CONSTRUCTION STRUCTURE BODY, STRUCTURE UNIT, AND METHOD FOR THE UNIT

The present invention provides an architectural structure having a main frame of honeycomb configuration that is erected vertically and expands in a plane, a structural unit therefore, and a method for constructing the same.

An architectural structure having a main frame formed by connecting a plurality of structural units, wherein a virtual honeycomb configuration that is erected vertically and expands in a plane is provided with one structural unit (1, 2, 3, 4, 5, 6) disposed at a position that includes one apex (h1, h2, h3, h4, h5, h6) of a hexagonal cell (H1, H2) that is the unit cell thereof in front view, means are provided for rigidly joining two structural units by disposing joint surfaces, that are formed in part of the respective outer circumferential surfaces of the two structural units that adjoin each other, so as to oppose each other, while the surfaces (s1, s2, s3, s4, s5, s6) that are rigidly joined each crosses one of the sides of the hexagonal cell, and an opening (W) surrounded by all the structural units that are disposed on the hexagonal cell is formed in the mid portion of each hexagonal cell.
Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to an architectural structure built by connecting a plurality of structural units with each other, and particularly to an architectural structure comprising a main frame of honeycomb configuration that expands in a plane formed from hexagonal cells as unit cells. The invention also relates to the structural unit and a method of constructing the architectural structure by using the same.

Description of the Related Art

[0002] Several methods have been known for constructing a skeleton by using structural units made of precast concrete members. Japanese Unexamined Patent Publication (Kokai) No. 9-328816 discloses a precast concrete member used in an architectural structure constructed by connecting triangular unit cells in a dome configuration, and a method of connecting the same. In the architectural structure of Japanese Unexamined Patent Publication (Kokai) No. 9-328816, six legs extend radially from each apex of the triangular cell. The precast concrete member used in the construction of this structure includes a joint member having hexagonal shape in plan view that is located at the center and six column members that are connected to the six sides of the joint member. Each column member has thicker portions at both ends thereof, so that a PC steel is inserted into the shoulder of the thicker portion of one column member to pass through the joint member to the shoulder of the thicker portion of an opposing column member, and is fastened with post tension applied thereto. This is the method employed to connect the members in case the cell is constituted from an even number of column members that extend radially.

Japanese Unexamined Patent Publication (Kokai) No. 9-328816 shows a method for joining three column members (an odd number) to the side faces of a substantially triangular joint member in Fig. 8 and Fig. 9. The joint member has an anchor section formed therein and a PC steel that is embedded therein and protrudes at the distal end thereof from the joint member so as to be passed through the thicker portion of the column member and subjected to post tension for fastening.

[0003] Japanese Unexamined Patent Publication (Kokai) No. 2000-144909 discloses a trifurcated column used to form a structural column of an architectural structure or a bridge pier in a hexagonal structure. The trifurcated column is constituted from a hexagonal strut disposed vertically and three beams that are connected to the strut at the bottom thereof and extend obliquely downward. A structure having a configuration of hexagonal cell as shown in plan view of Fig. 4 of Japanese Unexamined Patent Publication (Kokai) No. 2000-144909 is formed by connecting the top end of the hexagonal strut and the bottom ends of the three beams successively.

[0004] It has been common in the prior art to construct a high-rise or super high-rise architectural structure in pure rigid frames formed by combining vertical columns and horizontal beams in a three dimensional grid. This construction method has such a drawback that the presence of a beam in every span poses a significant restriction on the design of interior space. A tube frame formed from columns disposed consecutively along the outer circumference of the building and beams that connect the columns, in contrast, has an advantage of greater degree of freedom in design, since an inner space that is free of columns and beams can be formed. It is also considered to have higher resistance to earthquakes and wind pressure since the entire building deforms like a tube.

[0005] Meanwhile a honeycomb structure constituted by connecting hexagonal cells as unit cells in a repetitive pattern has been known to be a rugged structure, and has been used in various sections of architectural structures and as building members (Japanese Unexamined Patent Publication (Kokai) No. 9-328816, Japanese Unexamined Patent Publication (Kokai) No. 9-4130, Japanese Unexamined Patent Publication (Kokai) No. 10-18431, etc.). As an application of the honeycomb structure to a tube frame, a structure is known in which 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.

[0006] Another application of honeycomb structure to a tube frame is described in Japanese Unexamined Patent Publication (Kokai) No. 6-287913, where formwork elements made of precast concrete in the form of columns having a hexagonal cross section are put into contact with each other on the side faces thereof so as to form a wall having a cross section of honeycomb configuration in the horizontal plane, and the structure is extended upward by repeating the placement of concrete into the column-shaped space delimited by the wall, thereby to construct a bridge pier.

[0007] Further, Japanese Unexamined Patent Publication (Kokai) No. 61-83738 and Japanese Unexamined Patent Publication (Kokai) No. 53-43217 are cited in an international search report of International Patent Application PCT/JP2006/316868 upon which the priority claim of this application is based. Japanese Unexamined Patent Publication (Kokai) No. 61-83738 discloses a structure formed by connecting a plurality of triangular panel units with each other in a plane via hinges provided at the apexes of the panel units in such a manner as the panels can swing, lifting or pressing down the assembly into a dome configuration, and fixing the panels. Japanese Unexamined Patent Publication (Kokai) No. 53-43217 discloses a wall structure formed by connect-
ing panel units of rectangular parallelepiped shape with each other by means of tendons. Japanese Unexamined Patent Publication (Kokai) No. 61-36435 discloses a dome structure formed by connecting panel units of a hexagonal or pentagonal shape with each other.

[0008] Although the structure disclosed in Japanese Unexamined Patent Publication (Kokai) No. 9-60301 has a honeycomb configuration that extends as a flat horizontal plane, the structure is essentially different from a honeycomb configuration that is erected substantially vertically and expands in a plane such as the tube frame that constitutes the outer circumference of a building. The same argument applies also to Japanese Unexamined Patent Publication (Kokai) No. 6-287913.

[0009] A tube frame formed from hexagonal cells connected together in a honeycomb configuration, if realized, is expected to be an extremely rugged structure. Construction of such a tube frame requires a method for forming a flat or curved surface erected by connecting hexagonal cells. Since the honeycomb structure is a collection of unit structures of essentially the same shape, it is more convenient in terms of the construction works to repeat the connection of structural units of the same shape, rather than connecting individual columns and beams. Accordingly, there are demands for structural units of a standardized shape that allow to efficiently construct a structure of honeycomb configuration.

[0010] The precast concrete member described in Japanese Unexamined Patent Publication (Kokai) No. 9-328816 makes it possible to construct an architectural structure constituted from unit structures each having the shape of legs extending radially from the center. However, the center at which all the legs join is where the stress is concentrated, and therefore it is not desirable in terms of structural stability to connect all the column members to one joint member at the center.

[0011] The trifurcated pillar of Japanese Unexamined Patent Publication (Kokai) No. 2000-144909 is a unit structure where four legs extend from the center radially in the three dimensional space, and the hexagonal structure formed by connecting these members inevitably makes a three dimensional hexagonal structure. As a result, it is not possible to use this structure to form the flat or curved surface of a tube frame formed from hexagonal cells connected together in a honeycomb configuration.

[0012] Japanese Unexamined Patent Publication (Kokai) No. 61-83738 describes a method of constructing a structure by connecting all panels in a plane in advance, deforming the assembly into a dome shape and fastening it, not a method of constructing the entire structure by successively connecting the individual panel units. The structure described in Japanese Unexamined Patent Publication (Kokai) No. 53-43217 is constructed by connecting panel units by means of tendons disposed in a vertical or horizontal direction, and has no relation to a honeycomb structure. The structure described in Japanese Unexamined Patent Publication (Kokai) No. 61-36435 is primarily intended to ensure the structural strength by forming a dome shape. Thus the inventions of Japanese Unexamined Patent Publication (Kokai) No. 61-83738 and Japanese Unexamined Patent Publication (Kokai) No. 53-43217 are not capable of providing a tube frame having a main frame of honeycomb configuration formed by connecting structural units together.

**SUMMARY OF THE INVENTION**

[0013] Thus, an object of the present invention is to provide an architectural structure having a main frame of honeycomb configuration that is erected vertically and expands in a plane. It is also an object of the present invention to provide a structural unit for constructing such an architectural structure and a method for constructing the same.

[0014] In order to achieve the objects described above, the present invention provides the following constitutions.

An architectural structure according to claim 1 is an architectural structure having a main frame formed by connecting a plurality of structural units, where a virtual honeycomb configuration that is erected vertically and expands in a plane is provided with one of the structural units (1, 2, 3, 4, 5, 6) disposed at a position that includes an apex (h1, h2, h3, h4, h5, h6) of a hexagonal cell (H1, H2) that is the unit cell thereof in front view, means are provided for connecting two adjacent structural units by disposing joint surfaces, that are formed in part of the outer circumference of the two structural units, to oppose each other, while the surfaces (s1, s2, s3, s4, s5, s6) that are joined cross one of the sides of the hexagonal cell, and an opening (W) surrounded by all structural units that are disposed on the hexagonal cell is formed in the mid portion of the hexagonal cell.

[0015] An architectural structure according to claim 2 has the constitution of the structural unit of claim 1 that is made of precast concrete, where the outer circumference thereof has a pair of panel surfaces consisting of a front surface and a back surface that oppose each other and a side face extending between edges of the pair of panel surfaces, and a plurality of the joint surfaces are provided as a part of the side faces.

[0016] An architectural structure according to claim 3 has the constitution of the structural unit of claim 2 that is made of precast concrete, where the pair of panel surfaces have a hexagonal shape in front view, and the side face between a side and one located next to the adjacent side of the hexagonal cell is used as the joint surface.

[0017] An architectural structure according to claim 4 is characterized in that the hexagonal shape of the pair of panel surfaces of claim 3 is formed from a short side and a long side that are disposed alternately, and that a side face between the short sides is used as the joint surface.

[0018] An architectural structure according to claim 5 has the constitution of the structural unit of claim 2 that...
is made of precast concrete, where the panel surface has three legs that extend in three directions from the center in front view, and the side face located at the distal end of each of the three legs is used as the joint surface.

**[0019]** An architectural structure according to claim 6 is an architectural structure having a main frame formed by connecting a plurality of structural units, where a virtual honeycomb configuration that is erected vertically and expands in a plane is provided with one of the structural units (7, 8, 9, 10, 11, 12, 13, 14, 15) disposed at the position including two adjacent apaxes of the hexagonal cell (H1, H2) that is the unit cell thereof, means are provided for connecting two adjacent structural units by disposing joint surfaces, that are formed in part of the outer circumference of the two adjacent structural units, to oppose each other, while the surfaces that are joined cross one of the sides of the hexagonal cell, and an opening (W) surrounded by all structural units that are disposed on the hexagonal cell is formed in the mid portion of the hexagonal cell.

**[0020]** An architectural structure according to claim 7 has the constitution of the structural unit of claim 6 that is made of precast concrete, where the outer circumference thereof has a pair of panel surfaces consisting of a front surface and a back surface that oppose each other and a side face extending between edges of the pair of panel surfaces, and a plurality of the joint surfaces are provided as a part of the side faces.

**[0021]** An architectural structure according to claim 8 has the constitution of the structural unit of claim 7 that is made of precast concrete, where each of the pair of panel surfaces has an octagonal shape in front view, and the side face between a side and one located next to the adjacent side of the octagonal cell is used as the joint surface.

**[0022]** An architectural structure according to claim 9 is characterized in that the octagonal shape of the pair of panel surfaces of claim 8 is formed from short sides and long sides that are disposed alternately, and that a side face between the short sides is used as the joint surface.

**[0023]** An architectural structure according to claim 10 has the constitution of the structural unit of claim 7 that is made of precast concrete, where the panel surface has four legs that extend in four directions from the center thereof in front view, and the side face located at the distal end of each of the four legs is used as the joint surface.

**[0024]** An architectural structure according to claim 11 has the constitution of claim 2 or 7 wherein the means of connecting the two adjacent structural members made of precast concrete comprises a tendon that crosses the opposing joint surfaces and passes through both structural units, and an anchoring member that applies a post tension to the tendon and secures both ends thereof on the side face of each structural unit.

**[0025]** An architectural structure according to claim 12 has the constitution of claim 1 or 6 wherein the structural unit is made of steel, reinforced concrete, steel-encased reinforced concrete or wood.

**[0026]** An architectural structure according to claim 13 is an architectural structure having a main frame formed by connecting a plurality of structural units, where a virtual honeycomb configuration that is erected vertically and expands in a plane is provided with first structural units (1, 2, 3, 4, 5, 6) each disposed at a position that includes an apex of the hexagonal cell (H1, H2) that is the unit cell thereof and second structural units (8, 9, 10, 11, 12, 13, 14, 15, 16) each disposed at a position that include two adjacent apaxes of the hexagonal cell, means are provided for connecting two of the first and/or the second structural units that adjoin each other by disposing the joint surfaces, that are formed in part of the outer circumference of the two structural units, to oppose each other, while the joined surfaces cross one of the sides of the hexagonal cell, and an opening (W) surrounded by all of the first and/or second structural units that are disposed on the hexagonal cell is formed in the mid portion of the hexagonal cell.

**[0027]** An architectural structure according to claim 14 has the constitution of claim 1, 2, 6, 7 or 13 wherein, among the structural units that are connected consecutively in the vertical direction, the structural units disposed at higher positions and the structural units disposed at lower positions have different shapes, so that the opening formed by the structural units disposed at higher positions is larger than the opening formed by the structural units disposed at lower positions.

**[0028]** A structural unit according to claim 15 is used to construct the architectural structure of any one of claims 1 to 14.

**[0029]** A structural unit according to claim 16 is a structural unit made of precast concrete that is used to form the main frame of the architectural structure of claim 1, wherein the outer circumference thereof has a pair of panel surfaces consisting of a front surface and a back surface that oppose each other and a side face extending between edges of the pair of panel surfaces, a plurality of joint surfaces for connecting adjacent structural units are provided as partial surfaces of the side faces, and a plurality of tendon insertion holes that pass between each of the plurality of joint surfaces and the other portion of the side face are provided in such a configuration that they do not overlap each other.

**[0030]** A structural unit according to claim 17 has the constitution of the structural unit of claim 16 that is made of precast concrete, wherein the panel surfaces have a hexagonal shape in front view, and the side face between a side and one located next to the adjacent side of the hexagonal cell is used as the joint surface.

**[0031]** A structural unit according to claim 18 is characterized in that the hexagonal shape of the panel surfaces of claim 17 is formed from short sides and long sides that are disposed alternately, and that a side face between the short sides is used as the joint surface.

**[0032]** A structural unit according to claim 19 has the
A method of constructing the architectural structure according to claim 29 is a method of constructing the architectural structure having a main frame formed by connecting a plurality of the structural units according to claim 16 or 20, the method comprises disposing two adjacent structural units so that the respective joint surfaces oppose each other in such a configuration that the tendon insertion holes thereof communicate with each other; passing a tendon through the communicating tendon insertion holes; and applying a post tension to the tendon to fasten it thereby to joint the two adjacent structural units.

(A) The invention according to claim 1, 6, 13 or 15 has mainly the effects described below. The architectural structure of the present invention has a main frame formed by connecting a plurality of structural units and, in one embodiment, each structural unit is disposed at a position including each apex of a hexagonal cell that is a unit cell of honeycomb configuration in front view, that is erected vertically and expands in a plane. In another embodiment, one structural unit is disposed at a position that includes two adjacent apaxes of a hexagonal cell that is a unit cell. In further another embodiment, first structural units each disposed at the position that includes one apex and second structural units each disposed at a position that includes two apaxes are used in a mixed arrangement. The virtual honeycomb configuration (may hereafter be referred to simply as honeycomb configuration) is not a member having physical existence, but a configuration envisioned to exist in the physical space for the purpose of defining the positions where the structural units are to be disposed and the relative positions of the adjacent structural units.

In any of the forms described above, the means are provided for joining two adjacent structural units by disposing joint surfaces, that are formed in a part of the outer circumference of the two adjacent structural units, to oppose each other, and the joined surfaces cross one of the sides of the hexagonal cell. Moreover, an opening surrounded by all the structural units that are disposed on the hexagonal cell is formed in the mid portion of the hexagonal cell, when the plurality of structural units are connected with each other.

The structural units that are connected with each other as described above can be disposed so as to cover the apaxes and sides of all hexagonal cells that constitute the virtual honeycomb configuration. That is, when reference is made to one hexagonal cell, a plurality (six, five, four or three) structural units are connected in a ring shape along the six sides of the hexagonal cell with an opening formed in the mid portion, thus realizing an architectural structure having a main frame of honeycomb configuration that is erected vertically and expands in a plane. Particularly the circumferential surface of the tube frame can be formed in a honeycomb structure. In addition, a slab can be installed at any desired position of the structural unit that constitutes the main frame of
honeycomb configuration, so that the height of each story can be freely set.

[0046] In the main frame of honeycomb configuration according to the present invention, the structural units are disposed so as to include the positions of the apexes of the hexagonal cell that are subjected to the highest concentration of stress. That is, since connection between the structural units is not made at the position of an apex, the structure is highly resistant to stresses. In comparison to a structure where linear members are connected at the apexes of triangular or hexagonal cells at which stress is concentrated as those described in Japanese Unexamined Patent Publication (Kokai) No. 9-328816 or Japanese Unexamined Patent Publication (Kokai) No. 9-60301, for example, the present invention provides higher structural stability. Moreover, in the main frame of honeycomb configuration of the present invention, the surface whereon two structural units are joined crosses one of the sides of the hexagonal cell. That is, joining of two structural units is made on a side of the hexagonal cell where stress is at the lowest level, thus resulting in a favorable situation. As a result, a frame of a large span can be constructed by using the main frame formed from the structural units of the present invention.

[0047] The structural unit of the present invention also allows a relatively high degree of freedom in designing the shape of a portion that is not restrained by the conditions of arrangement and connection described above. For example, the size of the opening formed in the mid portion of the hexagonal cell can be altered by changing the shape of the outer circumference other than the joint surface of the structural unit (namely a non-joint surface). It is also made possible to accommodate wide modifications of design.

[0048] Also the architectural structure formed from the structural units of the present invention is constructed by connecting the structural units having the same or similar shapes according to a basically repetitive pattern, and therefore the number of different versions of the structural units can be reduced to one kind, or two or three kinds at the most. This feature provides an advantage in terms of mass production. As a result, it is made possible to reduce the manufacturing cost, improve the construction process and reduce the period of construction work. However, the structural units of the present invention can be manufactured in a large variety of resembling shapes that can be connected to each other, and therefore there is no limitation to the number of kinds.

[0049] (B) The invention according to claims 2 to 5, 7 to 11 and 16 to 28 has mainly the effects described below. It is preferable to fabricate the structural unit of the present invention from precast concrete (hereinafter referred to as PC and a structural unit made of PC may be referred to as a PC panel). A PC panel has a pair of panel surfaces that are a front surface and a back surface opposing each other and a side face extending between the edges of the pair of panel surfaces, with the plurality of joint surfaces being provided as a part of the side face.

The PC panel is disposed so that the panel surface runs along the surface of the virtual honeycomb configuration. The panel surface may have such shapes as, for example, trifurcated, hexagonal, octagonal or X shape. The shape can be freely designed through the shape of the formwork.

[0050] The PC panel has higher strength than ordinary reinforced concrete, and is capable of constructing an architectural structure that is highly resistant to vibration. As a result, a building that is less susceptible to temblors and highly habitable can be realized.

[0051] The PC panels are manufactured at factories, and therefore can be easily subjected to quality control. As a result, it becomes easier to ensure reliability of safety of the structural units produced and the architectural structure built using the same, and it is also easy to keep record of the historical information of the structure.

[0052] The PC panel is highly rigid when the panel surface has a shape of a larger surface area (for example, hexagonal or octagonal). In addition, a shape of a larger surface area leads to a greater quantity of concrete and larger weight. A larger surface area has an adverse effect of decreasing the size of the opening that is formed by the structural units. When the PC panel has such a shape that has a smaller surface area, namely a shape similar to a linear member such as a trifurcated or X shape, the PC panel is less rigid and requires a smaller quantity of concrete resulting in lighter weight. A smaller surface area has an adverse effect of increasing the size of the opening that is formed by the structural units. An architectural structure with controlled rigidity can be constructed by combining two or more kinds of PC panels having different shapes (namely having different levels of rigidity).

[0053] For example, it is preferable to construct lower stories with PC panels that have a large surface area so as to form a small opening and construct upper stories with PC panels that have a small surface area so as to form a large opening (claim 14). The size of the openings may also be increased stepwise. The architectural structure constructed in this way has high resistance to earthquakes. It is because a high-rise or super high-rise architectural structure has higher resistance to earthquakes when it is lighter in weight in higher stories and heavier and stronger in lower stories. Also in such an architectural structure, concrete can be used in a rational way without being wasted as the quantity of concrete can be reduced in upper stories.

[0054] In addition, in case the structural unit is formed from a PC panel, the structural unit can be manufactured in a size that is convenient for the vehicle used to transport the structural units for improved efficiency of transportation. Use of PC also enables it to put formworks into port the structural units for improved efficiency of transportation.

[0055] In case high-strength concrete is used, the service life of the architectural structure can be elongated thus contributing to the preservation of resources and providing a structure that can be preferably used as the
skeleton in SI (skeleton infill) separation construction method.

0056] (C) The invention according to claim 11, 16 or 20 has mainly the effects described below. In case the structural units are formed from PC panels, it is preferable that the means of joining two adjacent structural units comprises a tendon that crosses the opposing joint surfaces and passes through both structural units, and anchoring members that apply a post tension to the tendon and fasten both ends thereof on the side face of each structural unit. Connection with high strength can be achieved by fastening the tendon while applying post tension thereto.

0057] Connection with high strength is achieved also by joining one PC panel to an adjacent panel unit by means of three or four tendons that extend in three or four directions.

0058] Applying pre-stress by means of post tension reduces the occurrence of deflection and cracks (should cracks occur, they would be closed by the pre-stress) in spite of long standing stress, and the entire cross section of the concrete member effectively counters against both compressive and tensile stresses. In addition, application of pre-stress is advantageous in protecting the inserted tendon from corrosion, since cracks are prevented from occurring.

0059] A main frame of honeycomb configuration constructed by using the structural units comprising the pre-stressed PC panels according to the present invention is stronger than a frame of the conventional rigid frame structure made of pre-stressed concrete. For example, a 15-storied building of the conventional rigid frame structure is fairly pliant with a natural period of vibration of about 1.5 seconds, while a 15-storied building of the present invention is very stiff with a natural period of vibration of about 0.3 seconds. This means that the present invention is suitable for an upper skeleton of a vibration-isolated building, because a pliant upper skeleton of a vibration-isolated building may compromise the vibration isolating effect of the isolator.

0060] (D) The invention according to claim 26 has mainly the effects described below. In case the structural unit is formed from a PC panel, it is preferable to provide a plurality of slab connecting holes that pass through the structural unit in a direction perpendicular to the pair of panel surfaces. Providing the slab connecting holes at proper positions where a slab can be connected makes it possible to insert the tendons through the concrete slab and secure it by applying a post tension. Thus strong connection with the slab can be achieved.

0061] (E) The invention according to claim 27 has mainly the effects described below. In case the structural unit is formed from a PC panel, it is preferable that the joint surface is formed from either two sloped surfaces in a ridge shape or two sloped surfaces in a valley shape. A structural unit having joint surfaces formed in a ridge shape and a structural unit having joint surfaces formed in a valley shape can be fitted with each other. This makes it possible to surely prevent rotational movement about an axis perpendicular to the joint surface, so as to maintain the rigid joint.

0062] (F) The invention according to claim 28 has mainly the effects described below. In case the structural units are formed from PC panels, the structural unit used in a portion where the virtual honeycomb configuration is curved has a bending section. When the structural units are arranged in such a way as the bending section runs along the direction of erecting the virtual honeycomb configuration, two surfaces adjoining on the bending section can be disposed at an angle from each other. The bending angle of the bending section may be relatively small, and a significant angle in the surface of the structure can be realized by repeating the small bending sections. Thus it is made possible to construct a tube frame that has a curved cross section (circle, oval or a part thereof) in the horizontal plane.

0063] (G) The invention according to claim 12 has mainly the effects described below. In accordance with the present invention, an architectural structure having a main frame of honeycomb configuration can be constructed from steel, reinforced concrete, steel-encased reinforced concrete or wood, as long as the structural units of a similar configuration can be manufactured from a material other than PC panels.

0064] (H) The invention according to claim 24 or 25 has mainly the effects described below. In case the structural unit to be disposed at two adjacent apexes of a hexagonal cell is formed from a PC panel, it may be significantly larger in size and weight than an ordinary PC panel. In such a case, it is preferable to use half-units, that are equal divisions of a PC panel. Use of the half-units enables it to construct the main frame of the present invention without troubles in manufacture, transportation and assembly.

0065] (I) The invention according to claim 29 has mainly the effects described below. The architectural structure having the main frame formed by connecting a plurality of the structural units formed from the PC panels is constructed by a method in which two adjacent structural units are disposed to have the joint surfaces opposing each other so that tendon insertion holes thereof are aligned, a tendon is inserted through the tendon insertion hole to pass through the two structural units, and the tendon is fastened by applying post tension to the tendon, thereby joining the two structural units. This method improves the workability of construction since the connection of a plurality of PC panels is completed by joining every two members. The construction work is simply to insert a tendon, apply post tension thereto and fasten both ends of the tendon, with less work load. In the case of a conventional rigid frame structure, in contrast, all long beams and pillars must be connected together and it is difficult to complete connection work by connecting every two members.

0066] In addition, the construction method of the present invention is a dry method that eliminates the need...
of curing of concrete required in a wet process such as reinforced concrete structure with on-site concrete placement, thus resulting in a shorter period of construction work.

BRIEF DESCRIPTION OF THE DRAWINGS

[0067]

Fig. 1 is a front view showing a partial constitution in one example of a main frame of the architectural structure constructed by using the structural units of the present invention, (A1) showing a part of the main frame that uses unit 1, (A2) showing modifications of unit 1, (B1) showing a part of the main frame that uses unit 4, and (B2) showing modifications of unit 4.

Fig. 2 is a front view showing a partial constitution in another example of the main frame of the architectural structure constructed by using a plurality of structural units of the present invention, (A) showing a part of the main frame that uses the unit 2 shown in Fig. 1, and (B) showing a part of the main frame that uses the unit 5 shown in Fig. 1.

Fig. 3 is a front view showing a partial constitution in another example of the main frame of the architectural structure constructed by using the structural units of the present invention, (A1) showing a part of the main frame that uses unit 7, (A2) showing modifications of unit 7, (B1) showing a part of the main frame that uses unit 10, and (B2) showing modifications of unit 10.

Fig. 4 is a front view showing a partial constitution in another example of the main frame of the architectural structure constructed by using a plurality of structural units of the present invention, (A) showing a part of the main frame that uses unit 8 shown in Fig. 3, and (B) showing a part of the main frame that uses unit 11 shown in Fig. 3.

Fig. 5 is a front view showing an example of an arrangement pattern of the structural units according to the honeycomb configuration formed from the hexagonal cells H1.

Fig. 6 is a front view showing an example of an arrangement pattern of the structural units according to the honeycomb configuration formed from the hexagonal cells H2.

Fig. 7(A) is a perspective overview of the tube frame 100 that serves as the main frame constructed by using the trifurcated structural units, (B) is an enlarged front view of a part of the tube frame 100 shown in Fig. 7(A), and (C) is a top view.

Fig. 8 is a partially enlarged view of the main frame 100 shown in Fig. 7.

Fig. 9 is an enlarged perspective view showing the state of two structural units shown in Fig. 8 being joined in more detail.

Fig. 10 shows an example of the structural unit, (A) being a top view and (B) being a sectional view taken along line X-X.

Fig. 11 is a perspective view showing a part of the main frame constructed by using a modification of the unit shown in Fig. 10.

Fig. 12 is a perspective view showing a method of joining the unit shown in Fig. 10 and a slab.

Fig. 13(A) shows a part of an example of a main frame constructed by using still another modification of the unit shown in Fig. 10, (B) is a top view of the unit used to construct the main frame shown in (A), and (C) is a front view thereof.

Fig. 14 shows a modification of the unit shown in Fig. 10, (A) is a perspective overview, and (B) is a front view showing a part of the main frame.

Fig. 15 is a front view showing a part of the main frame of the architectural structure constructed by using the structural units of the present invention.

Fig. 16 is a partially enlarged perspective view of the main frame shown in Fig. 15.

Fig. 17 is a perspective overview of the unit shown in Fig. 16.

Fig. 18 shows the unit shown in Fig. 17, (A) being a front view, (B) being a top view, (C) being a sectional view taken along line Y-Y and (D) being a sectional view taken along line Z-Z.

Fig. 19 is a perspective overview showing the unit that is a special case of the unit shown in Fig. 17.

Fig. 20(A) is a perspective overview of a modification of the unit shown in Fig. 17, (B) is a rear view showing the state of the unit shown in (A) being joined and (c) is a top view showing the state of the units being joined.

Fig. 21(A) is a front view of a modification of the unit shown in Fig. 17, and (B) is a top view.

Fig. 22 is a front view showing a part of the main frame of the architectural structure constructed by using the structural units of the present invention.

Fig. 23 is a partially enlarged perspective view of the main frame 103 shown in Fig. 22.

Fig. 24(A) is a front view, (B) is a top view and (C) is a perspective overview of the unit shown in Fig. 23.

Fig. 25 shows a modification of the unit shown in Fig. 24, (A) being a front view showing the state of the unit being joined, and (B) being a top view thereof.

Fig. 26 is a front view showing a part of the main frame of the architectural structure constructed by using the structural units of the present invention.

Fig. 27 is a partial perspective view of the main frame constituted from the same units as those of the main frame shown in Fig. 26.

Fig. 28(A) to (D) are perspective overviews of the units shown in Fig. 27.

Fig. 29 is a perspective overview of the main frame that is another example but has the same shape as that of the main frame shown in Fig. 27.

Fig. 30(A) to (D) are perspective overviews of the half-units shown in Fig. 29.

Fig. 31(A1) and (A2) are front and top views, respec-
tively, of the state of joining a modification of the unit shown in Fig. 27, and (B1) and (B2) are front and top views, respectively, of the state of joining a modification of another unit shown in Fig. 27.

Fig. 32(A1) and (A2) are a front view and a top view, respectively, of the state of a modification of the unit shown in Fig. 27 being joined, and (B1) and (B2) are front and top views, respectively, of the state of a modification of another unit shown in Fig. 27 being joined.

Fig. 33 is a partial perspective view of the main frame of the architectural structure, that is one example of the present invention using members other than PC panels.

DETAILED DESCRIPTION OF THE INVENTION

[0068] Basic embodiments of the present invention will now be described with reference to Figs. 1 to 6. While Figs. 1 to 6 illustrate examples where the structural units formed from the PC panels that are preferable for the present invention are used, the structural units of the present invention are not limited to PC panels. Hereinafter the structural unit may be referred to simply as “unit”.

Fig. 1 is a front view showing a partial constitution in one example of a main frame of an architectural structure constructed by using a plurality of structural units of the present invention. The portion depicted is, for example, a part of a tube frame that constitutes the exterior of the building. Two-way arrow X and Y indicates the horizontal directions and two-way arrow Z indicates the vertical directions (the same applies to subsequent figures). Fig. 1 (A1) shows a part of the main frame that uses unit 1. Fig. 1 (A2) shows unit 2 and unit 3 that are modifications of unit 1. Fig. 1 (B1) shows a part of the main frame that uses unit 4. Fig. 1 (B2) shows unit 5 and unit 6 that are modifications of unit 4.

[0070] Fig. 1 shows the front view of the main frame and the structural unit, where the structural units 1 to 6 that are formed from PC panels have predetermined thicknesses (dimension perpendicular to the paper of drawing, the same applies to similar drawings).

[0071] Fig. 1 shows a part of a virtual honeycomb configuration that is erected vertically and expands in a plane, indicated by alternate dot and dash line. A hexagonal cell H1 that is a unit cell is disposed so that the top side (line between apex h1 and apex h2) and the bottom side (line between apex h4 and apex h5) lie in horizontal directions.

[0072] The "virtual honeycomb configuration" in the present invention is an imaginary entity having the honeycomb pattern consisting of hexagonal cell H1 (or hexagonal cell H2 of Fig. 2) disposed in two dimensional repetition without a gap. The word "virtual" means that the virtual honeycomb configuration is not a member of physical existence. However, virtual honeycomb configuration is an important concept for defining the positions where the structural units are to be disposed and the relative positions of the adjacent structural units. Accordingly, the present invention will be described in this specification on the assumption that the virtual honeycomb configuration exists in the physical space.

[0073] The virtual honeycomb configuration is basically erected vertically and expands in a plane. Designs where the virtual honeycomb configuration is erected at a predetermined angle from the vertical direction for an aesthetical reason are within the scope of the present invention. The term "plane" in this specification includes flat plane and curved plane (the same applies to the description that follows).

[0074] The hexagonal cell H1 that is a unit cell may not necessarily be an equilateral hexagon, but is at least symmetrical with respect to its vertical centerline (the same applies to the hexagonal cell H2 of Fig. 2). Each of the six sides of the unit cell is shared by adjoining two unit cells, and each of six apaxes h1 to h6 is shared by three adjoining unit cells.

[0075] Making reference to Fig. 1 (A1), six units 1 are disposed at positions that include the apaxes h1, h2, h3, h4, h5 and h6 of the hexagonal cell H1. Two units disposed at adjacent apaxes (for example, h1 and h2, or h2 and h3) are joined together with the joint surfaces provided in a part of the circumferences thereof opposing each other. Each of six surfaces s1, s2, s3, s4, s5 and s6 that are joined crosses one of the sides of the hexagonal cell H1. For example, surface s1 crosses the side between the apaxes h1 and h2. In other words, connection of units is made on sides of the hexagonal cell H1, not on apaxes. As a result, all units disposed on the hexagonal cell H1 are connected with each other to form a ring, and an opening W surrounded by these units is formed in the mid portion of the hexagonal cell H1. It may also be that the opening W is surrounded by non-joint surfaces of the units.

[0076] As described above, the plurality of structural units are disposed so as to occupy all apaxes and sides of the plurality of hexagonal cells that constitute the honeycomb configuration, and adjoining structural units are connected together with the joint surfaces thereof opposing each other. For the means of connection, it is convenient in the case of structural units made of PC panels, for example, to insert a tendon so as to cross the opposing joint surfaces of two units and apply a post tension to the tendon to fasten, but such means are not limited to this method. Although it is preferable to connect the units rigidly, the connection may also be of an intermediate type between rigid connection and flexible connection, or even flexible connection. While a honeycomb structure has an effect of transforming a part of bending force into axial force and transmitting it, connecting the units by rigid joint is effective in absorbing a part of bending force that has not been transformed into axial force.

[0077] The unit 1 shown in Fig. 1 (A1) has such a constitution that has a trifurcated panel surface in front view where the side face located at the distal end of each of the three legs, that extend from the center in three
H1 connected together in the honeycomb configuration. For example, a tube frame formed from hexagonal cells located on the sides of the hexagonal cell correspond to as shown in Fig. 1, the members of the structural unit reality of the structural units on the apexes and sides of the hexagonal cell H1. As shown in Fig. 1 (A1) where units 2 and 3 are indicated by dashed lines, the shapes of units 1 to 3 are the same in the position and shape of the joint surfaces (position relative to the hexagonal cell and shape, the same applies to the description that follows), with only the non-joint surfaces being different in shape. Units that have the same joint surfaces can be joined together even when their non-joint surfaces have different shapes (the same applies to examples of other units that follow). The shape of the non-joint surface can vary continuously, for example, between the valley shape of unit 1 to the ridge shape of unit 3. The shape of the non-joint surfaces may be a collection of a plurality of flat or curved surfaces, concave surfaces or convex surfaces. The shapes of several units will be described in detail in examples to be given later.

As will be clearly seen from Fig. 1 (A1), the opening W formed by unit 1 is the largest and the opening W formed by unit 3 is the smallest. Thus the larger the panel surface of the unit is, the smaller the opening W that is formed. When the shape of the non-joint surface is different, the shape of the opening W surrounded by the non-joint surfaces is also different.

Referring to Fig. 1 (B1), six units 4 are disposed at positions that include the apexes h1, h2, h3, h4, h5 and h6 of the hexagonal cell H1. As shown by the dashed lines that depict units 5 and 6, units 4 to 6 have the same position and shape of the joint surface, and are different only in the shape of the non-joint surface. Units 4 to 6 are disposed on the hexagonal cell H1 that is the same as that of Fig. 1 (A1), but have joint surfaces of larger areas than those of units 1 to 3. As a result, surfaces s1 to s6 where adjacent units are joined together have larger areas than those of Fig. 1 (A1), and the openings W formed thereby are smaller. Unit 4 has concave non-joint surfaces. Unit 5 has a panel surface of an equilateral hexagonal shape, a similar form to that of unit 2. Unit 6 has convex non-joint surfaces.

The main frame constitutes a main portion of the exterior of the building. Fig. 3 (A1) shows a part of the main frame that uses unit 7. Fig. 3 (A2) shows unit 8 that uses unit 10. Fig. 2 (B2) shows unit 11 and unit 12 that are modifications of unit 10. Unit 11 is a non-joint surface. Units 4 to 6 indicated by dashed lines are used in a similar manner. Fig. 2 (B) shows a part of the main frame that uses unit 5 shown in Fig. 1. Units 4 and 6 indicated by dashed lines are used in a similar manner.

The hexagonal cells H2 that are unit cells of a virtual honeycomb configuration depicted by alternate dot and dash line in Fig. 2 are disposed so that the left side (line between apex h5 and apex h6) and the right side (line between apex h2 and apex h3) lie in vertical directions. The hexagonal cell H2 and the hexagonal cell H1 are, in case they are equilateral hexagons, 60 degrees apart from each other. A tube frame formed from the hexagonal cells H2 connected together in a honeycomb configuration is substantially constituted from vertical pillars and diagonal pillars disposed alternately and beams disposed continuously in a zigzag manner.

In units 1 to 6 shown in Fig. 1 and Fig. 2, one unit is disposed on each apex of the hexagonal cell H1 or H2. This means that one unit is shared by three adjacent hexagonal cells H1 or H2.

Fig. 3 is a front view partially showing the constitution in another example of a main frame of an architectural structure constructed by using a plurality of structural units of the present invention. The portion depicted is, for example, a part of a tube frame that constitutes the exterior of the building. Fig. 3 (A1) shows a part of the main frame that uses unit 7. Fig. 3 (A2) shows unit 8 and unit 9 that are modifications of unit 7. Fig. 3 (B1) shows a part of the main frame that uses unit 10. Fig. 3 (B2) shows unit 11 and unit 12 that are modifications of unit 10. Fig. 3 shows a part of a virtual honeycomb configuration that is erected vertically and expands in a plane by alternate dot and dash line. A hexagonal cell H1 that is a unit cell thereof is disposed so that the top side (line between apex h1 and apex h2) and the bottom side (line between apex h4 and apex h5) lie in horizontal directions.

Referring to Fig. 3 (A1), three units 7 are disposed at positions that include first pair of apexes h1 and h2, second pair of apexes h3 and h4 and third pair of apexes h5 and h6, each of which is a pair of adjacent apexes of the hexagonal cell H1. Two units disposed at adjacent apexes (for example, the first pair of apexes h1 and h2 and the second pair of apexes h3 and h4) are joined together with the joint surfaces provided in a part.
of the circumferences thereof opposing each other. Each of the three surfaces s2, s4 and s6 that are joined crosses one of the sides of the hexagonal cell H1. For example, surface s2 crosses the side between the apexes h2 and h3. In other words, connection of units is made on sides of the hexagonal cell H1, not on apexes. As a result, all units disposed on the hexagonal cell H1 are connected with each other to form a ring, and an opening W surrounded by these units is formed in the mid portion of the hexagonal cell H1. It may also be that the opening W is surrounded by the non-joint surfaces of the units.

(0088) The phrase “adjacent apexes” refers to the apexes located at both ends of one side of the hexagonal cell that constitutes the honeycomb configuration. Each of the plurality of units disposed in a ring on one hexagonal cell may not necessarily be disposed on two apexes within the hexagonal cell, but one apex of the hexagonal cell and one apex of an adjacent hexagonal cell may be treated as a pair (refer to Fig. 6 and Fig. 9 to be described later).

(0089) The unit 7 shown in Fig. 3 (A1) has four legs that branch off in two directions from both ends of one rod in front view, and the side face located at the distal end of each of the four legs that extend in four directions is used as the joint surface with adjoining units. The concave side face interposed between two joint surfaces is a non-joint surface. The unit 7 can have a shape formed by integrating the joint surfaces of one leg of each of two units 1 shown in Fig. 1. In other words, disposing two units shown in Fig. 1 and disposing one unit shown in Fig. 3 can result in the same shape in some cases.

(0090) Fig. 3 (A2) shows modifications. Unit 8 has an octagonal shape in front view, with the eight sides thereof constituted from short sides and long sides disposed alternately. Side faces a, b, c and d that include short sides serve as the joint surfaces with the adjacent units, and side faces e, f, g and h that include long sides are non-joint surfaces. Unit 9 has such a modified shape of unit 8 that the long side is changed to have a ridge at the center. As shown in Fig. 3 (A1) where units 8 and 9 are indicated by dashed lines, the shapes of units 7 to 9 are the same in the position and shape of the joint surfaces, with only the non-joint surfaces being different in shape. The shape of the non-joint surface can vary continuously, for example, between the valley shape of unit 7 and the ridge shape of unit 9. The shapes of several units will be described in detail in examples to be given later.

(0091) As will be clearly seen from Fig. 3 (A1), the opening W formed by the units 7 is the largest and the opening W formed by the units 9 is the smallest. Thus the larger the panel surface of the unit is, the smaller the opening W that is formed. When the shape of the non-joint surface is different, the shape of the opening W formed thereby is also different.

(0092) Referring to Fig. 3 (B1), three units 10 are disposed at positions that include first pair of apexes h1 and h2, second pair of apexes h3 and h4 and third pair of apexes h5 and h6, each of which is a pair of adjacent apexes of the hexagonal cell H1. As shown by the dashed lines that depict units 11 and 12, units 10 to 12 have the same position and shape of the joint surface, and are different only in the shape of the non-joint surface. Units 10 to 12 are disposed on the hexagonal cell H1 that is the same as that of Fig. 3 (A1), but have joint surfaces of larger areas than those of units 7 to 9. As a result, surfaces s2, s4 and s6 where adjacent units are joined together have larger areas than those of Fig. 3 (A1), and the opening W formed thereby is smaller. Unit 10 has concave non-joint surfaces. Unit 11 has octagonal panel surfaces with a similar configuration to that of unit 8, although this is a modification with a different ratio of lengths between short sides and long sides. Unit 12 has convex non-joint surfaces.

(0093) Fig. 4 is a front view showing a partial constitution in another example of a main frame of an architectural structure constructed by using a plurality of structural units of the present invention. Fig. 4 (A) shows a part of the main frame that uses unit 8 shown in Fig. 3. Units 7 and 9 indicated by dashed lines are used in a similar manner. Fig. 4 (B) shows a part of the main frame that uses unit 11 shown in Fig. 3. Units 10 and 12 indicated by dashed lines are used in a similar manner.

(0094) The hexagonal cell H12 that is a unit cell of a virtual honeycomb configuration depicted by alternate dot and dash line in Fig. 4 is disposed so that the left side (line between apex h5 and apex h6) and the right side (line between apex h2 and apex h3) lie in vertical directions. The tube frame formed from the hexagonal cells H2 that are connected together in a honeycomb configuration is substantially constituted from vertical pillars and diagonal pillars disposed alternately and beams disposed continuously in a zigzag manner.

(0095) The arrangements of the units shown in Fig. 3 and Fig. 4 are mere examples, and the arrangement of units that includes a pair of adjacent apexes of the hexagonal cell H1 or H2 is not limited to this. Although not shown, for example, three units may be disposed in such an arrangement that h2 and h3 form the first pair, h4 and h5 form the second pair and h6 and h1 form the third pair in Fig. 3 and Fig. 4.

(0096) In the arrangement of units shown in Fig. 3 and Fig. 4, all of the three units are disposed on the three pairs of apexes included in one hexagonal cell, although one of the units may be disposed on a pair of one apex of the hexagonal cell and one apex of a different hexagonal cell (provided that the pair of apexes are located on both ends of one side). Other modifications of arrangement will be described later with reference to Fig. 5 and Fig. 6.

(0097) In the case of units 7 to 12 shown in Fig. 3 and Fig. 4, one unit is disposed so as to include two apexes of the hexagonal cell H1 or H2. This means that one unit is shared by four hexagonal cells H1 or H2.

(0098) Fig. 5 is a front view showing an example of an arrangement pattern of the structural units according to the honeycomb configuration formed from the hexagonal
cells H1. Units 8 shown in Fig. 3 are disposed in an arrangement pattern A for the upper portion and in an arrangement pattern B for the lower portion in this example. Similar arrangements can be made by using any of the units 7 to 9 shown in Fig. 3 or mixing these units.

In the arrangement pattern A, arrangement of three units shown in Fig. 3 is repeated. In the arrangement pattern A, three kinds of openings Wa, Wb and Wc are formed. The openings Wa and Wb have triangular shapes disposed in reverse orientations, and the opening Wc is a hexagon. The opening Wa is surrounded by three units, and these three units occupy two apexes included in this hexagonal cell (the same applies to the opening Wb). The opening Wc is surrounded by six units, and each of these six units does not occupy two apexes included in this hexagonal cell, but occupies one apex of the hexagonal cell and one apex of adjacent hexagonal cells.

In the arrangement pattern B, one unit occupies two apexes located on both ends of the top side and the bottom side (in horizontal direction) in all hexagonal cells H1. As a result, four units are disposed on one hexagonal cell. Among the four units, two units occupy four apexes of the top side and the bottom side, and the other two units occupy one apex of the hexagonal cell and one apex of the adjacent hexagonal cells. In the arrangement pattern B, a rectangular opening Wd is formed.

Further, the arrangement patterns A and B can be connected continuously, and a pentagonal window We is formed in the border between these arrangement patterns.

Fig. 6 shows an example where another mixed pattern is included in an upper portion. On the left hand side of the mixed pattern, units 7 are connected on the uppermost units of the units 8 in the arrangement pattern A. Units 8 and 7 have the same joint surfaces and can therefore be connected with each other. On the right hand side of the mixed pattern, units 1 shown in Fig. 1 are connected on the uppermost units of the units 8 in the arrangement pattern B, and units 7 are connected on the units 1. Units 1 to 3 shown in Fig. 1 and units 7 to 9 shown in Fig. 3 have the same joint surfaces and can therefore be connected with each other in a mixed arrangement.

Examples described below are intended merely to exemplify these modifications, and do not restrict the present invention.

Example 1

By making reference to Figs. 7 to 14, examples of architectural structures having a main frame formed by connecting structural units that are disposed in a virtual honeycomb configuration will be described. Fig. 7(A) to (C) show an example of the main frame of the architectural structure constructed by using the structural units 1 having a trifurcated shape shown in Fig. 1. (A) is a perspective view of a tube frame 100 that serves as the main frame. (B) is an enlarged front view of a part of the tube frame 100 of Fig. 7(A). (C) is a top view.

The tube frame 100 shown in Fig. 7(A) is constructed in accordance with the virtual honeycomb configuration formed from the hexagonal cells H1 as the unit cells shown in Fig. 1, and the virtual honeycomb configuration as a whole has a tubular shape. The axis of the tube extends in the vertical direction. In case the trifurcated unit 1 is used as the structural unit to be disposed on the virtual honeycomb configuration, the main frame, upon completion of its construction, shows a shape substantially identical with the virtual honeycomb configuration in overview. This is because joining the legs of two adjacent units 1 together forms one diagonal pillar or
beam, and the diagonal pillar or beam occupies one side of the hexagonal cell of the virtual honeycomb configuration.

[0112] The hexagonal cell H1 formed in an equilateral hexagonal shape is a mere example, and the shape may not necessarily be an equilateral hexagon as long as it is symmetrical with respect to its vertical centerline.

[0113] As shown in Fig. 7(B), six units 1 disposed on one hexagonal cell H1 form a structure of a hexagonal configuration (which will be referred to as hexagonal structure section). One hexagonal structure section includes only two legs of the three legs of each unit 1. The hexagonal structure section is constituted from six linear structural members; a top side member r1, a top right side member r2, a bottom right side member r3, a bottom side member r4, a bottom left side member r5, and a top left side member r6. In the tube frame constructed in this way, the beams do not continue in the horizontal direction and the pillars are diagonal pillars that are disposed continuously in a zigzag manner, a constitutional feature that makes the tube frame of the present invention essentially different from a tube frame of a conventional rigid structure.

[0114] As shown in Fig. 7(B), the hexagonal structure section formed from six units 1 is symmetrical with respect to its vertical centerline. For the right sides, for example, the top right side member r2 and the bottom right side member r3 that are two diagonal pillars inclined in opposite directions with respect to the vertical direction are joined together. The top right side member r2 is inclined by an angle α with respect to the vertical direction, and the bottom right side member r3 is inclined by an angle -α with respect to the vertical direction. The bottom left side member r5 and top left side member r6 that form the sides on the left side are also diagonal pillars that are inclined similarly. The top side member r1 and the bottom side member r4 are horizontal beams. The pillars are joined rigidly to each other, and the pillars and the beams are joined rigidly to each other.

[0115] The architectural structure having such a constitution has a tubular structure that is capable of exerting a great bearing force against horizontal load applied from any direction. Also in the tube frame formed from the hexagonal structure section, all joints of the pillars and beams show a well-balanced stability. As a result, bending stress generated by load in the joint of pillar and beam is less than the stress generated in a tube frame of a conventional rigid frame structure. This is because a part of the bending force is transformed into axial force against members (pillars and beams) and is transmitted. In addition, the PC member has higher strength against compressive force, and provides advantage in bearing an axial force.

[0116] Further as shown in Fig. 7(B), the tube frame 100 has no joint surface between units 1 on the joint between a pillar and a beam. The joint surfaces between units 1 are located at an intermediate point between beams, and such point between pillars. In this regard, too, the tube frame of the present invention is advantageous in terms of structural resistance.

[0117] As shown in the top view of Fig. 7(C), the tube frame 100 of the example shown has a substantially rectangular cross section. The surface of the hexagonal structure section formed at each of the four corners of the cross section is directed toward the apex of the rectangle, with the four corners of the rectangle being cut off. While the side face of tube frame 100 shown in Fig. 7 substantially consists of flat surface, the cross section may be a circle (the tube frame forms a curved surface) or any polygon, or may even include a concave portion. In case the virtual honeycomb configuration includes a curved surface or bend, it may be formed by using a structural unit having a special configuration which will be described later.

[0118] Fig. 8 is a partially enlarged view of the main frame 100 shown in Fig. 7 (Fig. 8 shows the hexagonal cell H1 as an equilateral hexagon). As shown, six units 1(1) to 1(6) are used for one hexagonal cell H1 (the numbers given in parentheses are the numbers used to identify the units disposed in one hexagonal cell H1, the same applies hereafter). The unit 1 is a PC member that has three legs extending from the center in three directions. The panel surface is triruncated in front view. The branching point of each unit 1 is located at the apexes h1 to h6 of the hexagonal cell H1. Joints s1 to s6 between adjacent units 1 are located at mid points of the sides of the hexagonal cell H1, not at the apexes of the hexagonal cell H1. The legs of each unit 1 occupy one half of the length of each side of the hexagonal cell H1. Two of the three legs belong to one hexagonal cell and the remaining one belongs to another hexagonal cell. For every unit 1, two of the three legs are used as diagonal pillars and the remaining one is used as a beam.

[0119] The opening W surrounded by six units 1(1) to 1(6) that are disposed on the hexagonal cell H1 is formed in the mid portion of the hexagonal cell H1. In this example, the opening W has a hexagonal shape disposed in the same orientation as the hexagonal cell H1.

[0120] As shown in Fig. 8, two adjacent units 1 are joined together with the joint surfaces thereof opposing each other at the mid point of each side of the hexagonal cell H1. Connection of two adjacent units 1 is made by means of tendons 21a, 21b and 21c indicated by dashed line. For example, units 1(1) and 1(2) are penetrated by the tendon 21a passing through the joint surfaces thereof that oppose each other. The tendon 21a is subjected to a post tension and both ends thereof are then fastened by means of a pair of anchoring members 22a, 22a. Similarly, units 1(2) and 1(3) are penetrated by the tendon 21b that is fastened by means of anchoring members 22b, 22b. Similarly, units 1(3) and 1(4) are penetrated by the tendon 21c that is fastened by means of anchoring members 22c, 22c. By joining every pair of adjacent units in this way, each joint surface is prevented from rotating, thus providing a rigid joint. Moreover, strength of the rigid joint is increased by the post tension of the tendon.
[0121] Fig. 9 is an enlarged perspective view showing the joint between two structural units in more detail. In Fig. 9, a lower leg of the unit 1(3) and an upper leg of the unit 1(4) are joined together to form the diagonal pillar of the lower right side of the hexagonal structure section, with the joint surface thereof located at the mid point of the diagonal pillar. When the joint surfaces located at the distal ends of the legs of both units are disposed to oppose each other, the members are aligned so that the tendon insertion holes (to be described in detail with reference to Fig. 10) formed in the units communicate with each other. Then the tendon 21c is inserted into the tendon insertion holes that have been put into communication with each other. The tendon 21c normally comprises PC steel. The tendon 21c normally comprises PC steel. The tendon 21c is inserted through the valley between two legs of the unit 1(3) to the valley between two legs of the unit 1(4). Then the tendon 21c is subjected to a post tension and both ends thereof are fastened by means of anchoring members 22c, 22c.

[0122] Every connection between two adjacent units is made as described above. As a result, three tendons that extend in different directions seemingly cross each other in a mid portion in the unit 1. While the mid portion of the unit 1 is located at an apex of the hexagonal cell and is therefore subjected to concentrated stress. However, since there is no joint in this portion and three tendons are disposed therein, an extremely strong structure is realized. Also, connection between two adjacent units is made at the mid point of each side where relatively small stress is generated, which is advantageous for the structure.

[0123] Applying pre-stress by means of post tension reduces the occurrence of deflection and cracks in spite of long standing stress, and the entire cross section of the concrete member effectively counters against both compressive and tensile stresses. As a result, a frame of a large span can be constructed. In addition, the application of pre-stress is advantageous in protecting the inserted tendon from corrosion, since cracks are prevented from occurring (these advantages are provided similarly by examples that follow).

[0124] When joining the joint surfaces of two units, it is preferable to form a narrow gap between the two joint surfaces that oppose each other, and fill the gap with mortar, resin mortar, grout or the like that has higher strength than PC. Such a filler enables it to accommodate errors in the construction work, thereby improving the efficiency of construction work (the same applies to examples that follow).

[0125] Fig. 10 shows the constitution of the unit 1 in detail. Fig. 10(A) is a side view from the side of joint surface 1a at the distal end of one leg, and Fig. 10(B) is a sectional view taken along line X-X in (A).

[0126] The unit 1 is a PC panel manufactured using a predetermined formwork. As will be clearly seen from Fig. 10(B), the unit 1 has a trifurcated panel surface in front view and has a predetermined thickness between a front panel surface 1i and a back panel surface 1j as shown in Fig. 10(A). The unit 1 has three legs that extend from the center C in three directions, and side faces 1a, 1b, 1c at the distal ends of the legs are joint surfaces. The joint surfaces 1a, 1b, 1c are perpendicular to the directions in which the respective legs extend. Each leg has a constant width in front view, and has a rectangular cross section. The thickness and width of each leg are determined in accordance with the architectural structure to be constructed.

[0127] The side surfaces other than that located at the distal ends of the legs are non-joint surfaces. A valley is formed by non-joint surfaces 1d2 and 1d3 between the joint surfaces 1a and 1b. A valley is formed by non-joint surfaces 1e2 and 1e3 between the joint surfaces 1b and 1c. A valley is formed by non-joint surfaces 1f2 and 1f3 between the joint surfaces 1c and 1a.

[0128] As shown in Fig. 10(B), the unit 1 has three tendon insertion holes 1a3, 1b3, 1c3 bored therein. These tendon insertion holes are formed during manufacture of the PC panel and sheaths (not shown) for passing the tendons are embedded therein. While the three tendon insertion holes 1a3, 1b3, 1c3 appear to cross each other in front view, actually they are disposed at different positions in the direction of thickness so as not to overlap each other as shown in Fig. 10 (A). The tendon insertion hole 1a3 passes through from the joint surface 1a along the longitudinal direction of the first leg to the bottom of valley 1e1 between the second leg and the third leg. The tendon insertion hole 1b3 passes through from the joint surface 1b along the longitudinal direction of the second leg to the bottom of valley 1f1 between the third leg and the first leg. The tendon insertion hole 1c3 passes through from the joint surface 1c to the bottom of valley 1d1 between the first leg and the second leg.

[0129] The unit 1 shown in Fig. 10 has three legs that have the same length and are disposed at equal angles (120 degrees) from each other. The unit 1 having such a configuration is used in the case where the hexagonal cell H1 has an equilateral hexagonal shape as shown in Fig. 8. In this case, every leg may be used as either a diagonal pillar or beam. This means that the unit 1 can be used in any orientation and provides an advantage of convenience for the construction work.

[0130] Although the hexagonal cell H1 is symmetrical with respect to a vertical centerline as described with reference to Fig. 7, it may not be an equilateral hexagon. That is, the side corresponding to a diagonal pillar and a side corresponding to a beam may be different in length. In the latter case, the unit 1 has one leg used as a beam of a length different from the length of two legs used as diagonal pillars. In this case, too, two legs used as diagonal pillars should be equal in length. While the angles which the leg used as a beam extends with the two legs used as diagonal pillars must be equal, this angle may be different from the angle between the two legs used as diagonal pillars.

[0131] Fig. 11 is a perspective view showing a part of a main frame constructed by using a modification of the
unit 1. The modification is a combination of two kinds of units 1A and 1B, which are disposed alternately on the hexagonal cell. The modification is different from the unit 1 described previously in the shape of the joint surface of each leg.

[0132] The joint surfaces of the three legs of the unit 1A form ridges, each consisting of two sloped surfaces (1A4 and 1A5, 1B4 and 1B5, 1C4 and 1C5). In contrast, the joint surfaces of the three legs of the unit 1B form valleys, each consisting of two sloped surfaces (1A6 and 1A7, 1B6 and 1B7, 1C6 and 1C7).

[0133] The ridge of the joint surface of unit 1A and the valley of the joint surface of unit 1B have shapes that fit with each other. Accordingly, units 1A and 1B are disposed alternately and are joined together so that the joint surfaces fit with each other. Fastening of the units by applying post tension with the tendons is carried out similarly to the embodiment described previously. When the units are joined together by causing the joint surfaces to fit with each other, the leg can be reliably prevented from rotating, by the interlocking between the ridge and valley shapes, thus producing a stronger structure.

[0134] The shapes of the joint surfaces of the two kinds of unit that fit with each other are not limited to the ridge and valley shapes shown in Fig. 11. A combination of other shapes may be employed as long as the effect of preventing the rotation about the axis can be achieved. For example, a square protrusion may be formed at the center of one joint surface and a square recess may be formed at the center of another joint surface, so as to fit the square protrusion and the square recess with each other. The example of the fitting shapes in a ridge shape and valley shape shown in Fig. 11 are simple and therefore can be easily processed. In addition, since the joint surface is inclined resulting in a larger contact area, an effect of increasing the joint strength is achieved.

[0135] Fig. 12 is a perspective view showing a method of joining the unit 1 and a slab. A plurality of slab connection holes 1g that penetrate the panel surfaces on the front and back are provided for one leg among the three legs of the unit 1. Then the unit 1 is disposed so that the leg having the slab connection holes 1g formed therein serves as a beam. On the other hand, the PC slab 30 has a plurality of tendons 31 embedded therein in advance. The slab connection holes 1g are formed at positions that correspond to the plurality of tendons 31, with the holes having a diameter that allows to insert the tendons.

[0136] To join the unit 1 and the PC slab 30, each tendon 31 is inserted into the slab connection hole 1g and is fastened by an anchoring member in the state of being subjected to post tension.

[0137] Fig. 13(A) shows a part of an example of main frame 101 constructed by using another modification of the unit 1. The main frame 101 employs the virtual honeycomb configuration, that is not flat but is curved, as the basis of the structure. The main frame 101 has the overall shape of a cylindrical tube frame. Fig. 13(B) is a top view of a unit 1C used to construct the main frame 101 shown in (A), and Fig. 13(C) is a front view thereof.

[0138] As shown in Fig. 13(B) and Fig. 13(C), panel surface 1C11 of a leg (that has a joint surface 1Ca at the distal end thereof in this example), that forms a beam, of the unit 1C forms an angle β with a panel surface 1C12 of other two legs (that have joint surfaces 1Cb, 1Cc at the distal ends thereof in this example), that form diagonal pillars. In other words, the former leg is bent at a bend portion 1Ck from the latter two legs. A main frame having curved surface can be constructed by joining units 1C having such bend portion 1Ck. In another example, the bent unit 1C may be used at a bending position where two flat surfaces of the main frame intersect (for example, corner of the tube frame shown in Fig. 7). The angle β is set to such an extent that would not have adverse influence on joining of two units 1C by means of the tendon subjected to post tension or on joining of the unit 1C with other units that can be joined.

[0139] Further, use of the bent unit 1C makes it possible to continuously form not only a curved surface that bends in one direction but also a curved surface that bends in the opposite direction. For example, a curved surface that undulates when viewed from above.

[0140] In case the main frame is parallel to the vertical direction also in the curved surface portion such as in the tube frame shown in Fig. 13(A), the units 1C are disposed so that the bend portion 1Ck lies in parallel to the vertical direction. In another example, the main frame may not be parallel to the vertical direction in the curved surface portion (such as a curved surface like a part of a dome). In this case, the direction of the bend portion 1Ck is set so as to correspond to the direction in which the surface of the main frame bends.

[0141] Combining the flat unit 1 shown in Fig. 10 and the bent unit 1C shown in Fig. 13 makes it possible to construct a main frame having a flat surface portion and a curved surface portion.

[0142] Fig. 14 shows a unit 1D that is a modification of the unit 1 shown in Fig. 10, (A) is a perspective overview, and (B) is a front view showing a part of the main frame formed by connecting six units 1D that are disposed on a hexagonal cell.

[0143] The shapes and positions of joint surfaces 1Da, 1Db and 1Dc of the unit 1D are the same as those of the unit 1, and therefore the unit 1D can be joined with the unit 1 or the unit 1C. The unit 1D is different from the unit 1 in the shape of the non-joint surface. The unit 1D has a shape in which the valley of the non-joint surface is modified to decrease the depth. The legs of the unit 1D do not have a constant width, and the width increases from the joint surfaces 1Da, 1Db and 1Dc toward the center. For example, angle δ extended by the side face 1D13 and the adjacent joint surface 1Da (also the angle extended by the side face 1D12 and the adjacent joint surface 1Dc) is an obtuse angle (δ is 90 degrees in the unit 1). Any modification of the unit 1 where the angle in the panel surface falls in a range of $90^\circ \leq \delta < 120^\circ$ will be
faces may be used as joint surfaces depending on the long side faces as joint surfaces. However, the long side opening $W$ can be obtained than in the case of using the three short side faces as joint surfaces, a larger long side faces of each unit as non-joint surfaces and the three posed alternately. It is preferable to use the three short side faces to join other each and joined together. Each of the six surfaces $s_1, s_2, s_3, s_4, s_5$ and $s_6$ that are jointed crosses one of the sides of the hexagonal cell $H_1$. Two joint surfaces are used to join one unit with the adjoining units on both sides thereof on the hexagonal cell $H_1$. As a result, the six units are connected with each other to form a ring, and an opening $W$ (indicated by thick alternate two dots and dash line) surrounded by these units is formed at the center of the hexagonal cell $H_1$. In this state, the remaining one joint surface of each unit extends radially from the center and can join with the short side face of one unit included in the adjacent hexagonal cell.

Example 2

By making reference to Figs. 15 to 21, another example of an architectural structure having a main frame formed by connecting structural units that are disposed in a virtual honeycomb configuration will be described. Fig. 15 is a front view showing a part of a main frame 102 of the architectural structure formed by using the structural units, for example, a part of a tube frame similar to that shown in Fig. 7(A). Fig. 16 is a partially enlarged perspective view of the main frame 102 shown in Fig. 15.

The main frame 102 shown in Fig. 15 is constructed by connecting the structural units 2 shown in Fig. 1 that are disposed for the virtual honeycomb configuration formed from the hexagonal cells $H_1$ (indicated by thick alternate dot and dash line) as the unit cells shown in Fig. 1.

The unit 2 has a hexagonal panel with six sides as shown in Fig. 15 in front view, and has a predetermined thickness (in the direction perpendicular to the paper of drawing). In other words, the unit has six side faces extending between the sides of the pair of panel surfaces on the front and back as shown in Fig. 16. In the example shown, the six sides that constitute the periphery of the hexagonal panel surface consist of two kinds of sides of different lengths, long sides and short sides, disposed alternately. Accordingly, the side face extending between short sides on both panel surfaces is a short side face and the side face extending between long sides on both panel surfaces is a long side face. In each unit, the three short side faces and the three long side faces are disposed alternately. It is preferable to use the three short side faces of each unit as joint surfaces and the three long side faces of each unit as non-joint surfaces. By using the three short side faces as joint surfaces, a larger opening $W$ can be obtained than in the case of using the long side faces as joint surfaces. However, the long side faces may be used as joint surfaces depending on the example of an architectural structure having a main frame formed by connecting the structural units that are disposed in a virtual honeycomb configuration will be described. Fig. 15 is a front view showing a part of a main frame 102 of the architectural structure formed by using the structural units, for example, a part of a tube frame similar to that shown in Fig. 7(A). Fig. 16 is a partially enlarged perspective view of the main frame 102 shown in Fig. 15.

The main frame 102 shown in Fig. 15 is constructed by connecting the structural units 2 shown in Fig. 1 that are disposed for the virtual honeycomb configuration formed from the hexagonal cells $H_1$ (indicated by thick alternate dot and dash line) as the unit cells shown in Fig. 1.

The unit 2 has a hexagonal panel with six sides as shown in Fig. 15 in front view, and has a predetermined thickness (in the direction perpendicular to the paper of drawing). In other words, the unit has six side faces extending between the sides of the pair of panel surfaces on the front and back as shown in Fig. 16. In the example shown, the six sides that constitute the periphery of the hexagonal panel surface consist of two kinds of sides of different lengths, long sides and short sides, disposed alternately. Accordingly, the side face extending between short sides on both panel surfaces is a short side face and the side face extending between long sides on both panel surfaces is a long side face. In each unit, the three short side faces and the three long side faces are disposed alternately. It is preferable to use the three short side faces of each unit as joint surfaces and the three long side faces of each unit as non-joint surfaces. By using the three short side faces as joint surfaces, a larger opening $W$ can be obtained than in the case of using the long side faces as joint surfaces. However, the long side faces may be used as joint surfaces depending on the application. In a special example where the short sides and the long sides have the same length, the panel surface has an equilateral hexagonal shape (structural unit 5 shown in Fig. 1).

As shown in Fig. 15, six units 2(1), 2(2), 2(3), 2(4), 2(5) and 2(6) are disposed at positions that include the apexes $h_1, h_2, h_3, h_4, h_5$ and $h_6$ of the hexagonal cell $H_1$ that is the unit cell of the virtual honeycomb configuration. Joint surfaces that are the short side faces of adjoining units are disposed to oppose each other and joined together. Each of the six surfaces $s_1, s_2, s_3, s_4, s_5$ and $s_6$ that are jointed crosses one of the sides of the hexagonal cell $H_1$. Two joint surfaces are used to join one unit with the adjoining units on both sides thereof on the hexagonal cell $H_1$. As a result, the six units are connected with each other to form a ring, and an opening $W$ (indicated by thick alternate two dots and dash line) surrounded by these units is formed at the center of the hexagonal cell $H_1$. In this state, the remaining one joint surface of each unit extends radially from the center and can join with the short side face of one unit included in the adjacent hexagonal cell.

As will be clearly seen from Fig. 15, one unit 2 is disposed on one apex that is shared by three adjoining hexagonal cells $H_1$, and is shared by three hexagonal cells $H_1$.

The hexagonal shape of the panel surface of the unit 2 may be varied with different ratios of the short side and the long side. When hexagons of the same width (distance between the opposing short side and long side) are compared, the larger the difference between the short side and the long side is, the larger the opening $W$ formed in the mid portion of the hexagonal cell $H_1$. Also, the opening $W$ is an equilateral hexagon and the smallest when all sides have the same length. On the other hand, the area of the joint between the short side faces is smaller when the difference between the short side and the long side is larger, and the area of the joint is the largest when all sides have the same length. A larger area of the joint is advantageous in terms of strength. The lengths and proportion of the short side and the long side are determined in accordance with the required strength of the architectural structure, size of the opening and other factors. However, since the present invention is a structure based on a honeycomb configuration, sufficient strength can be ensured even when the difference between the short side and the long side is increased, which is advantageous for providing a larger opening.

With reference made to Fig. 15 and Fig. 16, tendon insertion holes are provided in advance at the positions in each unit indicated by dashed line. The tendon insertion holes have a sheath (not shown) embedded therein. One tendon insertion hole penetrates the unit at a right angle to one of the joint surfaces of the unit. As a result, one unit has three tendon insertion holes that extend in three different directions (60 degrees apart from each other).

When the short side faces of two units 2(1) and
2(2) are disposed to oppose each other as shown in Fig. 16, for example, the tendon insertion holes provided on both units communicate with each other so as to form one tendon insertion hole that continues from the long side face located on the right hand side of the unit 2(1) to the long side face located on the left hand side of the unit 2(2). In other words, the short side faces of both units are put in contact with each other so as to align the tendon insertion holes of the two units.

[0156] Then the tendon 21a is inserted through the tendon insertion hole and is subjected to a post tension so as both ends thereof are fastened by means of a pair of anchoring members 22a, 22a thereby firmly joining the units 2(1) and 2(2) together. The unit 2(2) is further joined with unit 2(3) by means of second tendon 21b and a pair of anchoring members 22b, 22b. Furthermore, the unit 2(2) is joined with unit 2(5) included in the adjacent hexagonal cell by means of third tendon 21c and anchoring members 22c, 22c.

[0157] When units are connected with each other as described above, one unit is joined with adjacent three panel units by tendons 21a, 21b, 21c that extend in three different directions, and therefore each joint surface is prevented from rotating, thus providing a rigid joint. Thus it is made possible to construct the architectural structure comprising a main frame that is rigidly joined in a honeycomb configuration.

[0158] With reference to Fig. 15 again, in the main frame formed by connecting the structural units that are disposed in a virtual honeycomb configuration consisting of hexagonal cell H1 as the unit cells, two sides at the top and bottom of the hexagonal cell H1 are disposed in parallel to each other in the horizontal direction. Take the units in two rows m and n that run in the vertical direction, and the units in each row are disposed in a zigzag configuration and are connected together by rigid joints. This constitution has, when diagonal pillars disposed in a zigzag configuration by connecting apexes h3', h2, h3, h4, h3' and h4' of a plurality of hexagonal cells H1 arranged in the vertical direction (for example, example shown in Fig. 8) are assumed, a function similar to that of the diagonal pillars and provides a structure that is capable of favorably transforming vertical and horizontal loads into axial forces. In addition, use of the planar members instead of linear members such as diagonal pillars gives the structure more strength.

[0159] In the honeycomb structure that uses the units 2, the panel units located at the apexes of the hexagonal cell H1 where the stress is most concentrated are planar members that have two-dimensional expansion and there is no joint within this portion, so that the structure is highly resistant to stresses. The joints are located at mid points of the sides of the hexagonal cell H1 where less stress is generated, thus providing another advantage.

[0160] With reference to Fig. 17 and Fig. 18, the structure of the unit 2 shown in Fig. 15 and Fig. 16 will be described in detail. Fig. 17 is a perspective view showing the overview of the unit 2. Fig. 18(A) is a front view, Fig. 18(B) is a top view, Fig. 18(C) is a sectional view taken along line Y-Y and Fig. 18(D) is a sectional view taken along line Z-Z. The unit 2 is a PC panel manufactured by using a predetermined formwork.

[0161] As shown in Fig. 17 and Fig. 18, a front panel surface 2i and a back panel surface 2j (at the bottom in Fig. 17) have the identical hexagonal shape, with corresponding sides being disposed parallel to each other. For example, a short side 2a1 of the panel surface 2i and a short side 2a2 of the panel surface 2j are parallel to each other, and a long side 2f1 of the panel surface 2i and a long side 2f2 of the panel surface 2j are parallel to each other. The distance between the front panel surface 2i and the back panel surface 2j is the thickness of the panel 2.

[0162] The short sides and the long sides are disposed alternately in the panel surfaces 2i and 2j. For example, in the panel surface 2i, the sides are disposed in the order of short side 2a1, long side 2d1, short side 2b1, long side 2e1, short side 2c1 and long side 2f1. The short sides all have the same length and the long sides all have the same length.

[0163] In addition, six side faces 2a, 2d, 2b, 2e, 2c, 2f are provided that are perpendicular to the panel surfaces 2i, 2j and extend between corresponding sides. The side faces 2a, 2b, 2c that extend between the short sides are short side faces that make joint surfaces, and the side faces 2d, 2e, 2f that extend between the long sides are long side faces that make non-joint surfaces.

[0164] Furthermore, as shown in Fig. 18(A), tendon insertion holes 2a3 (between the short side face 2a and the long side face 2e), 2b3 (between the short side face 2b and the long side face 2f) and 2c3 (between the short side face 2c and the long side face 2d) are provided between the opposing side faces among the six side faces. Each of the tendon insertion holes 2a3, 2b3 and 2c3 is perpendicular to a pair of opposing side faces. The tendon insertion holes 2a3, 2b3, 2c3 preferably open at substantially the center of each side face. In front view, every tendon insertion hole passes through the center of the unit, forming an angle of 60 degrees between the tendon insertion holes. While the three tendon insertion holes appear to cross each other in front view, actually they are disposed at different positions within the thickness of the unit so as not to overlap each other as shown in Fig. 18(B) and Fig. 18(C). It is preferable, however, that all tendon insertion holes are located as near the center within the thickness of the unit as possible, for the purpose of balancing.

[0165] The dimensions of each portion of the unit 2 are determined in accordance with the requirements and conditions of the architectural structure to be constructed, the conditions of transportation, etc.

[0166] Fig. 19 is a perspective view showing the overview of unit 5 that is a special case of the unit 2. Portions that correspond to those of the unit 2 shown in Fig. 17 are identified by the same reference numerals. The unit
is different from the unit 2 shown in Fig. 17 in that a pair of panel surfaces 5i and 5j are shaped in an equilateral hexagon, namely six sides thereof have the same length. The units 5 can be joined with each other by, for example, using the side faces 5a, 5b, 5c that are located at every other position as the joint surfaces. In other respects, it is the same as the unit 2 shown in Fig. 17.

[0167] Although not shown, a modification of the unit 2 having a hexagonal shape where two long sides among the three long sides of the panel surface are the same in length and the remaining one side has a different length may be used.

[0168] Fig. 20 (A) is a perspective view showing the overview of a structural unit 2A that is capable of joining with the unit 2 of Fig. 17, as an example of structural units used when the virtual honeycomb configuration has a curved surface or a bending portion. Fig. 20 (A) is a perspective overview thereof.

[0169] In the unit 2A, one short side face 2Ac forms a small angle $\beta_1$ from the direction C that is perpendicular to the panel surfaces 2Ai, 2Aj. A honeycomb structure having a curved surface can be constructed by using such units 2A.

[0170] Fig. 20 (B) is a rear view (inside of the main frame) of a structure formed by connecting the unit 2A (1) shown in (A) and another structural panel unit 2A(2) of the same shape with the respective short side faces 2Ac(1) and 2Ac(2) disposed to oppose each other, and Fig. 20 (C) is a top view thereof. As shown in the top view, the two units 2A(1) and 2A(2) that are joined together and the respective panel surfaces 2Ai(2) and 2Aj(2) thereof form a bending portion with an angle of 180° -$\beta_1$. A curved surface can be formed by repeating such a joint.

[0171] The angle $\beta_1$ is such a small angle that a joint strength comparable to that of the unit 2 shown in Fig. 16 can be obtained by passing a tendon through the units 2A(1) and 2A(2) and fastening the tendon with post tension applied thereto. Accordingly, while the short side face 2Ac that serves as the joint surface is inclined, it may be regarded as being virtually perpendicular to the panel surfaces 2Ai, 2Aj. The tendon insertion hole 2Ac3 that opens in the short side face 2Ac can also be regarded as being virtually perpendicular to the side face.

[0172] Fig. 21 (A) is a front view showing a unit 2B that is capable of joining with the unit 2 described above, in another example of the structural units used when the virtual honeycomb configuration has a curved surface or a bending portion. Fig. 21 (B) is a top view thereof.

[0173] As shown in Fig. 21 (A) and (B), the front panel surface of the unit 2B consists of two surfaces 2Bi1 and 2Bi2 that form an angle $\beta_2$ at a boundary thereof that is a bend 2Bk that runs along a straight line where the surfaces intersect to form the bend. The same applies also to the rear panel. Thus the unit 2B is bent along the bend 2Bk. A main frame having a curved surface can be constructed by joining the units 2B that have such a bend 2Bk with each other. In case the main frame is parallel to the vertical direction also in the curved portion as in the cylindrical tube frame shown in Fig. 13(A), the units 2B are disposed so that the bend 2Bk is parallel to the vertical direction. The bend 2Bk is directed in accordance with the direction in which the surface of the main frame bends. While the bend 2Bk is located at the center in the example shown, it may also be located to the left or to the right of the center. The bent unit 2B may also be used in a bending portion where two flat surfaces of the main frame intersect (for example, the corner of the tube frame shown in Fig. 7). The angle $\beta_2$ is set to such an extent that would not have adverse influence on joining of two units 2B by means of tendon subjected to post tension or on joining of the unit 2B with other units that can be joined.

[0174] Use of the bent unit 2B makes it possible to continuously form not only a curved surface that bends in one direction but also a curved surface that bends in the opposite direction. For example, a curved surface that undulates when viewed from above may be formed.

[0175] Combining the flat unit 2 shown in Fig. 17 and the bent unit 2B shown in Fig. 21 makes it possible to construct a main frame that has both a flat surface portion and a curved surface portion at will.

Example 3

[0176] By making reference to Figs. 22 to 25, another example of an architectural structure having a main frame formed by connecting structural units that are disposed in a virtual honeycomb configuration will be described. Fig. 22 is a front view showing a part of a main frame 103 of the architectural structure formed by using the structural units, for example, a part of a tube frame similar to that shown in Fig. 7(A). Fig. 23 is a partially enlarged perspective view of the main frame 103 shown in Fig. 22.

[0177] The main frame shown in Fig. 22 is constructed for the lower portion K1 by connecting the structural units 5 shown in Fig. 2 that are disposed in the virtual honeycomb configuration consisting of the hexagonal cell H2 (indicated by thick alternate dot and dash line) shown in Fig. 2, and connecting the structural units 4 shown in Fig. 2 for the upper portion K2. The unit 5 has an equilateral hexagonal panel surface as described for a modification of the unit 2 with reference to Fig. 19. The unit 4 is a modification of the unit 5 where a non-joint surface is formed from a concave surface.

[0178] In the lower portion K1, six units 4 are disposed so as to include the positions of apaxes h1 to h6 of the hexagonal cell H2, and two adjoining units are joined by disposing the joint surfaces thereof to oppose each other at the mid point of each side. The joint surfaces s1 to s6 cross the respective sides perpendicularly. As a result, six units 4 are connected together in a ring shape. In the upper portion K2, six units 5 are disposed on the hexagonal cell H2 and are similarly connected with each other. The units 4 and the units 5 are different in the shape of the non-joint surface, but are the same in the position
and shape of the joint surface, and therefore can be joined with each other.

In the lower portion K1, a hexagonal opening Wf is formed in the mid portion of the hexagonal cell H2 and, in the upper portion K2, a substantially circular opening Wg is formed in the mid portion of the hexagonal cell H2. In the border area, an opening Wh having an irregular shape is formed. The unit 4 has a smaller panel area (hence a smaller volume) than that of the unit 5, and therefore the opening Wg is larger than the opening Wf accordingly. A smaller volume of the unit means lighter weight and a smaller quantity of concrete. Being lighter in weight makes the unit suitable for use in upper stories that are subjected to relatively less loads. It is preferable to use units of smaller volume in higher stories since it reduces the load on the lower stories. In the lower stories, heavier loads from the structure above can be borne by using units made of a sufficient quantity of concrete.

With reference made to Fig. 22 and Fig. 23, tendon insertion holes are provided in advance at the positions in each unit indicated by dashed line. The tendon insertion holes have a sheath (not shown) embedded therein. One tendon insertion hole penetrates the unit at a right angle to one of the joint surfaces of the unit. As a result, one unit has three tendon insertion holes that extend in three different directions (60 degrees apart from each other).

When joint surfaces of two units 4(1) and 4(2) are disposed to oppose each other as shown in Fig. 23, for example, the tendon insertion holes provided on both units communicate with each other. Then the tendon 21a is inserted through the tendon insertion hole with a post tension applied thereto, and both ends thereof are fastened by means of a pair of anchoring members 22a, 22a thereby firmly joining the units 4 (1) and 4(2). Further the unit 4(2) and unit 4 (3) are joined by means of second tendon 21b and anchoring members 22b, 22b and the unit 4(3) and the unit 4(4) are joined by means of third tendon 21c and the anchoring members 22c, 22c.

By joining the units together in this way, every unit can be connected with three adjacent units by means of the three tendons 21a, 21b, 21c that extend in three different directions, so that each joint surface is prevented from rotating, thus providing a rigid joint. This makes it possible to construct the architectural structure having the main frame formed by rigidly joining the units in a honeycomb configuration.

With reference to Fig. 24, the structure of the unit 4 shown in Fig. 22 and Fig. 23 will be described in detail. Fig. 24(A) is a front view, Fig. 24(B) is a top view and Fig. 24(C) is a perspective overview.

As shown in Fig. 24, the front panel surface 4i and the back panel surface 4j have the same shape. The profiles of the panel surfaces 4i, 4j are formed from three sides located at every other positions of the equilateral hexagon and three concave curves located therebetween. Flat side faces 4a, 4b, 4c that include the straight sides serve as the joint surfaces with the adjacent units.

The concave surfaces 4d, 4e, 4f located between the joint surfaces are non-joint surfaces.

Furthermore, tendon insertion holes 4a3 (between the joint surface 4a and the concave surface 4e), 4b3 (between the joint surface 4b and the concave surface 4f) and 4c3 (between the joint surface 4c and the concave surface 4d) are provided between the opposing side faces among the six side faces. The tendon insertion holes 4a3, 4b3, 4c3 are perpendicular to the joint surfaces 4a, 4b, 4c, respectively. The tendon insertion holes 4a3, 4b3, 4c3 preferably open in the joint surfaces and in the concave surfaces at substantially the center thereof. In the front view of Fig. 24(A), every tendon insertion hole passes through the center of the unit, forming an angle of 60 degrees between the tendon insertion holes. The tendon insertion holes are disposed at different positions within the thickness of the unit so as not to overlap each other as shown in Fig. 24(B) and Fig. 24(C). It is preferable, however, that all tendon insertion holes are located as near the center within the thickness of the unit as possible, for the purpose of balancing.

The dimensions of each portion of the unit 4 are determined in accordance with the requirements and conditions of the architectural structure to be constructed, the conditions of transportation and other factors.

Fig. 25(A) is a front view showing a unit 4A that is one example of the structural unit used when the virtual honeycomb configuration has a curved surface or a bending portion, in a state of being joined with the unit 4. Fig. 25 (B) is a top view thereof.

As shown in Fig. 25(A) and (B), the front panel surface of the unit 4A consists of two surfaces 4A1 and 4A2 that form an angle β at a boundary thereof that is a bend 4Ak that runs along a straight line at which the surfaces intersect to form the bend. The same applies also to the rear panel. Thus the unit 4A is bent along the bend 4Ak. A main frame having a curved surface can be constructed by joining the units 4A that have such a bend 4Ak and the unit 4 described previously. The degree of bending increases as more units 4A are added and connected. In case the main frame is parallel to the vertical direction also in the curved portion as in the cylindrical tube frame shown in Fig. 13(A), the units 4A are disposed so that the bend 4Ak is parallel to the vertical direction. The bend 4Ak is directed in accordance with the direction in which the surface of the main frame bends. While the bend 4Ak is located at the center in the example shown, it may also be located to the left or to the right of the center.

The bent unit 4A may also be used in a bending portion where two flat surfaces of the main frame intersect (for example, the corner of the tube frame shown in Fig. 7). The angle β is set to such an extent that would not have adverse influence on joining of two units 4A by means of tendon subjected to post tension or on joining of the unit 4A with other units that can be joined.

Use of the bent unit 4A makes it possible to continuously form not only a curved surface that bends in one direction but also a curved surface that bends in
the opposite direction. For example, a curved surface that undulates when viewed from above.

Example 4

[0191] By making reference to Figs. 26 to 31, another example of the architectural structure having a main frame formed by connecting structural units that are disposed in a virtual honeycomb configuration will be described.

Fig. 26 is a front view showing a part of a main frame 104 of the architectural structure formed by using the structural units, for example, a part of a tube frame similar to that shown in Fig. 7(A). Fig. 27 is a partial perspective view of the main frame constituted from the same units as those of the main frame 104 shown in Fig. 26.

[0192] In the lowest portion K1 of the main frame shown in Fig. 26, the structural units 8 shown in Fig. 4 are disposed in the arrangement pattern B shown in Fig. 6 for the virtual honeycomb configuration consisting of the hexagonal cell H2 (indicated by thick alternate dot and dash line). A second portion K2, a third portion K3, and top portion K4, each of which comprises structural units of different shapes, are constructed consecutively on the lowest portion K1. The structural unit 13, the structural unit 14 and the structural unit 15 used in the second portion K2, the third portion K3 and the top portion K4, respectively, are modifications similar to the structural unit 7 shown in Fig. 3 and Fig. 4.

[0193] The units 8, 13, 14 and 15 are each disposed at a position that includes a pair of adjoining apexes of the hexagonal cell H2. For example, among the units 8 of the lowest portion K1, unit 8(1) occupies the apex h1 and one apex of the adjacent hexagonal cell, unit 8(2) occupies the apexes h2 and h3, unit 8(3) occupies the apex h4 and one apex of the next hexagonal cell, and unit 8(4) occupies the apexes h5 and h6. In each of the units disposed as described above, side faces located at the top right, top left, bottom right and bottom left are used as joint surfaces. Two units that adjoin each other are joined together with the corresponding joint surfaces disposed to oppose each other, and four units 8 are connected together in a ring configuration. These connections are rigid joints. Each of the four surfaces s1, s3, s4 and s6 that are joined crosses one of the sides of the hexagonal cell H2. For the unit 13 in the second portion K2, the unit 14 in the third portion K3 and the unit 15 in the top portion K4, the units are disposed and joined similarly, although lengths of the sides of the hexagonal cell H2 are different. The units 8, 13, 14 and 15 are the same in the position and shape of the joint surface although the shape of the non-joint surface of the panel surface is different, and therefore can be joined with each other.

[0194] There may be a case where the shape of the hexagonal cell that is the unit cell of the virtual honeycomb configuration changes from the bottom toward the top as in example shown in Fig. 26. Each hexagonal cell is symmetrical with respect to the vertical centerline, although the shape is different. In a portion where units of different shapes adjoin each other, there is a hexagonal cell that is not symmetrical with respect to the horizontal centerline.

[0195] In the lowest portion K1, a rectangular opening Wh is formed in the mid portion of the hexagonal cell H2, in the second portion K2 a substantially oval opening Wi is formed in the mid portion of the hexagonal cell H2, in the third portion K3 a substantially rhombic opening Wj is formed in the mid portion of the hexagonal cell H2, and in the top portion K4 a rhombic opening Wk is formed in the mid portion of the hexagonal cell H2. The higher from the lowest portion K1 upward to the top portion K4, the smaller the units are in panel area (hence smaller in volume) and therefore the larger the opening is accordingly. A smaller volume of the unit means lighter weight and a smaller quantity of concrete. Being lighter in weight makes the unit suitable for use in upper stories that are subjected to relatively less loads. It is preferable to use units of smaller volume in higher stories since it reduces the load on the lower stories. In the lower stories, heavier loads from the structure above can be borne by using units made of a sufficient quantity of concrete.

[0196] With reference made to Fig. 26 and Fig. 27, tendon insertion holes are provided at the positions in each unit indicated by dashed line to penetrate through in advance. The tendon insertion holes have a sheath (not shown) embedded therein. One tendon insertion hole opens at one end thereof in one of the joint surfaces, and opens at another end in one of the non-joint surfaces. As a result, one unit has four tendon insertion holes that extend in four different directions.

[0197] When the joint surface located at the top left of the unit 8 and the joint surface located at the bottom right of the unit 13 are disposed to oppose each other as shown in Fig. 27, for example, the tendon insertion holes provided in both units communicate with each other. Then the tendon 21a is inserted through the tendon insertion hole with a post tension applied thereto, and one end thereof is fastened on the lower side face of the unit 8 by means of the anchoring member 22a and the other end thereof is fastened on the upper side face of the unit 13 by means of anchoring member. The second tendon 21b is inserted through the tendon insertion holes of the unit 8 and another unit 8 located at the lower left and one end thereof is fastened on the upper side face of the unit 8 by means of the anchoring member 22b and the other end thereof is fastened on the lower side face of the another unit 8 located at the lower left by means of the anchoring member 22b. The third tendon 21c is inserted through the tendon insertion holes of the unit 8 and another unit 8 located at the lower right and one end thereof is fastened on the top end of the unit 8 by means of the anchoring member 22c and the other end thereof is fastened on the bottom side face of the another unit 8 located at the lower right by means of the anchoring member 22c. The fourth tendon 21d is inserted through the tendon
insertion holes of the unit 8 and the unit 13 located at the top right and one end thereof is fastened on the lower side face of the unit 8 by means of the anchoring member 22d and the other end thereof is fastened on the upper side face of the unit 13 located at the top right by means of the anchoring member 22d.  

**[0198]** All of the units shown in Fig. 27 are joined together in this way by means of the tendons subjected to post tension. Every unit is joined with four adjacent units by means of the four tendons 21a, 21b, 21c, 21d that extend in four different directions, so that each joint surface is prevented from rotating, thus providing a rigid joint. This makes it possible to construct the architectural structure having the main frame formed by rigidly joining the units in a honeycomb configuration.  

**[0199]** While the tendon insertion holes that communicate in two units do not necessarily run straight in the main frame shown in Fig. 26 and Fig. 27, it is a common practice to embed sheaths in a curved configuration in PC panels.  

**[0200]** Fig. 28 is a perspective overview of the units shown in Fig. 26 and Fig. 27, (A) showing the unit 8, (B) showing the unit 13, (C) showing the unit 14 and (D) showing the unit 15.  

**[0201]** As shown in Fig. 28(A), the unit 8 has an octagonal panel surface 8i on the front (the same for the rear surface). The octagon has a shape produced by cutting off the four corners of a rectangle, and the periphery of the panel surface is constituted from short sides and long sides that are disposed alternately. Four small side faces 8a, 8b, 8c, 8d interposed between the short sides serve as the joint surfaces. The remaining four large side faces 8e, 8f, 8g, 8h are non-joint surfaces. The tendon insertion hole 8a3 is provided between the joint surface 8a and the non-joint surface 8g, the tendon insertion hole 8b3 is provided between the joint surface 8b and the non-joint surface 8g, tendon insertion hole 8c3 is provided between the joint surface 8c and the non-joint surface 8e, and tendon insertion hole 8d3 is provided between the joint surface 8d and the non-joint surface 8e. The tendon insertion holes 8a3 and 8b3 preferably open substantially at the center of the non-joint surface 8g. The tendon insertion holes 8c3 and 8d3 preferably open substantially at the center of the non-joint surface 8e.

**[0202]** When viewed from the panel surface 8i side, the tendon insertion holes 8a3 and 8d3 appear to cross each other, while the tendon insertion holes 8b3 and 8c3 appear to cross each other. Actually, the tendon insertion holes are disposed at positions within the thickness of the unit 8 where they do not overlap each other. It is preferable, however, that all tendon insertion holes are located as near the center within the thickness of the unit as possible, for the purpose of balancing.

**[0203]** As shown in Fig. 28(B), the unit 13 has joint surfaces 13a to 13d and non-joint surfaces 13e to 13h, while the joint surfaces are the same as those of the unit 8 of (A) and the non-joint surfaces are the non-joint surfaces of the unit 8 modified into concave surfaces. Four tendon insertion holes 13a3, 13b3, 13c3, 13d3 are provided similarly to the case of the unit 8, while one end of each tendon insertion hole opens in each joint surface and the other end thereof opens in the bottom of the recess of the non-joint surface 13e or 13g.

**[0204]** As shown in Fig. 28(C), the unit 14 has joint surfaces 14a to 14d and non-joint surfaces 14e to 14h. While the joint surfaces are the same as those of the unit 8 of (A), the non-joint surfaces are the non-joint surfaces of the unit 8 modified into concave surfaces, which are deeper than those of the unit 13. Four tendon insertion holes 14a3, 14b3, 14c3, 14d3 are provided similarly to the case of the unit 8. While one end of each tendon insertion hole opens in each joint surface and the other end thereof opens in the bottom of the recess of the non-joint surface 14e or 14g.

**[0205]** As shown in Fig. 28(D), the unit 15 has joint surfaces 15a to 15d and non-joint surfaces 15e to 15h. While the joint surfaces are the same as those of the unit 8 of (A), the non-joint surfaces are the non-joint surfaces of the unit 8 modified into concave surfaces, which are V-shaped and are deeper than that of the unit 14. In other words, the unit has four legs that extend from the center in four directions with side faces located at the distal ends of the four legs serving as the joint surfaces. Four tendon insertion holes 15a3, 15b3, 15c3, 15d3 are provided similarly to the case of the unit 8. While one end of each tendon insertion hole opens in each joint surface and the other end thereof opens in the bottom of the V-shaped recess of the non-joint surface 15e or 15g.

**[0206]** Fig. 29 is a perspective overview of a main frame 105 that is another example although having the same shape as that of the main frame shown in Fig. 27. The main frame 105 shown in Fig. 29 is constituted from units that are a little different from the unit shown in Fig. 27.

**[0207]** When the units 8, 13, 14 and 15 shown in Fig. 27 are joined so that each unit forms one story of a building, these units are fairly large and heavy for ordinary PC panels, giving rise to the possibility of decreasing the efficiency of manufacturing, transportation and assembly. Therefore, it is made possible to ensure the efficiency of manufacturing, transportation and assembly and make the main frame 105 capable of functioning similarly to the main frame 104 formed from the units 8, 13, 14 and 15 shown in Fig. 27, by using half-units, that are made by dividing each unit into halves at the center, as the unit of manufacturing the PC panels. Since two half-units that constitute one unit have an identical shape, they can be manufactured with only one kind of formwork.

**[0208]** A panel made by integrating half-units 8m and 8n corresponds to the unit 8 shown in Fig. 27, a panel made by integrating half-units 13m and 13n corresponds to the unit 13 shown in Fig. 27, a panel made by integrating half-units 14m and 14n corresponds to the unit 14 shown in Fig. 27, and a panel made by integrating half-units 15m and 15n corresponds to the unit 15 shown in Fig. 27. As a panel formed by joining half-units is joined
by means of four tendons 21a to 21d similarly to the units 8, 13, 14 and 15 shown in Fig. 27, the half-units are joined together at the same time.

[0209] Fig. 30 is an perspective overview of the unit 8 shown in Fig. 29. (A) showing half-units of the unit 8, (B) showing half-units of the unit 13. (C) showing half-units of the unit 14 and (D) showing half-units of the unit 15. 

[0210] As shown in Fig. 30(A), the half-units 8m and 8n of the unit 8 are the products of equally dividing the unit 8 along dividing surfaces 8t, 8u that cross a pair of non-joint surfaces that oppose each other. The dividing surface 8t is where tendon insertion holes 8ma3, 8mb3, 8mc3 and 8md3 open, and the dividing surface 8u is where tendon insertion holes 8na3, 8nb3, 8nc3 and 8nd3 open. A PC panel having the same shape as the unit 8 is formed by bringing the dividing surface 8t of the half unit 8m and the dividing surface 8u of the half unit 8n into contact with each other, with the tendon insertion holes communicating with each other in the same arrangement of the tendon insertion holes as in the unit 8. As shown in Fig. 29, the half-units 8m and 8n are rigidly joined with each other by passing tendons through the tendon insertion holes that communicate with each other and fastening the tendons with post tension applied thereto. The same applies to the half-units of the units 13, 14 and 15 shown in Fig. 30(B) to Fig. 30(D).

[0211] Fig. 31 and Fig. 32 show units 8A, 13A, 14A and 15A in one example of the structural units used in a case where the virtual honeycomb configuration has a curved surface or a bending portion. Fig. 31(A1) and (A2) are front and top views, respectively, of the unit 8A joined with the unit 8, and (B1) and (B2) are front and top views, respectively, of the unit 13A joined with the unit 13. Similarly, Fig. 32(A1) and (A2) are front and top views, respectively, of the unit 14A joined with the unit 14, and (B1) and (B2) are front and top views, respectively, of the unit 15A joined with the unit 15. 

[0212] As shown in Fig. 31(A1) and (A2), the front panel surface of the unit 8A consists of two surfaces 8A1 and 8A2 that form an angle $\beta$ at a boundary thereof that is a bend 8Ak that runs along a straight line where the surfaces intersect to form the bend. The same applies also to the rear panel. Thus the unit 8A is bent along the bend 8Ak. Main frame having a curved surface can be constructed by joining the units 8A that have such a bend 8Ak and the unit 8B described previously. The degree of bending increases as more units 4A are added and connected to the unit 8A. In case the main frame is parallel to the vertical direction also in the curved portion as in the cylindrical tube frame shown in Fig. 13(A), the units 8A are disposed so that the bend 8Ak is parallel to the vertical direction. The bend 8Ak is directed in accordance with the direction in which the surface of the main frame bends. While the bend 8Ak is located at the center in the example shown, it may be located to the left or to the right.

[0213] The bent unit 8A may also be used in a bending portion where two flat surfaces of the main frame intersect (for example, the corner of the tube frame shown in Fig.

7). The angle $\beta$ is set to such an extent that would not have adverse influence on joining of two units 8A by means of tendon subjected to post tension or on joining of the unit 8A with other units that can be joined.

[0214] Use of the bent unit 8A makes it possible to continuously form not only a curved surface that bends in one direction but also a curved surface that bends in the opposite direction. For example, a curved surface that undulates when viewed from above. The same applies also to units 13A, 14A and 15A.

Example 5

[0215] Fig. 33 is a partial perspective view of a main frame of an architectural structure, that is one example of the present invention using members other than PC panels. The main frame shown in Fig. 33 has the same shape as that of the main frame shown in Fig. 9, although each unit is made of steel. Unit 16 has a profile substantially similar to the periphery of the unit 1, and has three legs that extend in three directions made of steel. The unit 16 is preferably manufactured in a factory similarly to the PC panel in advance. In the example shown, the unit 16 is made of an H beam, although the unit 16 may have any cross sectional shape. The unit 16 has flange-like joint surfaces 16a, 16b, 16c joined by welding or the like at the distal ends of the three legs, that enable it to connect to adjacent units 16 by joining the corresponding joint surfaces together by means of bolts. The joint may also be made by welding, but use of bolts is more efficient.

[0216] Provided that units of a similar shape to that of any of the examples of PC panels described above are used, a similar main frame can be constructed with members other than PC panels, although not shown in the drawing. Thus an architectural structure having a main frame of honeycomb structure can be constructed from steel, reinforced concrete, steel-encased reinforced concrete or wood.

Claims

1. An architectural structure having a main frame formed by connecting a plurality of structural units, wherein a virtual honeycomb configuration that is erected vertically and expands in a plane is provided with one of the structural units (1, 2, 3, 4, 5, 6) disposed at a position that includes one apex (h1, h2, h3, h4, h5, h6) of a hexagonal cell (H1, H2) that is the unit cell thereof in front view, means are provided for joining the two structural units by disposing joint surfaces, that are formed in part of the respective outer circumferential surfaces of the two structural units that adjoin each other, so as to oppose each other, while the surfaces (s1, s2, s3, s4, s5, s6) that are joined each lies on one of the sides of the hexagonal cell and crosses the side, and an opening (W) surrounded by all the structural units that are
An architectural structure having a main frame disposed on the hexagonal cell is formed in the mid portion of each hexagonal cell.

The architectural structure according to claim 1, wherein the structural unit is made of precast concrete, where the outer circumference thereof has a pair of panel surfaces consisting of a front surface and a back surface that oppose each other and a side face extending between edges of the pair of panel surfaces, and a plurality of the joint surfaces are provided as a part of the side faces.

The architectural structure according to claim 2, wherein the structural unit is made of precast concrete, where the pair of panel surfaces have a hexagonal shape in front view, and the side face between a side and one located next to the adjacent side of the hexagonal cell is used as the joint surface.

The architectural structure according to claim 2 or 7, wherein the octagonal shape of the pair of panel surfaces is formed from short sides and long sides that are disposed alternately, and that a side face between the short sides is used as the joint surface.

The architectural structure according to claim 1 or 6, wherein the structural unit is made of steel, reinforced concrete, steel-encased reinforced concrete or wood.

An architectural structure having a main frame formed by connecting a plurality of structural units, wherein a virtual honeycomb configuration that is erected vertically and expands in a plane is provided with one of the structural units (7, 8, 9, 10, 11, 12, 13, 14, 15) disposed at a position that includes two adjacent apexes of a hexagonal cell (H1, H2) that is the unit cell thereof in front view, means are provided for connecting the two adjacent structural units by disposing joint surfaces, that are formed in part of the respective outer circumferential surfaces of the two structural units that adjoin each other, to oppose each other, while the surfaces that are joined each cross one of the sides of the hexagonal cell, and an opening (W) surrounded by all the structural units that are disposed on the hexagonal cell is formed in the mid portion of each hexagonal cell.

The architectural structure according to claim 6, wherein the structural unit is made of precast concrete, where the outer circumference thereof has a pair of panel surfaces consisting of a front surface and a back surface that oppose each other and a side face extending between edges of the pair of panel surfaces, and a plurality of the joint surfaces are provided as a part of the side faces.

The architectural structure according to claim 7, wherein the structural unit is made of precast concrete, where each of the pair of panel surfaces has an octagonal shape in front view, and the side face between a side and one located next to the adjacent side of the octagonal cell is used as the joint surface.

The architectural structure according to claim 8, wherein the octagonal shape of the pair of panel surfaces is formed from short sides and long sides that are disposed alternately, and that a side face between the short sides is used as the joint surface.

The architectural structure according to claim 7, wherein the structural unit is made of precast concrete, where the panel surface has four legs that extend in four directions from the center thereof in front view, and the side face located at the distal end of each of the four legs is used as the joint surface.

The architectural structure according to claim 2 or 7, wherein the means of connecting the two adjacent structural units made of precast concrete comprises a tendon that crosses the opposing joint surfaces and passes through both structural units, and an anchoring member that applies a post tension to the tendon and secures both ends thereof on the side face of each structural unit.

An architectural structure having a main frame formed by connecting a plurality of structural units, wherein a virtual honeycomb configuration that is erected vertically and expands in a plane is provided with one of first structural units (1, 2, 3, 4, 5, 6) disposed at a position that includes one apex of a hexagonal cell (H1, H2) that is the unit cell thereof in front view, and second structural units (7, 8, 9, 10, 11, 12, 13, 14, 15) disposed at a position that includes two adjacent apexes of the hexagonal cell, means are provided for connection by disposing joint surfaces, that are formed in part of the respective outer circumferential surfaces of the two first and/or second structural units that adjoin each other, to oppose each other, while the surfaces that are joined each lies on one of sides of the hexagonal cell and crosses the side, and an opening (W) surrounded by all of the first and/or second structural units that are disposed on the hexagonal cell is formed in the mid portion of each hexagonal cell.
the structural units disposed at higher positions and the structural units disposed at lower positions have different shapes, so that the opening formed by the structural units disposed at higher positions is larger than the opening formed by the structural units disposed at lower positions.

15. A structural unit that is used to construct the architectural structure according to any one of claims 1 to 14.

16. A structural unit made of precast concrete that is used to form a main frame of the architectural structure according to claim 1, wherein the outer circumference thereof has a pair of panel surfaces consisting of a front surface and a back surface that oppose each other and a side face extending between edges of the pair of panel surfaces, a plurality of joint surfaces for connecting adjacent structural units are provided as partial surfaces of the side faces, and a plurality of tendon insertion holes that pass between each of the plurality of joint surfaces and the other portion of the side face are provided in such a configuration that they do not overlap each other.

17. The structural unit according to claim 16 that is made of precast concrete, wherein the panel surfaces have a hexagonal shape in front view, and the side face between a side and one located next to the adjacent side of the hexagonal cell is used as the joint surface.

18. The structural unit according to claim 17, wherein the hexagonal shape of the panel surfaces is formed from short sides and long sides that are disposed alternately, and that a side face between the short sides is used as the joint surface.

19. The structural unit according to claim 16 that is made of precast concrete, wherein the panel surfaces have three legs that extend in three directions from the center in front view, and the side face located at the distal end of each of the three legs is used as the joint surface.

20. A structural unit made of precast concrete that is used in the main frame of the architectural structure according to claim 6, wherein the outer circumference thereof has a pair of panel surfaces consisting of a front surface and a back surface that oppose each other, and a side face extending between edges of the pair of panel surfaces, a plurality of joint surfaces are provided as a part of the side faces for connecting the adjacent structural units, and a plurality of tendon insertion holes that pass between each of the plurality of joint surfaces and the other portion of the side face are provided in such a configuration that they do not overlap each other.

21. The structural unit according to claim 20 that is made of precast concrete, wherein the panel surfaces have an octagonal shape in front view, and the side face between a side and one located next to the adjacent side of the octagonal cell is used as the joint surface.

22. The structural unit according to claim 21, wherein the octagonal shape of the panel surfaces is formed from short sides and long sides that are disposed alternately, and that a side face between the short sides is used as the joint surface.

23. The structural unit according to claim 20 that is made of precast concrete, wherein the panel surface has four legs that extend in four directions from the center thereof in front view, and the side face located at the distal end of each of the four legs is used as the joint surface.

24. The structural unit according to claim 20 that is made of precast concrete, wherein half units, that are equal parts of the structural unit divided along a division plane crossing a pair of opposing non-joint surfaces, are joined with the division surfaces opposing each other so as to form the structural unit.

25. A half unit that has the shape of one of two members that are equal parts of the structural unit according to claim 20 divided along a division plane crossing a pair of opposing non-joint surfaces.

26. The structural unit according to claim 16 or 20, wherein a plurality of slab connecting holes are provided to pass through the structural unit in a direction perpendicular to the pair of panel surfaces.

27. The structural unit according to claim 16 or 20, wherein the joint surface is formed from either two sloped surfaces in a ridge shape or two sloped surfaces in a valley shape.

28. The structural unit according to claim 16 or 20, wherein it is disposed in a portion where the virtual honeycomb configuration has a curved surface, and has a bending portion.

29. A method of constructing the architectural structure according to claim 16 or 20, which comprises disposing two adjacent structural units so that the respective joint surfaces oppose each other in such a configuration as the tendon insertion holes thereof communicate with each other; passing a tendon through the communicating tendon insertion holes; and applying a post tension to the tendon to fasten it thereby to joint the two adjacent structural units.
FIG. 10

(A) Top view

(B) Sectional view taken along line X-X

First leg

Second leg

Third leg

Width direction

Thickness direction
FIG. 31

(A 1) Front view

(B 1) Front view

(A 2) Top view

(B 2) Top view
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

E04B1/35(2006.01)i, E04B1/20(2006.01)i, E04B1/22(2006.01)i

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

**B. FIELD(S) SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)


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


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

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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  "A" document defining the general state of the art which is not considered to be of particular relevance
  
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*E* document member of the same patent family

**Date of the actual completion of the international search**

24 January, 2007 (24.01.07)

**Date of mailing of the international search report**

06 February, 2007 (06.02.07)

**Name and mailing address of the ISA/ Japanese Patent Office**

**Authorized officer**

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