

DESCRIPTION

TITLE OF INVENTION: BEAM-COLUMN JOINT STRUCTURE

TECHNICAL FIELD

5 [0001]

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

Priority is claimed on Japanese Patent Application No. 2023-099747, filed on June 19, 2023, the content of which is incorporated herein by reference.

BACKGROUND ART

10 [0002]

The Northridge earthquake occurred in the United States of America in 1994.

A beam-column joint structure 200 shown in FIG. 20 was being used before the Northridge earthquake occurred (see Non Patent Document 1). That is, the beam-column joint structure 200 includes a column 201 and a beam 211. The column 201 has
15 a column main body 202 formed of an I-beam for columns (I-section steel), a pair of stiffeners (diaphragms, first reinforcement plates, or continuity plates) 203, and a shear plate 204.

The column main body 202 has a pair of column flanges 206 and a column web 207 and extends in a vertical direction.

20 Each stiffener 203 is a horizontal stiffener and is disposed along a horizontal plane. The stiffeners 203 are disposed at the same positions as a pair of beam flanges 216 to be described later in the beam 211 in the vertical direction. The stiffeners 203 are joined to the pair of column flanges 206 and the column web 207 of the column 201 (column main body 202) by welded section 208 formed by welding.

25 The shear plate 204 is joined to the column flange 206 of the column 201 by

welding or the like.

[0003]

The beam 211 has an I-beam for beams (I-section steel) 212 and a pair of backing bars 213. The I-beam for beams 212 is, for example, an H-section steel defined by Japanese Industrial Standards (JIS) G 3192: 2014 shapes, dimensions, mass, and their permissible variations of hot rolled steel sections (hereinafter, simply referred to as JIS G 3192).

The I-beam for beams 212 has the pair of beam flanges 216 and the beam web 217. The pair of beam flanges 216 are disposed to face each other in the vertical direction. Of the pair of beam flanges 216, the beam flange 216 disposed above is an upper flange 216A, and the beam flange 216 disposed below is a lower flange 216B.

[0004]

The beam flanges 216 are joined to the column flanges 206 of the column main body 202 by welded section 218 in a state in which the backing bars 213 are attached below the beam flanges 216. The beam web 217 and the shear plate 204 are connected to each other by fastening members 219 such as high-strength bolts. 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 be directly joined to the column flanges 206 by welding.

In the beam-column joint structure 200, the column 201 and the beam 211 are connected to each other by a joint part 222. The joint part 222 is a so-called pre-Northridge joint part.

Here, a portion of the column web 207 that is within the range of the beam 211 in the vertical direction is defined as a joint part panel 207a.

[0005]

As shown in FIG. 21, there are Types A to D corresponding to cracks represented by lines LA, LB, LC, and LD, as types of fracture of the beam-column joint structure 200 due to the Northridge earthquake.

Types A and B depend on the fracture toughness in a direction (S direction (plate thickness direction S) to be described later in FIG. 1) in which the column flange 206 is torn parallel to a main surface of the column flange 206. In Type C, the line LC representing the crack propagates through the beam flange 216.

Type D depends on the fracture toughness in a direction (L direction) in which the column flange 206 is divided in a material axis direction (longitudinal direction).

10 [0006]

As shown in FIG. 22, Type D is further induced by local bending deformation of the column flange 206 due to shear deformation of the joint part panel 207a. In a beam-column joint structure 200A shown in FIG. 22, a pair of beams 211 are joined to the column 201. Local kink deformation occurs in a range R1 in the column flange 206 of the column 201 and a range R2 in the beam flange 216 of the beam 211. These ranges R1 and R2 are portions where local bending deformation occurs.

As described above, all of the above cases except for Type C 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.

20 [0007]

The beam-column joint structures used in the current aseismic structures in Europe and the United States are based on the fracture type at the joint part 222 of the beam-column joint structure 200 in the Northridge earthquake, so the detailed structure (details) of the joint part is determined to withstand repeated deformation many times.

25 As a detailed structure, as shown in FIG. 23, a beam-column joint structure

200B is required to take the following measures (1) to (3).

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

(2) The joint part panel 207a of the column 201 is reinforced with a doubler plate (second reinforcement plate) 225 so as to increase the thickness of the column web
5 207.

(3) After an end part of a beam 211A is welded on site, the backing metal 213 attached to the lower flange 216B of the beam 211A is removed and reinforcing welding is performed.

That is, the beam 211A has no backing metal 213 around the lower flange 216B
10 in each configuration of the beam 211. The doubler plate 225 is provided on the column 201 and joined to the joint part panel 207a.

[0008]

A joint part 222A between the column 201 and the beam 211A is a so-called post-Northridge joint part. The joint part 222A is a joint part for preventing fractures of
15 Types A to D.

The plastic deformation of the column flange 206 and the joint part panel 207a is suppressed by the measures (1) and (2). For example, an arc gauging method is used to remove the backing bar 213 in the measure (3). At the portion where the backing bar 213 has been removed, the reinforcing welding is performed upward from below the
20 removed portion. Due to the reinforcing welding, slits that serve as the origin of fracture are eliminated.

These measures are effective measures for preventing brittle fracture at an early stage in a case where a steel material having relatively low fracture toughness in the S direction and the L direction is used for the column flange 206.

25 Citation List

Non Patent Document

[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, 2022], Internet <<http://www.dpri.kyoto-u.ac.jp/nenpo/no39/39b1/a39b1p02.pdf>>

SUMMARY OF INVENTION

10 Technical Problem

[0010]

However, in the joint part 222A of the beam-column joint structure 200B, all the energy due to the seismic external force was absorbed by plastic deformation of the beam 211A, so the ultimate performance of the joint part 222A was limited by local buckling of the beam 211A. In addition, the reinforcement with stiffeners and doubler plates and removal of backing bars are a large load on factory production and on-site construction, and are factors that reduce the productivity for architectural steel frames.

Meanwhile, it is desired to ensure the structural stability of buildings using beam-column joint structures.

20 [0011]

The present invention has been made in view of such problems, and an object thereof is to ensure the structural stability of buildings using beam-column joint structures, and to provide a beam-column joint structure that has a joint part having high energy absorption performance.

25 Solution to Problem

[0012]

In order to solve the above problems, the present invention proposes the following aspects.

(1) Aspect 1 of the present invention is a beam-column joint structure including:

- 5 a column having a column main body formed of an I-beam for columns, a square steel tubing, or a weld assembled box cross-section; and a beam having an I-beam for beams in which a pair of beam flanges of the I-beam for beams are directly joined to joint plates of the column main body through welded section, in which the joint plate is a column flange of the I-beam for columns, or a flat plate part of the square steel tubing and the
- 10 weld assembled box cross-section, when a position where a central axis of the column main body intersects with a central axis of the I-beam for beams is defined as an intersect position, a ratio of a full plastic strength of the column to a full plastic strength of the beam at the intersect position is 1.5 or more and 3.0 or less, and a ratio of a full plastic strength of the beam to a full plastic strength of a portion, that is within a range of a
- 15 height of the beam in a vertical direction, of a column web of the column main body formed of the I-beam for columns or the flat plate part extending along a longitudinal direction of the beam in the column main body formed of the square steel tubing or the weld assembled box cross-section at the intersect position is 1.05 or more and 1.5 or less.

[0013]

- 20 In the invention, as a result of intensive examinations, the present inventors have found that, in order to increase the energy absorption performance at the joint part between the column and the beam in the beam-column joint structure, it is necessary to absorb the energy acting on the beam-column joint structure not only in the beam but also in the joint part panel. In particular, a configuration is preferable in which the joint
- 25 part panel, that is expected to have a stable increase in strength after plasticization as

long as the column flange does not fracture, yields first, and following the increase in strength of the joint part panel due to yielding, the beam yields. That is, in order for the joint part panel to first undergo yielding, a beam-panel strength ratio, which is a ratio of the full plastic strength of the beam to the full plastic strength of the joint part panel, may
5 be 1.05 or more.

In addition, the strength of the joint part panel can be expected to increase up to about 1.5 times the full plastic strength by strain hardening due to repeated plastic deformation. That is, by setting the beam-panel strength ratio to 1.5 or less, not only the joint part panel but also the beam can be plasticized during the process of increasing the
10 strength after the joint part panel yields first, and the energy acting on the beam-column joint structure can be absorbed by both the beam and the joint part panel. Therefore, the energy absorption performance at the joint part between the column and the beam can be increased.

[0014]

15 Meanwhile, it is necessary to prevent the collapse of a building's stories due to the yielding of the column in order to ensure the structural stability of the building using the beam-column joint structure. Therefore, it is necessary to sufficiently strengthen the column with respect to the beam. In view of the increase in strength after plasticization of the beam, a column-beam strength ratio, which is a ratio of the full plastic strength of
20 the column 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 from being economically unreasonable, the column-beam strength ratio is preferably suppressed to be about 2.5 to 3.0 or less.

As described above, by setting the beam-panel strength ratio to 1.05 or more and
25 1.5 or less and setting the column-beam strength ratio to 1.5 or more and 3.0 or less, it is

possible to ensure the structural stability of the building using the beam-column joint structure, and it is possible to provide a beam-column joint structure that has a joint part having high energy absorption performance.

[0015]

5 (2) Aspect 2 of the present invention may be the beam-column joint structure according to (1), further including: a backing bar joined to each of a lower flange disposed on a lower side of the pair of beam flanges and the joint plate through the welded section, in which the backing bar is attached below the lower flange, a bevel is formed on an upper surface of the backing bar so as to be directed downward gradually
10 as approaching the joint plate, and the welded section is also formed in the bevel.

In the invention, the portion joined to the joint plate in the connection surface between the backing bar and the welded section is inclined relative to the joint plate without being orthogonal thereto. Therefore, for example, it is possible to reduce the strain concentration at a tip end of a slit generated at the boundary between the joint plate
15 and the backing bar due to a load such as a bending moment acting on the beam, and it is possible to suppress the propagation of a crack from the tip end of the slit toward the welded section or the joint plate (base metal of the joint plate).

[0016]

 (3) Aspect 3 of the present invention may be the beam-column joint structure
20 according to (1) or (2), in which Charpy absorbed energy $vE_{-20(S)}$ in a plate thickness direction of the joint plate at -20°C is 35 J or more.

In the invention, the toughness of the joint plate in the plate thickness direction at -20°C is higher by a certain or more level than that of a general joint plate. In general, the toughness of the joint plate increases with the increasing joint plate's
25 temperature. Since the toughness is further increased at a temperature at which the joint

plate is actually used, it is possible to suppress the fracture of the joint plate in the plate thickness direction even in a case where the joint plate is directly joined to the pair of beam flanges of the I-beam for beams of the beam through the welded section.

[0017]

- 5 (4) Aspect 4 of the present invention may be the beam-column joint structure according to any one of (1) to (3), in which Charpy absorbed energy $vE_{0(s)}$ in the plate thickness direction of the joint plate at 0°C is 47 J or more.

In the invention, the toughness of the joint plate in the plate thickness direction at 0°C is increased by a certain or more level. In general, the toughness of the joint

- 10 plate increases with the increasing joint plate's temperature. Since the toughness is further increased at a temperature at which the joint plate is actually used, it is possible to suppress the fracture of the joint plate in the plate thickness direction even in a case where the joint plate is directly joined to the pair of beam flanges of the I-beam for beams of the beam through the welded section.

15 [0018]

(5) Aspect 5 of the present invention may be the beam-column joint structure according to any one of (1) to (4), in which a first reinforcement plate disposed at the same position as the pair of beam flanges in the vertical direction and joined to the column main body is not provided.

- 20 In the invention, since the column does not have the first reinforcement plate joined to the column main body, the column can be relatively easily constructed.

[0019]

- (6) Aspect 6 of the present invention may be the beam-column joint structure according to any one of (1) to (5), in which a second reinforcement plate joined to the
25 column web or the flat plate part to increase a thickness of the column web or the flat

plate part is not provided.

In the invention, since the column does not have the second reinforcement plate joined to the column web or the flat plate part, the column can be relatively easily constructed.

5 Advantageous Effects of Invention

[0020]

With a beam-column joint structure of the present invention, it is possible to ensure the structural stability of buildings using beam-column joint structures, and it is possible to provide a beam-column joint structure that has a joint part having high energy
10 absorption performance.

BRIEF DESCRIPTION OF DRAWINGS

[0021]

[FIG. 1] A perspective view of a main part of a beam-column joint structure of one embodiment of the present invention.

15 [FIG. 2] An enlarged view of the part A1 in FIG. 1.

[FIG. 3] A view showing a shape of a Charpy test piece, in which (A) is a plan view, (B) is a front view, and (C) is a cross-sectional view taken along the cutting-plane line A3-A3 in (A).

[FIG. 4] A view describing a test piece and a notch direction when a Charpy test
20 piece is obtained from a rolled steel material.

[FIG. 5] A view showing a procedure for collecting a Charpy test piece in a plate thickness direction from a column flange.

[FIG. 6] A view showing test results according to JIS Z 2242 using a Charpy test piece in which a flat surface with a notch formed thereon is orthogonal to a rolling
25 direction.

[FIG. 7] A view showing test results according to JIS Z 2242 using a Charpy test piece in which a flat surface with a notch formed thereon is orthogonal to a plate thickness direction.

[FIG. 8] A front view describing a building using a beam-column joint structure.

5 [FIG. 9] is a front view describing an outline of a testing device for a beam-column joint structure.

[FIG. 10] A view describing loading history 1 acting on a sample 1.

[FIG. 11] A view describing loading history 2 acting on a sample 2.

[FIG. 12] A view showing experimental results of the U.S. Federal Emergency
10 Management Agency.

[FIG. 13] A view showing experimental results of Shin's literature.

[FIG. 14] A view showing experimental results of the sample 1.

[FIG. 15] A view showing results of comparison between the example and joint parts of the related art.

15 [FIG. 16] A photograph showing experimental results of the example.

[FIG. 17] A view comparing strength ratios and maximum story drifts in the beam-column joint structure of the example and the prior research.

[FIG. 18] A perspective view of a main part in a first modification example of the beam-column joint structure of one embodiment of the present invention.

20 [FIG. 19] A perspective view of a main part in a second modification example of the beam-column joint structure of one embodiment of the present invention.

[FIG. 20] A front view of a main part of a beam-column joint structure used before the Northridge earthquake.

[FIG. 21] An enlarged view of a main part describing a fracture type of the same
25 beam-column joint structure.

[FIG. 22] A side view showing a state in which a joint part panel of a beam-column joint structure undergoes shear deformation.

[FIG. 23] A perspective view of a main part of a beam-column joint structure used in the related art after the Northridge earthquake.

5 DESCRIPTION OF EMBODIMENTS

[0022]

Hereinafter, one embodiment of a beam-column joint structure according to the present invention will be described with reference to FIGS. 1 to 19.

[0023]

10 [1. Configuration of Building]

[1-1. Configuration of Beam-Column Joint structure]

As shown 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. The number of the beams 211B of the beam-column joint structure
15 1 is not limited, and may be one or three or more.

The column 11 has a column main body 12 formed of an I-beam for columns (I-section steel). The column main body 12 extends in a vertical direction (or a first direction). The column main body 12 has a pair of column flanges (joint plates) 16 and a column web 17. The pair of column flanges 16 and the web 17 are preferably formed
20 of a rolled steel material.

[0024]

The pair of column flanges 16 are disposed to face each other in a plate thickness direction S. The column web 17 is disposed between the pair of column flanges 16. The column web 17 is joined to the centers of the pair of column flanges 16
25 in a width direction.

For example, the column main body 12 is formed of a high-toughness steel material. In the chemical composition of the column main body 12, the S content is preferably relatively low. In general, S is an element that combines with Mn in the steel material and is contained in the steel material as an impurity. S forms MnS and acts to embrittle the steel material. In a case where the S content in the column main body 12 is relatively low, the toughness of the column main body 12 can be relatively increased.

[0025]

In this example, the column 11 has neither a stiffener 203 nor a doubler plate 225 as shown in FIG. 23 and the like. The column 11 may have at least one of the stiffener 203 and the doubler plate 225.

[0026]

As shown in FIGS. 1 and 2, the beam 211B has a pair of backing bars 21 instead of the pair of backing bars 213 in each configuration of the beam 211 (in this example, extending in a second direction, which is a horizontal direction).

As shown in FIG. 2, in this example, a bevel 216a is formed on an end part of each beam flange 216 on the column flange 16 side so as to be directed downward gradually as approaching the column flange 16.

In this example, the first and second directions are substantially orthogonal to each other.

[0027]

The backing bar 21 has a rectangular parallelepiped shape. Each backing bar 21 is attached below each beam flange 216 (lower flange 216B). More specifically, each backing bar 21 is attached to each of the beam flange 216 and the column flange 16 from below each beam flange 216 by fillet welding, tack welding, or the like. The backing bar 21 may not be used for an upper flange 216A, and the backing bar 213 may

be used.

A bevel 21a is formed on an end part of an upper surface of the backing bar 21 on the column flange 16 side so as to be directed downward gradually as approaching the column flange 16. That is, the backing bar 21 is chamfered. The bevel 21a is
 5 connected to the bevel 216a of the beam flange 216. A welded section 218 is disposed in each of the bevel 216a of the beam flange 216 (on the bevel 216a) and the bevel 21a of the backing bar 21 (on the bevel 21a). The backing bar 21 is joined to each of the beam flange 216 (lower flange 216B) and the column flange 16 through the welded section 218.

10 As described above, each beam flange 216 is directly joined to each of the column flanges 16 of the column main body 12 through the welded section 218.

Between the column flange 16 and the backing bar 21, it is difficult to place the welded section 218, and a slit 21b is easily formed.

[0028]

15 Here, as shown in FIG. 1, a portion of the column web 17 that is within the range of the beam 211B in the vertical direction is defined as a joint part panel 17a. The position where a central axis O1 of the column main body 12 intersects with a central axis O2 of the beam 211B (I-beam for beams) is defined as an intersect position P1.

In the beam-column joint structure 1, the column 11 and the pair of beams 211B
 20 are connected to each other at joint parts 23. The intersect position P1 is a node of the joint part 23.

The column main body 12 is formed of an I-beam for columns, but the column main body may be formed of a square steel tubing or a weld assembled box cross-section (weld assembled box cross-section column).

25 [0029]

[1-2. Examination of Materials of Column Flange]

As shown in FIG. 1, for example, in a case where a load F1 that is a bending moment acts on the pair of beams 211B, a force acts in the plate thickness direction S on the column flange 16 that is a joint plate. The inventors thought that, by using a material having high toughness in the plate thickness direction S for the column flange 16, even if the joint part panel 17a undergoes shear deformation when the load F1 acts, and the column flange 16 thus undergoes bending deformation, the column flange 16 would resist the load in the plate thickness direction S and absorb the energy from the load F1.

In a case where a force in the plate thickness direction S acts on a column flange having low toughness in the plate thickness direction S, there is a concern that divot fracture may occur in the column flange.

[0030]

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

The notch 151 extends in a direction orthogonal to the axial direction and is formed over the entire width of the Charpy test piece 150.

[0031]

FIG. 4 will be used to describe a test piece and a notch direction when a Charpy test piece 150 is collected from a rolled steel material 155 of the column flange 16 or the like. In FIG. 4, the Charpy test piece 150 is schematically shown including the shape of a notch 151 to be described later.

The rolled steel material 155 is manufactured by thinning steel in the plate thickness direction (thickness direction) S and extending the steel in a rolling direction (rolled direction) L by a rolling mill. Here, a direction orthogonal to the plate thickness direction S and the rolling direction L is referred to as a width direction T. The rolling direction L and the width direction T are both plate thickness orthogonal directions (directions orthogonal to the plate thickness direction S). For example, a Charpy test piece 150 in which a flat surface S1 with a notch 151 formed thereon is orthogonal to the plate thickness direction S and a depth direction of the notch 151 is parallel to the width direction T is denoted by "S-T" or "Charpy test piece 150_{ST}".

In JIS Z 2242, Charpy test pieces 150_{LS}, 150_{LT}, 150_{TS}, and 150_{TL} are used in which a flat surface S1 with a notch 151 formed thereon is orthogonal to the rolling direction L or the width direction T. The Charpy impact test using the Charpy test pieces 150_{ST} and 150_{SL} orthogonal to the plate thickness direction S is performed according to the procedure of JIS Z 2242, except for the procedure for collecting the Charpy test pieces 150 to be used.

[0032]

FIG. 5 shows a procedure for collecting 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 of the column flange 16 facing the plate thickness direction S, to which an extending bar 156 to be described later is joined, is referred to as a surface 16a.

The distance between the notch 151 of the Charpy test piece 150_{SL} and the surface 16a in the plate thickness direction S is defined as t2 (mm).

[0033]

A cylindrical extending bar 156 is joined to the surface 16a of the column flange 16 by friction pressure welding. The reason why the friction pressure welding is performed for joining is to keep a heat-affected zone (HAZ) formed in a joint part between the column flange 16 and the extending bar 156 as small as possible.

Accordingly, the Charpy test pieces 150 can be produced in such a manner that the notches 151 of the Charpy test pieces 150 are not thermally affected.

In this case, the extending bar 156 is disposed so that its axial direction is along 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 forms the extending bar 156 is preferably the same as the material that forms the column flange 16. The friction pressure welding is performed so that the entire cross section of the extending bar 156 is joined to the surface 16a of the column flange 16.

[0034]

For example, in a case where the plate thickness t1 is 40 mm or less, the distance t2 is set to (t1/4). In a case where the plate thickness t1 is more than 40 mm, the distance t2 is set to 10 mm. In the joint part between the column flange 16 and the extending bar 156, a heat-affected zone is formed although its range is small. Therefore, the distance t2 is preferably set according to the plate thickness t1 as described above.

For example, the plate thickness t1 of the column flange 16 is 19 mm or more.

[0035]

In general, the greater the Charpy absorbed energy measured according to JIS Z

2242, the higher the toughness.

[0036]

FIG. 6 shows test results according to JIS Z 2242 using the Charpy test piece 150_{LT} in which a flat surface S1 with a notch 151 formed thereon is orthogonal to the rolling direction L. In FIG. 6, the horizontal axis represents a temperature (°C) of the Charpy test piece 150_{LT}, and the vertical axis represents Charpy absorbed energy (J). Hereinafter, the Charpy absorbed energy obtained from the Charpy test pieces 150_{LS}, 150_{LT}, 150_{TS}, and 150_{TL} in which a flat surface S1 with a notch 151 formed thereon is orthogonal to the rolling direction L is referred to as Charpy absorbed energy $vE_{(L, T)}$ in the rolling direction L.

Although the plate thickness orthogonal direction is the rolling direction L, the plate thickness orthogonal direction may be the width direction T.

[0037]

White circles represent the results obtained from a high-toughness steel material used for the column flange 16. A solid line L1 represents a curve approximating the results represented by the white circles. White triangles represent the results obtained from a general steel material (hereinafter, referred to as a steel material of the related art) used for a comparative column flange 16 in the related art. A dotted line L2 represents a curve approximating the results represented by the white triangles.

A line L3 represents required performance based on the Eurocodes and the American Institute of Steel Construction (AISC). The required performance is that the Charpy absorbed energy is 27 J or more at -21°C to -20°C.

[0038]

In both of the high-toughness steel material and the steel material of the related art, the Charpy absorbed energy increased as the temperature increased. The Charpy

absorbed energy of the high-toughness steel material was equal to or more than the Charpy absorbed energy of the steel material of the related art, regardless of the temperature.

At -60°C to 80°C , the Charpy absorbed energy of any of the high-toughness steel material and the steel material of the related art satisfied the required performance based on the Eurocodes and the AISC.

[0039]

Here, measured Charpy absorbed energy $vE_{-20(L, T)}$ of the high-toughness steel material in the rolling direction L at -20°C based on JIS Z 2242 is shown as a point $P_{-20(L, T)}$ in FIG. 6. Charpy absorbed energy $vE_{0(L, T)}$ of the high-toughness steel material in the rolling direction L at 0°C based on JIS Z 2242 is shown as a point $P_{0(L, T)}$ in FIG. 6.

[0040]

FIG. 7 shows test results according to JIS Z 2242 using the Charpy test piece 150_{SL} in which a flat surface S1 with a notch 151 formed thereon is orthogonal to the plate thickness direction S. The meanings of the axes, legends, and lines L1 and L2 are the same as those in FIG. 6. In a case of the Charpy test piece 150_{SL}, the required performance is not defined in the Eurocodes and the AISC.

Hereinafter, the Charpy absorbed energy obtained from the Charpy test pieces 150_{ST} and 150_{SL} in which a flat surface S1 with a notch 151 formed thereon is orthogonal to the plate thickness direction S is referred to as Charpy absorbed energy $vE_{(S)}$ in the plate thickness direction S.

In a case of the Charpy test piece 150_{SL}, the same tendency as that in the Charpy test piece 150_{LT} was observed. Furthermore, in a case of the Charpy test piece 150_{SL}, the difference between the Charpy absorbed energy of the high-toughness steel material and the Charpy absorbed energy of the steel material of the related art was large.

[0041]

Here, measured Charpy absorbed energy $vE_{-20(S)}$ of the high-toughness steel material in the plate thickness direction S at -20°C based on JIS Z 2242 is shown as a point $P_{-20(S)}$ in FIG. 7. Charpy absorbed energy $vE_{0(S)}$ of the high-toughness steel

5 material in the plate thickness direction S at 0°C based on JIS Z 2242 is shown as a 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 47 J or more. The Charpy absorbed energy $vE_{0(S)}$ is preferably 47 J or more. The Charpy absorbed energy $vE_{0(S)}$ is more preferably

10 70 J or more.

[0042]

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

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

15 That is, 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 is preferably equal to or more than a certain ratio to the toughness of the column flange 16 in the rolling direction L corresponding to the Charpy absorbed energy $vE_{-20(L, T)}$.

In addition, the Charpy absorbed energy $vE_{0(L, T)}$ and the Charpy absorbed

20 energy $vE_{0(S)}$ at 0°C preferably satisfy Expression (7).

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

That is, 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 is preferably equal to or more than a certain ratio to the toughness of the column flange 16 in the rolling direction L

25 corresponding to the Charpy absorbed energy $vE_{0(L, T)}$.

[0043]

In this way, in a case where the toughness of the column flange 16 in the plate thickness direction S is equal to or more than a certain ratio to the toughness of the column flange 16 in the rolling direction L, the difference in toughness of the column flange 16 depending on the direction is reduced, and stable propagation of cracks is induced, resulting in ductile fracture properties. Therefore, the joint part has higher energy absorption performance.

As a method of measuring the toughness of a member, for example, ISO 148-1: 2016 metallic materials - Charpy 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, or the like may be used as other standards that provide the same results as the results obtained according to JIS Z 2242.

[0044]

Furthermore, the Charpy absorbed energy $vE_{-20(L, T)}$ and the Charpy absorbed energy $vE_{-20(S)}$ at -20°C satisfy Expression (6').

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

That is, the toughness of the column flange 16 in the rolling direction L corresponding to the Charpy absorbed energy $vE_{-20(L, T)}$ at -20°C is preferably equal to or more 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 Expression (7').

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

That is, the toughness of the column flange 16 in the rolling direction L corresponding to the Charpy absorbed energy $vE_{0(L, T)}$ at 0°C is preferably equal to or more than the toughness of the column flange 16 in the plate thickness direction S corresponding to the Charpy absorbed energy $vE_{0(S)}$.

5 [0045]

In this way, in a case where the toughness of the column flange 16 in the rolling direction L is equal to or more than the toughness of the column flange 16 in the plate thickness direction S, the fracture in the plate thickness direction is suppressed. Thus, even in a case where cracks propagate through the plate thickness, the propagation of the cracks is stabilized and ductile fracture properties are exhibited, resulting in a joint part having higher energy absorption performance.

[0046]

[1-3. Provisions on Full Plastic Strength of Each Configuration of Beam-Column Joint Structure]

15 In general, in the design of beam-column joint structures, intersect positions are used as a reference when the full plastic strengths of columns, beams, and the like are calculated. The full plastic strength means an external force that, in a case where a member such as a beam has a shape extending in a predetermined reference direction, acts on the member, so that the entire cross section of the member orthogonal to the reference direction is in a plastic state.

Here, the ratio of a full plastic strength M_{pc} of the column 11 to a full plastic strength M_{pb} of the beam 211B at the intersect position P1 is defined as a column-beam strength ratio (M_{pc}/M_{pb}). The ratio of the full plastic strength M_{pb} of the beam 211B to a full plastic strength M_{pp} of the joint part panel 17a at the intersect position P1 is defined as a beam-panel strength ratio (M_{pb}/M_{pp}).

In the following [4.], the ranges of the column-beam strength ratio and the beam-panel strength ratio for ensuring the structural stability of a building 2 and for providing a beam-column joint structure 1 that has a joint part 23 having high energy absorption performance will be examined.

5 [0047]

[1-4. Method of Calculating Full Plastic Strength]

An example of a method of calculating the full plastic strength will be described using a building 4 using a beam-column joint structure 3 shown in FIG. 8. The beam-column joint structure 3 includes one column 11 and six beams 211B. In this example,
10 it is assumed that the six beams 211B have the same height and that the distances (height of the column 11) between the beams 211B adjacent to each other in a vertical direction are the same.

End parts of the six beams 211B on sides not joined to the column 11 are joined to second columns 51.

15 Here, the direction in which the pair of second columns 51 are arranged is referred to as a horizontal direction. The position where a central axis O1 of the column 11 or a central axis O3 of the second column 51 intersects with a central axis O2 of the beam 211B is referred to as a node.

[0048]

20 Symbols for the specifications of the beam-column joint structure 3 are defined as follows. The units and the like shown in Table 1 to be described later are used as units for the symbols.

L_L, R_L : Distances between nodes of the left and right beams 211B with respect to the joint part 23

25 L_L', R_L' : Internal lengths of the left and right beams 211B with respect to the joint

part 23

t_h, b_h : Distances between nodes of the upper and lower columns 11 with respect to the joint part 23

5 t_h', b_h' : Internal lengths of the upper and lower columns 11 with respect to the joint part 23

$b_L Z_p, b_R Z_p$: Plastic section moduli of the left and right beams 211B with respect to the joint part 23

$c_T Z_p, c_B Z_p$: Plastic section moduli of the upper and lower columns 11 with respect to the joint part 23

10 $b_L F, b_R F$: Reference strengths of the material strengths of the left and right beam 211B with respect to the joint part 23

$c_T F, c_B F$: Reference strengths of the material strengths of the upper and lower columns 11 with respect to the joint part 23

$p F$: Reference strength of the material strength of the joint part panel 17a

15 [0049]

b_H : Height of the beam 211B

c_H : Height of the column 11

b_{tf} : Thickness of the beam flange 216

c_{tf} : Thickness of the column flange 16

20 t_p : Thickness of the web 17 (in a case where the column main body is formed of a square steel tubing or a weld assembled box cross-section, the thickness of a flat plate part of the square steel tubing or the weld assembled box cross-section (see the flat plate part 33B of FIG. 18))

d_b : Distance between the plate thickness centers of the pair of beam flanges 216

25 $(= b_H - b_{tf})$

d_c : Distance between the plate thickness centers of the pair of column flanges 16

(= $cH - ct_f$)

Here, an effective volume V_e of the joint part panel is obtained by Expressions

(11) and (12).

5 [0050]

$$\begin{aligned} V_e &= d_c \cdot d_b \cdot t_p \quad (\text{In a case where the column body includes an H-section steel column}) \quad \cdot \cdot (11) \\ V_e &= 2d_c \cdot d_b \cdot t_p \quad (\text{In a case where the column body includes a square steel tube}) \quad \cdot \cdot (12) \end{aligned}$$

[0051]

In this case, the full plastic strength M_{pb} of the beam 211B is obtained by

Expression (15). The full plastic strength M_{pc} of the column is obtained by Expression

10 (16). The full plastic strength M_{pp} of the joint part panel is obtained by Expression (17).

[0052]

$$\begin{aligned} M_{pb} &= {}_{bL}Z_p \cdot {}_{bL}F \cdot \frac{{}_L l}{{}_L l'} + {}_{bR}Z_p \cdot {}_{bR}F \cdot \frac{{}_R l}{{}_R l'} \quad \cdot \cdot (15) \\ M_{pc} &= {}_{cT}Z_p \cdot {}_{cT}F \cdot \frac{{}_T h}{{}_T h'} + {}_{cB}Z_p \cdot {}_{cB}F \cdot \frac{{}_B h}{{}_B h'} \quad \cdot \cdot (16) \\ M_{pp} &= V_e \cdot \frac{{}_p F}{\sqrt{3}} \cdot \frac{1}{1 - \frac{{}_b H}{{}_T h + {}_B h} - \frac{{}_c H}{{}_L l + {}_R l}} \quad \cdot \cdot (17) \end{aligned}$$

[0053]

For example, the floor heights (corresponding to the distances ${}_T h$ and ${}_B h$) above

15 and below the joint part 23 are assumed to be 4,500 mm. The distances ${}_L l$ and ${}_R l$

between the nodes of the beams 211B are assumed to be 9,000 mm.

For Cases 1 to 5 shown in Table 1, the beam-panel strength ratio and the column-beam strength ratio were obtained.

[0054]

[Table 1]

Case	Main Body Type	Cross-Sectional Dimensions of Column Main Body					Cross-Sectional Dimensions of I-Beam for Beams					Floor Height	
		Height	Width	Thickness	Thickness	Reference Strength	Height	Width	Thickness	Thickness	Reference Strength	t_h, b_h	t_h', b_h'
		cH mm	cB mm	c_{tw} mm	c_{tf} mm	c_{tF}, c_{bF} N/mm ²	bH mm	bB mm	b_{tw} mm	b_{tf} mm	b_{tF}, b_{bF} N/mm ²		
1	H-Section Steel	458	427	40	50	235	500	250	12	25	235	4,500	4,000
2	Weld Assembled Box Cross-Section	750	750	36	36	325	1,000	400	22	40	325	4,500	3,500
3	H-Section Steel	700	300	16	28	325	600	200	12	22	325	4,500	3,900
4	Weld Assembled Box Cross-Section	500	500	19	19	325	600	250	12	28	325	4,500	3,900
5	Weld Assembled Box Cross-Section	400	400	22	22	325	600	200	12	16	325	4,500	4,100

Case	Span of Beam		Distance between Plate Thickness Centers		Joint Part Panel			Plastic Section Modulus		Full Plastic Strength			Beam-Panel Strength Ratio	Column-Beam Strength Ratio
	L_L, R_L mm	L_L', R_L' mm	d_c mm	d_b mm	Thickness	Reference Strength	Effective Volume	$c_{tF}Z_p, c_{bF}Z_p$ mm ³	$b_{tF}Z_p, b_{bF}Z_p$ mm ³	M_{pb} kNm	M_{pc} kNm	M_{pp} kNm	M_{pb}/M_{pp} -	M_{pc}/M_{pb} -
					t_p mm	p_F N/mm ²	V_c mm ³							
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

[0055]

5

For example, a column main body formed of an I-beam for columns is used in

Case 1. The cross-sectional dimensions of the column main body were $H-458 \times 427 \times 40 \times 50$ (height $\times$ width $\times$ web thickness $\times$ flange thickness, unit: mm), and the reference strengths c_{tF} and c_{bF} were set to 235 N/mm².

In Case 1, the beam-panel strength ratio was 1.411, and the column-beam strength ratio was 2.983.

[0056]

[1-5. Configuration of Building]

5 The building 2 is provided with a floor slab (not shown) or the like. The floor slab is supported from below by the beams 211B and the like of the beam-column joint structure 1. The building 2 may have a plurality of stories (floors) separated in the vertical direction by floor slabs or the like.

For example, the building 2 is used by placing equipment such as a desk or a file
10 cabinet on the floor slab.

[0057]

[2. Method of Manufacturing High-Toughness Steel Material]

In the chemical composition of the high-toughness steel material, the S content is 0.011 mass% or less. The S content can be measured using a combustion-infrared
15 absorption method. The chemical composition of other elements of the high toughness steel material may be appropriately set.

An example of the chemical composition includes 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.

[0058]

20 The high-toughness steel material can be obtained by heating a cast slab having the above-described chemical composition to 1,050°C to 1,350°C and performing finish rolling at 600°C to 950°C.

In addition, it is preferable that accelerated cooling is performed after the finish rolling and is stopped at 100°C or higher and 600°C or lower.

25 [0059]

[3. Experiment for Examining Strength Ratio of Beam-Column Joint Structure]

The beam-column joint structure 1 was attached to an experimental device 160 shown in FIG. 9 to perform an experiment. Hereinafter, in the pair of beams 211B of the beam-column joint structure 1, one beam may be referred to as a beam 211BA, and
 5 the other beam may be referred to as a beam 211BB. The beam-column joint structure 1 is installed to be laid down on its side, compared with its placement in an actual building, and is installed so that the structural planes of the column and the beam are on the horizontal plane.

The experimental device 160 includes a reaction wall connecting jig 161, beam
 10 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.

[0060]

The reaction wall connecting jig 161 is attached to a reaction wall in the experiment site. The beam jacks 162A and 162B, and the axial force frame 165 are
 15 fixed to the reaction wall connecting jig 161. The column jack 163 is fixed to an end part of the axial force frame 165 on the side opposite to an end part to which the reaction wall connecting jig 161 is joined.

The beam jack 162A moves an end part of the beam 211BA on the side opposite to an end part joined to the column main body 12 upwards and downwards alternately.
 20 The beam jacks 162B moves an end part of the beam 211BB on the side opposite to an end part joined to the column main body 12 downwards and upwards alternately.

The column jack 163 moves the lower end part of the column main body 12.

The lateral stiffening jig 164, and the pantograph jigs 166A and 166B are attached to a reaction floor in the experiment site, and suppress the deformation of the
 25 column main body 12 and the beam 211B of the test specimen beyond the structural

plane.

Both ends of the reaction force jig 167 are joined to the lower end part of the column main body 12 and the reaction wall connecting jig 161. The reaction force jig 167 transmits a reaction force generated by the beam jacks 162A and 162B.

5 [0061]

The specifications of the beam-column joint structure 1 are as shown in Table 2.

[0062]

[Table 2]

Column Main Body				Beam (I-Beam for Beams)				Column- Beam Strength Ratio -	Beam- Panel Strength Ratio -
Cross-Sectional Dimensions	Length mm	Yield Strength N/mm ²	Tensile Strength N/mm ²	Cross-Sectional Dimensions	Length mm	Yield Strength N/mm ²	Tensile Strength N/mm ²		
H-498 × 432 × 45 × 70	4550	379	546	H-650 × 300 × 16 × 25	8000	380	513	2.34	1.43

[0063]

10 As shown in Table 2, the cross-sectional dimensions of the column main body 12 were set to H-498 × 432 × 45 × 70. The length of the column main body 12 was set to 4,550 mm. In the column main body 12, the yield strength was set to 379 N/mm², and the tensile strength was set to 546 N/mm².

The column main body 12 is made of the high-toughness steel material shown in
15 FIGS. 6 and 7, and its chemical composition contains, by mass%, C: 0.16%, Si: 0.30%, Mn: 1.40%, P: 0.017%, and S: 0.004%. The S content of the high-toughness steel material is relatively lower than that of a general steel material.

[0064]

As shown in Table 2, the cross-sectional dimensions of the I-beam for beams
20 212 were set to H-650 × 300 × 16 × 25. The length of the I-beam for beams 212 (distance between the beam jacks 162A and 162B) was set to 8,000 mm. In the I-beam for beams 212, the yield strength was set to 380 N/mm², and the tensile strength was set

to 513 N/mm².

In this case, the column-beam strength ratio was 2.34, and the beam-panel strength ratio was 1.43.

[0065]

5 The beam-column joint structure 1 has neither a stiffener nor a doubler plate, and backing bars having a bevel are left on both of the upper flange 216A and the lower flange 216B of the beam flange 216.

[0066]

 The experimental device 160 moves the end part of the beam 211BA upward by
10 the beam jack 162A and moves the end part of the beam 211BB downward by the beam jack 162B at the same time, to set a first moving state. In addition, the experimental device 160 moves the end part of the beam 211BA downward by the beam jack 162A and moves the end part of the beam 211BB upward by the beam jack 162B at the same time, to set a second moving state. The experimental device 160 alternately repeats the
15 first moving state and the second moving state as a cycle to apply a load that causes antisymmetric bending of the beam-column joint structure 1.

 Samples 1 and 2 in which the same configuration was provided for the beam-column joint structure 1 were prepared. A load was applied to the sample 1 with loading history 1 shown in FIG. 10, and a load was applied to the sample 2 with loading
20 history 2 shown in FIG. 11.

[0067]

 In FIGS. 10 and 11, the horizontal axis represents a cycle (loading cycle), and the vertical axis represents a story drift (rad) of the beam-column joint structure 1.

 The loading history 1 is loading history used as standard loading history for a
25 performance confirmation test for an aseismic structural joint part specified in the U.S.

design standard ANSI/AISC341-16. AISC is an organization that sets standards for steel structures in the U.S. and issues aseismic design regulations for steel structures and the like. The loading history 2 is loading history used in the aseismic structure examination project SAC. The SAC is a project organized to examine measures against the fracture of weld joint parts of steel structures generated by the Northridge earthquake.

In both of the samples 1 and 2, by the column jack 163, a constant compressive axial force (5,000 kN), that is 20% of a yield axial force, was applied to 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.

10 [0068]

Here, the experimental results of the joint part in the prior research are shown in FIGS. 12 and 13. In FIGS. 12 and 13 and FIG. 14 to be described later, the horizontal axis represents a story drift (rad), and the vertical axis represents a story shear force (kN) that is a load.

15 FIG. 12 shows the experimental results in 1997 of the U.S. Federal Emergency Management Agency (hereinafter, simply referred to as FEMA). The joint part used in this experiment is a pre-Northridge joint part.

FIG. 13 shows the experimental results from Shin's literature (hereinafter, also simply referred to as Shin. see [7.]). The joint part used in this experiment is a post-Northridge joint part.

20 Northridge joint part.

FIG. 14 shows the results obtained from the sample 1 (example) of the present test.

[0069]

The horizontal axis range is identical in FIGS. 12 to 14, and the vertical axis range is identical in FIGS. 12 to 14. Since the story shear force on the vertical axis

25 range is identical in FIGS. 12 to 14. Since the story shear force on the vertical axis

changes according to the cross-sectional dimensions of the test specimen or the like, a direct comparison is not possible. Meanwhile, the story drift on the horizontal axis represents the deformation performance of the beam-column joint structure. This means that high deformation performance is achieved in a case where the story shear force is held up to a region with a large story drift. It was found that the maximum story drift in FIG. 14 is 0.08 rad, which is significantly larger than the maximum story drifts in FIGS. 12 and 13, and high deformation performance is achieved.

In addition, in FIGS. 12 to 14, the regions surrounded by curves as the experimental results represent the energy absorbed by the beam-column joint structure, and the cumulative absorbed energy in each loading cycle represents the energy absorption performance of the beam-column joint structure. In FIG. 14, the story shear force is held in more cycles than in FIGS. 12 and 13, and thus the cumulative absorbed energy is extremely large. Therefore, it was found that the joint part 23 of the beam-column joint structure 1 shown in FIG. 14 has higher energy absorption performance than the joint parts of FEMA and Shin.

[0070]

FIG. 15 shows the results of comparison between the beam-column joint structure 1 of the example and a joint part of the related art such as FEMA. FIG. 15 also shows the results of Chi & Uang's literature (hereinafter, also simply referred to as Chi & Uang. see [7.]), Ricles's literature (hereinafter, also simply referred to as Ricles. see [7.]), and Rahiminia & Namba's literature (hereinafter, also simply referred to as Rahiminia & Namba. see [7.]) as joint parts of the related art.

Regarding the joint parts, the joint part classification, and the presence or absence of stiffener, doubler plate, and backing bar are shown. "Left" in the column of the backing bar means that the backing bar is left so that the backing bar is present.

"Removed" in the column of the backing bar means that the backing bar has been removed so that there is no backing bar.

[0071]

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

[0072]

The upper portion of FIG. 15 shows the story drift (rad) as deformation performance for each joint part. In FIG. 15, the required performance (0.04) in the U.S. design standard AISC341-18 is represented by a solid line L5.

In the U.S. design standard AISC341-18, a load according to a loading procedure 1 is assumed. The U.S. design standard AISC341-18 stipulates that the required performance of a joint part for a aseismic structure is that 80% or more of the full plastic strength remains when the story drift reaches 0.04 rad.

[0073]

FIG. 15 shows the test results of the beam-column joint structure 1 of the example.

In the column of the joint part panel yielding, "Yes" means that the joint part panel yields during the test, and "No" means that the joint part panel does not yield during the test. In the column of the productivity and constructability, "×" (bad) means that the productivity and constructability are poor, and "○" (good) means that the productivity and constructability are good. In the column of the aseismic performance, "×" means that the aseismic performance is poor, "○" means that the aseismic performance is good, and "◎" (very good) means that the aseismic performance is very good.

For example, in the beam-column joint structure 1 of the example, the joint part

panel yielded during the test. The beam-column joint structure 1 had good productivity and constructability since it had neither a stiffener nor a doubler plate, and its aseismic performance was very good.

[0074]

5 The joint part 23 of the beam-column joint structure 1 of the example significantly exceeds the required performance of the U.S. design standard AISC341-18 represented by the line L5. The samples 1 and 2 showed almost the same fracture type. Therefore, it was shown that the joint part 23 of the beam-column joint structure 1 of the example stably exceeded the required performance of a joint part of a aseismic structure
10 under the test conditions applied this time.

The ultimate state of the joint part 23 of the beam-column joint structure 1 of the example is similar to Type D of Non Patent Document 1. That is, the cracks generated on the surface of the column flange 16 showed a fracture morphology in which the cracks penetrated through the plate thickness.

15 [0075]

However, as shown in FIG. 16, the generation and propagation of a crack LF occur on the upper flange 216A side, and the backing bar 213 with the bevel 21a formed thereon functions effectively as a unit for preventing the fracture originating from the lower flange 216B.

20 As shown in FIG. 16, white plaster is applied to the surface of the beam-column joint structure 1 in advance. In the beam-column joint structure 1, the plaster of a plasticized portion is peeled off, and the black base color of the column main body 12 and the like is revealed. That is, it was found that not only the column 11 and the beam 211B undergo kink deformation, but also the joint part panel 17a, and the beam flange
25 216 and the beam web 217 at the end of the beam 211B are plasticized and absorb

energy.

[0076]

In addition, today, research on the redundancy against collapse due to an extremely large earthquake exceeding the scale assumed in the design and on the evaluation of the residual performance after the earthquake (determination on whether repair is possible) is being advanced. It was found that, among these, the performance of the joint part 23 of the beam-column joint structure 1 of the example has high superiority from these viewpoints.

[0077]

10 [4. Examination of Strength Ratio]

The beam-column joint structure 1 of the example, and the column-beam strength ratios, beam-panel strength ratios, and maximum story drifts obtained from Shin's literature, Rahiminia & Namba's literature, and Ricles's literature are shown in FIG. 17. Shin's literature, Rahiminia & Namba's literature, and Ricles's literature are based on the prior research.

The presence or absence of a stiffener and the like in the examples and the prior research are shown in Table 3.

[0078]

[Table 3]

	Example	Shin, 2017						
		UT01	UT02	UT03	UT04	UT05	UT06	UT08
Stiffener	Absence	Presence	Presence	Presence	Absence	Absence	Absence	Presence
Doubler plate	Absence	Absence	Presence	Presence	Absence	Presence	Presence	Presence
Backing bar	Left	Removed	Removed	Removed	Removed	Removed	Removed	Removed
Slab	Absence	Absence	Absence	Absence	Absence	Absence	Absence	Absence

	Rahiminia and Namba, 2013						Ricles, 2000				
	HI06F	HI08F	HI10F	HI13F	HI05F W07	HI05F W05	C1	C2	C3	C4	C5
Stiffener	Presence	Presence	Presence	Presence	Presence	Presence	Absence	Presence	Absence	Presence	Absence
Doubler Plate	Presence	Presence	Presence	Presence	Presence	Presence	Presence	Presence	Presence	Presence	Presence
Backing bar	Left	Left	Left	Left	Left	Left	Removed	Removed	Removed	Removed	Removed
Slab	Absence	Absence	Absence	Absence	Absence	Absence	Absence	Absence	Absence	Absence	Presence

[0079]

In a case where a slab is provided, the slab is supported from below by beams.

- 5 For example, in UT01 of Shin's literature, a stiffener is provided, but there is no doubler plate. There is neither backing bar nor slab.

[0080]

[5. Effects of Present Embodiment]

- As described above, as a result of intensive examinations, the present inventors
- 10 have found that, in order to increase the energy absorption performance at the joint part
- 23 between the column 11 and the beam 211B in the beam-column joint structure 1, it is necessary to absorb the energy acting on the beam-column joint structure 1 not only in the beam 211B but also in the joint part panel 17a. In particular, a configuration is preferable in which the joint part panel 17a, that is expected to have a stable increase in
- 15 strength after plasticization as long as the column flange 16 does not fracture, yields first,

and following the increase in strength of the joint part panel 17a due to yielding, the beam 211B yields. That is, in order for the joint part panel 17a to first undergo yielding, the beam-panel strength ratio, which is a ratio of the full plastic strength M_{pb} of the beam 211B to the full plastic strength M_{pp} of the joint part panel 17a, may be 1.05 or more.

In addition, the strength of the joint part panel 17a can be expected to increase up to about 1.5 times the full plastic strength by strain hardening due to repeated plastic deformation. That is, by setting the beam-panel strength ratio to 1.5 or less, not only the joint part panel 17a but also the beam 211B can be plasticized during the process of increasing the strength after the joint part panel 17a yields first, and the energy acting on the beam-column joint structure 1 can be absorbed by both the beam 211B and the joint part panel 17a. Therefore, the energy absorption performance at the joint part 23 between the column 11 and the beam 211B can be increased.

[0081]

Meanwhile, it is necessary to prevent the story collapse due to the yielding of the column 11 in order to ensure the structural stability of the building 2 using the beam-column joint structure 1. Therefore, it is necessary to sufficiently strengthen the column 11 with respect to the beam 211B. In view of the increase in strength after plasticization of the beam 211B, the column-beam strength ratio, which is a ratio of the full plastic strength of the column 11 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 from being economically unreasonable, the column-beam strength ratio is preferably suppressed to be about 2.5 to 3.0 or less.

[0082]

In contrast, in the prior research shown in FIG. 17, there are few cases where the

joint part panel yields first and the beam-panel strength ratio is 1.05 or more. The reason for this is thought to be that the joint part panel has been avoided from yielding first in the steel materials and joining details of the related art.

In the prior research, in a case where the beam-panel strength ratio is 1.05 or more, the column-beam strength ratio is 1.5 or less in the majority of cases, and in the prior research in which the joint part panel yields first, it is found that this is based on the assumption that the column strength is relatively small.

In a case where the column-beam strength ratio is large, exceeding 1.5, the plate thickness of the column flange is large, and the influence of the local bending deformation (kink) of the column flange is significant, which may cause a problem of early fracture. In contrast, in a case where the column-beam strength ratio is small, since the plate thickness of the column flange is relatively small, the influence of the local bending deformation of the column flange when the joint part panel yields is small, and the problem of fracture is less likely to occur. For these reasons, it is thought that the prior research has avoided a beam-column joint structure having a strength balance in which the beam-panel strength ratio is within a range of 1.05 or more and 1.5 or less (range R6 shown in FIG. 17) and the column-beam strength ratio is within a range of 1.5 or more and 3.0 or less (range R7 shown in FIG. 17).

[0083]

By setting the beam-panel strength ratio to 1.05 or more and 1.5 or less and setting the column-beam strength ratio to 1.5 or more and 3.0 or less, it is possible to ensure the structural stability of a building 2 using the beam-column joint structure 1, and it is possible to provide a beam-column joint structure 1 that has a joint part 23 having high energy absorption performance.

In a case where the column 11 of the beam-column joint structure 1 has neither

stiffener 203 nor doubler plate 225, the column 11 can be easily produced and constructed.

[0084]

In Table 1, a case 1 is a beam-column joint structure using an H-section steel for the column 11, and a case 2 is a beam-column joint structure using a weld assembled box cross-section for the column 11. Both of the cases satisfy the ranges of the beam-panel strength ratio and the column-beam strength ratio, and are examples.

A case 3 does not satisfy the range of the beam-panel strength ratio and is a comparative example. A case 4 does not satisfy the range of the column-beam strength ratio and is a comparative example. A case 5 does not satisfy the ranges of the beam-panel strength ratio and the column-beam strength ratio, and is a comparative example.

[0085]

The bevel 21a is formed on the backing bar 21. Therefore, the portion joined to the column flange 16 in the connection surface between the backing bar 21 and the welded section 218 is inclined relative to the column flange 16 without being orthogonal thereto. Therefore, for example, it is possible to reduce the strain concentration at a tip end of the slit 21b generated at the boundary between the column flange 16 and the backing bar 21 due to a load such as a bending moment acting on the beam 211B, and it is possible to suppress the propagation of a crack from the tip end of the slit 21b toward the welded section 218 or the column flange 16.

[0086]

The Charpy absorbed energy $vE_{-20(S)}$ in the plate thickness direction S of the column flange 16 at -20°C based on JIS Z 2242 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 or more level. In general, the toughness of the column flange increases

with the increasing column flange's temperature. Since the toughness is further increased at a temperature at which the column flange 16 is actually used, it is possible to suppress the fracture of the column flange 16 in the plate thickness direction S even in a case where the column flange 16 is directly joined to the pair of beam flanges 216 of the I-beam for beams 212 of the beam 211B through the welded section 218.

The Charpy absorbed energy $vE_{-20(S)}$ and the Charpy absorbed energy $vE_{-20(L, T)}$ may satisfy Expression (6). In this case, 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 is equal to or more than a certain ratio to the toughness of the column flange 16 in the rolling direction L corresponding to the Charpy absorbed energy $vE_{-20(L, T)}$. Therefore, the difference in toughness of the column flange 16 depending on the direction is reduced, and stable propagation of cracks is induced, resulting in ductile fracture properties. Therefore, the joint part has higher energy absorption performance.

[0087]

The Charpy absorbed energy $vE_{0(S)}$ in the plate thickness direction S of the column flange 16 at 0°C based on JIS Z 2242 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 or more level. In general, the toughness of the column flange increases with the increasing column flange's temperature. Since the toughness is further increased at a temperature at which the column flange 16 is actually used, it is possible to suppress the fracture of the column flange 16 in the plate thickness direction S even in a case where the column flange 16 is directly joined to the pair of beam flanges 216 of the I-beam for beams 212 of the beam 211B through the welded section 218.

The Charpy absorbed energy $vE_{0(S)}$ and the Charpy absorbed energy $vE_{0(L, T)}$ may satisfy Expression (7). In this case, 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 is equal to or more than a certain ratio to the toughness of the column flange 16 in the rolling direction L corresponding to the Charpy absorbed energy $vE_{0(L, T)}$. Therefore, the difference in toughness of the column flange 16 depending on the direction is reduced, and stable propagation of cracks is induced, resulting in ductile fracture properties. Therefore, the joint part has higher energy absorption performance.

[0088]

The column 11 may not have the stiffener 203. In this case, the column 11 can be relatively easily processed.

The column 11 may not have the doubler plate 225. In this case, the column 11 can be relatively easily processed.

[0089]

[6. Others]

Although one embodiment of the present invention has been described in detail above with reference to the drawings, specific configurations are not limited to the embodiment, and modifications, combinations, deletions, and the like in the configurations may be made without departing from the gist of the present invention.

For example, in the embodiment, in the beam-column joint structure 1, the backing bars 21 and 213 may be removed and not provided. For example, in a case where the backing bar 21 is removed and not provided, for example, in FIG. 2, a shape including no backing bar 21 is provided, and the shape of the welded section 218 and the like is the same as that shown in FIG. 2.

[0090]

A column main body 32 of a column 31 may be formed of a weld assembled box cross-section as in a beam-column joint structure 1A of a first modification example

shown in FIG. 18. FIG. 18 shows the column main body 32 with a part fractured. In this example, the column main body 32 is configured by welding a pair of flat plate parts (joint plates) 33A and a pair of flat plate parts 33B to each other. The pair of flat plate parts 33A are disposed to face each other. The pair of flat plate parts 33B are disposed to face each other. The flat plate parts 33B are joined to end parts of the pair of flat plate parts 33A.

The pair of beam flanges 216 of the I-beam for beams 212 are directly joined to the flat plate parts 33A through the welded section 218. The pair of flat plate parts 33B extend along the longitudinal direction of the beam 211B.

10 [0091]

A joint part panel 33Ba is a portion of the pair of flat plate parts 33B that is within the range of the beam 211B in the vertical direction. In the beam-column joint structure 1A, the column 31 and the pair of beams 211B are connected to each other at joint parts 35. With respect to the joint part panel 33Ba, the beam-panel strength ratio is defined in the same manner as in the present embodiment.

The beam-column joint structure 1A of the first modification example may have at least one of the stiffener 203 and the doubler plate 225.

Even in the beam-column joint structure 1A of the first modification example, the column-beam strength ratio is 1.5 or more and 3.0 or less. The beam-panel strength ratio based on the joint part panel 33Ba is 1.05 or more and 1.5 or less.

[0092]

A column main body 42 of a column 41 may be formed of a square steel tubing manufactured by bending and welding a steel plate as in a beam-column joint structure 1B of a second modification example shown in FIG. 19. FIG. 19 shows the column main body 42 with a part fractured.

[0093]

The I-beam for columns and the I-beam for beams are not limited to the H-section steel defined by JIS G 3192, and may be steel materials having an H-shaped cross section orthogonal to the axial direction.

5 [0094]

[7. Document List]

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INDUSTRIAL APPLICABILITY

[0095]

The beam-column joint structure can ensure the structural stability of buildings using beam-column joint structures, and can be applied to a beam-column joint structure
25 that has a joint part having high energy absorption performance. Therefore, great

industrial applicability is achieved.

REFERENCE SIGNS LIST

[0096]

	1, 1A, 1B Beam-column joint structure
5	11, 31, 41 Column
	12, 32, 42 Column main body
	16 Column flange (joint plate)
	17 Column web
	21 Backing bar
10	21a Bevel
	33A Flat plate part (joint plate)
	211B Beam
	212 I-beam for beams
	203 Stiffener (first reinforcement plate)
15	216 Beam flange
	216B lower flange
	218 Welded section
	225 Doubler plate (second reinforcement plate)
	O1, O2 Central Axis
20	P1 Intersect position
	S Plate thickness direction

CLAIMS

[Claim 1] A beam-column joint structure comprising:

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

5 a beam having an I-beam for beams in which a pair of beam flanges of the I-beam for beams are directly joined to joint plates of the column main body through welded section,

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

10 when a position where a central axis of the column main body intersects with a central axis of the I-beam for beams is defined as an intersect position,

a ratio of a full plastic strength of the column to a full plastic strength of the beam at the intersect position is 1.5 or more and 3.0 or less, and

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

20 [Claim 2] The beam-column joint structure according to claim 1, further comprising:

a backing bar joined to each of a lower flange disposed on a lower side of the pair of beam flanges and the joint plate through the welded section,

wherein the backing bar is attached below the lower flange,

a bevel is formed on an upper surface of the backing bar so as to be directed
25 downward gradually as approaching the joint plate, and

the welded section is also formed in the bevel.

[Claim 3] The beam-column joint structure according to claim 1 or 2,

wherein Charpy absorbed energy $vE_{-20(s)}$ in a plate thickness direction of the joint plate at -20°C is 35 J or more.

5 [Claim 4] The beam-column joint structure according to any one of claims 1 to 3,

wherein Charpy absorbed energy $vE_{0(s)}$ in a plate thickness direction of the joint plate at 0°C is 47 J or more.

[Claim 5] The beam-column joint structure according to any one of claims 1 to 4,

10 wherein a first reinforcement plate disposed at the same position as the pair of beam flanges in the vertical direction and joined to the column main body is not provided.

[Claim 6] The beam-column joint structure according to any one of claims 1 to 5,

wherein a second reinforcement plate joined to the column web or the flat plate part to increase a thickness of the column web or the flat plate part is not provided.