

DESCRIPTION

TITLE OF INVENTION: STEEL MATERIAL AND USE OF STEEL MATERIAL

TECHNICAL FIELD

[0001]

The present invention relates to a steel material used for a plate of a column main body to be joined in a beam-column joint structure and use of the steel material.

Priority is claimed on Japanese Patent Application No. 2023-099748, filed on June 19, 2023, the content of which is incorporated herein by reference.

BACKGROUND ART

[0002]

The Northridge earthquake occurred in the United States of America in 1994. A beam-column joint structure 200 shown in FIG. 19 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 a column main body 202 formed of an I-beam for columns (I-section steel), a pair of stiffeners (diaphragms) 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.

Each stiffener 203 is a horizontal continuity plate 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 sections 208 formed by welding.

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 I-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 sections 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. 20, 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 (plate thickness direction S) 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 (rolling direction L) in which

the column flange 206 is divided in a material axis direction (longitudinal direction). As shown in FIG. 21, 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. 21, 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.

[0006]

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.

[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 of the joint part is determined to withstand repeated deformation many times.

As a detailed structure, as shown in FIG. 22, 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 225 so as to increase the thickness of the column web 207.
- (3) After an end part of a beam 211A is welded on site, the backing bar 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 bar 213 around the lower flange 216B 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 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 removed portion. Due to the removal of the backing bar 213, slits that serve as the origin of fracture are eliminated, and due to the reinforcing welding, the stress concentration on the welded sections 218 of the lower flange 216B is reduced.

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 plate thickness direction S and the rolling direction L direction is used for the column flange 206.

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-](http://www.dpri.kyoto-u.ac.jp/nenpo/no39/39b1/a39b1p02.pdf)

[u.ac.jp/nenpo/no39/39b1/a39b1p02.pdf](http://www.dpri.kyoto-u.ac.jp/nenpo/no39/39b1/a39b1p02.pdf)>

SUMMARY OF INVENTION

Technical Problem

[0010]

However, the measures (1) to (3) above are all heavy in terms of manufacturing and construction. In addition, the joint part 222A of the beam-column joint structure 200B may not exhibit the energy absorption performance depending on the mode of fracture when absorbing the energy due to the seismic external force.

[0011]

The present invention has been made in view of the above problems, and it is an object of the present invention to provide a steel material used for a plate of a column main body to be joined in a beam-column joint structure having a joint part with a high energy absorption property, and a use of the steel material.

Solution to Problem

[0012]

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

(1) A first aspect of the present invention is a steel material used for a plate of a column main body to be joined that is directly joined to a pair of beam flanges through welded sections, in a beam-column joint structure having a column which has the column main body, and a beam which has an I-beam for beams having the pair of beam flanges, wherein an amount of S is 0.011 mass% or less, and $vE_{-20(S)}$, $vE_{-20(L,T)}$, $vE_{0(S)}$, and $vE_{0(L,T)}$ satisfy at least one of a combination of Expressions (1A) and (1B), and a combination of Expressions (2A) and (2B), the $vE_{-20(S)}$ being a Charpy absorbed energy of the plate in a plate thickness direction at -20°C based on JIS Z 2242: 2018 and the $vE_{-20(L,T)}$ being a Charpy absorbed energy of the plate in a rolling direction at -20°C based on JIS Z 2242: 2018, and the $vE_{0(S)}$ being a Charpy absorbed energy of the plate in a plate thickness direction at 0°C based on JIS Z 2242: 2018, and the $vE_{0(L,T)}$ being a Charpy absorbed energy of the plate in a rolling direction at 0°C based on JIS Z 2242: 2018.

$$vE_{-20(S)} \geq 35J \dots (1A)$$

$$vE_{-20(L,T)} \geq vE_{-20(S)} \dots (1B)$$

$$vE_{0(S)} \geq 47J \dots (2A)$$

$$vE_{0(L,T)} \geq vE_{0(S)} \dots (2B).$$

[0013]

(2) The steel material according to the (1) may contain at least one of V: 0.005 to 0.10%, and Nb: 0.005 to 0.10%.

[0014]

(3) A second aspect of the present invention is a use of a steel material as a plate of a column main body to be joined that is directly joined to a pair of beam flanges through welded sections, in a beam-column joint structure having a column which has the column main body, and a beam which has an I-beam for beams having the pair of beam flanges, wherein an amount of S is 0.011 mass% or less, and $vE_{-20(S)}$, $vE_{-20(L,T)}$, $vE_{0(S)}$, and $vE_{0(L,T)}$ satisfy at least one of a combination of Expressions (1A) and (1B), and a combination of Expressions (2A) and (2B), the $vE_{-20(S)}$ being a Charpy absorbed energy of the plate in a plate thickness direction at -20°C based on JIS Z 2242: 2018 and the $vE_{-20(L,T)}$ being a Charpy absorbed energy of the plate in a rolling direction at -20°C based on JIS Z 2242: 2018, and the $vE_{0(S)}$ being a Charpy absorbed energy of the plate in a plate thickness direction at 0°C based on JIS Z 2242: 2018, and the $vE_{0(L,T)}$ being a Charpy absorbed energy of the plate in a rolling direction at 0°C based on JIS Z 2242: 2018.

$$vE_{-20(S)} \geq 35J \dots (1A)$$

$$vE_{-20(L,T)} \geq vE_{-20(S)} \dots (1B)$$

$$vE_{0(S)} \geq 47J \dots (2A)$$

$$vE_{0(L,T)} \geq vE_{0(S)} \dots (2B).$$

Advantageous Effects of Invention

[0015]

According to the present invention, it is possible to provide a steel material used for a plate of a column main body to be joined in a beam-column joint structure having a joint part with a high energy absorption property, and a use of the steel material.

BRIEF DESCRIPTION OF DRAWINGS

[0016]

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

[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 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: 2018 using a Charpy test piece in which a flat surface with a notch formed thereon is orthogonal to a rolling direction.

[FIG. 7] A view showing test results according to JIS Z 2242: 2018 using a Charpy test piece in which a flat surface with a notch formed thereon is orthogonal to a plate thickness direction.

[FIG. 8] is a front view describing an outline of a testing device for a beam-column joint structure.

[FIG. 9] A view describing loading history 1 acting on a sample 1.

[FIG. 10] A view describing loading history 2 acting on a sample 2.

[FIG. 11] A view showing experimental results of the U.S. Federal Emergency Management Agency.

[FIG. 12] A view showing experimental results of Shin's literature.

[FIG. 13] A view showing experimental results of the sample 1.

[FIG. 14] A view showing results of comparison between the example and joint parts of the related art.

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

[FIG. 16] 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.

[FIG. 17] 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. 18] A perspective view of a main part in a third modification example of the

beam-column joint structure of one embodiment of the present invention.

[FIG. 19] A front view of a main part of a beam-column joint structure used before the Northridge earthquake.

[FIG. 20] An enlarged view of a main part describing a fracture type of the same beam-column joint structure.

[FIG. 21] A side view showing a state in which a joint part panel of a beam-column joint structure undergoes shear deformation.

[FIG. 22] A perspective view of a main part of a beam-column joint structure used in the related art after the Northridge earthquake.

DESCRIPTION OF EMBODIMENTS

[0017]

The present inventors have studied a steel material for a column (hereinafter, sometimes simply referred to as a steel material) in a beam-column joint structure capable of ensuring a deformation performance equal to or higher than that of a post-Northridge joint part.

Generally, the higher the temperature of the joint plate in the steel material for the column, the higher the toughness becomes. Since the toughness is further increased at the temperature at which the joint plate is actually used, even when the pair of beam flanges of the I-beams for beams of the beam are directly joined to the joint plate through the welded sections, the joint plate can be prevented from being fractured in the direction orthogonal to the plate thickness direction (LA, LB in FIG. 20).

When the fracture in the direction perpendicular to the plate thickness direction (LA and LB in FIG. 20) is suppressed, the crack generated on the surface of the joint plate from the portion where the lower flange of the beam is joined propagates in the plate thickness direction of the joint plate (LD in FIG. 20).

If the fracture in the direction perpendicular to the plate thickness direction (LA and LB in Fig. 20) is not suppressed, the crack will propagate in the direction perpendicular to the plate thickness direction (LA and LB in Fig. 20), and the continuity of the path for transmitting the tensile force acting from the lower flange of the beam to the column

will be lost, and the resistance of the beam-column joint portion will immediately decrease.

The present inventors have found that, a crack propagates in the plate thickness direction of the joint plate (LD in FIG. 20) by using a steel material for a column, which has a relationship between the plate thickness direction and the rolling direction appropriately controlled at a predetermined temperature, as a joint plate, thus,

(a) the continuity of the path of transmission of the tensile force acting from the lower flange of the beam to the column is not lost; and

(b) the resistance of the beam-column joint portion remains stable during the crack propagation,

whereby the energy absorption performance at the joint between the column and the beam is enhanced.

[0018]

Furthermore, the present inventors have found that when the toughness of the joint plate in the plate thickness direction is higher than that of a general joint plate by a certain amount, and when the toughness in the direction perpendicular to the plate thickness direction is higher than that in the plate thickness direction, the crack stably propagates in the plate thickness direction of the joint plate (LD in FIG. 20). That is, by using a steel material for a column, which has an appropriately controlled relationship between the Charpy absorbed energy in the plate thickness direction and the Charpy absorbed energy in the rolling direction at a predetermined temperature, as a joint plate, it is possible to suppress the fracture from the lower flange of the beam, and the resistance of the beam-column joint portion is stable until the end is reached by the fracture of the upper flange, and the energy absorption performance at the joint between the column and the beam can be maintained.

[0019]

The present invention was made based on the above findings. Hereinafter, a beam-column joint structure to which a steel material according to an embodiment of the present invention will be described with reference to FIGS. 1 to 18.

[0020]

[1. Configuration of Building]

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

As shown in FIG. 1, a beam-column joint structure 1 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 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. The column main body 12 has a pair of column flanges 16 and a column web 17. The column flange 16 is a joint plate to which a beam is joined, as described later. That is, as in the present embodiment in which the column 11 has a column main body 12 configured by the I-beam for columns, the column flange 16 functions as the joint plate.

The pair of column flanges 16 and the column web 17 are preferably formed of a rolled steel material.

[0021]

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 in a width direction T.

[0022]

The chemical composition of the column flange 16 will be described below. In the following description, "%" relating to the content means "% by mass".

In the column flange 16, it is important to secure the toughness in the plate thickness direction S at -20°C or 0°C. In the present invention, the S content in the column flange 16 is controlled to be 0.011% or less.

Generally, S is an element that is combined with Mn in the steel material and is contained in the steel material as an impurity. S combines with Mn and Ca in the steel material to form inclusions of MnS and CaS, and has the function of causing the steel

material to become brittle. These inclusions are pressed and flattened in the plate thickness direction S by rolling, and thus particularly deteriorate the toughness in the plate thickness direction S. Therefore, by controlling the S content of the column flange 16 to 0.011% or less, the toughness of the column flange 16 can be made relatively high. The S content is preferably 0.006% or less, and more preferably 0.003% or less.

Although the lower the S content, the more preferable, the reduction of the S content to 0.001% or less, which inevitably occurs, causes a high load in the desulfurization process, and leads to an increase in the production cost. Therefore, the lower limit of the S content may be set to more than 0.001% or more than 0.002%.

Conventionally, the S content of steel materials used for column members of buildings is about 0.02 to 0.03%. In the present application, the idea of reducing the S content more than before is reached based on the new finding that increasing the toughness in the plate thickness direction S contributes to improving the energy absorption performance. As a measure for reducing the S content to 0.011% or less, for example, a desulfurization method is devised in the steel making stage. Specifically, the S content can be reduced by performing a pre-molten iron treatment before refining in a converter using a desulfurizing agent (CaO or the like) and further performing reduction refining in a converter or electric furnace.

In addition, in accordance with JIS G 0320 "Standard test method for heat analysis of steel products", the S content can be measured by, for example,

JIS G1215-1 "Gravimetric method after separation of iron (Iron separation barium sulfate gravimetric method)",

JIS G1215-2 "Gravimetric method after chromatographic separation (Chromatographic separation by weighing of barium sulfate)",

JIS G1215-3 "Methylene blue spectrophotometric method after separation of hydrosulfide (Methylene blue absorption spectrophotometry for hydrogen sulfide vapor separation)", and

JIS G1215-4 "Infrared absorption method after combustion in an induction furnace

(High-frequency induction heating combustion - Infrared absorption method)".

[0023]

In the present invention, as described above, it is important to control the S content as the chemical component of the column flange 16. Other elements may be appropriately selected within a range that the strength and weldability of the column can be obtained. An example of the chemical composition is a chemical composition containing C: 0.05 to 0.20%, Si: 0.05 to 0.60%, Mn: 0.50 to 2.00%, Teal: 0.002 to 0.060%, Cu: 0 to 0.50%, Ni: 0 to 0.50%, Cr: 0 to 0.40%, Mo: 0 to 0.20%, Nb: 0 to 0.10%, V: 0 to 0.10%, Ti: 0 to 0.05%, B: 0 to 0.10%, Ca: 0 to 0.10%, W: 0 to 0.50%, Zr: 0 to 0.50%, P: 0.035% or less, S: 0.011% or less, N: 0.10% or less, O: 0.50% or less, with the balance being Fe and impurities.

[0024]

In addition, the addition of a small amount of V and Nb has the effect of suppressing recrystallization of austenite and refining crystal grains, thereby securing the strength and toughness of the steel material. Therefore, especially when the thickness of the steel material is large (for example, 25 mm or more), it is preferable that the composition contains at least one of V: 0.005% to 0.10%, and Nb: 0.005 to 0.10%.

[0025]

Within the above range of chemical composition, the carbon equivalent Ceq calculated from the following Expression (1) may be 0.26% or more and 0.48% or less.

$$Ceq(\%) = \text{Min} (C + Mn/6 + Si/24 + Ni/40 + Cr/5 + Mo/4 + V/14, C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15) \dots (1)$$

In the above Expression (1), C, Mn, Si, Ni, Cr, Mo, V, Cu and B are the contents of each element in the steel material expressed in mass%, and 0 is substituted for the term of the element not contained.

Namely, the carbon equivalent Ceq (%) is the smaller one of the calculated values of the $C + Mn/6 + Si/24 + Ni/40 + Cr/5 + Mo/4 + V/14$, and $C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15$.

The former Expression is an expression defined by JIS (Japan Industrial Standards), and the latter Expression is an expression defined by IIW (International Institute of

Welding). The minimum value of the values calculated from the two expressions is determined as the carbon equivalent C_{eq} , and by controlling this value to 0.26% or more and 0.48% or less, the maximum hardness of the weld heat-affected zone can be suppressed, and the toughness of the weld heat-affected zone can be more reliably ensured.

[0026]

Within the above chemical composition range, the weld crack susceptibility composition PCM calculated from the following Expression (2) may be 0.14% or more and 0.29% or less.

$$PCM(\%) = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B \dots (2)$$

In the above Expression (2), C, Mn, Si, Ni, Cr, Mo, V, Cu and B are the contents of each element in the steel material expressed in mass%, and 0 is substituted for the term of the element not contained.

[0027]

In the present application, C, Mn and Si are important for achieving both strength and toughness, and the weld crack susceptibility composition PCM calculated from the above Expression (2) is preferably set to 0.14% or more.

On the other hand, in order to prevent cracking of the first layer during welding, it is preferable that the weld crack susceptibility composition PCM calculated from Expression (2) is controlled to 0.29% or less.

[0028]

In the present embodiment, the column 11 is configured to have neither a stiffener 203 nor a doubler plate 225 as shown in FIG. 22 and the like. However, the column 11 may be configured to have at least one of the stiffener 203 and the doubler plate 225, for the sake of the reinforcement.

[0029]

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.

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 as gradually approaching the column flange 16.

[0030]

The backing bar 21 has a rectangular parallelepiped shape. Each backing bar 21 is attached from below each beam flange 216 (lower flange 216B). It should be noted that, in the example shown in FIG. 1, the backing bar 21 is further attached to the upper flange 216A, but the backing bar 21 may not be attached to the upper flange 216A. A welded section 218 is disposed between the bevel 216a of the beam flange 216 and the column flange 16. 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.

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.

At the contacting face between the column flange 16 and the backing bar 21, the welded section 218 is slightly melted in, but a slit 21b is formed where a stress is concentrated according to the shape.

[0031]

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.

In the beam-column joint structure 1, the column 11 and the pair of beams 211B are connected to each other at joint parts 23.

[0032]

[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.

[0033]

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.

[0034]

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 G 0416, 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} in which a flat surface S1 formed with a notch 151 is 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.

[0035]

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 t_1 (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 t_2 (mm).

[0036]

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.

[0037]

For example, in a case where the plate thickness t_1 is 40 mm or less, the distance t_2 is set to $(t_1/4)$. In a case where the plate thickness t_1 is more than 40 mm, the distance t_2 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 t_2 is preferably set according to the plate thickness t_1 as described above.

For example, the plate thickness t_1 of the column flange 16 is 19 mm or more.

[0038]

In general, the greater the Charpy absorbed energy measured according to JIS Z 2242, the higher the toughness.

[0039]

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 or the width direction T is referred to as Charpy absorbed energy $vE_{(L,T)}$ in the rolling direction L.

[0040]

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.

[0041]

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, however, the difference of the Charpy absorbed energy at -20°C and 0°C was small. 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.

[0042]

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.

[0043]

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.

In the following description, the Charpy absorbed energy based on JIS Z 2242 obtained from the Charpy test pieces 150_{ST} and 150_{SL} in which the plane S1 on which the notch 151 is formed is perpendicular to the plate thickness direction S or the Charpy test pieces taken at a position where these pieces are rotated around an axis parallel to the plate thickness direction S is generally called "Charpy absorbed energy in the plate thickness direction" and is expressed as $vE_{(S)}$. Further, the Charpy absorbed energy in the plate thickness direction S at the Charpy test temperature $T^{\circ}\text{C}$ is expressed as $vE_{T(S)}$. That is, the Charpy absorbed energy in the plate thickness direction S at the Charpy test temperature of 0°C is expressed as $vE_{0(S)}$, and the Charpy absorbed energy in the plate

thickness direction S at the Charpy test temperature of -20°C is expressed as $vE_{-20(S)}$. 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. Furthermore, the experimentations on the beam-column joint structure described later revealed that even if the $vE_{-20(L,T)}$ and $vE_{0(L,T)}$ of the Charpy test pieces 150_{LT} were steel materials having no significant difference from the conventional steel materials, there were cases where a large difference occurred in the energy absorption performance of the beam-column joint structure. It was found that this difference can be explained by newly focusing on the difference in $vE_{(S)}$ by the Charpy test piece 150_{SL}, which has not been focused on before. That is, it was found that the energy absorption performance of the beam-column joint structure can be significantly improved by using a steel material having an excellent value of $vE_{(S)}$.

[0044]

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 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 35 J or more. The Charpy absorbed energy $vE_{-20(S)}$ is preferably 47 J or more.

The Charpy absorbed energy $vE_{0(S)}$ is 47 J or more. The Charpy absorbed energy $vE_{0(S)}$ is preferably 70 J or more.

[0045]

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

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

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

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).

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

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 higher than the toughness of the column flange 16 in the rolling direction L corresponding to the Charpy absorbed energy $vE_{0(L,T)}$, by a certain ratio or more..

[0046]

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 $vE_{0(S)}$.

[0047]

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 S 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.

[0048]

The steel material of the present application is characterized as a use (application, utility) as a plate of a column main body to be joined in a beam-column joint structure. A beam-column joint structure is provided with a column having a column main body and a beam having an I-beam for beams having a pair of beam flanges.

The joint plate of the column main body is a portion directly joined to the pair of beam flanges through welded sections.

When the steel material described above is used as the plate of the column main body to be joined in the beam-column joint structure, the energy absorption performance at the joint part of the column and the beam can be enhanced; the steel material is the material in which an amount of S is 0.011 mass% or less, and $vE_{-20(S)}$, $vE_{-20(L,T)}$, $vE_{0(S)}$, and $vE_{0(L,T)}$ satisfy at least one of a combination of Expressions (1A) and (1B), and a combination of Expressions (2A) and (2B), the $vE_{-20(S)}$ being a Charpy absorbed energy of the plate in a plate thickness direction at -20°C based on JIS Z 2242: 2018 and the $vE_{-20(L,T)}$ being a Charpy absorbed energy of the plate in a rolling direction at -20°C based on JIS Z 2242: 2018, and the $vE_{0(S)}$ being a Charpy absorbed energy of the plate in a plate thickness direction at 0°C based on JIS Z 2242: 2018, and the $vE_{0(L,T)}$ being a Charpy absorbed energy of the plate in a rolling direction at 0°C based on JIS Z 2242: 2018.

$$vE_{-20(S)} \geq 35J \dots (1A)$$

$$vE_{-20(L,T)} \geq vE_{-20(S)} \dots (1B)$$

$$vE_{0(S)} \geq 47J \dots (2A)$$

$$vE_{0(L,T)} \geq vE_{0(S)} \dots (2B)$$

[0049]

[1-5. Configuration of Building]

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 cabinet on the floor slab.

[0050]

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

The amount of S in the slab, which is the base plate of the high-toughness steel material, is required to be reduced to 0.011 mass% or less. For example, a pre-molten iron treatment is performed before refining in a converter using a desulfurizing agent (CaO or the like), and further, reduction refining is performed in a converter or an electric furnace as necessary, and then, continuous casting is performed to produce a slab.

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.

[0051]

[3. Experiment for Examining Energy Absorption Performance of Beam-Column Joint Structure]

The beam-column joint structure 1 was attached to an experimental device 160 shown in FIG. 8 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 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 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.

[0052]

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 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. 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 applies a compressive axial force in the axis direction 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 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 shearing force applied to the column by a force from the beam jacks 162A and 162B to the reaction wall connecting jig 161.

[0053]

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

[0054]

[Table 1]

Column Main Body				Beam (I-beam for beams)			
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

[0055]

As shown in Table 1, the cross-sectional dimensions of the column main body 12 were set to $H-498 \times 432 \times 45 \times 70$. 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/mm^2 , and the tensile strength was set to 546 N/mm^2 .

[0056]

As shown in Table 1, the cross-sectional dimensions of the I-beam for beams 212 were set to $H-650 \times 300 \times 16 \times 25$. 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/mm^2 , and the tensile strength was set to 513 N/mm^2 .

[0057]

The column main body 12 is made of a high-toughness steel shown in FIGS. 6 and 7, and the chemical composition is designed as shown in Table 2. The I-beam for beams 212 is made of a general steel material, JIS G 3136 SN490B.

[0058]

[Table 2]

(mass%)											
	C	Si	Mn	T.Al	P	S	N	Others	Balance	Expression (1)	Expression (2)
Ex. 1	0.16	0.3	1.4	0.032	0.017	0.004	0.004	Cu=0.012 Ni=0.012 Cr=0.022 Mo=0.006 V=0.042 Ti=0.001 Ca=0.003	Fe + impurity	0.41	0.251

[0059]

The experimental device 160 moves the end part of the beam 211BA upward by 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 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. 9, and a load was applied to the sample 2 with loading history 2 shown in FIG. 10.

[0060]

In FIGS. 9 and 10, the horizontal axis represents a 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 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.

[0061]

Here, the experimental results of the joint part in the prior research are shown in FIGS. 11 and 12. In FIGS. 11 and 12 and FIG. 13 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.

FIG. 11 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. 12 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.

FIG. 13 shows the results obtained from the sample 1 (example) of the present test. The horizontal axis range is identical in FIGS. 11 to 13, and the vertical axis range is identical in FIGS. 11 to 13. 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 is a dimensionless quantity that 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. 13 is 0.08 rad, which is significantly larger than the maximum story drifts in FIGS. 11 and 12, and high deformation performance is achieved.

It is reported that similar tests were conducted on a steel material having a composition with S content of 0.019 mass% and a steel material having a composition with S content of 0.025 mass%, and the story drift was 0.03 rad and 0.07 rad, respectively (Shin, 2017). This is because the toughness in the plate thickness direction is low due to the high S content. As described above, it is understood that when the S content is high, high deformation performance cannot be exhibited.

[0062]

[Table 3]

	(mass%)					
	C	Si	Mn	P	S	N
Ex. 2	0.08	0.26	1.35	0.016	0.019	NA
Ex. 3	0.08	0.24	1.36	0.009	0.025	NA

[0063]

In addition, in FIGS. 11 to 13, 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. 13, the story shear force is held in more cycles than in FIGS. 11 and 12, 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. 13 has higher energy absorption performance than the joint parts of FEMA and Shin.

[0064]

FIG. 14 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. 14 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.

[0065]

The upper portion of FIG. 14 shows the story drift (rad) as deformation performance for each joint part.

In FIG. 14, 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 history 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 resistance remains when the story drift reaches 0.04 rad.

[0066]

FIG. 14 shows the test results of the beam-column joint structure 1 of the example.

In the column of the aseismic performance, "×" (bad) means that the aseismic performance is poor, "○" (good) means that the aseismic performance is good, and "◎" (very good) means that the aseismic performance is very good.

[0067]

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 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 direction S.

[0068]

However, as shown in FIG. 15, the generation and propagation of the crack LF occurs on the upper flange 216A side, which shows that the fracture originating from the lower flange 216B is suppressed by using the steel material of the present invention for the column flange 16.

[0069]

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.

[0070]

[5. Effects of the Present Embodiment]

[0071]

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 is 35 J or more. Therefore, 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.
[0072]

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 is 47 J or more. Therefore, 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.

[0073]

[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 may not be provided.

[0074]

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. 16.

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 sections 218. The pair of flat plate parts 33B extend along the longitudinal direction of the beam 211B.

[0075]

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.

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.

[0076]

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. 17. In this case, a flat portion of the square steel tubing functions as a joint plate.

[0077]

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

Further, instead of the I-beam for columns, a cross H-shaped steel composed of an I-beam for columns and a pair of CT-section steels joined to both surfaces of the column web may be used. That is, as in a beam-column joint structure 1C of the third modification shown in FIG. 18, the column main body 52 of the column 51 may be formed of a cross H-shaped steel formed of the I-beam for columns 521 and a pair of CT-section steels 522 joined to both surfaces of the column web. In this case, the pair of flange portions 521A of the I-beam for columns 521 functions as a joint plate. Instead of the H-shaped steel, a cross H-shaped steel formed by welding steel plates may be used. In addition, the same type effect can be expected in the case of a circular steel pipe or a circular or rectangular CFT instead of the I-beams for columns. In the case of a circular steel pipe, the peripheral surface portion functions as a joint plate.

[0078]

[7. Document List]

Shin : Shin, S. 2017, "Experimental and analytical investigation of panel zone behavior in steel moment frames", PhD Thesis, Department of Civil, Architectural and Environmental Engineering, University of Texas at Austin, TX, USA.

Chi & Uang : Chi, B., and C.-M. Uang. 2002, "Cyclic response and design recommendations of reduced beam section moment connections with deep columns", Journal of Structural Engineering, 128 (4): 464-473, American Society of Civil Engineers.

Richles: Richles, 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.

INDUSTRIAL APPLICABILITY

[0079]

According to the present invention, it is possible to provide a steel material used for a joint plate of a column main body to be joined in a beam-column joint structure having a joint part with a high energy absorption property, and a use of the steel material.

REFERENCE SIGNS LIST

[0080]

1, 1A, 1B Beam-column joint structure

11, 31, 41 Column

12, 32, 42 Column main body

16 Column flange (joint plate)

17 Column web

21 Backing bar

33A Flat plate part (joint plate)

211B Beam

212 I-beam for beams

216 Beam flange

216B lower flange

218 Welded section

S Plate thickness direction

CLAIMS

[Claim 1]

A steel material used for a plate of a column main body to be joined that is directly joined to a pair of beam flanges through welded sections, in a beam-column joint structure having a column which has the column main body, and a beam which has an I-beam for beams having the pair of beam flanges, wherein

an amount of S is 0.011 mass% or less, and

$vE_{-20(S)}$, $vE_{-20(L,T)}$, $vE_{0(S)}$, and $vE_{0(L,T)}$ satisfy at least one of a combination of Expressions (1A) and (1B), and a combination of Expressions (2A) and (2B),

the $vE_{-20(S)}$ being a Charpy absorbed energy of the plate in a plate thickness direction at -20°C based on JIS Z 2242: 2018 and the $vE_{-20(L,T)}$ being a Charpy absorbed energy of the plate in a rolling direction at -20°C based on JIS Z 2242: 2018, and

the $vE_{0(S)}$ being a Charpy absorbed energy of the plate in a plate thickness direction at 0°C based on JIS Z 2242: 2018, and the $vE_{0(L,T)}$ being a Charpy absorbed energy of the plate in a rolling direction at 0°C based on JIS Z 2242: 2018,

$$vE_{-20(S)} \geq 35\text{J} \dots (1A)$$

$$vE_{-20(L,T)} \geq vE_{-20(S)} \dots (1B)$$

$$vE_{0(S)} \geq 47\text{J} \dots (2A)$$

$$vE_{0(L,T)} \geq vE_{0(S)} \dots (2B).$$

[Claim 2]

The steel material according to Claim 1, containing at least one of

V: 0.005 to 0.10%, and

Nb: 0.005 to 0.10%.

[Claim 3]

Use of a steel material as a plate of a column main body to be joined that is directly joined to a pair of beam flanges through welded sections, in a beam-column joint structure having a column which has the column main body, and a beam which has an I-beam for beams having the pair of beam flanges, wherein

an amount of S is 0.011 mass% or less, and

$vE_{-20(S)}$, $vE_{-20(L,T)}$, $vE_{0(S)}$, and $vE_{0(L,T)}$ satisfy at least one of a combination of Expressions (1A) and (1B), and a combination of Expressions (2A) and (2B),

the $vE_{-20(S)}$ being a Charpy absorbed energy of the plate in a plate thickness direction at -20°C based on JIS Z 2242: 2018 and the $vE_{-20(L,T)}$ being a Charpy absorbed energy of the plate in a rolling direction at -20°C based on JIS Z 2242: 2018, and

the $vE_{0(S)}$ being a Charpy absorbed energy of the plate in a plate thickness direction at 0°C based on JIS Z 2242: 2018, and the $vE_{0(L,T)}$ being a Charpy absorbed energy of the plate in a rolling direction at 0°C based on JIS Z 2242: 2018,

$$vE_{-20(S)} \geq 35\text{J} \dots (1A)$$

$$vE_{-20(L,T)} \geq vE_{-20(S)} \dots (1B)$$

$$vE_{0(S)} \geq 47\text{J} \dots (2A)$$

$$vE_{0(L,T)} \geq vE_{0(S)} \dots (2B).$$