predetermined angle to the end of the beam 12B, on the side of layer S, located at the end position of layer B. The predetermined angle is set so that the distance d2 between the end of beam M2 and the end of beam 12B becomes the distance between layer B and layer C. The hexagonal structural unit of layer C is connected to the end of the beam M2.

**[0073]** Fig. 7 shows only an example of the structure of the number of layers transition section, of which various modifications can be made. Typically, the number of layers may be increased in a section where stress is concentrated, and the number of layers can be decreased in a section subjected to smaller load. Such a scheme depends chiefly on the overall configuration of the tubular frame.

**[0074]** While the three-dimensional tubular architectural structure of the present invention is basically constituted from the tubular frame which as a whole comprises the first honeycomb structure and the second honeycomb structure, it is understood that a constitution having a structure other than the honeycomb structure described above being incorporated in part of the tubular frame falls within the scope of the present invention as long as it does not deviate from the spirit of the present invention and satisfies the laws of structural mechanics.

**[0075]** The three-dimensional tubular architectural

structure of the present invention can be constructed from various building materials, such as wood, steel, reinforced concrete (RC), steel framed reinforced concrete (SRC), concrete-filled steel tube (CFT) or pre-stressed concrete (PC).

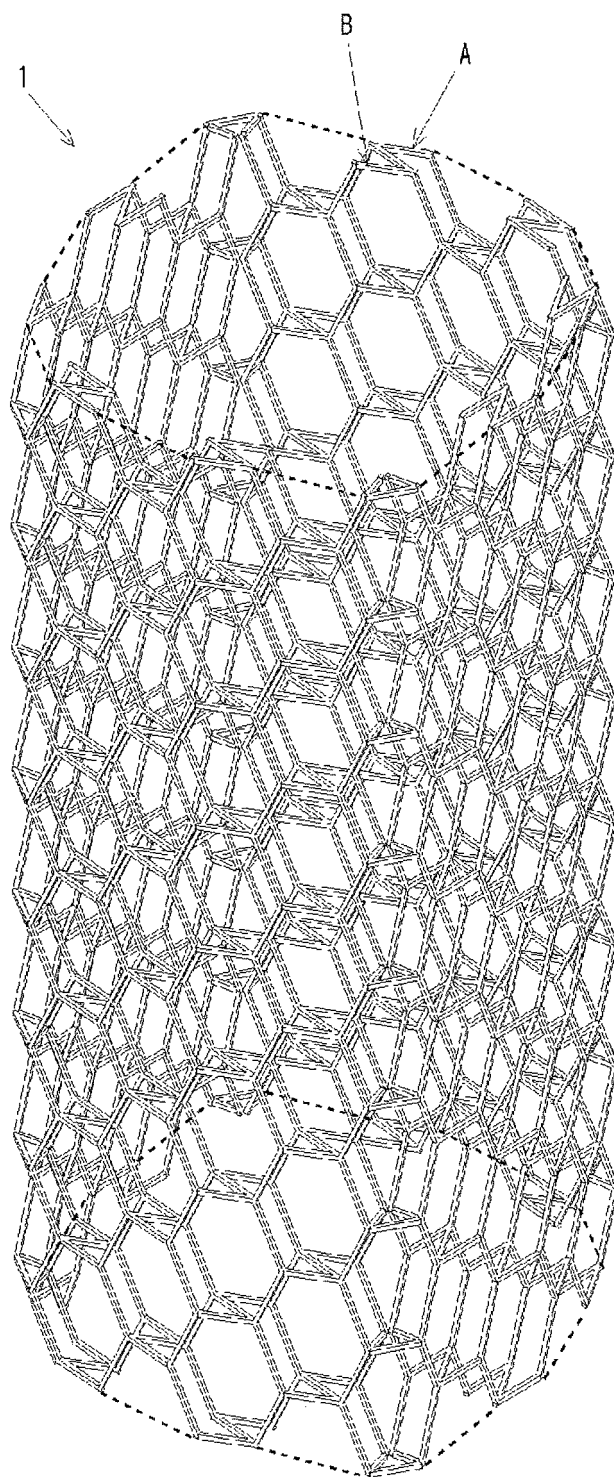
## Claims

1. A three-dimensional tubular architectural structure based on a three-dimensional tube frame formed from a main frame which is constituted by erecting a plurality of single-layer structural modules with a spacing from each other, the single-layer structural module being formed by rigidly connecting hexagonal structural units, with each side thereof being shared with the adjacent hexagonal structural units, in honeycomb configuration, wherein the structural members constituting the sides of said hexagonal structural unit are two inclined columns disposed on the left and two inclined columns disposed on the right which are inclined from the vertical direction in opposite directions from each other and are connected with each other, and beams corresponding to the top and bottom sides disposed in the horizontal direction, with each of the two sides on the left and the two sides on the right being disposed with an angle from the plane which includes said top side and said bottom side, adjacent two layers of the single-layer structural module of said main frame are connected with each other by a plurality of inter-layer tie beams, each of said hexagonal structural units in one of the single-layer structural modules and corresponding one of the hexagonal structural units in the other single-layer structural module being disposed to oppose each other, and in plan view of the main frame, a second hexagonal structural unit is formed from beams corresponding to the top side or the bottom side of two adjacent single-layer structural modules, the two inclined columns disposed on the left and the two inclined columns disposed on the right and the inter-layer tie beams connecting the two layers, and the second hexagonal structural unit is rigidly connected to the adjacent second hexagonal structural units so as to form honeycomb configuration.
2. The three-dimensional tubular architectural structure according to claim 1, wherein in plan view of the main frame, said inter-layer tie beams are located on the diagonal of a rectangle which comprises the top sides of the two hexagonal structural units which oppose each other as opposing sides of the rectangle, and on the diagonal of a rectangle which comprises the bottom sides as opposing sides of the rectangle.

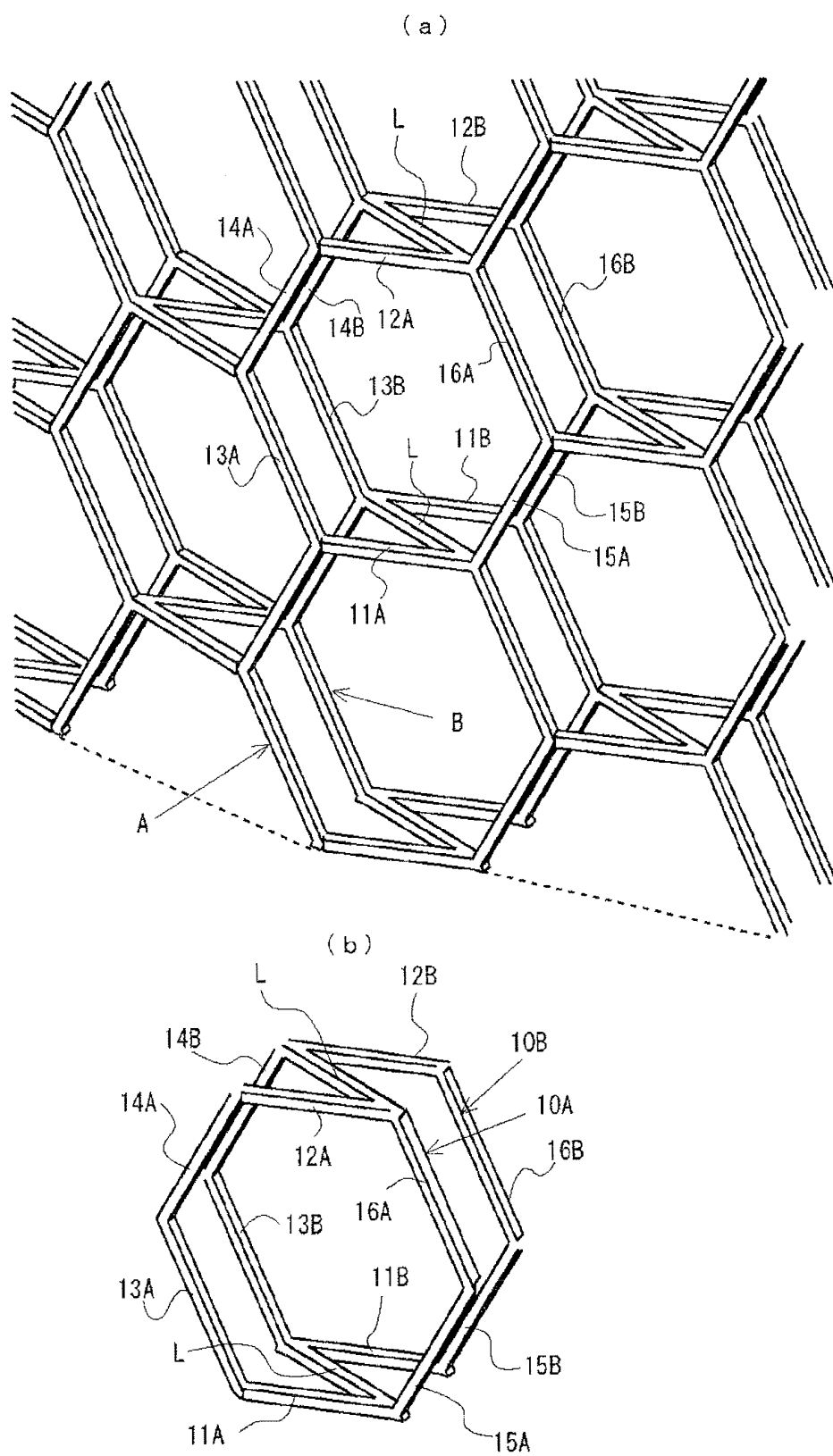
3. The three-dimensional tubular architectural structure according to claim 1 or 2, wherein said plurality of single-layer structural modules comprise two layers of single-layer structural module.  
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4. The three-dimensional tubular architectural structure according to any one of claims 1 to 3, wherein in case a slab is provided inside of the single-layer structural module disposed at the innermost position among said plurality of single-layer structural modules, edges of said slab are used as structural members instead of the beam corresponding to said top side or said bottom of said hexagonal structural unit in the single-layer structural module erected at the innermost position.  
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5. The three-dimensional tubular architectural structure according to any one of claims 1 to 4, wherein at corners of said three-dimensional tubular architectural structure which has substantially rectangular shape in plan view, at least the single-layer structural module disposed at the outermost position among said plurality of single-layer structural modules and the single-layer structural module located inside of and adjacent to the former are connected by inter-layer tie beams which form the equal sides of an isosceles triangle in plan view.  
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6. The three-dimensional tubular architectural structure according to any one of claims 1 to 5, wherein said main frame includes sections having different numbers of layers of said single-layer structural modules.  
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7. The three-dimensional tubular architectural structure according to any one of claims 1 to 6, wherein said three-dimensional tubular architectural structure partially includes a section formed from one layer of said three-dimensional tubular architectural structure.  
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8. The three-dimensional tubular architectural structure according to any one of claims 1 to 7, wherein a plurality of slabs are provided, as main frame, at intervals equal to the height of said hexagonal structural unit.  
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9. The three-dimensional tubular architectural structure according to any one of claims 1 to 7 wherein a plurality of slabs are provided, as main frame, at intervals equal to one half of the height of said hexagonal structural unit.  
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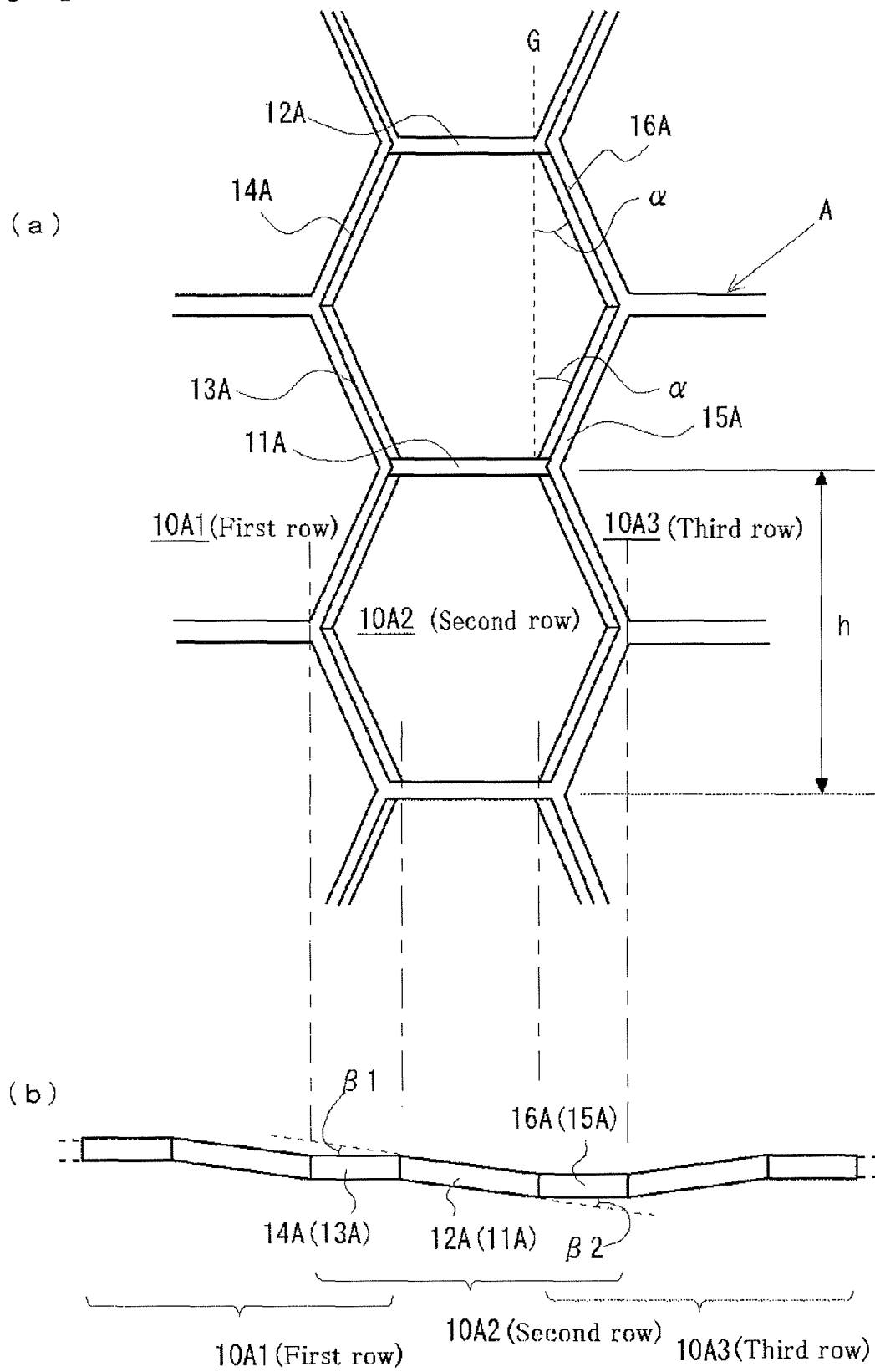
[Fig.1]



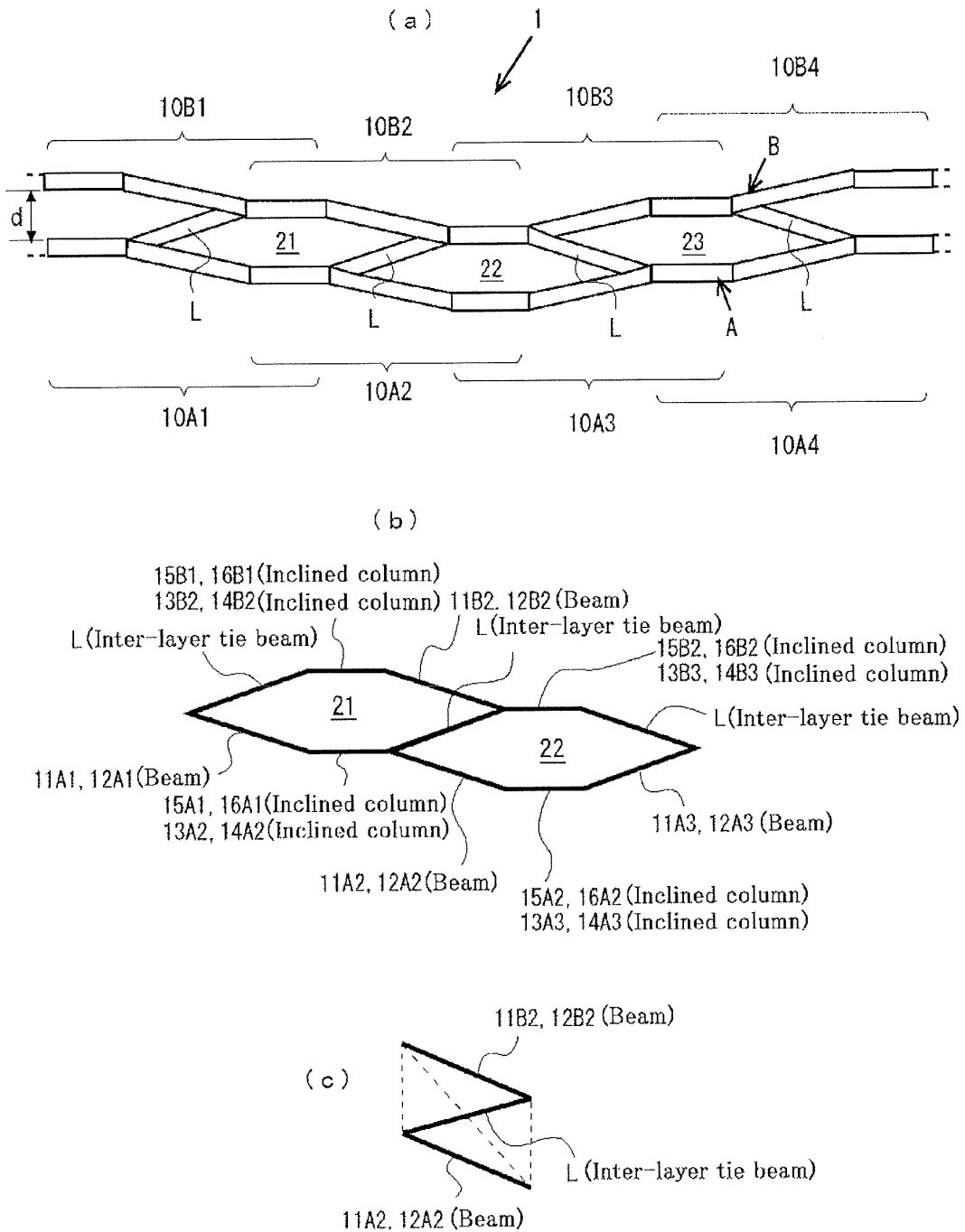
[Fig.2A]



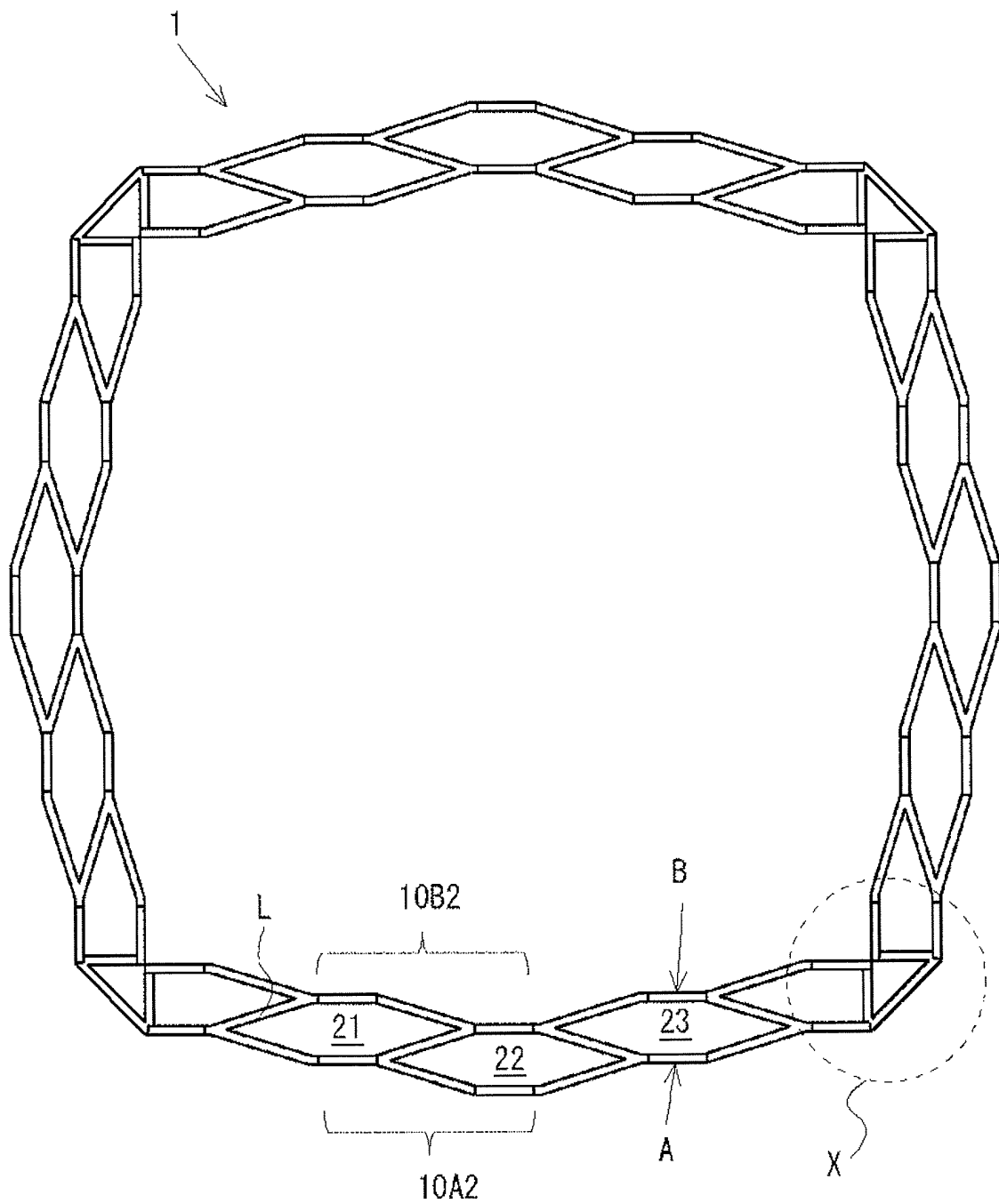
[Fig.2B]



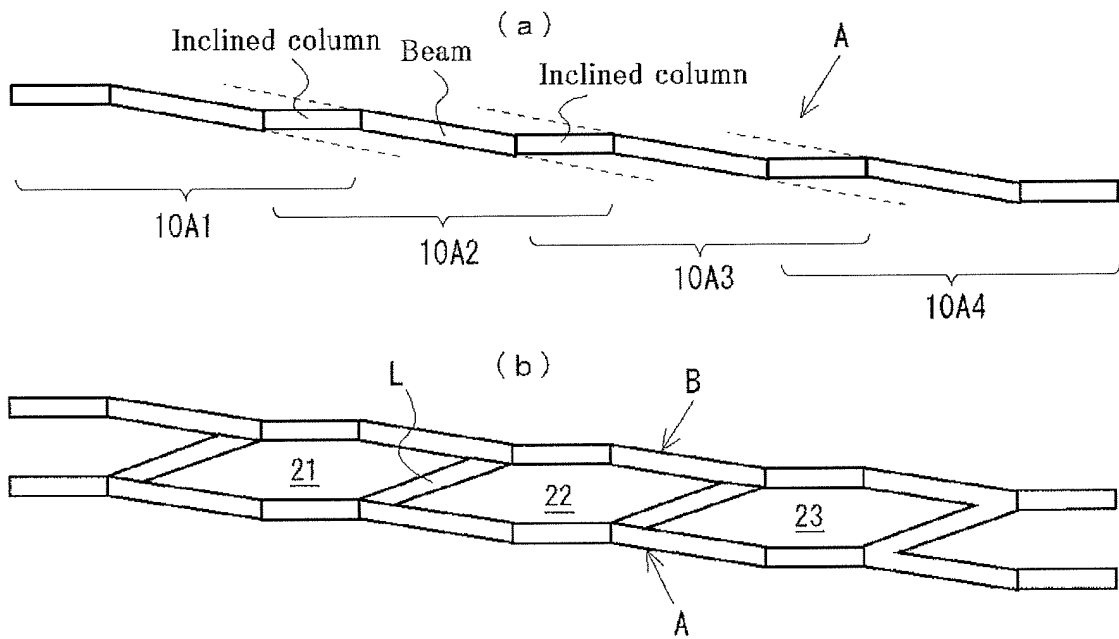
[Fig.2C]



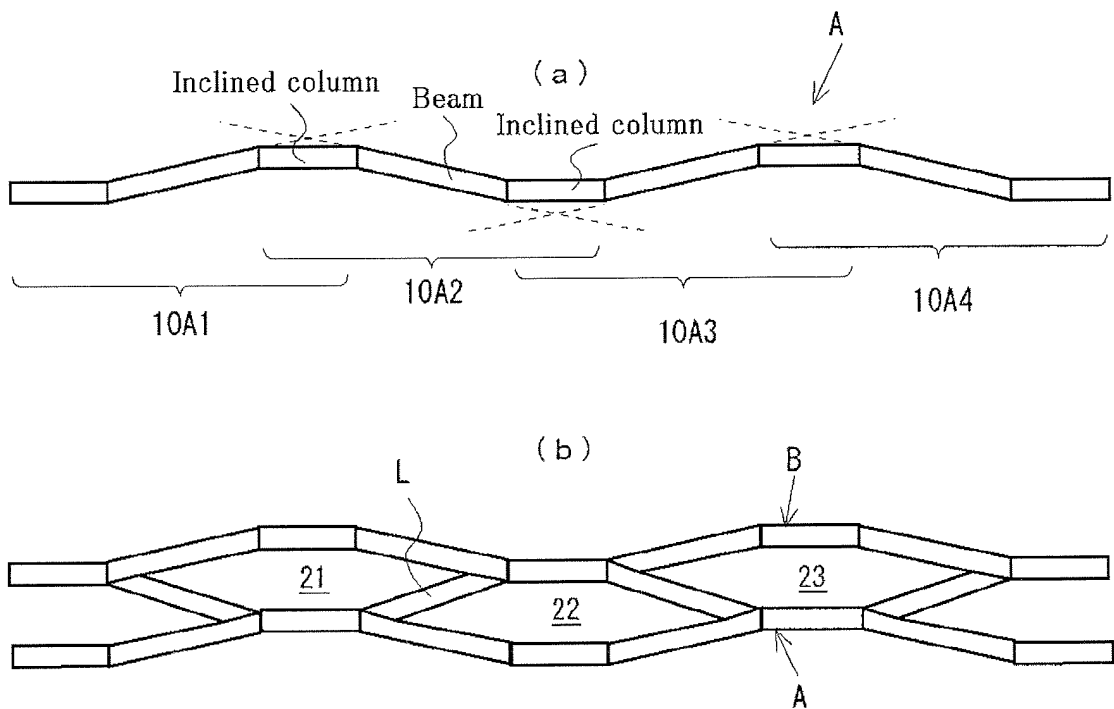
[Fig.2D]



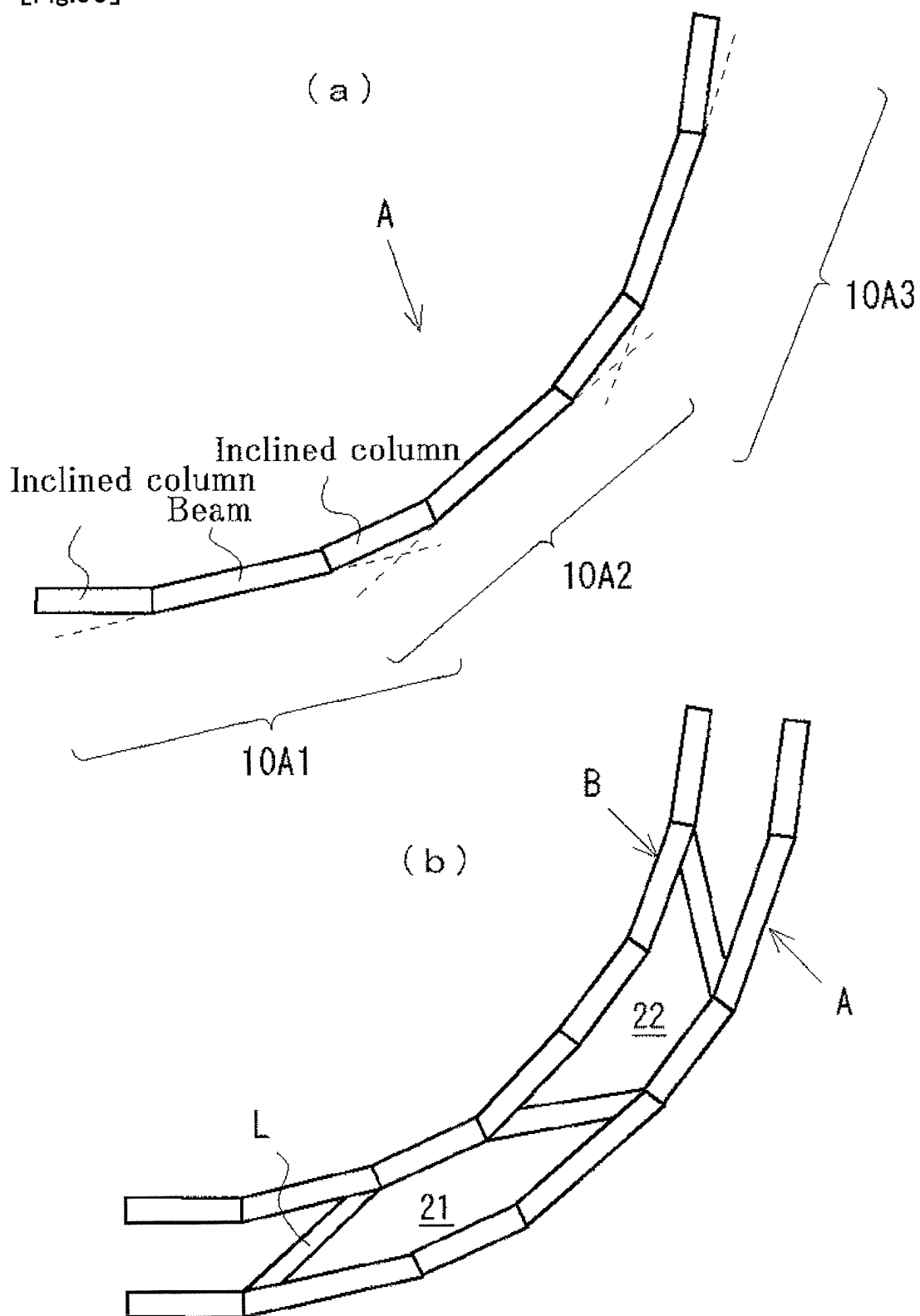
[Fig.3A]



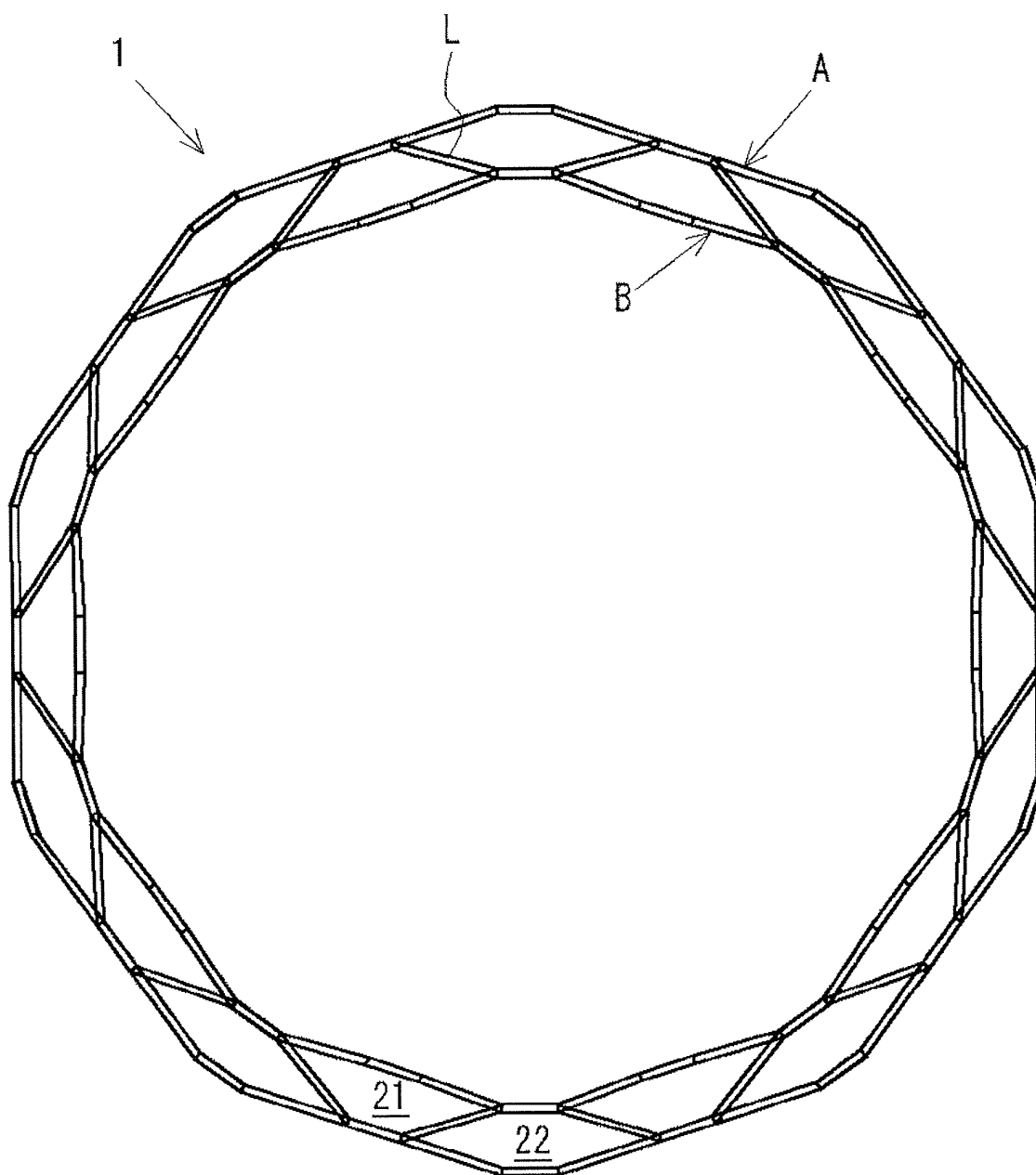
[Fig.3B]



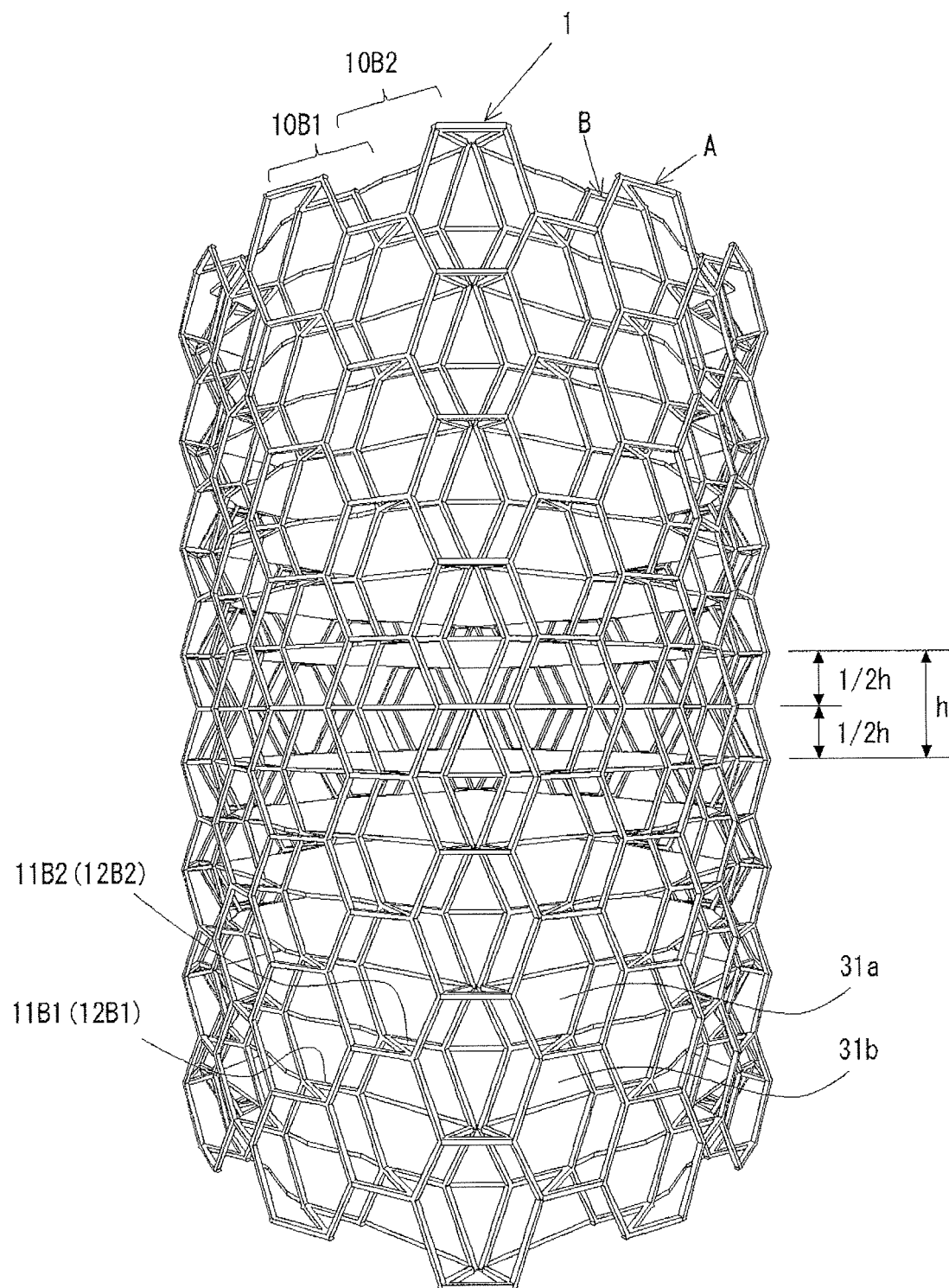
[Fig.3C]



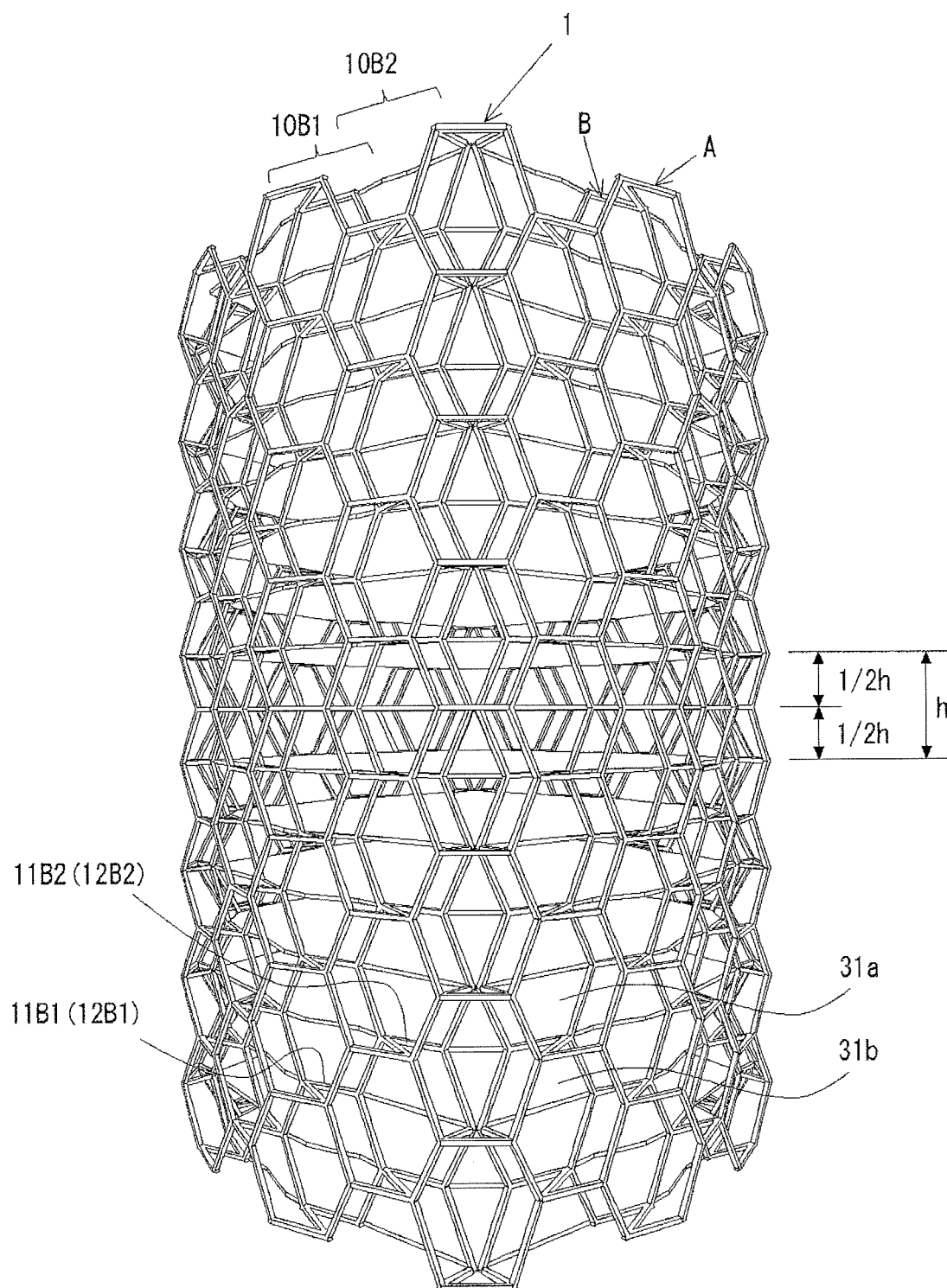
[Fig.3D]



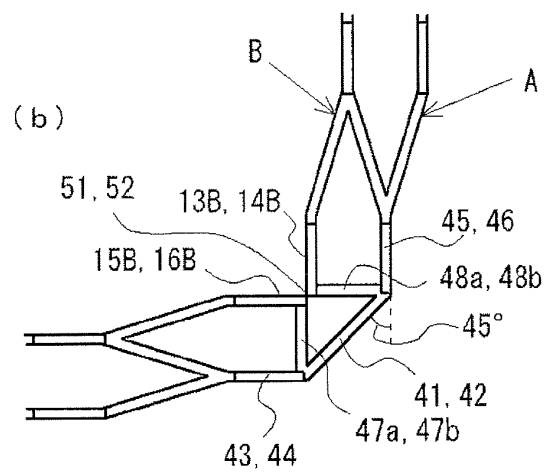
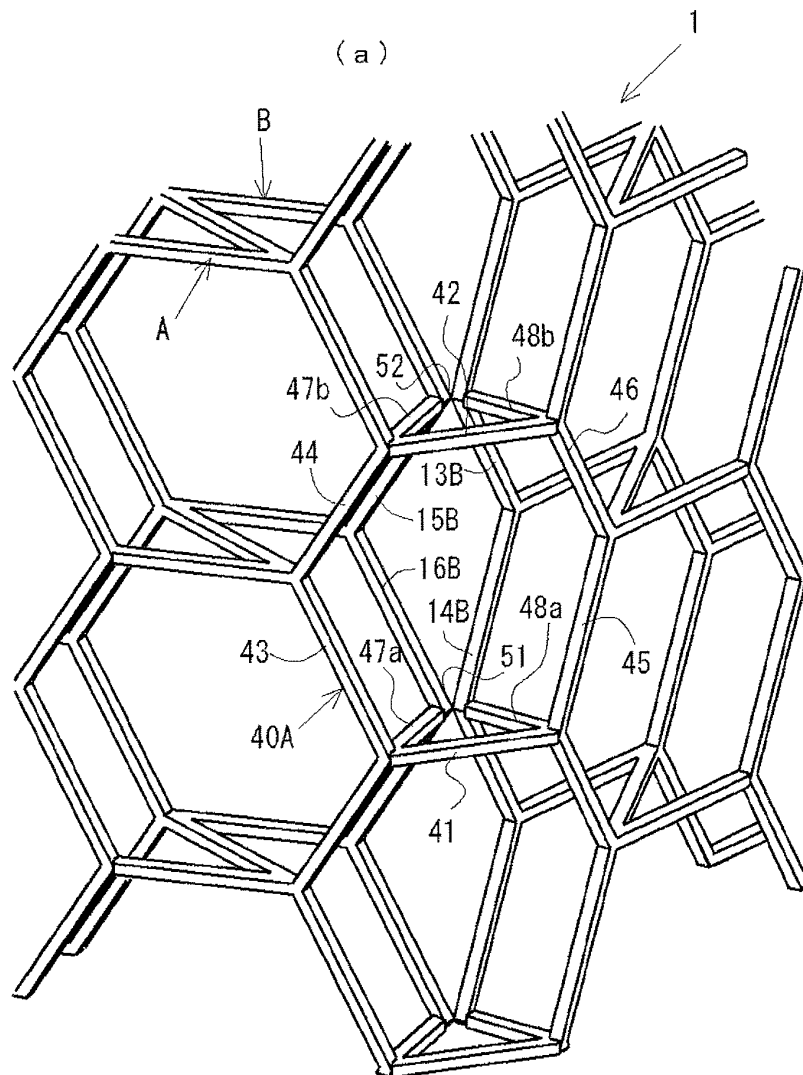
[Fig.4]



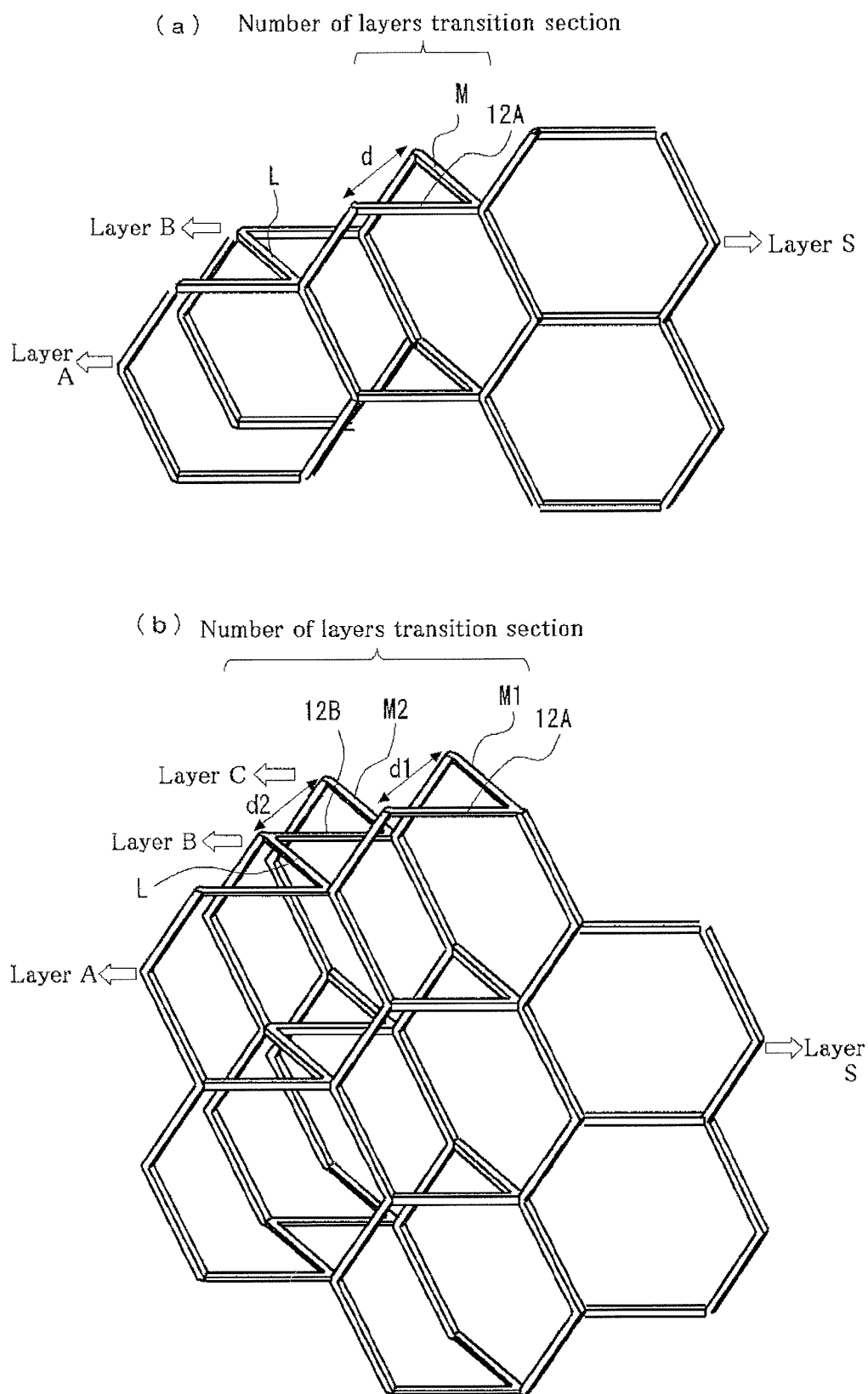
[Fig.5]



[Fig.6]



[Fig.7]



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2006/324813

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                           |                                                                                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| A. CLASSIFICATION OF SUBJECT MATTER                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                           |                                                                                   |
| E04B1/18(2006.01)i, E04B1/19(2006.01)i, E04B1/32(2006.01)i, E04B1/34(2006.01)i                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                           |                                                                                   |
| 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)<br>E04B1/18, E04B1/19, E04B1/32, E04B1/34                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                           |                                                                                   |
| Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched<br>Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2007<br>Kokai Jitsuyo Shinan Koho 1971-2007 Toroku Jitsuyo Shinan Koho 1994-2007                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                           |                                                                                   |
| Electronic data base consulted during the international search (name of data base and, where practicable, 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.                                                             |
| P, Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | JP 3811708 B1 (Sekisui Chemical Co., Ltd.),<br>23 August, 2006 (23.08.06),<br>Full text<br>(Family: none) | 1, 3-4<br>6-9                                                                     |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | JP 7-197535 A (Shimizu Corp.),<br>01 August, 1995 (01.08.95),<br>Fig. 3<br>(Family: none)                 | 1-9                                                                               |
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| <input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                           |                                                                                   |
| * Special categories of cited documents:<br>"A" document defining the general state of the art which is not considered to be of particular relevance<br>"E" earlier application or patent but published on or after the international filing date<br>"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)<br>"O" document referring to an oral disclosure, use, exhibition or other means<br>"P" document published prior to the international filing date but later than the priority date claimed<br>"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<br>"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<br>"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<br>"&" document member of the same patent family |                                                                                                           |                                                                                   |
| Date of the actual completion of the international search<br>11 January, 2007 (11.01.07)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                           | Date of mailing of the international search report<br>23 January, 2007 (23.01.07) |
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| Facsimile No.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                           | Telephone No.                                                                     |

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## REFERENCES CITED IN THE DESCRIPTION

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