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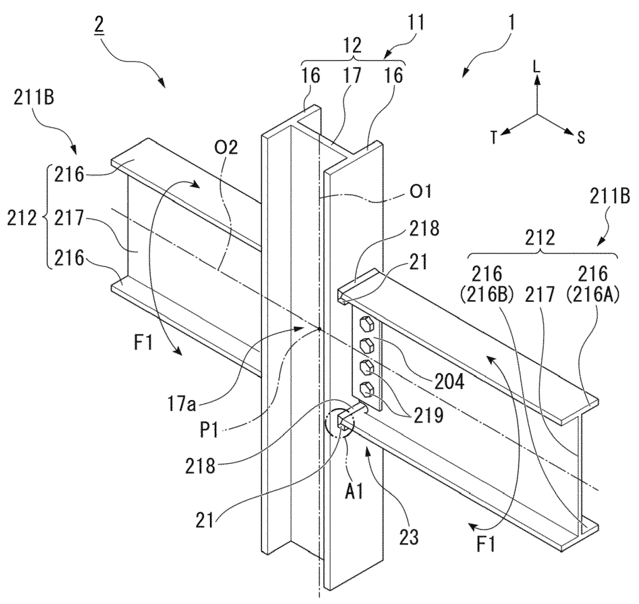
(54) BEAM-COLUMN JOINT STRUCTURE

(57) A beam-column joint structure (1) including: a column (11) and an I-beam (212) with a pair of beam flanges (216) of the I-beam joined directly to joint plates (16) of the column main body via a welded section (218); wherein at the intersect position (P1), the ratio of the full plastic strength of the column relative to the full plastic strength of the beam is 1.5 or more and 3.0 or less, and the ratio of the full plastic strength of the beam relative to the full plastic strength of a portion (17a) of the column in the range of the height of the beam in the vertical direction is 1.05 or more and 1.5 or less.

FIG. 1



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Description

TECHINICAL FIELD

[0001] The present invention relates to a beam-column joint structure.

BACKGROUND ART

[0002] The Northridge earthquake occurred in the United States of America in 1994. A beam-column joint structure 200 as in FIG. 20 was being used prior to the Northridge earthquake (see Non-Patent Document 1). In other words, the beam-column joint structure 200 includes columns 201 and beams 211. The column 201 includes a column main body 202 composed of an I-beam for columns, a pair of stiffeners (diaphragms, first reinforcement plate, continuity plate) 203, and a shear plate 204. The column main body 202 includes a pair of column flanges 206, a web for column 207, and extends in a vertical direction. Each stiffener 203 is a horizontal stiffener and is arranged along a horizontal plane. Each stiffener 203 is arranged in the vertical direction at the same position as a pair of beam flanges 216 described below on the beam 211. Each stiffener 203 is welded respectively to a pair of column flanges 206 and a web for column 207 of the column 201 (column main body 202) using a welded section 208 formed by welding. A shear plate 204 is joined to a column flange 206 of the column 201 by welding or the like.

[0003] The beam 211 has an I-beam (I-beam) 212 and a pair of backing bars 213. The I-beam 212 is an I-beam defined by, for example, JIS (Japanese Industrial Standards) G 3192: 2014 form, dimensions, mass of hot rolled steel, and their tolerances (hereinafter simply referred to as JIS G 3192). The I-beam 212 includes the pair of beam flanges 216 and the beam web 217. The pair of beam flanges 216 are arranged so as to face each other in the vertical direction. Of the pair of beam flanges 216, the beam flange 216 arranged above is an upper flange 216A, and the beam flange 216 arranged below is a lower flange 216B.

[0004] Each beam flange 216 is joined to the column flange 206 of the column main body 202 by a welded section 218 with a backing bar 213 attached below the beam flange 216. The beam web 217 and the shear plate 204 are mutually connected to each other by fastening members 219 such as high-strength bolts. Note that the beam web 217 may be connected by welding in addition to the connection by the shear plate 204 and the fastening members 219. In addition, the beam web 217 may also be welded directly to the column flange 206. The column 201 and the beam 211 are connected together by a joint section 222 in the beam-column joint structure 200. The joint section 222 is a so-called pre-Northridge joint section. Here, a section in the vertical direction in the range of the beam 211 on the web for column 207 is defined as a joint section panel 207a.

[0005] As illustrated in FIG. 21, there are Type A to Type D failure modes corresponding to cracks represented by lines LA, LB, LC, and LD of the beam-column joint structure 200 due to the Northridge earthquake. Types A and B depend on the fracture toughness in the direction (Z direction) in which the column flange 206 is torn parallel to the main surface of the column flange 206. In Type C, the crack line LC propagates and penetrates through the beam flange 216. Type D depends on the fracture toughness in the direction (L direction) dividing the column flange 206 in the material axial direction (longitudinal direction).

[0006] As illustrated in FIG. 22, Type D is also induced by local bending deformation of the column flange 206 due to shear deformation of the joint section panel 207a. In addition, a pair of beams 211 are joined to the column 201 in a beam-column joint structure 200A illustrated in FIG. 22. Local kink deformation occurs respectively in a range R1 portion of the column flange 206 of the column 201 and a range R2 portion of the beam flange 216 of the beam 211. The portions within these ranges R1 and R2 are portions where local bending deformation occurs. In this manner, except for Type C, all of them show that cracks were generated and propagated at the slit formed between the backing bar 213 of the lower flange 216B and the column 201.

[0007] The beam-column joint structure used in current earthquake-resistant structures in Europe and the United States is based on the failure mode at the joint section 222 of the beam-column joint structure 200 in the Northridge earthquake. The detail structure of the joint section is determined to withstand a plurality of cycles of deformation. As a specific detailed structure, as illustrated in FIG. 23, it is mandatory for a beam-column joint structure 200B to take the following measures (1) to (3).

(1) The column 201 is reinforced with the stiffener 203.

(2) The joint section panel 207a of the column 201 is reinforced with a doubler plate (second reinforcement plate) 225 so as to thicken the web of the column 207.

(3) After welding the end portion of a beam 211A on site, the backing bar 213 attached to the lower flange 216B of the beam 211A is removed and reinforcement welding is performed. In other words, the beam 211A does not have the backing bar 213 around the lower flange 216B in each configuration of beam 211. The doubler plate 225 is provided on the column 201 and joined to the joint section panel 207a.

[0008] A joint section 222A between the column 201 and the beam 211A is a so-called Post-Northridge joint section. The joint section 222A is a joint section for preventing Type A to Type D failures. The measures (1) and (2) suppress the plastic deformation of the column flange 206 and the joint section panel 207a. For example, an arc gouging method is used to remove the backing bar

213 in measure (3). Reinforcement welding is performed upward from below the removed portion at the portion where the backing bar 213 is removed. Reinforcing welding eliminates slits that become a starting point for failure. These countermeasures are effective countermeasures for preventing early brittle fracture when using a steel material with relatively low fracture toughness in the Z direction and the L direction for the column flange 206.

Prior Art Documents:

[0009] Non-Patent Document 1: Masayoshi Nakashima, "Behavior and Comparison of Damage to Beam-to-Column Connections of Steel Building Structures Observed in the U.S. Northridge and Hyogoken-Nanbu Earthquakes", [online], April 1996, Disaster Prevention Research Institute, Kyoto University Annual Report, No. 39, B-1, [searched on August 3, 2020], Internet <http://www.dpri.kyoto-u.ac.jp/nenpo/no39/39 b1/a39b1p02.pdf>

SUMMARY OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0010] However, in the joint section 222Aofthe beam-column joint structure 200B, all the energy due to the seismic external force is absorbed by plastic deformation of the beam 211A, so the ultimate performance of the joint section 222Ais limited by the local buckling of the beam 211A. In addition, the reinforcement with stiffeners and doubler plates and removal of backing bars imposes a heavy load on factory production and on-site construction, and is a factor in reducing the productivity for architectural steel frames. On the other hand, ensuring the structural stability of buildings in which beam-column joint structures are used is desirable.

[0011] In light of the foregoing, an object of the present invention is to ensure the structural stability of a building in which a beam-column joint structure is used, and to provide a beam-column joint structure having joint sections with high energy absorption performance.

MEANS FOR SOLVING THE PROBLEM

[0012] In order to solve the above problems, the present invention proposes the following means.

(1) An aspect 1 of the present invention is a beam-column joint structure, comprising:

a column having a column main body comprising an I-beam of the column, or a square steel tubing, or a weld assembled box cross-section; and

a beam comprising an I-beam where a pair of beam flanges of the I-beam are respectively joined directly to joint plates of the column main body via a welded section; wherein

the joint plate is a column flange of the I-beam of the column or a flat plate part of the square steel tubing or weld assembled box cross-section,

with the intersect position specified as the position where the center axis of the column main body and the center axis of the I-beam intersect, the ratio of the full plastic strength of the column relative to the full plastic strength of the beam at the intersect position is 1.5 or more and 3.0 or less, and

at the intersect position on a web for column of the column main body comprising the I-beam of the column or the flat plate part extending in the longitudinal direction of the beam on the column main body comprising the square steel tubing or weld assembled box cross-section, the ratio of the full plastic strength of the beam relative to the full plastic strength of the portion in the height range of the beam in the vertical direction is 1.05 or more and 1.5 or less.

[0013] With the present invention, as a result of extensive studies, the inventors have found that in order to improve the energy absorption performance of the joint section between the column and the beam in the beam-column joint structure, the energy acting on the beam-column joint structure must be absorbed not only in the beam but also by the joint section panel. In particular, a configuration where the joint section panel, for which stable yield strength increase after plastification can be anticipated as long as the column flange does not break, yields first, and then in conjunction with an increase in yield strength of the joint section panel due to yielding, the beam also yields, is preferable. In other words, the beam-panel strength ratio, which is the ratio of the full plastic strength of the beam relative to the full plastic strength of the joint section panel, should be 1.05 or more so that the joint section panel yields first.

[0014] In addition, the yield strength of the joint section panel can be expected to increase to about 1.5 times the full plastic strength due to strain hardening due to repeated plastic deformation. In other words, by setting the beam-panel strength ratio to 1.5 or less, not only the joint section panel but also the beam can be plastified in the process of increasing the yield strength after initial yielding of the joint section panel and energy acting on the beam-column joint structure can be absorbed by both the beam and the joint section panel. Therefore, the energy absorption performance at the joint section between the column and the beam can be increased.

[0015] On the other hand, in order to ensure the structural stability of the building in which the beam-column joint structure is used, it is necessary to prevent the collapse of buildings provided with stories due to yielding of the columns. Therefore, the column needs to be sufficiently strong relative to the beam. Considering the increase in the yield strength after plastification of the beam, the column-beam strength ratio, which is the ratio of the full plastic strength of the column relative to the full plastic strength of the beam, is preferably 1.5 or more. In order to prevent the column from having excessive performance and being economically unreasonable, the column-beam strength ratio is preferably suppressed to roughly 2.5 to 3.0 or less.

[0016] As described above, by setting the beam-panel strength ratio to 1.05 or more and 1.5 or less and the column-beam strength ratio to 1.5 or more and 3.0 or less, the structural stability of the building using the beam-column joint structure can be achieved and the beam-column joint structure can be provided with joint sections having high energy absorption performance.

[0017] (2) An aspect 2 of the present invention may be the beam-column joint structure according to (1), further including:

> a backing bar joined to a lower flange arranged on the lower of the pair of beam flanges and to the joint plate, respectively, via the welded section; wherein an upper surface of the backing bar has a bevel formed that going downward gradually approaches the joint plate, and
> the welded section is formed in the bevel as well.

[0018] With the present invention, the portion of the connection surface between the backing bar and the welded section that is joined to the joint plate is not perpendicular to the plate to be joined but is inclined. Therefore, for example, due to a load such as a bending moment acting on the beam, strain concentration at the tip of the slit generated at the boundary between the joint plate and the backing bar can be mitigated, and the tip of the slit can be used to suppress the propagation of cracks toward the welded section or joint plate (base material of the joint plate).

[0019] (3) An aspect 3 of the present invention may be the beam-column joint structure according to (1) or (2), where at -20°C, the Charpy absorbed energy vE-20(S) in the plate thickness direction of the joint plate is 35 J or more.

[0020] With the present invention, the toughness in the plate thickness direction of the joint plate at -20° C is increased by a certain level or more. In general, the higher the temperature of the joint plate, the higher the toughness of the joint plate. Since the toughness of the joint plate is even higher at the temperature at which the plate is actually used, it is possible to suppress the breakage of the joint plate in the plate thickness direction even when the joined plate is directly joined to a pair of beam flanges of an I-beam provided on the beam via a welded section.

[0021] (4) An aspect 4 of the present invention may be the beam-column joint structure according to one of from (1) to (3), where at 0°C, the Charpy absorbed energy vE0(S) in the plate thickness direction of the joint plate is 47 J or more.

[0022] With the present invention, the toughness in the plate thickness direction of the joint plate at 0° C is increased by a certain level or more. In general, the higher the temperature of the joint plate, the higher the toughness of the joint plate. Since the toughness of the joint plate is even higher at the temperature at which the plate is actually used, it is possible to suppress the breakage of the joint plate in the plate thickness direction even when the joined plate is directly joined to a pair of beam flanges of an I-beam provided on the beam via a welded section.

[0023] (5) An aspect 5 of the present invention may be the beam-column joint structure according to any one of from (1) to (4), where a first reinforcement plate arranged at the same position as the pair of beam flanges in the vertical direction and joined to the column main body is not provided.

[0024] With the present invention, since the column does not have the first reinforcement plate that is joined to the column main body, the column can be constructed relatively easily.

[0025] (6) An aspect 6 of the present invention may be the beam-column joint structure according to any one of from (1) to (5), where a second reinforcement plate is joined to the web for column or the flat plate part for increasing thickness of the web for column or where the flat plate part is not provided.

[0026] With the present invention, since the column does not have the second reinforcement plate that is joined to the web for column, the column can be constructed relatively easily.

EFFECT OF THE INVENTION

[0027] In the beam-column joint structure of the present invention, structural stability of a building in which the beam-column joint structure is used can be ensured, and a beam-column joint structure having joint sections with high energy absorption performance can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028]

> FIG. 1 is a perspective view of a main part of a beam-column joint structure according to an embodiment of the present invention;
> FIG. 2 is an enlarged view of the A1 section in FIG. 1;
> FIG. 3 is a diagram illustrating the shape of a Charpy test piece, where (A) is a plan view, (B) is a front view, and (C) is a cross-sectional view along cutting line A3-A3 in (A);
> FIG. 4 is a diagram describing a test piece and notch orientation when obtaining a Charpy test piece from rolled steel;
> FIG. 5 is a diagram illustrating a procedure for obtaining a Charpy test piece in the plate thickness

direction from a column flange;

FIG. 6 is a diagram illustrating test results according to JIS Z 2242 using a Charpy test piece in which the plane on which notches are formed is perpendicular to the rolled direction;

FIG. 7 is a diagram illustrating test results according to JIS Z 2242 using a Charpy test piece in which the plane on which notches are formed is perpendicular to the plate thickness direction;

FIG. 8 is a front view illustrating a building in which a beam-column joint structure is used;

FIG. 9 is a front view illustrating an overview of a test apparatus for a beam-column joint structure;

FIG. 10 is an explanatory diagram for loading history 1 applied to sample 1;

FIG. 11 is an explanatory diagram for loading history 2 applied to sample 2;

FIG. 12 is a diagram illustrating experimental results from the US Federal Emergency Management Agency;

FIG. 13 is a diagram showing the experimental results of Shin's article;

FIG. 14 is a diagram illustrating experimental results of sample 1;

FIG. 15 is a diagram comparing the embodiments with conventional joint sections;

FIG. 16 is a photograph showing the test results of one embodiment;

FIG. 17 is a diagram comparing the strength ratio and the maximum story drift angle in the beam-column joint structure of the embodiments;

FIG. 18 is a perspective view of a main part in Modified Example 1 of the beam-column joint structure of one embodiment of the present invention;

FIG. 19 is a perspective view of a main part in Modified Example 2 of the beam-column joint structure of one embodiment of the present invention;

FIG. 20 is a front view of a main part of a beam-column joint structure used before the Northridge earthquake;

FIG. 21 is an enlarged view of a main part for describing the failure mode of this same beam-column joint structure;

FIG. 22 is a side view illustrating a state in which a joint section panel of the beam-column joint structure is shear-deformed; and

FIG. 23 is a perspective view of a main part of the beam-column joint structure conventionally used after the Northridge earthquake.

EMBODIMENTS OF THE INVENTION

[0029] An embodiment of a beam-column joint structure according to the present invention will be described below with reference to FIG. 1 to FIG. 19.

1. Building configuration

1-1. Beam-column joint structure configuration

[0030] As illustrated in FIG. 1, a beam-column joint structure 1 of the present embodiment is used for a building 2. The beam-column joint structure 1 includes a column 11 and a pair of beams 211B. Note that the number of beams 211B included in the beam-column joint structure 1 is not limited and may be 1 beam or 3 or more beams. The column 11 includes a column main body 12 composed of an I-beam for columns. The column main body 12 extends in a vertical direction (or in a first direction). The column main body 12 includes a pair of column flanges (joint plates) 16 and a web for column 17. The pair of column flanges 16 and web 17 are preferably formed out of rolled steel.

[0031] The pair of column flanges 16 are arranged mutually opposed in the plate thickness direction S. The web for column 17 is arranged between the pair of column flanges 16. The web for column 17 is joined respectively to the pair of column flanges 16 centered in the width direction. For example, the column main body 12 is formed using high toughness steel. The chemical composition of the column main body 12 preferably has a relatively low S content. In general, S is an element that combines with Mn in steel material and is included in steel material as an impurity. S forms MnS, and has the effect of embrittlement of the steel material. Relatively low S content in the column main body 12 enables achieving relatively high toughness of the column main body 12.

[0032] In this example, as illustrated in FIG. 23 and the like, the column 11 does not have a stiffener 203 or a doubler plate 225. Note that the column 11 may have at least one of the stiffener 203 and the doubler plate 225.

[0033] As illustrated in FIG. 1 and FIG. 2, in each of the structures of the beam 211 (extending in a second direction, which in this example is the horizontal direction), the beam 211B includes a pair of backing bars 21 in place of the pair of backing bars 213. In the example illustrated in FIG. 2, on the end part of each beam flange 216 on the column flange 16 side, a bevel 216a is formed that going downward gradually approaches the column flange 16. In this example, the first and second directions are substantially orthogonal to each other.

[0034] The backing bar 21 has a rectangular body shape. Each of the backing bars 21 are attached below the respective beam flanges 216 (lower flange 216B). More specifically, each of the backing bars 21 are attached to each of the beam flanges 216 and column flange 16 below each of the beam flanges 216 using fillet, tack welding, or the like. Note that non-use of a backing bar 21 on an upper flange 216A is feasible or a backing bar 213 may be used. A bevel 21a is formed on the end part of the upper surface of the backing bar 21 on the column flange 16 side that going downward gradually approaches the column flange 16. In other words, the backing bar 21 is chamfered. The bevel 21a lines up with the bevel 216a of the beam flange 216. A welded section 218 is arranged both inside the bevel 216a of the beam flange 216 and inside the bevel 21a of the backing bar 21. The backing bar 21 is joined respectively to the beam flange 216 (lower flange 216B) and the column flange 16 via the welded section 218. In this manner, each of the beam flanges 216 are respectively joined directly to the column flange 16 of the column main body 12 via the welded section 218. The welded section 218 is difficult to arrange between the column flange 16 and the backing bar 21 and a slit 21b is likely to be formed.

[0035] Here, as illustrated in FIG. 1, a section in the vertical direction in the range of the beam 211B on the web for column 17 is defined as a joint section panel 17a. The position of intersection of a center axis O1 of the column main body 12 and the center axis O2 of the beam 211B (I-beam) is defined as an intersect position P1. The column 11 and the pair of beams 211B are connected together by a joint section 23 in the beam-column joint structure 1. The intersect position P1 is a node of the joint section 23. Note that the column main body 12 is composed of an I-beam but the column main body may be composed of a square steel tubing or a weld assembled box cross-section (weld assembled box cross-section column).

1-2. Examination of Materials for Column Flanges

[0036] As illustrated in FIG. 1, if a load F1 that is a bending moment acts on the pair of beams 211B, for example, a force acts in the plate thickness direction S on the column flange 16 that is the joint plate. The present inventors considered that by using a material with a high level of toughness in the plate thickness direction S for the column flange 16, even if shear deformation of a joint section panel 17a caused by application of the load F1 generates bending deformation of the column flange 16, the column flange would resist the load in the plate thickness direction S and absorb the energy from the load F1. A force applied on a column flange in the plate thickness direction S having low toughness in the plate thickness direction S will likely cause a divot fracture in the column flange.

[0037] JIS Z 2242:2018 Charpy impact test method for metal materials (hereinafter simply referred to as JIS Z 2242) is known as a method for measuring the toughness of a member. As illustrated in FIG. 3, a Charpy test piece 150 is used for testing in JIS Z 2242. The length of the Charpy test piece 150 in the axial direction is 55 mm. The cross-sectional shape of the Charpy test piece 150 orthogonal to the axial direction is a 10 mm × 10 mm rectangular shape. A notch 151 is formed on the outer surface of the Charpy test piece specimen 150 centered in the axial direction. The notch 151 is formed on the flat surface S1 orthogonal to the axial direction. The notch 151 is a V notch with a depth of 2 mm. The notch 151 is formed over a part of the depth direction of the Charpy test piece 150. The notch 151 is formed extending in a direction perpendicular to the axial direction over the full width of the Charpy test piece 150.

[0038] FIG. 4 will be used to describe obtaining a Charpy test piece 150 from rolled steel 155 such as the column flange 16 and describe the orientation of the test piece and the notch. Note that FIG. 4 schematically illustrates the Charpy test piece 150 including the shape of the notch 151, described below. Rolled steel 155 is manufactured in a rolling mill by reducing the thickness of the steel in the plate thickness direction and extending the steel in the rolled direction. Here, the direction orthogonal to both the plate thickness direction S and the rolled direction L is called the width direction T. The rolled direction L and the width direction T are both plate thickness orthogonal directions (directions orthogonal to plate thickness direction S). For example, the flat surface S1 that the notch 151 is formed on is orthogonal to the plate thickness direction S and the Charpy test piece 150 where the depth direction of the notch 151 is parallel to the width direction T is identified as "S-T" or "Charpy test piece 150_{ST}." Charpy test pieces 150_{LS}, 150_{LT}, 150_{TS}, and 150_{TL} where the flat surface S1 on which the notch 151 is formed orthogonal to the roll direction L or the width direction T are used in JIS Z 2242. The Charpy impact tests that use the Charpy test pieces 150_{ST}, 150_{SL} that are orthogonal to the plate thickness direction S are performed using the procedure for JIS Z 2242 other than the procedure for obtaining the Charpy test piece 150.

[0039] FIG. 5 illustrates a procedure for obtaining the Charpy test piece 150_{SL} from the column flange 16. Here the plate thickness of the column flange 16 is defined as t1 (mm). A surface facing the plate thickness direction S of the column flange 16 that an extending bar 156, described below, is joined to, is referenced as surface 16a. A distance in the plate thickness direction S between the notch 151 of the Charpy test piece 150_{SL} and the surface 16a is defined as t2 (mm).

[0040] The cylindrical extending bar 156 is joined to the surface 16a of the column flange 16 using a friction weld joint. The reason that joining is performed using a friction weld joint is to suppress the heat-affected zone (HAZ) formed in the joint section of the column flange 16 and the extending bar 156 to a size that is as small as possible. Thereby, a Charpy test piece 150 can be prepared without any thermal effect on the notch 151 of the Charpy test piece 150. Here, the axial direction of the extending bar 156 is arranged to align with the plate thickness direction S. For example, the length of the extending bar 156 is 120 mm and the diameter of the extending bar 156 is 30 mm. The material that the extending bar 156 is formed with is preferably the same as the material that the column flange 16 is formed with. The friction weld joint is performed so as to join the entire cross section of the extending bar 156 on the surface 16a of the column flange 16.

[0041] For example, in the case that the plate thickness t1 is 40 mm or less, the distance t2 is set to (t1/4). If the plate thickness exceeds 40 mm, the distance t2 is set to

10 mm. The distance t2 is preferably set according to the thickness t1 as described above since a narrow heat-affected zone is formed over a narrow area at the joint section of the column flange 16 and the extending bar 156. For example, the plate thickness t1 of the column flange 16 is 19 mm or more.

[0042] In general, the higher the Charpy absorbed energy measured by JIS Z 2242, the higher the toughness.

[0043] FIG. 6 illustrates JIS Z 2242 test results using the Charpy test piece 150_{LT} where the flat surface S1 the notch 151 is formed on is orthogonal to the roll direction L. In FIG. 6, the horizontal axis represents the temperature (°C) of the Charpy test piece 150_{LT}, and the vertical axis represents the Charpy absorbed energy (J). Hereinafter, the Charpy absorbed energy from Charpy test pieces 150_{LS}, 150_{LT}, 150_{TS}, and 150_{TL} with the flat surface S1 where the notch 151 is formed orthogonal to the roll direction L is called the roll direction L Charpy absorbed energy vE(L, T). Note that the plate thickness orthogonal direction is taken as the roll direction L but the plate thickness orthogonal direction may be the width direction T.

[0044] The white circles indicate the results of the high toughness steel used for the column flange 16. The solid line L1 indicates an approximating curve of the results indicated by the white circles. The white triangles indicate results based on normal steel material (hereinafter called conventional steel material) used for a comparable conventional column flange 16. The dotted line L2 indicates an approximating curve of the results indicated by the white triangular marks. Line L3 indicates performance required based on Eurocodes and from the American Institute of Steel Construction (AISC). The required performance is a Charpy absorbed energy of 27 J from -21°C to -20°C.

[0045] For both high toughness steel and conventional steel material, the Charpy absorbed energy increased as temperature increased. Regardless of temperature, the high toughness steel Charpy absorbed energy was higher than the conventional steel material Charpy absorbed energy. In the range of -60°C to 80°C, the Charpy absorbed energy for both the high toughness steel and the conventional steel material met the required performance based on the Eurocodes and the AISC.

[0046] Here, the Charpy absorbed energy $vE_{-20(L,T)}$ in the roll direction L of the high toughness steel at -20°C measured based on JIS Z 2242 is illustrated as point $P_{-20(L,T)}$ in FIG. 6. The Charpy absorbed energy $vE_{0(L,T)}$ in the roll direction L of the high toughness steel at 0°C based on JIS Z 2242 is illustrated as point $P_{0(L,T)}$ in FIG. 6.

[0047] FIG. 7 illustrates JIS Z 2242 test results using the Charpy test piece 150_{SL} where the flat surface S1 the notch 151 is formed on is orthogonal to the plate thickness direction S. The axes, legend, and meanings of lines L1 and L2 are the same as in FIG. 6. In the case of Charpy test piece 150_{SL}, the required performance is not specified in Eurocodes or in the AISC. Hereinafter, the Charpy absorbed energy from Charpy test pieces 150_{ST}, and 150_{SL} with the flat surface S1 where the notch 151 is formed being orthogonal to the plate thickness direction S is called the plate thickness direction S Charpy absorbed energy $vE_{(S)}$. For the case of the Charpy test piece 150_{SL} as well, the same trend as for the Charpy test piece 150_{LT} is seen. Furthermore, for the case of the Charpy test piece 150_{SL}, the difference between the Charpy absorbed energy of the high toughness steel and the Charpy absorbed energy of the conventional steel material became larger.

[0048] Here, the Charpy absorbed energy $_{-20(S)}$ in the plate thickness direction S of the high toughness steel at -20°C measured based on JIS Z 2242 is illustrated as point $PvE_{-20(S)}$ in FIG. 7. The Charpy absorbed energy $vE_{0(S)}$ in the plate thickness direction S of the high toughness steel at 0°C based on JIS Z 2242 is illustrated as point $P_{0(S)}$ in FIG. 7. The Charpy absorbed energy $vE_{-20(S)}$ is preferably 35 J or more. The Charpy absorbed energy $vE_{-20(S)}$ is more preferably 47J or more. The Charpy absorbed energy $vE_{0(S)}$ is preferably 47J or more. The Charpy absorbed energy $vE_{0(S)}$ is more preferably 70J or more.

[0049] The Charpy absorbed energy $vE_{-20(L, T)}$ and the Charpy absorbed energy $vE_{-20(S)}$ at -20°C preferably satisfy the formula (6).

$$vE_{-20(S)} \geq 0.5 \times vE_{-20(L,T)} \quad (6)$$

[0050] In other words, the ratio of the toughness of the column flange 16 in the plate thickness direction S corresponding to the Charpy absorbed energy $vE_{-20(S)}$ at -20°C and the toughness of the column flange 16 in the roll direction L corresponding to the Charpy absorbed energy $vE_{-20(L, T)}$ is preferably at or above a certain ratio. In addition, the Charpy absorbed energy $vE_{0(L, T)}$ and the Charpy absorbed energy $vE_{0(S)}$ at 0°C preferably satisfy the formula (7).

$$vE_{0(S)} \geq 0.5 \times vE_{0(L, T)} \quad (7)$$

[0051] In other words, the ratio of the toughness of the column flange 16 in the plate thickness direction S corresponding to the Charpy absorbed energy $vE_{0(S)}$ at 0°C and the toughness of the column flange 16 in the roll direction L corresponding to the Charpy absorbed energy $vE_{0(L, T)}$ is preferably at or above a certain ratio.

[0052] In this manner, the ratio of the toughness of the column flange 16 in the plate thickness direction S and the toughness of the column flange 16 in the roll direction L is at or above a certain ratio, reducing the difference in toughness of the column flange 16 based on direction, thereby inducing stable crack growth, and achieving a joint section with ductile fracture properties and high energy absorption performance. Furthermore, the Charpy absorbed energy $vE_{-20(L, T)}$ and the Charpy absorbed energy $vE_{-20(S)}$ at -20°C preferably satisfy the formula

(6').

$$vE_{-20(L,T)} \geq vE_{-20(S)} \qquad (6')$$

[0053] In other words, the toughness of the column flange 16 in the roll direction L corresponding to the Charpy absorbed energy $vE_{-20(L,T)}$ at -20°C is preferably the equivalent or higher than the toughness of the column flange 16 in the plate thickness direction S corresponding to the Charpy absorbed energy $vE_{-20(S)}$. In addition, the Charpy absorbed energy $vE_{0(L,T)}$ and the Charpy absorbed energy $vE_{0(S)}$ at 0°C preferably satisfy the formula (7').

$$vE_{0(L,T)} \geq vE_{0(S)} \qquad (7')$$

[0054] In other words, the toughness of the column flange 16 in the roll direction L corresponding to the Charpy absorbed energy $vE_{0(L,T)}$ at 0°C is preferably the equivalent or higher than the toughness of the column flange 16 in the plate thickness direction S corresponding to the Charpy absorbed energy $vE_{0(S)}$. In this manner, the toughness of the column flange 16 in the roll direction L is the equivalent or greater than the toughness of the column flange 16 in the plate thickness direction, suppressing fracture in the plate thickness direction so that if a crack penetrates the direction of the plate thickness, the crack growth is stabilized, and a joint section with high ductile fracture properties and energy absorption performance is achieved. Other methods for measuring the toughness of members that provide results similar to those of JIS Z 2242 include ISO 148-1:2016 Metallic Materials-Carpy pendulum impact test Part 1: Test method, ASTM E23-18 Standard Test Methods for Notched Bar Impact Testing of Metallic Materials, BS EN ISO 148-1:2016 Metallic Materials-Charpy pendulum impact test Part 1: Test method, DIN EN ISO 148-1:2016 Metallic Materials -Charpy pendulum impact test Part 1: Test method, and the like.

1-3. Specifications of the Full Plastic Strength for each Configuration of the Beam-column Joint Structure

[0055] In general, intersect positions are used when calculating the full plastic strength of the columns and beams in the design of the beam-column joint structure. Note that the full plastic strength means when an external force acts on a member extending in a standard direction, the external force that causes the full cross section orthogonal to the standard direction to enter a plastic state. Here, the ratio of the full plastic strength M_{pc} of the column 11 relative to the full plastic strength M_{pb} of the beam 211B at the intersect position P1 is specified as the column-beam strength ratio (M_{pc}/M_{pb}). At the intersect position P1, the ratio of the full plastic strength M_{pb} of the beam 211B relative to the full plastic strength M_{pp} of the joint section panel 17a is specified as the beam-panel strength ratio (M_{pb}/M_{pp}). In [4.] below, regarding the issue of the present invention, the scope of the column-beam strength ratio and beam-panel strength ratio to provide a beam-column joint structure 1 having a joint section 23 with high energy absorption performance to ensure structural stability of the building 2 is investigated.

1-4. Full Plastic Strength Calculation Method

[0056] An example of a method for calculating the full plastic strength for a building 4 that uses a beam-column joint structure 3 illustrated in FIG. 8 will be described. The beam-column joint structure 3 includes one column 11 and six beams 211B. In this example, it is assumed that the six beams 211B have the same height and that the distances between adjacent beams 211B in the vertical direction (heights of columns 11) are the same. An end part of the six beams 211B not joined to the column 11 are respectively joined to a second column 51. Here, the direction a pair of second columns 51 are lined up in is called the left-right direction. A position where the center axis O1 of the column 11 or a center axis O3 of the second column 51 and the center axis O2 of the beam 211B intersect is called a node.

[0057] Symbols for the specifications of the beam-column joint structure 3 are defined as follows. Note that the units and the like indicated in Table 1 below are used as the units for each symbol.

- ${}_{L}l$, ${}_{R}l$: distances between nodes of the left and right beams 211B with respect to the joint section 23
- ${}_{L}l'$, ${}_{R}l'$: inner length of the left and right beams 211B with respect to the joint section 23
- ${}_{T}h$, ${}_{B}h$: distance between nodes of upper and lower columns 11 with respect to joint section 23
- ${}_{T}h'$, ${}_{B}h'$: inner length of upper and lower columns 11 with respect to joint section 23
- ${}_{bL}Z_p$, ${}_{bR}Z_p$: plastic section modulus of left and right beams 211B with respect to joint section 23
- ${}_{cT}Z_p$, ${}_{cB}Z_p$: plastic section modulus of upper and lower columns 11 with respect to joint section 23
- ${}_{bL}F$, ${}_{bR}F$: standard strength of the material strength of the left and right beams 211B with respect to the joint section 23
- ${}_{cT}F$, ${}_{cB}F$: standard strength of the material strength of the upper and lower columns 11 with respect to the joint section 23
- ${}_{p}F$: standard strength of the material strength of the joint section panel 17a
- ${}_{b}H$: height of beam 211B
- ${}_{c}H$: height of column 11
- ${}_{b}t_f$: thickness of beam flange 216
- ${}_{c}t_f$: thickness of column flange 16
- t_p: Thickness of the web 17 (when the column main body is composed of a square steel tubing or a weld assembled box cross-section, the thickness of the flat plate part of the rectangular steel pipe or weld assembled box cross-section (see flat plate part 33B

in FIG. 18))

d_b: distance between the pair of beam flanges 216 and the center of the plate thickness (= ${}_bH$ - ${}_bt_f$)

d_c: distance between the pair of column flanges 16 and the center the plate thickness (= ${}_cH$ - ${}_ct_f$)

[0058] Here, the effective volume ve of the joint section panel is obtained using equations (11) and (12).

Equation 1

[0059] Here, the full plastic strength M_{pb} of the beam 211B is obtained using equation (15). The full plastic strength M_{pc} of the column is obtained using equation (16). The full plastic strength M_{pp} of the joint section panel is obtained using equation (17).

Equation 2

[0060] For example, assume the story height of the upper and lower of the joint sections 23 (equivalent to distance ${}_Th$, ${}_Bh$) is 4500 mm. Assume that the distances ${}_Ll$ and ${}_Rl$ between the nodes of the beams 211B are 9000 mm. The beam-panel strength ratio and column-beam strength ratio are determined for case 1 to case 5 indicated in Table 1.

Table 1

[0061] For example, in case 1, a column main body composed of an I-beam is used. The cross-sectional dimensions of the column main body were H-458 × 427 × 40 × 50 (height × width × web thickness × flange thickness in mm), and the standard strengths ${}_{cT}F$ and ${}_{cB}F$ were 235 N/mm^2. In case 1, the beam-panel strength ratio was 1.411 and the column-beam strength ratio was 2.983.

1-5. Other Building Configurations

[0062] The building 2 includes floor slabs (not shown) and the like. The floor slab is supported from below by the beams 211B of the beam-column joint structure 1 and the like. The building 2 may have a plurality of stories (floors) separated vertically by floor slabs or the like. For example, the building 2 is used with facilities such as desks and document shelves placed on the floor slabs.

2. Manufacturing Method of High Toughness Steel

[0063] The S content in the chemical composition of high toughness steel is 0.011% by mass or less. Note that the S content can be measured using a combustion-infrared absorption method. Chemical compositions of other elements in the high toughness steel may be appropriately set. An example of the chemical composition is C: 0.05 to 0.20% (mass%), Si: 0.05 to 0.60%, Mn: 0.50 to 2.00%, P: 0.035% or less, and S: 0.011% or less. A high toughness steel material can be obtained by heating a cast slab having the chemical composition described above to 1050 to 1350°C and performing finish rolling at 600 to 950°C. In addition, accelerated cooling is preferably performed following finish rolling with the accelerated cooling stopped at 100°C or higher and 600°C or lower.

3. Investigation Experiment of Strength Ratio of Beam-column Joint Structure

[0064] The beam-column joint structure 1 was mounted on test device 160 illustrated in FIG. 9 and a test was performed. Hereafter, of the pair of beams 211B provided on the beam-column joint structure 1, there are cases where a first is called beam 211BA and a second is called beam 211BB. Note that the beam-column joint structure 1 is installed lying down as compared with the arrangement of that in an actual building so the structural surface of the columns and beams is set up as a horizontal surface. The test device 160 includes a reaction wall connecting jig 161, beam jacks 162A and 162B, a column jack 163, a lateral stiffening jig 164, an axial force frame 165, pantograph jigs 166A and 166B, and a reaction force jig 167.

[0065] The reaction wall connecting jig 161 is attached to a reaction wall of the test site. The beam jacks 162A and 162B and the axial force frame 165 are secured to the reaction wall connecting jig 161. The column jack 163 is secured to the end part of the axial force frame 165 on the side to the opposite of the end part which is connected to the reaction wall connecting jig 161. The beam jack 162A alternates up and down between the end of the beam 211BA connected to the column main body 12 and the end on the opposite side. The beam jack 162B alternates up and down between the end of the beam 211BB connected to the column main body 12 and the end on the opposite side. The column jack 163 is moved to the bottom end part of the column main body 12. The lateral stiffening jig 164 and pantograph jigs 166A and 166B are attached to a reaction floor of the site location suppressing deformation of the column main body 12 of the test specimen and the beam 211B outside the structural plane. Both ends of the reaction force jig 167 are connected to the lower end part of the column main body 12 and to the reaction wall connecting jig 161. The reaction force jig 167 transfers reaction forces generated by the beam jacks 162A and 162B.

[0066] Specifications of the beam-column joint structure 1 are indicated in Table 2.

Table 2

[0067] As illustrated in Table 2, the cross-sectional dimensions of the column main body 12 are H-498 × 432 × 45 × 70. The length of the column main body 12 was set to 4550 mm. The column main body 12 had a yield strength of 379 N/mm^2 and a tensile strength of 546

N/mm^2. The column main body 12 is composed of the high toughness steel indicated in FIG. 6 and FIG. 7, and has a chemical composition of C: 0.16%, Si: 0.30%, Mn: 1.40%, P: 0.0.17%, and S: 0.004% on a % by mass basis. The S content of the high toughness steel is relatively low.

[0068] As illustrated in Table 2, the cross-sectional dimensions of the I-beam 212 are H-650 × 300 × 16 × 25. The length of the I-beam 212 (distance between beam jack 162A and beam jack 162B) is set to 8,000 mm. The I-beam 212 had a yield strength of 380 N/mm^2 and a tensile strength of 513 N/mm^2. Here, the column-beam strength ratio was 2.34 and the beam-panel strength ratio was 1.43. The beam-column joint structure 1 does not have a stiffener or doubler plate while a backing bar with a bevel is left on both the upper flange 216A and lower flange 216B of the beam flange 216.

[0069] Simultaneous with moving the end part of the beam 211BA upward using the beam jack 162A, the test device 160 moves the end part of the beam 211BB downward using the beam jack 162B, setting a first movement state. In addition, simultaneous with moving the end part of the beam 211BA downward using the beam jack 162A, the test device 160 moves the end part of the beam 211BB upward using the beam jack 162B, setting a second movement state. The test device 160 alternates between the first movement state and the second movement state as one cycle, applying inversely symmetrical loads on the beam-column joint structure 1. Samples 1 and 2 having the same configuration as the beam-column joint structure 1 were prepared. A load was applied on sample 1 according to loading history 1 indicated in FIG. 10 and a load was applied on sample 2 according to loading history 2 indicated in FIG. 11.

[0070] In FIG. 10 and FIG. 11, the horizontal axis indicates the loading cycle and the vertical axis indicates the story drift angle (rad) of the beam-column joint structure 1. The loading history 1 is the loading history used in the standard loading history of performance confirmation experiments of earthquake resistant joints defined by the US design standard ANSI/AISC341-16. AISC is an organization that establishes standards for steel structures in the United States, and issues seismic design codes for steel structures. Loading history 2 is the loading history used in the seismic structure study project SAC. SAC is a project organized for the purpose of examining countermeasures related to welded joint fractures in steel structures caused by the Northridge earthquake. For both samples 1 and 2, the column jack 163 was used to apply a constant compressive axial force (5000 kN) that is 20% of the yield axial force on the column main body 12. While the constant compressive axial force was applied to the column main body 12, a plurality of cycles of loads were applied to the pair of beams 211B.

[0071] Here, FIG. 12 and FIG. 13 indicate joint section test results of previous research. In FIG. 12, FIG. 13, and FIG. 14 described below, the horizontal axis indicates story drift angle (rad) and the vertical axis indicates the story shear force (kN) that is the load. FIG. 12 indicates 1997 test results of the US Federal Emergency Management Agency (hereinafter simply called FEMA). The joint section used in this experiment is the pre-Northridge joint section. FIG. 13 indicates test results from Shin's literature (hereinafter, simply called Shin, see [7.]). The joint section used in this experiment is the post-North ridge joint section. FIG. 14 indicates the results from Sample 1 (embodiment) of this test.

[0072] FIG. 12 to FIG. 14 use the same range for the horizontal axis. FIG. 12 to FIG. 14 use the same range for the vertical axis. The story shear force on the vertical axis changes based on the cross-sectional dimensions of the test specimen and they cannot be directly compared. On the other hand, the story drift angle on the horizontal axis represents the deformation performance of the beam-column joint structure. Here, maintaining story shear force up to areas with large story drift angle means high deformation performance is achieved. The maximum story drift angle of FIG. 14 is 0.08 rad which is higher than the maximum story drift angle in FIG. 12 and FIG. 13, and thus higher deformation performance is achieved. In addition, in FIG. 12 to FIG. 14, the area surrounded by the test result curves represents the energy absorbed by the beam-column joint structure and the accumulation of the energy absorbed in each load cycle in the energy absorption performance of the beam-column joint structure. Compared to FIG. 12 and FIG. 13, FIG. 14 indicates maintaining story shear force for a higher number of cycles; therefore, the accumulated absorbed energy is extremely high. Therefore, it can be seen that the joint section 23 of the beam-column joint structure 1 illustrated in FIG. 14 has higher energy absorption performance than the joint sections for FEMA and Shin.

[0073] FIG. 15 illustrates a results comparison of the joint sections for the beam-column joint structure 1 of the embodiment and for conventional joint sections such as FEMA. As conventional joint sections, FIG. 15 indicates results from Chi & Uang literature (hereinafter simply called Chi & Uang, see [7.]), Ricles literature (hereinafter, simply called Ricles, see [7.]), and Rahiminia & Namba literature (hereinafter, simply called Rahiminia & Namba, see [7.]). For each joint section, the type of joint, the presence or absence of stiffeners, doubler plates, and backing bar is indicated. If the backing bar column is "left," this means that a backing bar is left and a backing bar is present. If the backing bar column is "removed," this means that a backing bar is removed and a backing bar is not present.

[0074] For example, the beam-column joint structure 1 of the embodiment does not have a stiffener or doubler plate but has a backing bar.

[0075] The upper part of FIG. 15 indicates story drift angle (rad) as deformation performance for each joint section. In FIG. 15, the required performance (0.04) of the US design standard AISC341-18 is represented by a solid line L5. The US design standard AISC341-18 assumes loads according to Loading Procedure 1. The US design standard AISC341-18 stipulates that 80% or more of the full plastic strength must remain when the story drift angle reaches 0.04 rad as the required performance of joint sections for earthquake-resistant structures.

[0076] FIG. 15 illustrates test results of the beam-column joint structure 1 of the embodiment and the like. In the joint section panel yield column, "Yes" means that the joint section panel yields during the test, and "No" means that the joint section panel does not yield during the test. In the manufacturability and workability columns, "×" means that manufacturability and workability are poor, and "o" means that manufacturability and workability are favorable. In the seismic performance column, "x" means poor seismic performance, "o" means good seismic performance, and "◎" means very good seismic performance. For example, in the beam-column joint structure 1 of the embodiment, the joint section panel yielded during the test. The beam-column joint structure 1 has good manufacturability and workability because it does not have stiffeners and doubler plates, and seismic performance is very good.

[0077] The joint section 23 of the beam-column joint structure 1 of the embodiment greatly exceeds the required performance of the US design standard AISC341-18 represented by the line L5. Samples 1 and 2 exhibited approximately similar failure modes. This indicates that the joint section 23 of the beam-column joint structure 1 of the embodiment stably exceeds the required performance of the joint section of the earthquake-resistant structure under these test conditions. Note that the ultimate state of the joint section 23 of the beam-column joint structure 1 of the embodiment is similar to Type D of Non-Patent Document 1. In other words, the crack generated on the surface of the column flange 16 exhibited a fracture mode in which the crack penetrated in the plate thickness direction.

[0078] However, as illustrated in FIG. 16, the crack LF is initiated and propagated on the side of the upper flange 216A, and the backing bar 213 having the bevel 21a formed thereon exhibits effective functionality as means for preventing fracture originating from the lower flange 216B. Note that as illustrated in FIG. 16, white plaster is coated on the surface of the beam-column joint structure 1 in advance. With the beam-column joint structure 1, the plaster is peeled off from the plastified section, and the black color of the column main body 12 and the like is visible. In other words, it was found that not only the column 11 and the beam 211B were kink-deformed, but also the joint section panel 17a, the beam flange 216 at the end of the beam 211B, and beam web 217 were plastified to absorb the energy.

[0079] In addition, research is currently underway on the degree of margin (redundancy) against collapse due to a large-scale earthquake that exceeds the scale assumed in the design, and on the evaluation of the remaining performance after the earthquake (determination of whether repair is possible). Of these, the performance of the joint section 23 of the beam-column joint structure 1 of the embodiment was found to have high superiority from these viewpoints.

4. Examination of Strength Ratio

[0080] FIG. 17 illustrates the column-beam strength ratio, beam-panel strength ratio, and maximum story drift angle obtained from the beam-column joint structure 1 of the embodiment, Shin's literature, Rahiminia & Namba's literature, and Ricles' literature. Shin's literature, Rahiminia & Namba's literature, and Ricles' literature are literature for previous research. Table 3 indicates the presence or absence of stiffeners in the embodiment and past research.

Table 3

[0081] In addition, when there is a slab, the slab is supported from below by beams. For example, the UT01 in Shin's literature has a stiffener but no doubler plate. No backing bar and no slab.

5. Effects of the Present Embodiment

[0082] As described above and as a result of extensive studies, the inventors have found that in order to improve the energy absorption performance of the joint section 23 between the column 11 and the beam 211B in the beam-column joint structure 1, the energy acting on the beam-column joint structure 1 must be absorbed not only in the beam 211B but also in the joint section panel 17a. In particular, a configuration where the joint section panel 17a, for which stable yield strength increase after plasticization can be anticipated as long as the column flange 16 does not break, yields first, and then in conjunction with increase in yield strength of the joint section panel 17a due to yielding, the beam 211B also yields, is preferable. In other words, the beam-panel strength ratio, which is the ratio of the full plastic strength M_{pb} of the beam 211B relative to the full plastic strength M_{pp} of the joint section panel 17a, should be 1.05 or more so that the joint section panel 17a yields first.

[0083] In addition, the yield strength of the joint section panel 17a can be expected to increase to about 1.5 times the full plastic strength due to strain hardening due to repeated plastic deformation. In other words, by setting the beam-panel strength ratio to 1.5 or less, not only the joint section panel 17a but also the beam 211B can be plastified in the process of increasing the yield strength after initial yielding of the joint section panel 17a and energy acting on the beam-column joint structure 1 can be absorbed by both the beam 211B and the joint section panel 17a. Therefore, energy absorption performance at the joint section 23 between the column 11 and the beam 211B can be increased. On the other hand, in order to ensure the structural stability of the building 2 in which the beam-column joint structure 1 is used, it is necessary to prevent story collapse due to yielding of the columns 11. Therefore, the column 11 needs to be sufficiently strong relative to the beam 211B. Considering the increase in the yield strength after plastification of the beam 211B, the column-beam strength ratio, which is the ratio of the full plastic strength of the column 11 relative to the full plastic strength of the beam 211B, is preferably 1.5 or more. In order to prevent the column 11 from having excessive performance and being economically unreasonable, the column-beam strength ratio is preferably suppressed to roughly 2.5 to 3.0 or less. On the other hand, according to the past research illustrated in FIG. 17, there are few cases where the joint section panel yields first and the beam-panel strength ratio is 1.05 or more. This is believed to be due to the fact that conventional steel materials and joint details have avoided the joint section panel yielding first. In past research, when the beam-panel strength ratio is 1.05 or more, the column-beam strength ratio is 1.5 or less most of the time. In past research where the joint section panel yields first, it can be seen that this is based on the assumption that the column strength is relatively small.

[0084] If the column-beam strength ratio exceeds 1.5, the plate thickness of the column flange is thick, and the effect of local bending deformation (kink) of the column flange becomes significant, and early breakage becomes a problem. On the other hand, when the column-beam strength ratio is small, the plate thickness of the flange is relatively thin, so the effect of local bending deformation of the column flange when the joint section panel yields is small; therefore, breakage is less likely to occur. It is thought that past research has avoided beam-column joint structures with a load-bearing balance that have a beam-panel strength ratio in the range of 1.05 or more and 1.5 or less (range R6 indicated in FIG. 17) and column-beam strength ratio in the range of 1.5 or more and 3.0 or less (range R7 shown in Figure 17) for these reasons. By setting the beam-panel strength ratio to 1.05 or more and 1.5 or less and the column-beam strength ratio to 1.5 or more and 3.0 or less, the structural stability of the building 2 using the beam-column joint structure 1 can be achieved and the beam-column joint structure 1 can be provided with joint sections 23 having high energy absorption performance.

[0085] The column 11 of the beam-column joint structure 1 not having the stiffener 203 or the doubler plate 225 facilitates fabrication and construction of the column 11. In Table 1, case 1 is a beam-column joint structure using an I-beam for the column 11, Case 2 is a beam-column joint structure using a weld assembled box cross-section for the column 11, but both satisfy the ranges of the beam-panel strength ratio and the column-beam strength ratio, and are embodiments. Case 3 is a comparative example that does not satisfy the range of the beam-panel strength ratio. Case 4 is a comparative example that does not satisfy the range of the column-beam strength ratio. Case 5 is a comparative example that does not satisfy the range of the beam-panel strength ratio or the column-beam strength ratio.

[0086] A bevel 21a is formed in the backing bar 21. Therefore, the portion of the connection surface between the backing bar 21 and the welded section 218 that is joined to the column flange 16 is not perpendicular to the column flange 16 but is inclined. For this reason, for example, based on a load such as a bending moment acting on the beam 211B, strain concentration at the tip of the slit 21b generated at the boundary between the column flange 16 and the backing bar 21 can be alleviated, thereby suppressing the propagation of a crack from the tip of the slit 21b toward the welded section 218 or column flange 16.

[0087] Based on JIS Z 2242, the Charpy absorbed energy $vE_{-20(S)}$ in the plate thickness direction S of the column flange 16 at -20°C may be 35 J or more. In this case, the toughness of the column flange 16 in the plate thickness direction S at -20°C is increased by a certain amount or more. Generally, the higher the temperature of the column flange, the higher the toughness of the column flange. At the temperature at which the column flange 16 is actually used, the toughness is further increased; therefore, in the case that the column flange 16 is joined directly to the pair of beam flanges 216 of the I-beam 212 provided on the beam 211B via the welded section 218, breakage of the column flange 16 in the plate thickness direction S can be suppressed. The Charpy absorbed energy $vE_{-20(S)}$, $vE_{-20(L,\ T)}$ may satisfy the equation (6). In this case, the ratio of the toughness of the column flange 16 in the plate thickness direction S corresponding to the Charpy absorbed energy $vE_{-20(S)}$ at -20°C and the toughness of the column flange 16 in the roll direction L corresponding to the Charpy absorbed energy $vE_{-20(L,\ T)}$ is preferably at or above a certain ratio. Therefore, the difference in toughness of the column flange 16 depending on the direction is reduced, and stable crack propagation is induced, resulting in a ductile fracture property and a joint section with higher energy absorption performance.

[0088] Based on JIS Z 2242, the Charpy absorbed energy $vE_{0(S)}$ in the plate thickness direction S of the column flange 16 at 0°C may be 47 J or more. In this case, the toughness of the column flange 16 in the plate thickness direction S at 0°C is increased by a certain amount or more. Generally, the higher the temperature of the column flange, the higher the toughness of the column flange. At the temperature at which the column flange 16 is actually used, the toughness is further increased; therefore, in the case that the column flange 16 is joined directly to the pair of beam flanges 216 of the I-beam 212 provided on the beam 211B via the welded section 218, breakage of the column flange 16 in the plate thickness direction S can be suppressed. The Charpy absorbed energy $vE_{0(S)}$, $vE_{0(L,\ T)}$ may satisfy the equation (7). In this case, the ratio of the toughness of the column flange 16 in the plate thickness direction S corresponding to the Charpy absorbed energy $vE_{0(S)}$ at 0°C and the toughness of the column flange 16 in the roll direction L corresponding to the Charpy absorbed energy $vE_{0(L,\ T)}$ is preferably at or above a certain ratio. Therefore, the difference in toughness of the column flange 16 depending on the direction is reduced, and stable crack propagation is induced, resulting in a ductile fracture property and a joint section with higher energy absorption performance.

[0089] There are cases where the column 11 is not provided with the stiffener 203. In this case, the column 11 can be formed relatively easily. There are cases where the column 11 is not provided with the doubler plate 225. In this case, the column 11 can be formed relatively easily.

6. Other

[0090] As has been described, embodiments of the present invention have been described in detail with reference to the drawings; however, specific configurations are not restricted to these embodiments and the present invention includes structural changes, combinations, and deletions and the like that do not deviate from the main points. For example, in the above embodiment, the beam-column joint structure 1 does not have to include the backing bar 21.

[0091] Similar to the beam-column joint structure 1A of the Modified Example 1 illustrated in FIG. 18, the column main body 32 of the column 31 may be configured with a weld assembled box cross-section. In FIG. 18, a portion of the column main body 32 is cut away for illustration. In this example, the column main body 32 is composed of welding a pair of flat plate parts (joint plates) 33A and a pair of flat plate parts 33B together. The pair of flat plate parts 33A are arranged so as to face each other. The pair of flat plate parts 33B are arranged so as to face each other. Each flat plate part 33B is joined to the ends of the pair of flat plate parts 33A. The pair of beam flanges 216 of the I-beam 212 are respectively joined directly to each of the flat plate parts 33A via a welded section 218. The pair of flat plate parts 33B extend along the longitudinal direction of the beam 211B.

[0092] A joint section panel 33Ba is a portion of the pair of flat plate parts 33B within the range of the beam 211B in the vertical direction. The column 31 and the pair of beams 211B are connected together by a joint section 35 in the beam-column joint structure 1A. The beam-column joint structure 1A of Modified Example 1 may have at least one of the stiffener 203 and doubler plate 225. In the case of the beam-column joint structure 1A of Modified Example 1, the column-beam strength ratio is 1.5 or more and 3.0 or less. The beam-panel strength ratio based on the joint section panel 33Ba is 1.05 or more and 1.5 or less.

[0093] Similar to a beam-column joint structure 1B of Modified Example 2 illustrated in FIG. 19, a column main body 42 of column 41 may be composed of square steel tubing manufactured by bending and welding a steel plate. In FIG. 19, a portion of the column main body 42 is cut away for illustration.

[0094] The I-beam for columns and the I-beam are not limited to the I shaped steel specified by JIS G 3192, and may be a steel material having an I-shaped cross section perpendicular to the axial direction.

7. List of Documents

[0095]

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Rides: Rides, J. M., C. Mao, L.-W. Lu, and J. W. Fisher. 2000, Development and evaluation of improved details for ductile welded unreinforced flange connections, SAC Background Document, Report No. SAC/BD-00/24, SAC Joint Venture, Sacramento, CA, USA.

Rahiminia & Namba: Rahiminia, F., and H. Namba, 2013, "Joint panel in steel moment connections, part 1: experimental tests results", Journal of Constructional Steel Research, 89: 272-283.

EXPLANATION OF CODES

[0096]

1, 1A, 1B. Beam-column joint structure
11, 31, 41. Column
12, 32, 42. Column main body
16. Column flange (joint plate)
17. Web for column
21. Backing bar
21a. Bevel
33A. Flat plate part (joint plate)
211B. Beam
212. I-beam
203. Stiffener (first reinforcement plate)
216. Beam flange
216B. Lower flange
218. Welded section
225. Doubler plate (second reinforcement plate)
01, 02. Center axis
P1. Intersect position
S. Plate thickness direction

Claims

1. A beam-column joint structure (1, 1A, 1B), comprising:

a column (11, 31, 41) having a column main body

(12, 32, 42) comprising an I-beam of the column, or a square steel tubing, or a weld assembled box cross-section; and

a beam (211B) comprising an I-beam where a pair of beam flanges (216) of the I-beam are respectively joined directly to joint plates of the column main body (12, 32, 42) via a welded section (218); wherein

the joint plate is a column flange (16) of the I-beam of the column or a flat plate part (33A) of the square steel tubing or weld assembled box cross-section,

with the intersect position (P1) specified as the position where the center axis of the column main body (12, 32, 42) and the center axis of the I-beam intersect, the ratio of the full plastic strength of the column (11, 31, 41) relative to the full plastic strength of the beam (211B) at the intersect position (P1) is 1.5 or more and 3.0 or less, and

at the intersect position (P1) on a web for column (17) of the column main body (12, 32, 42) comprising the I-beam of the column or the flat plate part (33A) extending in the longitudinal direction of the beam (211B) on the column main body (12, 32, 42) comprising the square steel tubing or weld assembled box cross-section, the ratio of the full plastic strength of the beam (211B) relative to the full plastic strength of the portion in the height range of the beam (211B) in the vertical direction is 1.05 or more and 1.5 or less.

2. The beam-column joint structure (1, 1A, 1B) according to claim 1, further comprising:

a backing bar (21) joined to a lower flange (216B) arranged on the lower of the pair of beam flanges (216) and to the joint plate (33A), respectively, via the welded section (218); wherein

an upper surface of the backing bar (21) has a bevel (21a) formed that going downward gradually approaches the joint plate (33A), and

the welded section (218) is formed in the bevel (21a) as well.

3. The beam-column joint structure (1, 1A, 1B) according to claim 1 or 2, wherein at -20°C, the Charpy absorbed energy $vE_{-20(S)}$ in the plate thickness direction of the joint plate (33A) is 35 J or more.

4. The beam-column joint structure (1, 1A, 1B) according to any one of claims 1 to 3, wherein at 0°C, the Charpy absorbed energy $vE_{0(S)}$ in the plate thickness direction of the joint plate (33A) is 47 J or more.

5. The beam-column joint structure (1, 1A, 1B) according to any one of claims 1 to 4, wherein a first reinforcement plate arranged at the same position as the pair of beam flanges (216) in the vertical direction and joined to the column main body (12, 32, 42) is not provided.

6. The beam-column joint structure (1, 1A, 1B) according to any one of claims 1 to 5, wherein a second reinforcement plate joined to the web for column (17) or the flat plate part (33A) for increasing thickness of the web for column (17) or the flat plate part (33A) is not provided.

FIG. 1

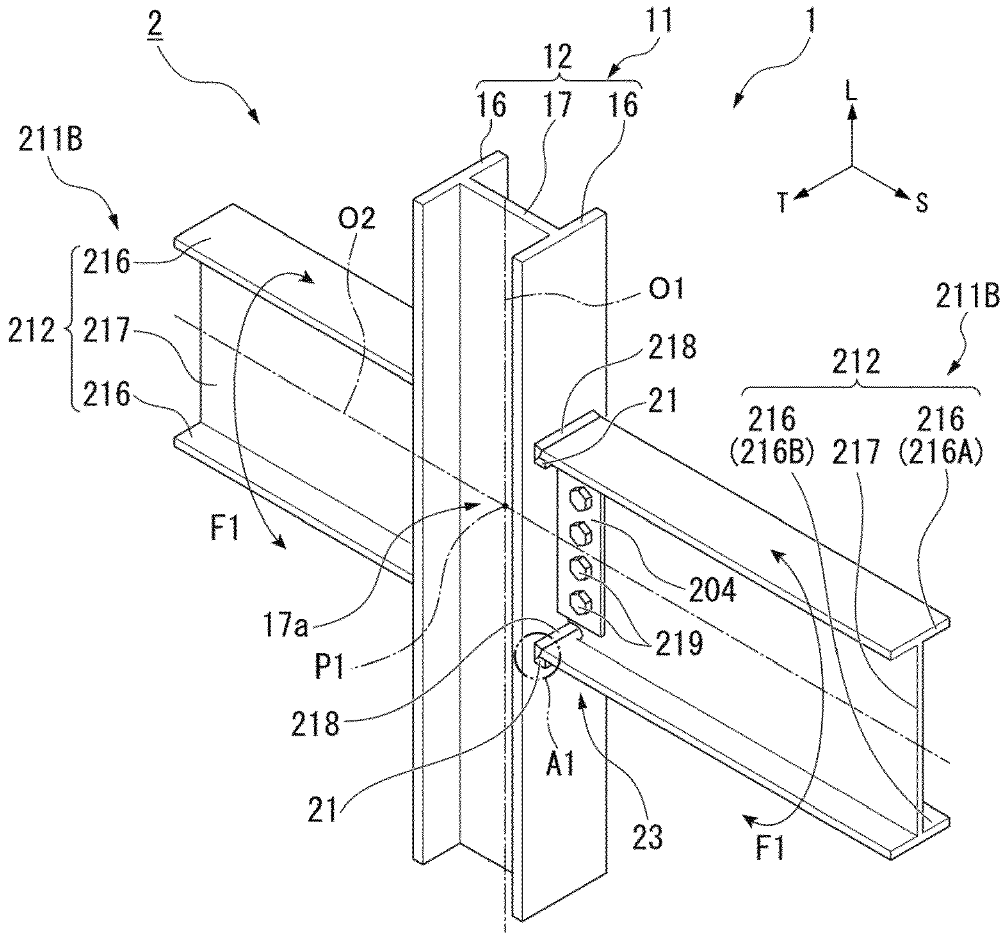

2
1
11
12
16
17
16
L
T
S
211B
O2
216
212
217
216
O1
211B
218
212
21
216
(216B)
217
216
(216A)
F1
204
17a
219
P1
218
A1
21
23
F1

FIG. 2

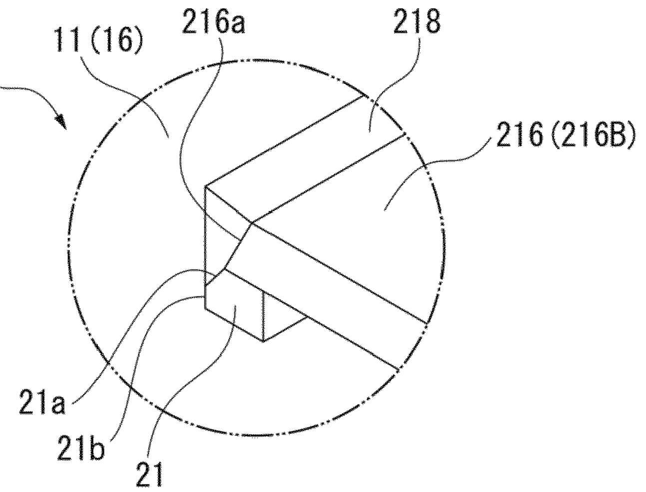

1
11 (16)
216a
218
216 (216B)
21a
21b
21

FIG. 3A

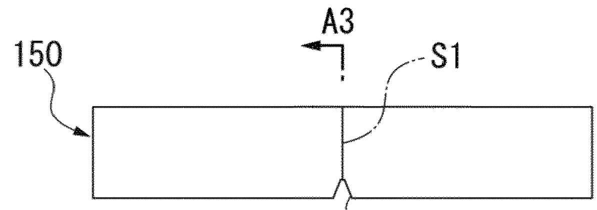


FIG. 3B

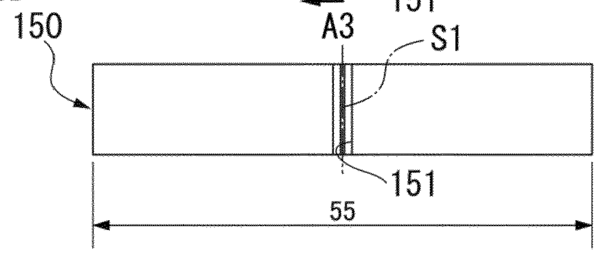


FIG. 3C

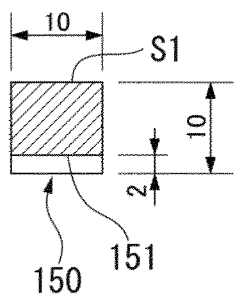


FIG. 4

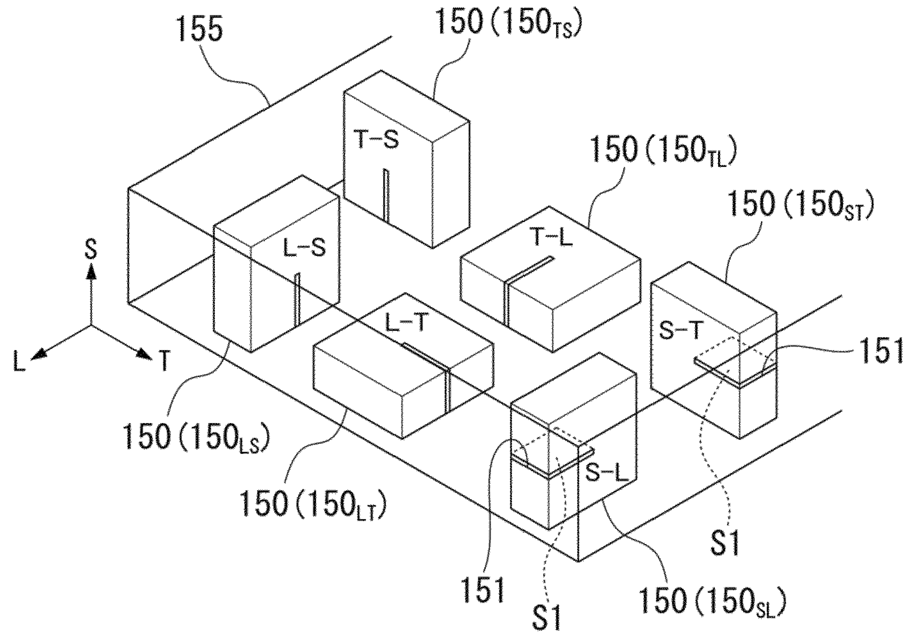


FIG. 5

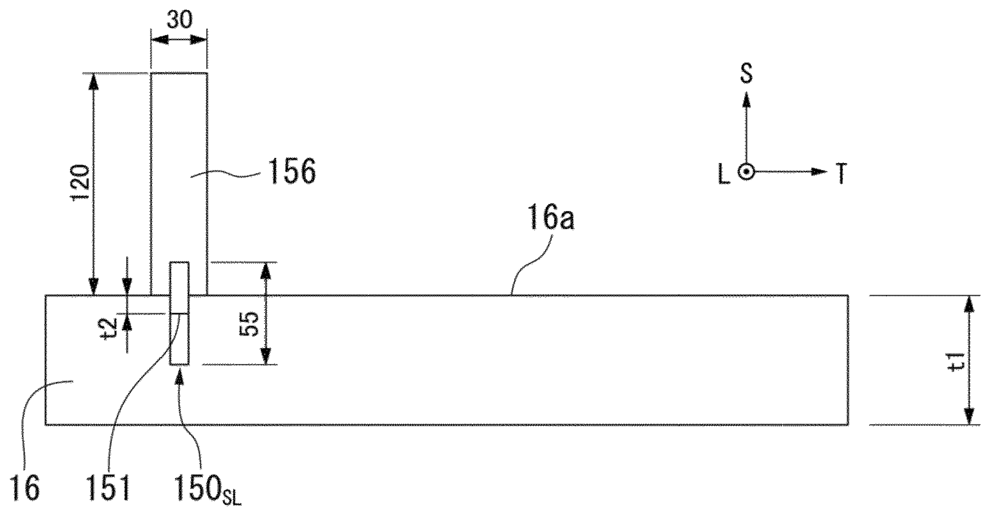

30
120
156
16a
S
L
T
t2
55
t1
16
151
150SL

FIG. 6

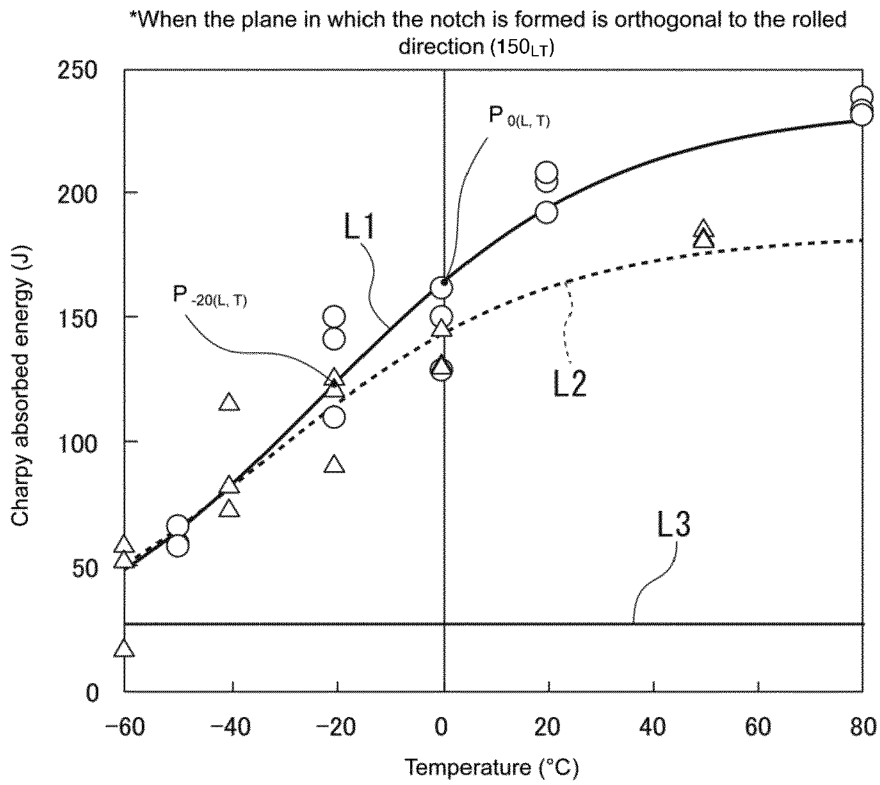
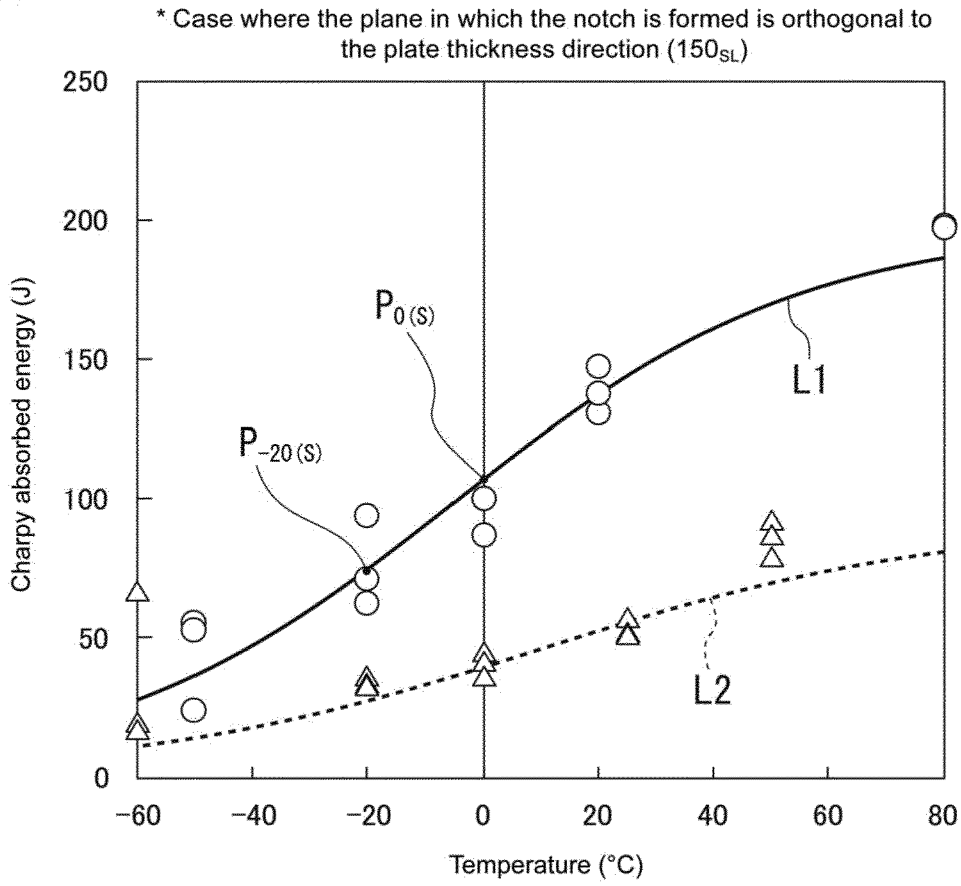

*When the plane in which the notch is formed is orthogonal to the rolled direction (150LT)
250
200
150
100
50
0
Charpy absorbed energy (J)
P 0(L, T)
L1
P -20(L, T)
L2
L3
−60
−40
−20
0
20
40
60
80
Temperature (°C)

FIG. 7


* Case where the plane in which the notch is formed is orthogonal to the plate thickness direction (150SL)
Charpy absorbed energy (J)
Temperature (°C)
250
200
150
100
50
0
−60
−40
−20
0
20
40
60
80
P0(S)
P−20(S)
L1
L2

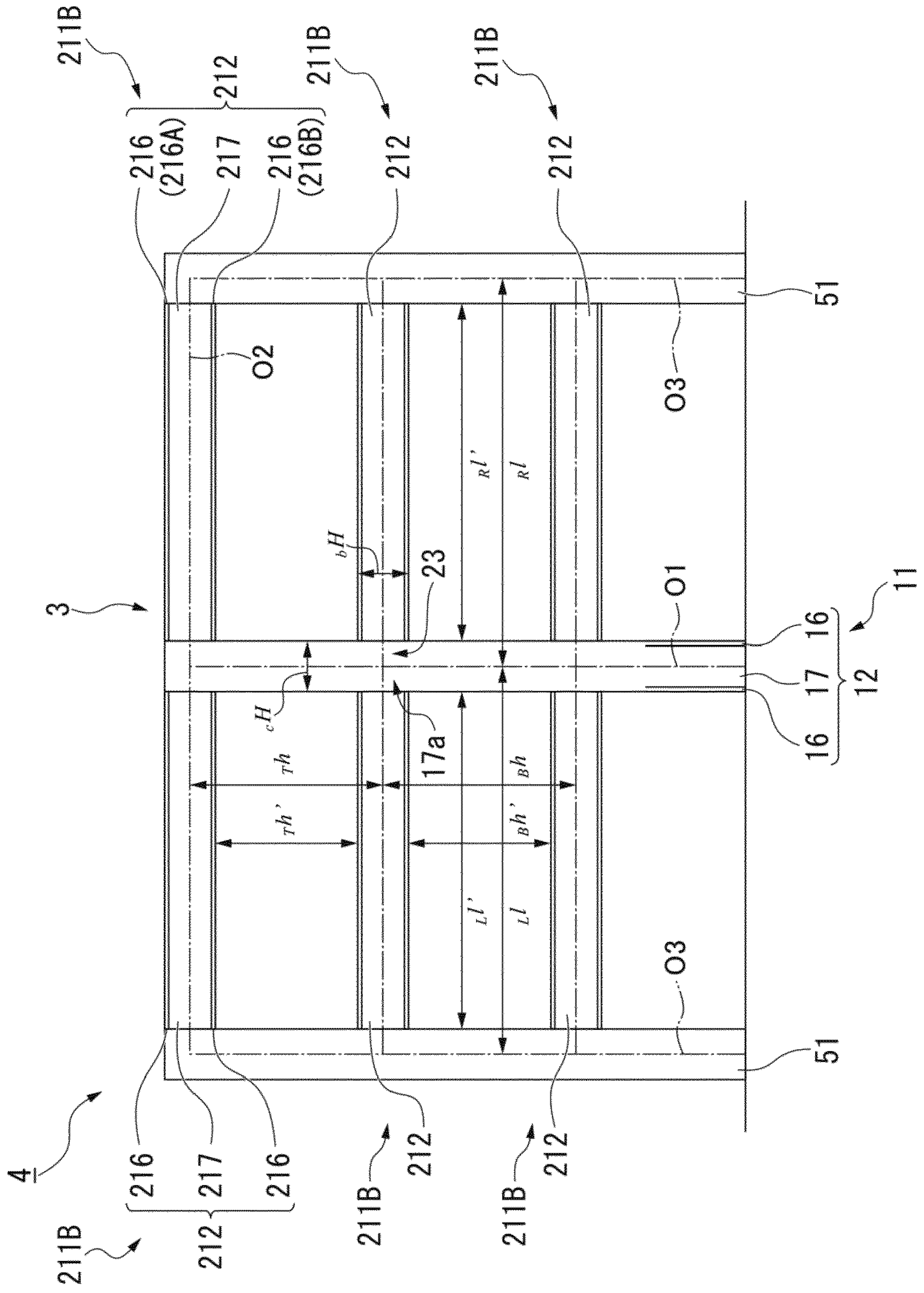


FIG. 8

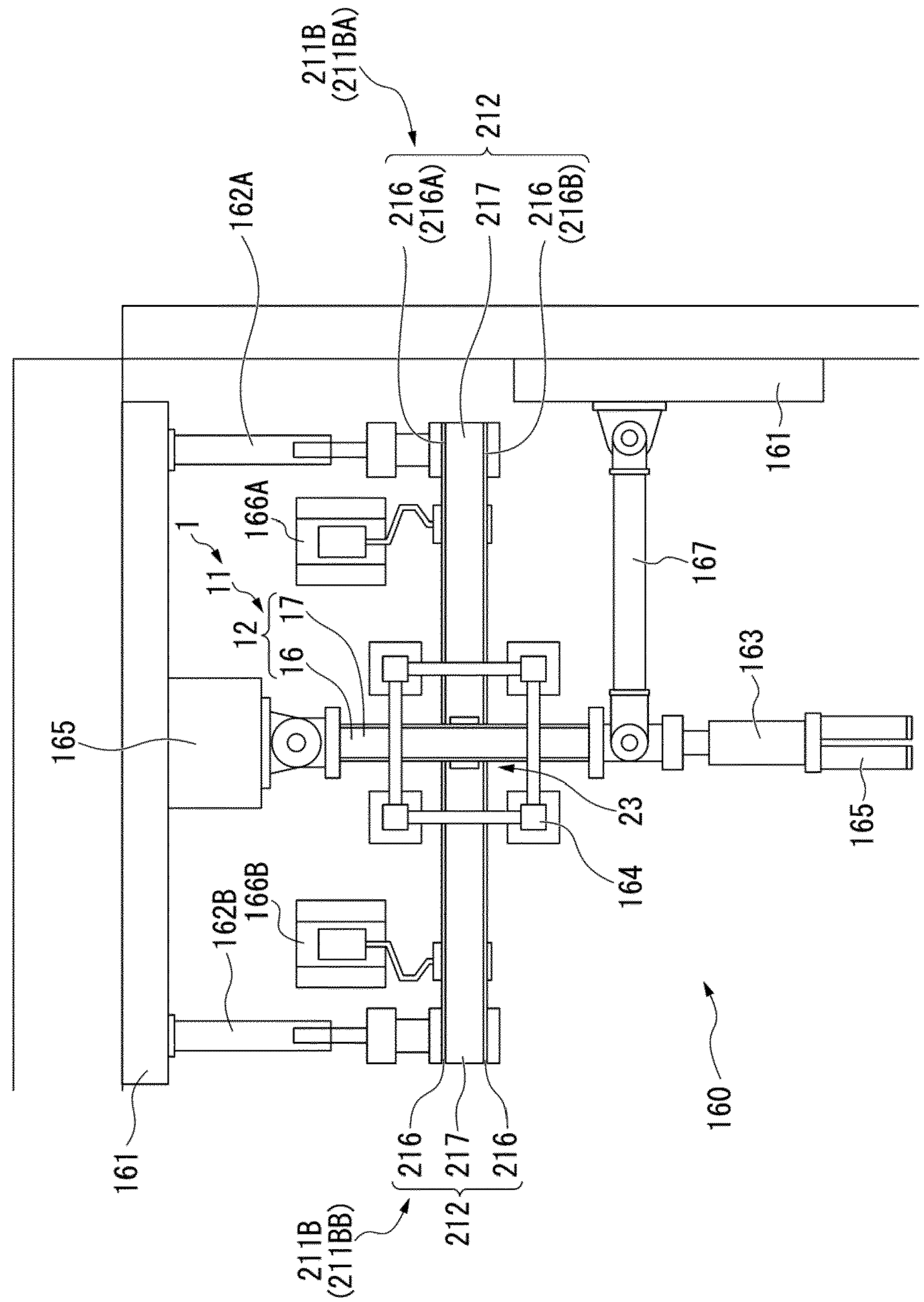

211B
(211BA)
212
216
(216A)
217
216
(216B)
162A
161
166A
1
11
12
17
16
165
167
163
23
165
164
162B
166B
160
216
217
216
212
211B
(211BB)
161

FIG. 9

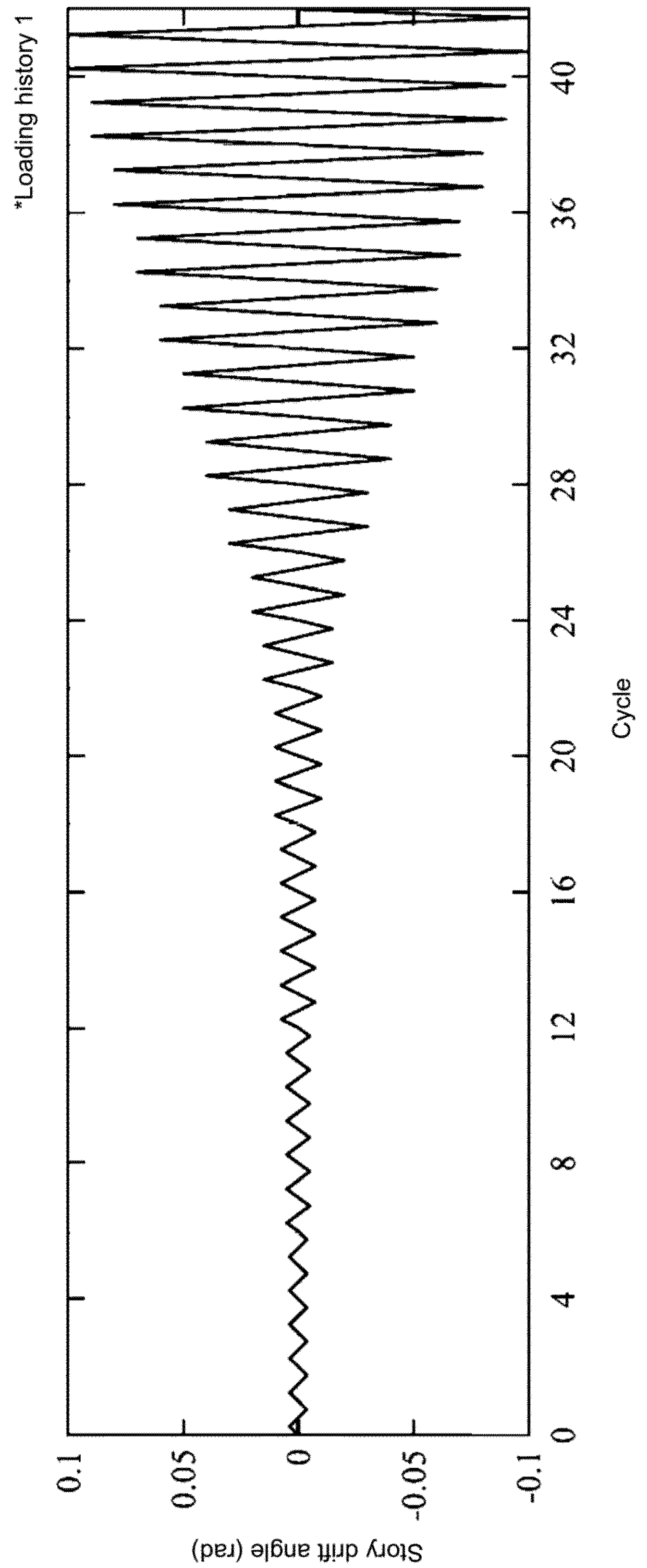

*Loading history 1
Story drift angle (rad)
0.1
0.05
0
-0.05
-0.1
Cycle
0
4
8
12
16
20
24
28
32
36
40

FIG. 10

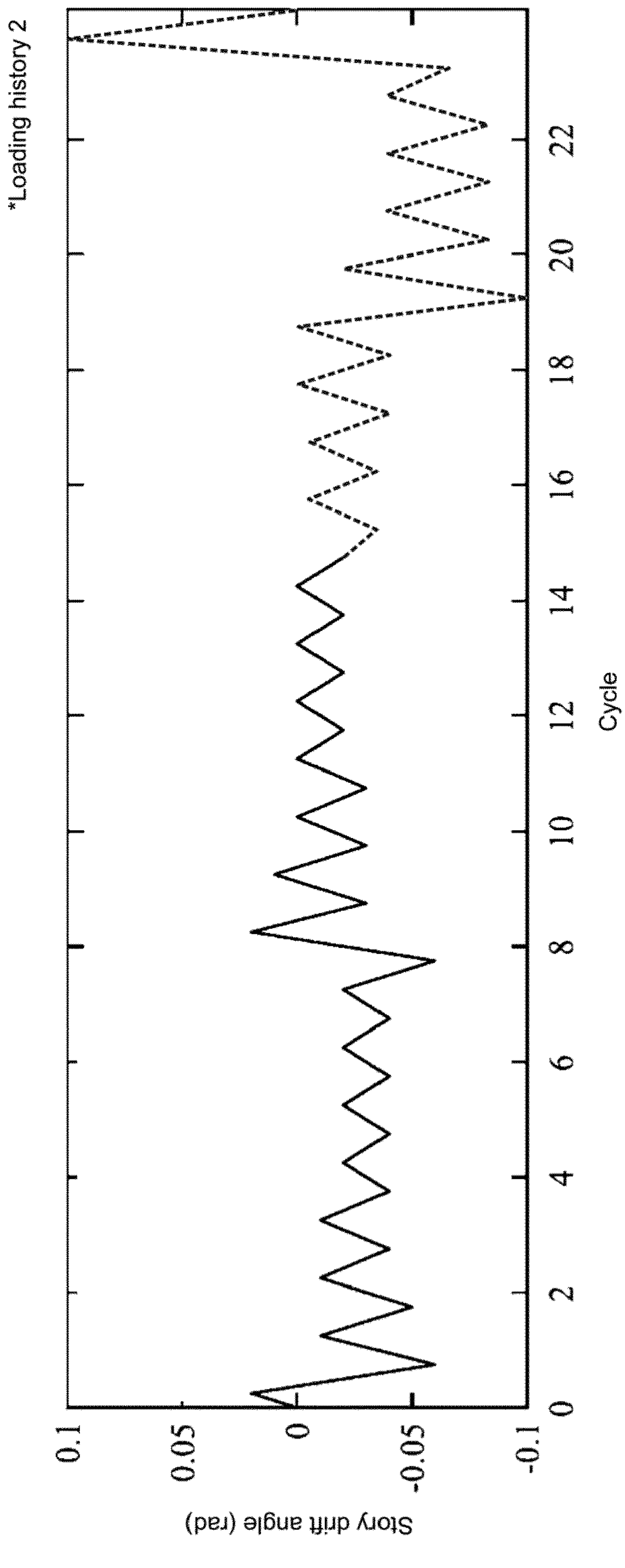

*Loading history 2
Story drift angle (rad)
0.1
0.05
0
-0.05
-0.1
Cycle
0
2
4
6
8
10
12
14
16
18
20
22

FIG. 11

FIG. 12

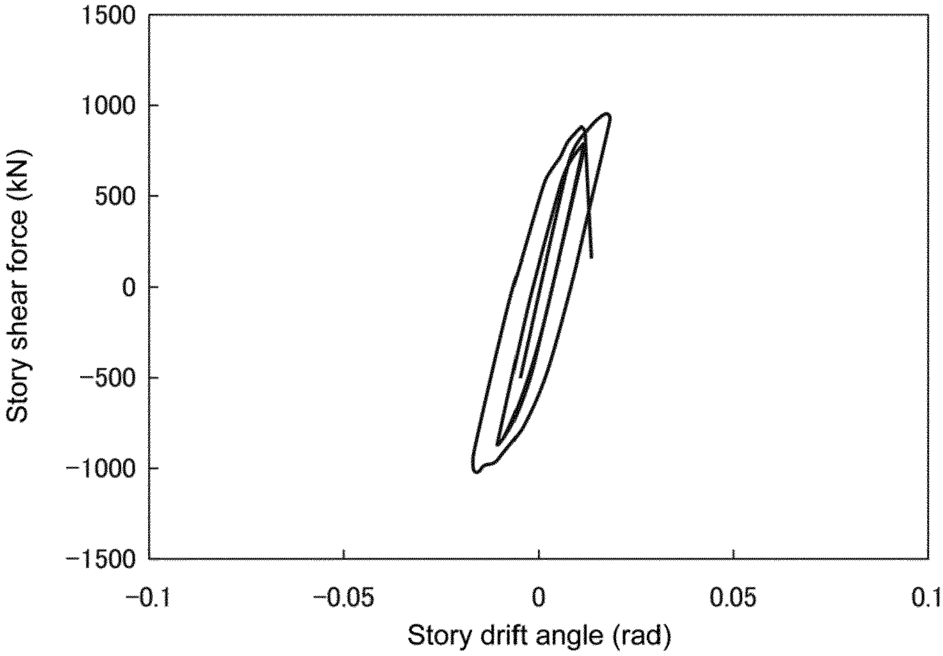

1500
1000
500
0
−500
−1000
−1500
Story shear force (kN)
−0.1
−0.05
0
0.05
0.1
Story drift angle (rad)

FIG. 13

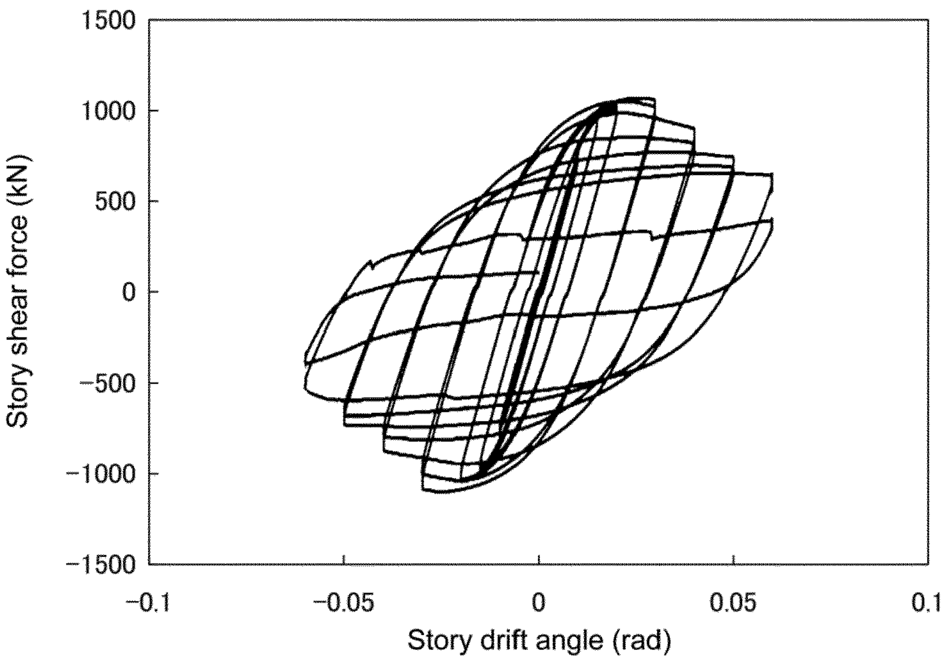

1500
1000
500
0
−500
−1000
−1500
Story shear force (kN)
−0.1
−0.05
0
0.05
0.1
Story drift angle (rad)

FIG. 14

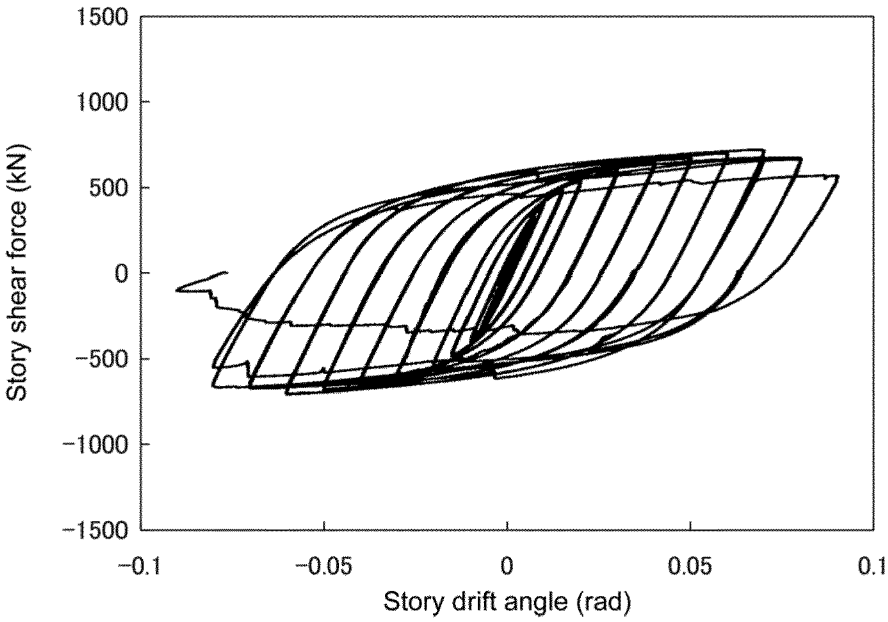
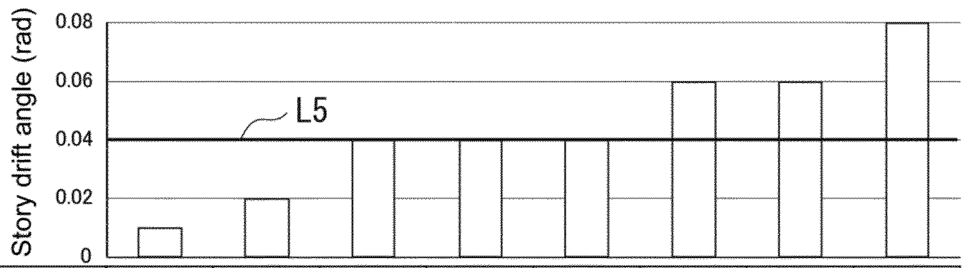
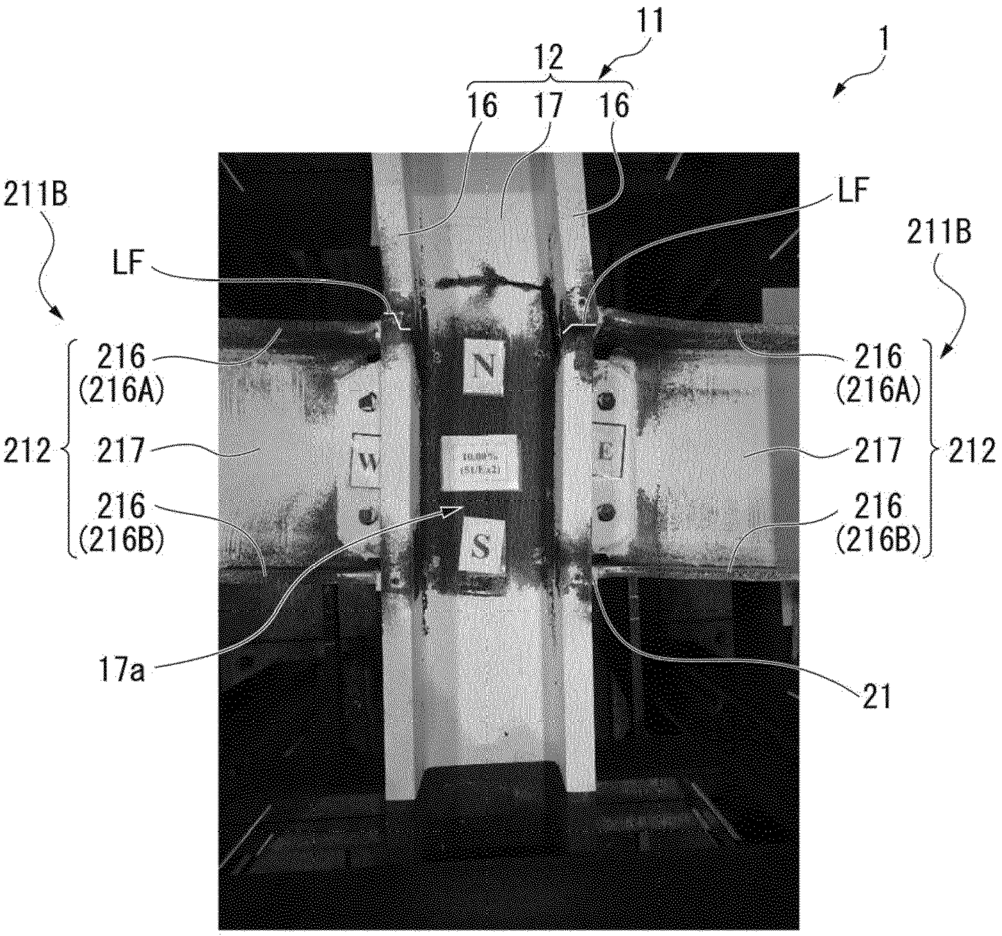


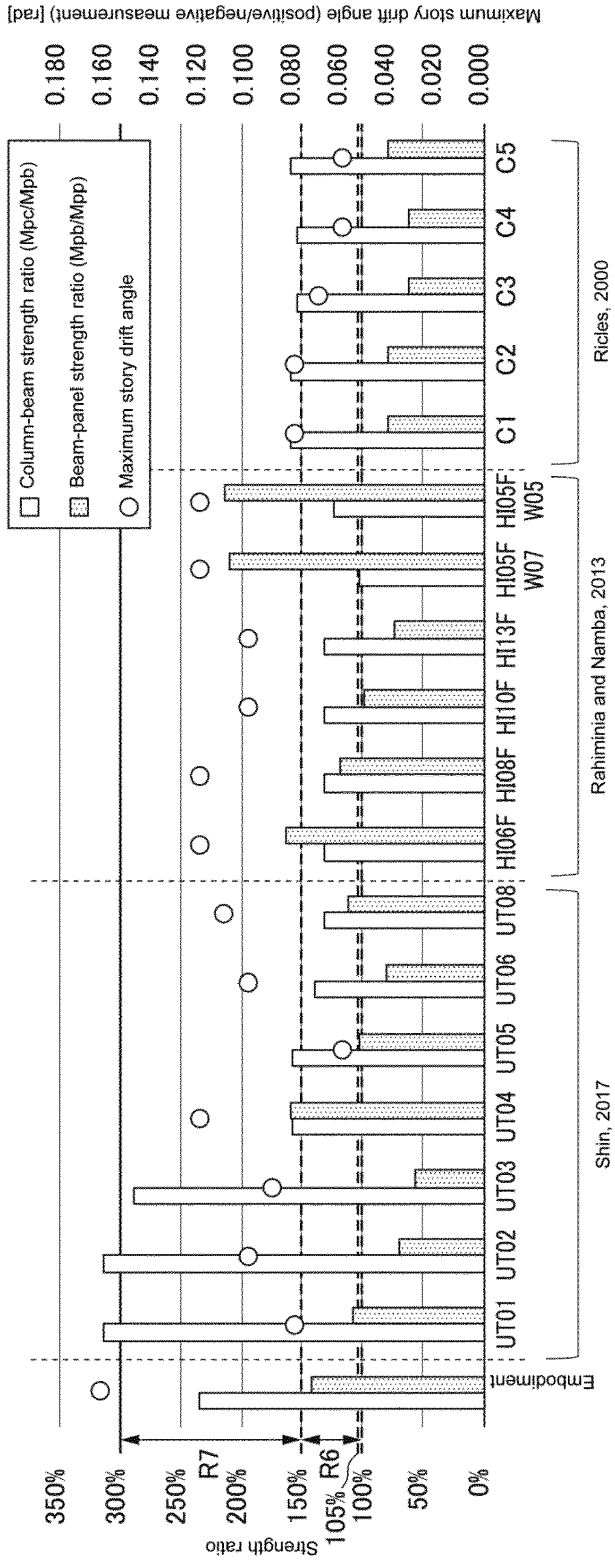
FIG. 15



Documents	FEMA, 1997	FEMA, 1997	Shin, 2017	Chi & Uang, 2002	Richles, 2000	Rahiminia & Namba, 2013	Shin, 2017	Embodiment
Joint section type	Pre-Northridge	Pre-Northridge	Post-Northridge	Post-Northridge	Post-Northridge	Post-Northridge	Post-Northridge	−
Stiffener	Present	Present	Present	Present	Present	Present	Present	None
Doubler plate	None	None	Present	None	None	None	None	None
Backing bar	Left	Left	Removal	Removal	Removal	Removal	Removal	Left
Joint section panel yielding	Do	Do	Don't	Do	Do	Do	Do	Do
Productivity and workability	○	○	×	×	×	×	×	○
Seismic performance	×	×	○	○	○	○	○	◎

FIG. 16


1
11
12
16
17
16
211B
LF
LF
211B
216
(216A)
216
(216A)
212
217
217
212
216
(216B)
216
(216B)
N
W
E
S
17a
21



Column-beam strength ratio (Mpc/Mpb)
Beam-panel strength ratio (Mpb/Mpp)
Maximum story drift angle
Maximum story drift angle (positive/negative measurement) [rad]
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
Strength ratio
350%
300%
250%
200%
150%
105%
100%
50%
0%
R7
R6
Embodiment
UT01
UT02
UT03
UT04
UT05
UT06
UT08
HI06F
HI08F
HI10F
HI13F
HI05F W07
HI05F W05
C1
C2
C3
C4
C5
Shin, 2017
Rahiminia and Namba, 2013
Ricles, 2000

FIG. 17

FIG. 18

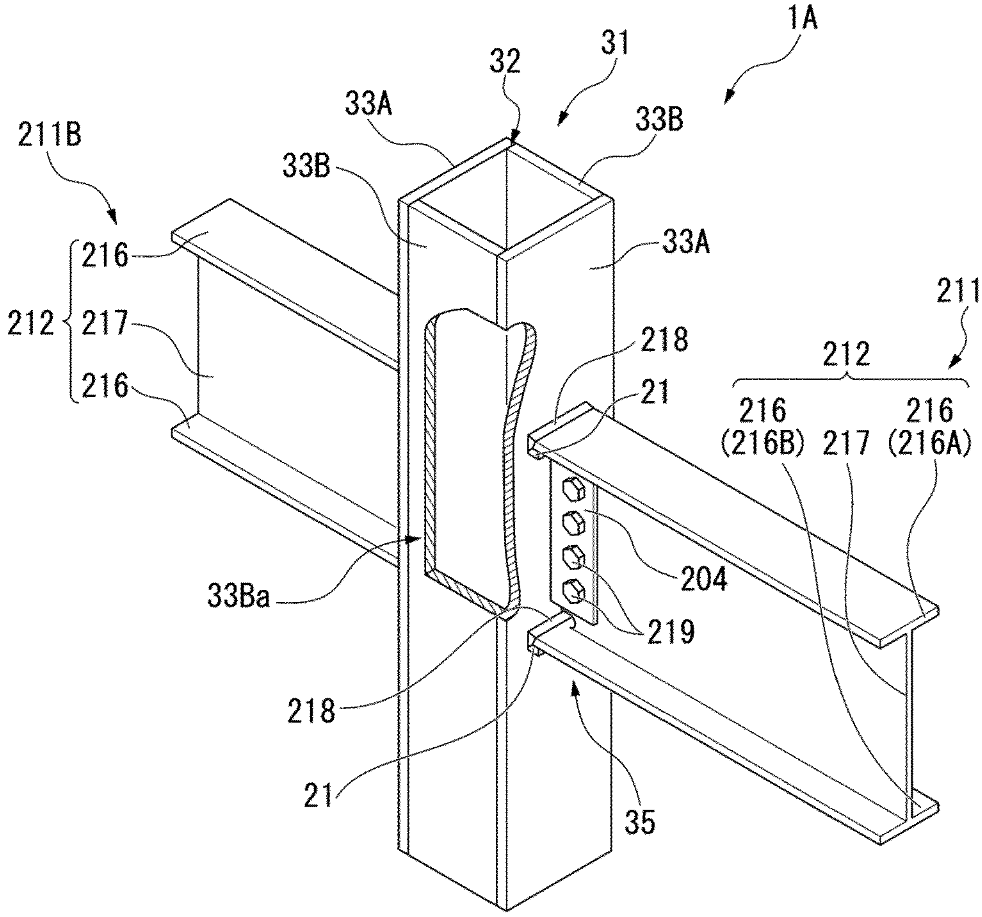

1A
31
32
33A
33B
33B
33A
211B
216
212
217
216
218
21
211B
212
216
(216B)
217
216
(216A)
204
219
33Ba
218
21
35

FIG. 19

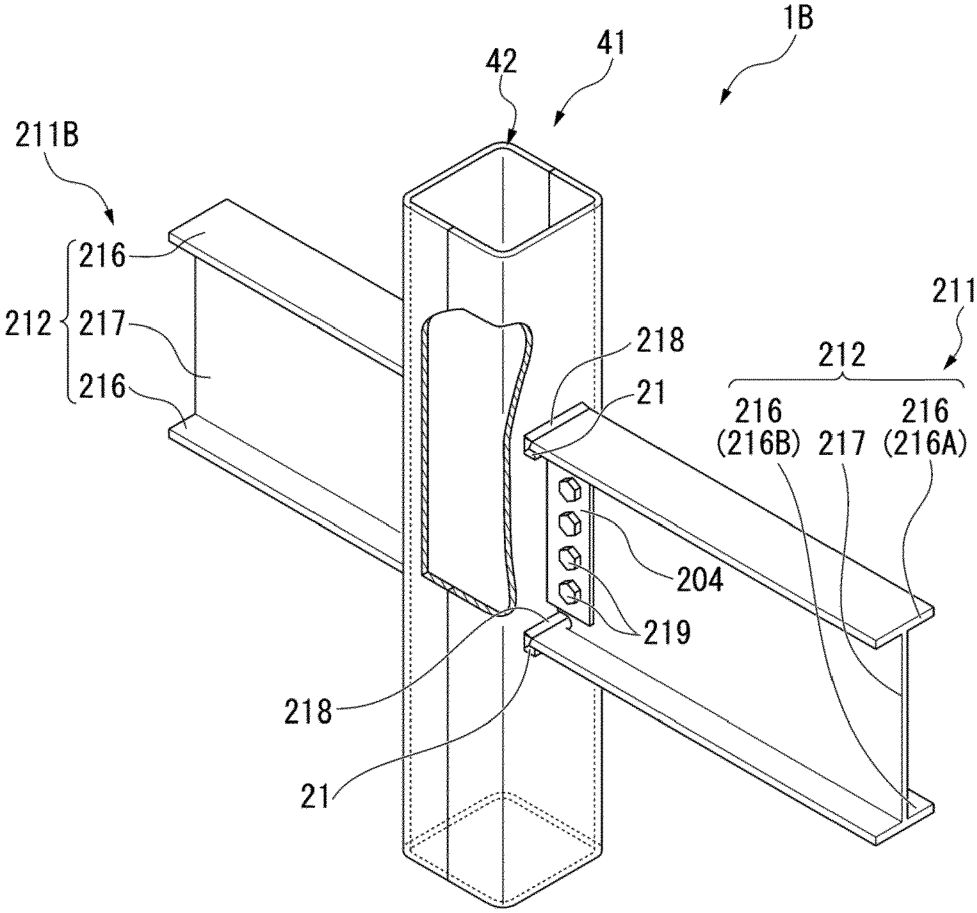

1B
42
41
211B
216
212
217
216
218
21
211B
212
216
(216B)
217
216
(216A)
204
219
218
21

FIG. 20

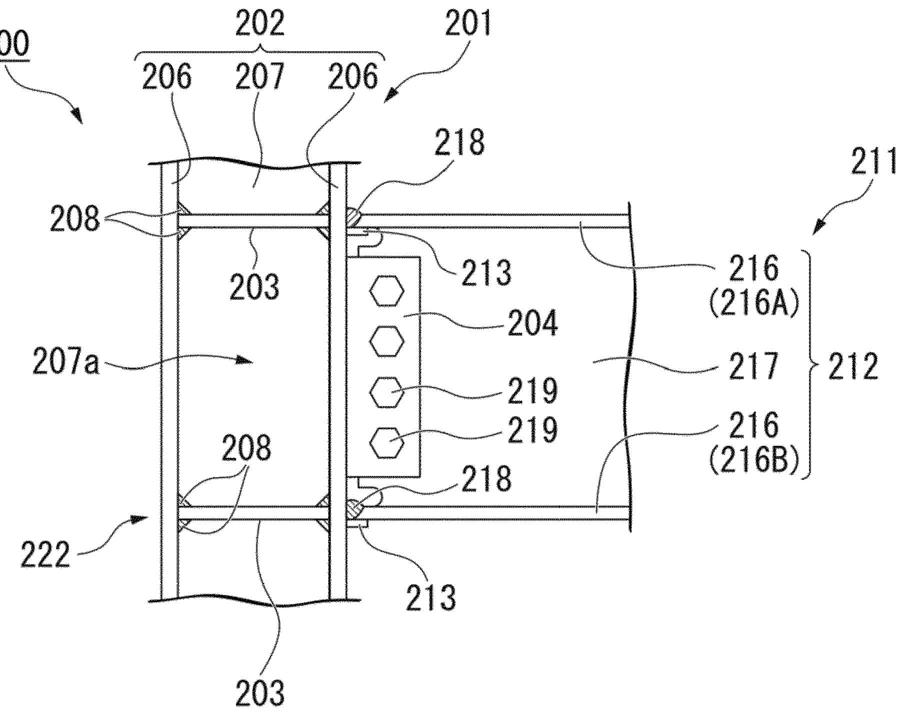

200
202
201
206
207
206
218
211
208
213
216
(216A)
203
204
207a
217
212
219
219
216
(216B)
208
218
222
213
203

FIG. 21

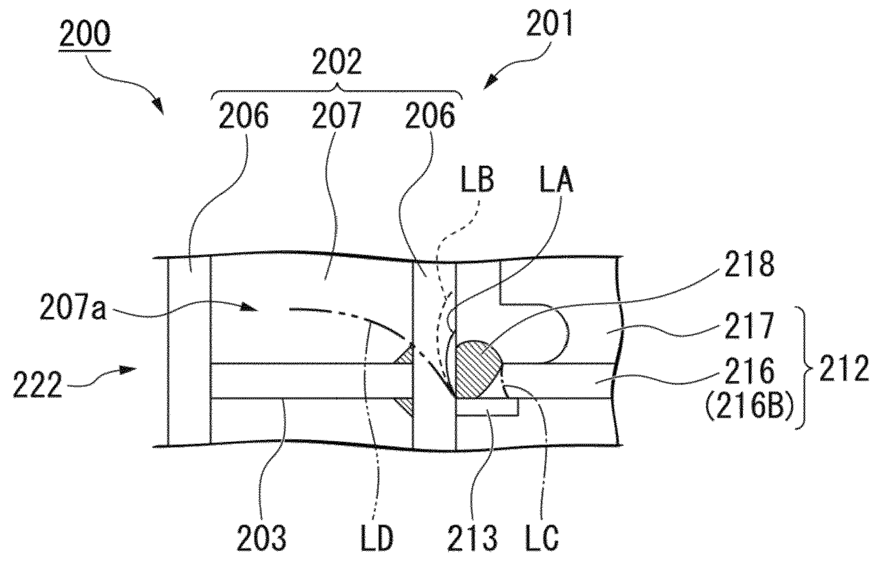

200
202
201
206
207
206
LB
LA
218
207a
217
222
216
(216B)
212
203
LD
213
LC

FIG. 22

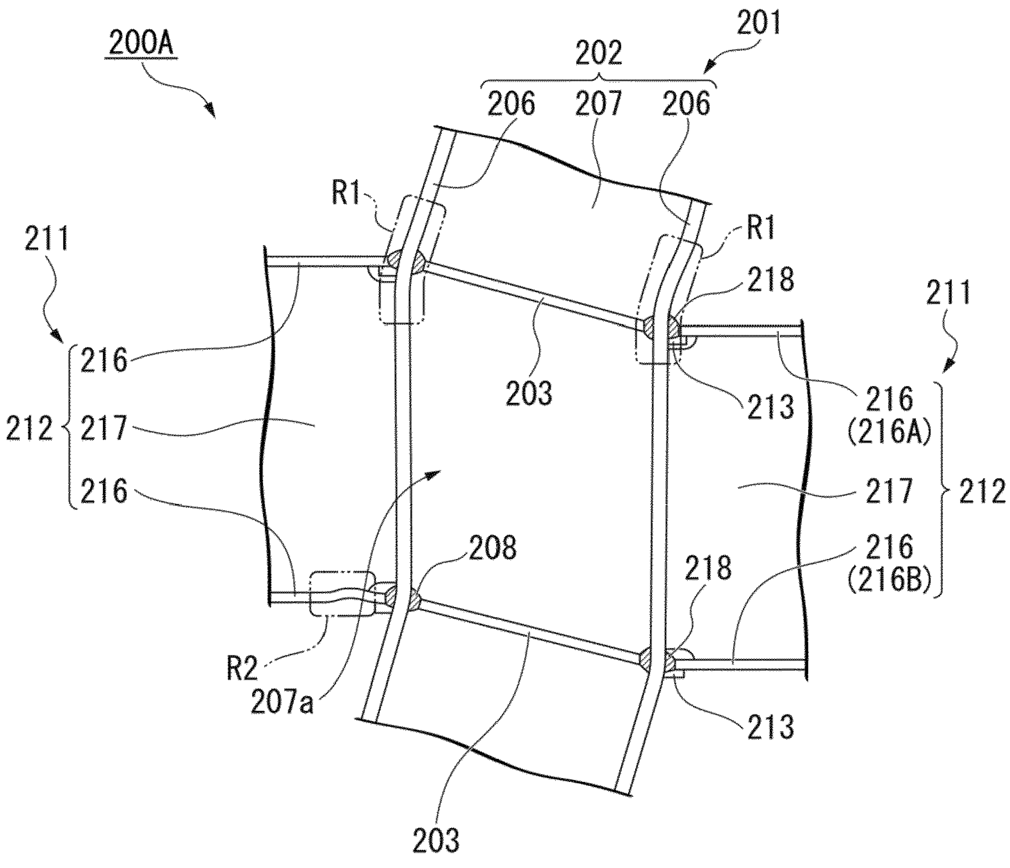
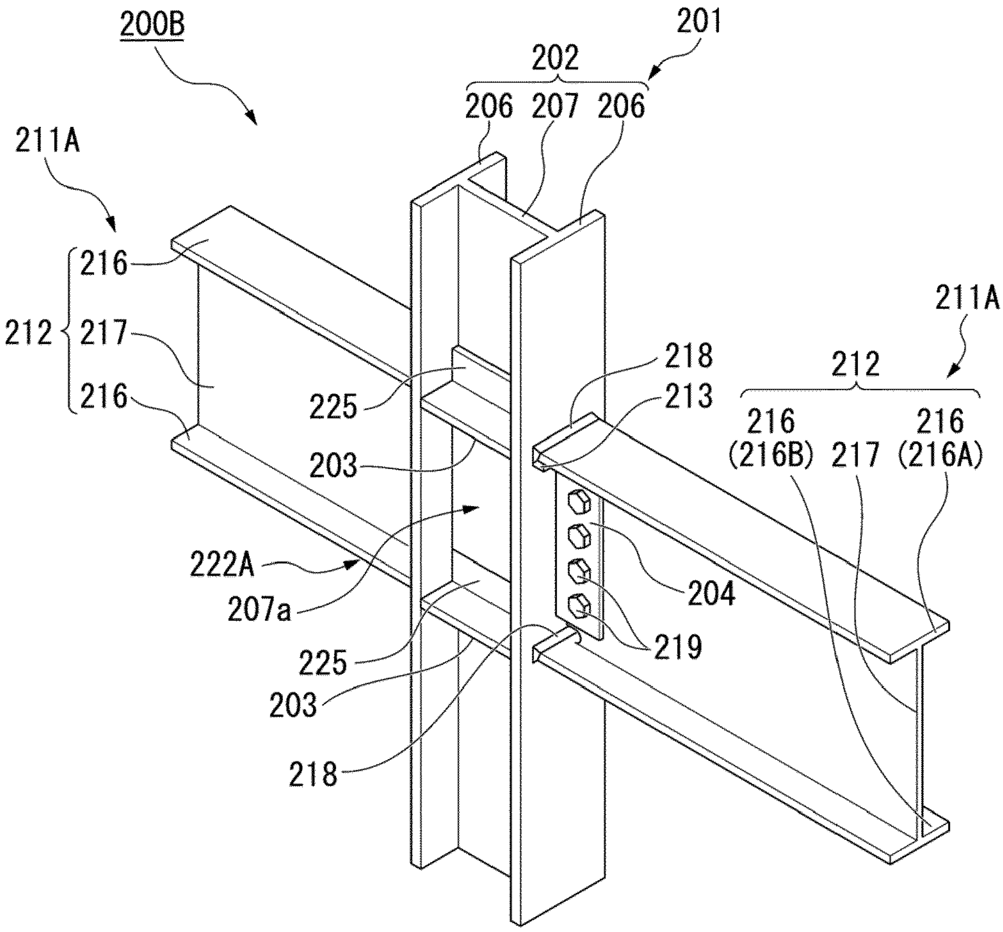

200A
201
202
206
207
206
R1
R1
211
218
211
216
203
213
216
(216A)
212
217
212
217
212
216
208
216
218
(216B)
R2
207a
213
203

FIG. 23


200B
201
202
206 207 206
211A
216
212
217
216
225
203
222A
207a
225
203
218
218
213
211A
212
216
(216B)
217
216
(216A)
204
219

Case	Type of column main body	Cross-sectional dimension of column main body					Cross-sectional dimension of I-beam					Story height	
		Height	Width	Thickness	Thickness	Standard strength	Height	Width	Thickness	Thickness	Standard strength		
		$_{c}H$	$_{c}B$	$_{c}t_{w}$	$_{c}t_{f}$	$_{cT}F, _{cB}F$	$_{b}H$	$_{b}B$	$_{b}t_{w}$	$_{b}t_{f}$	$_{bL}F, _{bR}F$	$_{T}h, _{B}h$	$_{T}h', _{B}h'$
		mm	mm	mm	mm	N/mm^2	mm	mm	mm	mm	N/mm^2	mm	mm
1	I-shaped steel	458	427	40	50	235	500	250	12	25	235	4,500	4,000
2	Weld assembled box section	750	750	36	36	325	1,000	400	22	40	325	4,500	3,500
3	I-shaped steel	700	300	16	28	325	600	200	12	22	325	4,500	3,900
4	Weld assembled box section	500	500	19	19	325	600	250	12	28	325	4,500	3,900
5	Weld assembled box section	400	400	22	22	325	600	200	12	16	325	4,500	4,100

Case	Beam span		Plate thickness center-to-center		Joint panel			Plastic section modulus		Full plastic strength			Beam panel	Column-beam strength ratio
					Thickness	Standard strength	Effective volume						Strength ratio	
	$_{L}l, _{R}l$	$_{L}l', _{R}l'$	d_c	d_b	t_p	$_{p}F$	V_e	$_{cT}Z_p$, $_{cB}Z_p$	$_{bL}Z_p$, $_{bR}Z_p$	M_{pb}	M_{pc}	M_{pp}	M_{pb}/M_{pp}	M_{pc}/M_{pb}
	mm	mm	mm	mm	mm	N/mm^2	mm^3	mm^3	mm^3	kNm	kNm	kNm	—	—
1	9,000	8,542	408	475	40	235	7,752,000	9,992,440	3,576,250	1,771	5,284	1,255	1.411	2.983
2	9,000	8,250	714	960	36	325	49,351,680	27,552,312	20,015,200	14,193	23,026	13,335	1.064	1.622
3	9,000	8,300	672	578	16	325	6,214,656	7,303,744	3,470,608	2,446	5,478	1,478	1.655	2.239
4	9,000	8,500	481	572	19	325	10,455,016	6,597,218	4,891,808	3,367	4,948	2,419	1.392	1.470
5	9,000	8,600	378	384	22	325	6,386,688	4,720,496	1,635,072	1,112	3,368	1,383	0.804	3.028

Table 1

Column main body				Beam (I-beam)				Column-beam strength ratio	Beam-panel strength ratio
Cross-sectional dimension	Length mm	Yield strength N/mm^2	Tensile strength N/mm^2	Cross-sectional dimension	Length mm	Yield strength N/mm^2	Tensile strength N/mm^2	–	–
H-498x432x45x70	4550	379	546	H-650x300x16x25	8000	380	513	2.34	1.43

Table 2

	Embodiment	Shin ,2017						
		UT01	UT02	UT03	UT04	UT05	UT06	UT08
Stiffener	None	Present	Present	Present	None	None	None	Present
Doubler plate	None	None	Present	Present	None	Present	Present	Present
Backing bar	Left	Removal	Removal	Removal	Removal	Removal	Removal	Removal
Slab	None	None	None	None	None	None	None	None

	Rahiminia and Namba ,2013						Ricles,2000				
	HI06F	HI08F	HI10F	HI13F	HI05F W07	HI05F W05	C1	C2	C3	C4	C5
Stiffener	Present	Present	Present	Present	Present	Present	None	Present	None	Present	None
Doubler plate	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
Backing bar	Left	Left	Left	Left	Left	Left	Removal	Removal	Removal	Removal	Removal
Slab	None	None	None	None	None	None	None	None	None	None	Present

Table 3

Equation 1

$$V_e = d_c \cdot d_b \cdot t_p$$ (When the column main body is an I-beam for columns) ・・（１１）

$$V_e = 2d_c \cdot d_b \cdot t_p$$ (When the column main body is square steel tubing) ・・（１２）

Equation 2

$$M_{pb} = {}_{bL}Z_p \cdot {}_{bL}F \cdot \frac{{}_L l}{{}_L l'} + {}_{bR}Z_p \cdot {}_{bR}F \cdot \frac{{}_R l}{{}_R l'}$$ ・・（１５）

$$M_{pc} = {}_{cT}Z_p \cdot {}_{cT}F \cdot \frac{{}_T h}{{}_T h'} + {}_{cB}Z_p \cdot {}_{cB}F \cdot \frac{{}_B h}{{}_B h'}$$ ・・（１６）

$$M_{pp} = V_e \cdot \frac{{}_pF}{\sqrt{3}} \cdot \frac{1}{1 - \frac{2_b H}{{}_T h + {}_B h} - \frac{2_c H}{{}_L l + {}_R l}}$$ ・・（１７）

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 23 17 9922

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	APPLIED TECHNOLOGY COUNCIL: "Benchmarking evaluation methodologies for existing reinforced concrete buildings", NIST, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST) , 1 March 2022 (2022-03-01), pages 1-222, XP061078667, DOI: 10.6028/NIST.GCR.22-917-51 Retrieved from the Internet: URL:https://nvlpubs.nist.gov/nistpubs/gcr/2022/NIST.GCR.22-917-51.pdf [retrieved on 2022-03-01] * pages 3-7,3-8; figures 3-3,3-4 * -----	1-6	INV. E04H9/02
A	NEHRP CONSULTANTS JOINT VENTURE: "Research plan for the study of seismic behavior and design of deep, slender wide flange structural steel beam-column members NIST GCR 11-917-13", NIST, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST) , 31 December 2011 (2011-12-31), pages 1-166, XP061049325, DOI: 10.6028/NIST.GCR.11-917-13 Retrieved from the Internet: URL:https://nvlpubs.nist.gov/nistpubs/gcr/2011/NIST.GCR.11-917-13.pdf [retrieved on 2011-12-31] * pages 2-6; figures 2-4 * -----	1-6	
	-/--		

TECHNICAL FIELDS SEARCHED (IPC)

E04H
E04B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	30 November 2023	Rosborough, John

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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O : non-written disclosure
P : intermediate document

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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 23 17 9922

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	APPLIED TECHNOLOGY COUNCIL: "Guidelines for nonlinear structural analysis and design of buildings. part IIa - steel moment frames NIST GCR 17-917-46v2", NIST, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST) , 30 April 2017 (2017-04-30), pages 1-145, XP061049386, DOI: 10.6028/NIST.GCR.17-917-46V2 Retrieved from the Internet: URL:https://nvlpubs.nist.gov/nistpubs/gcr/2017/NIST.GCR.17-917-46v2.pdf [retrieved on 2017-04-30] * pages A-2, paragraph 2; figure A1 * -----	2	

TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	30 November 2023	Rosborough, John

EPO FORM 1503 03.82 (P04C01)

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
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REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- Experimental and analytical investigation of panel zone behavior in steel moment frames. **SHIN, S.** PhD Thesis. Department of Civil, Architectural and Environmental Engineering, University of Texas, 2017 **[0095]**
- Cyclic response and design recommendations of reduced beam section moment connections with deep columns. **CHI, B.** ; **C.-M. UANG**. Journal of Structural Engineering. American Society of Civil Engineers, 2002, vol. 128, 464-473 **[0095]**
- **RIDES, J. M.** ; **C. MAO** ; **L.-W. LU** ; **J. W. FISHER**. Development and evaluation of improved details for ductile welded unreinforced flange connections. *SAC Background Document, Report No. SAC/BD-00/24, SAC Joint Venture, Sacramento, CA, USA*, 2000 **[0095]**
- **RAHIMINIA, F.** ; **H. NAMBA**. Joint panel in steel moment connections, part 1: experimental tests results. *Journal of Constructional Steel Research*, 2013, vol. 89, 272-283 **[0095]**