DESCRIPTION

METHOD OF DESIGNING COLUMN-BEAM JOINT, METHOD OF MANUFACTURING COLUMN-BEAM JOINT, AND COLUMN-BEAM JOINT STRUCTURE

Technical Field

[0001] The present disclosure relates to a method of designing a column-beam joint, a method of manufacturing a column-beam joint, and a column-beam joint structure.

Background Art

[0002] Japanese Patent Application Laid-Open (JP-A) No. 2016-142062 (Patent Literature 1) discloses a column-beam joint structure in which a reinforced concrete column and a steel beam are joined. In the column-beam joint structure described in Patent Literature 1, a recess is formed in the reinforced concrete column, an end of the steel beam is inserted into and disposed in the formed recess, and concrete is filled in the recess.

[0003] In the column-beam joint structure described in Patent Literature 1, a degree of fixation of the steel beam is adjusted by adjusting an embedded length of the end of the steel beam in the concrete filled in the recess. By adjusting the fixation degree, the end of the steel beam is semi-rigidly joined to the reinforced concrete column, and a bending moment acting on a joint between the reinforced concrete column and the steel beam and the steel beam is adjusted. Furthermore, by adjusting the fixation degree, a deflection at a center of the beam is reduced as compared with a case where the end of the steel beam is joined by pin. That is, rotational rigidity of the joint between the reinforced concrete column and the steel beam is adjusted. Hereinafter, the joint between the column and the beam is also referred to as a “column-beam joint” or simply referred to as a “joint”.

SUMMARY OF INVENTION

Technical Problem

[0004] However, Patent Literature 1 does not mention anything about resistance of the column-beam joint. Thus, when the rotational rigidity of the column-beam joint is secured for the purpose of adjusting the deflection and the bending moment of the steel beam, the resistance may be insufficient, and there is a possibility that Patent Literature 1 cannot be performed.

[0005] In Patent Literature 1, even when the embedded length of the end of the steel beam in the concrete approaches zero, the fixation degree does not approach zero. Thus, there is a possibility that the fixation degree is overestimated or underestimated when Patent Literature 1 is carried out beyond a range of a ratio of the embedded length to a beam depth in the experiment

and analysis described in Patent Literature 1. For this reason, there is a concern that the deflection of each beam is underestimated or the moment acting on the joint is underestimated.

[0006] The moment acting on the joint is calculated according to a load supported by the beam, a span of the beam, bending rigidity of the beam, and the rotational rigidity of the joint. However, when the acting moment exceeds moment resistance of the joint, there is a concern that the joint is plasticized, the fixation degree decreases below the calculated value, the deflection of the beam becomes larger than the calculated value, and the column is also damaged. This means that there is a possibility that a case where performance required in design is not satisfied is overlooked when Patent Literature 1 is performed.

[0007] Although the fixation degree also varies depending on a distance between the joints at respective ends of the steel beam, that is, the length of the beam, in Patent Literature 1, an influence of the distance between the joints is not considered.

[0008] In addition, in Patent Literature 1, the fixation degree of the joint is adjusted by adjusting the embedded length, however, in actual design, a diameter of the column is determined by the required performance of the column, and a maximum length where the beam can be embedded is restricted by the diameter of the column. In particular, when a plurality of beams are embedded from two or more directions such that the beam intersects a concrete column, the plurality of beams are arranged such that the beams do not overlap each other.

[0009] It is necessary to secure a filling property of concrete and a predetermined coverage thickness. For this reason, the maximum length where the beam can be embedded in the concrete is significantly restricted. In this case, in order to secure the rotational rigidity and the moment resistance of the joint, a length of a portion of the beam to be embedded needs to be the maximum length that can be employed in construction, and thus, there is a possibility that the embedded length cannot be adjusted.

[0010] From the above, the joint structure of Patent Literature 1 includes a possibility that actual implementation cannot be performed. In addition, Patent Literature 1 includes room for improvement from the viewpoint of accurately evaluating the rotational rigidity of the column-beam joint and imparting a required moment resistance according to the rotational rigidity of the joint.

[0011] In view of the above fact, an object of the present disclosure is to provide a method of designing a column-beam joint, a method of manufacturing a column-beam joint, and a column-beam joint structure capable of satisfying moment resistance while securing rotational rigidity of a joint between a column and a beam.

Solution to Problem

[0012] A method of designing a column-beam joint according to the present disclosure

includes a concrete column, a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state, and a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam, in which rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint is defined as a rotational rigidity S_j, a required moment resistance acting on the column-beam joint from the steel beam is calculated using a load supported by the steel beam and the rotational rigidity S_j, and at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam is adjusted such that the required moment resistance calculated does not exceed a maximum moment resistance that can be resisted by the column-beam joint.

[0013] Another method of designing a column-beam joint according to the present disclosure includes a concrete column, a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state, and a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam, in which rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint is defined as a rotational rigidity S_j, and required moment resistance acting on the column-beam joint from the steel beam is calculated using a load supported by the steel beam and the rotational rigidity S_j, which is determined by the following process A.

<Process A>

A total number of the resistance elements is denoted by n, i is a given natural number from 1 to n, and the resistance elements are denoted as resistance element i, the reaction force of the resistance element i is represented by a product of rigidity k_i of the resistance element i and a deformation amount, a rotation center of the portion of the steel beam inside the concrete of the column is denoted by a point at which the reaction force of the resistance element i and an external force are balanced, a distance between a line of action of a representative displacement of the resistance element i and the rotation center is denoted by $x_{d,i}$, a distance between a center of gravity of the reaction force of the resistance element i and the rotation center is denoted by $x_{l,i}$, and the rotational rigidity S_j is determined based on evaluation of a value obtained by the following Formula 1.

[Expression 1]

$$S_j = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 1}$$

[0014] In a method of manufacturing a column-beam joint according to the present disclosure,

at least one end in a longitudinal direction of a steel beam is embedded inside concrete of a column in a semi-rigid joint state, in a state in which a resistance element designed using the above-mentioned method of designing a column-beam joint is provided.

[0015] A column-beam joint structure according to the present disclosure includes a concrete column, a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state, and a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam. In this column-beam joint structure, when rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint is defined as a rotational rigidity S_j and a moment generated by a maximum resistance that can be resisted by the resistance element is defined as a maximum moment resistance that can be resisted by the column-beam joint, as a required moment resistance acting on the column-beam joint from the steel beam, at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam is adjusted such that the required moment resistance calculated using a load supported by the steel beam and the rotational rigidity S_j does not exceed the maximum moment resistance.

[0016] Another column-beam joint structure according to the present disclosure includes a concrete column, a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state, and a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam. In this column-beam joint structure, when rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint is defined as a rotational rigidity S_j, as a required moment resistance acting on the column-beam joint from the steel beam, the required moment resistance is set using a load supported by the steel beam and the rotational rigidity S_j, which is determined by the following process B.

<Process B>

A total number of the resistance elements is denoted by n, i is a given natural number from 1 to n, and the resistance elements are denoted as resistance element i, the reaction force of the resistance element i is represented by a product of rigidity k_i of the resistance element i and a deformation amount, a rotation center of the portion of the steel beam inside the concrete of the column is denoted by a point at which the reaction force of the resistance element i and an external force are balanced, a distance between a line of action of a representative displacement of the resistance element i and the rotation center is denoted by $x_{d,i}$, a distance between a center of gravity of the reaction force of the resistance element i and the rotation center is denoted by $x_{l,i}$, and the rotational rigidity S_j is determined as a value satisfying the following Formula 3.

[Expression 2]

$$S_j = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 3}$$

Advantageous Effects of Invention

[0017] According to the present disclosure, it is possible to provide a method of designing a column-beam joint, a method of manufacturing a column-beam joint, and a column-beam joint structure capable of satisfying moment resistance while securing rotational rigidity of a joint between a column and a beam.

BRIEF DESCRIPTION OF DRAWINGS

[0018] Fig. 1 is a side view illustrating a model of a joint between a column and a beam.

Fig. 2 is a side view illustrating the model of the joint between the column and the beam, and illustrates a section up to an inflection point in a length direction of a steel beam.

Fig. 3 is a side view illustrating a model for calculating rotational rigidity of the joint between the column and the beam, and illustrates a stress distribution of a reaction force due to bearing pressure resistance at an interface between concrete and upper and lower flanges of the column in a portion embedded in column concrete of the steel beam.

Fig. 4 is a perspective view schematically illustrating the bearing pressure resistance at the interface between the concrete and the upper and lower flanges of the column, and illustrates a state in which the reaction force due to the bearing pressure resistance has a linear stress gradient.

Fig. 5 is a perspective view schematically illustrating the bearing pressure resistance at the interface between the concrete and the upper and lower flanges of the column, and illustrates a state in which the reaction force due to the bearing pressure resistance is uniform stress.

Fig. 6 is a side view illustrating the model for calculating the rotational rigidity of the joint between the column and the beam, and illustrates the reaction force due to the bearing pressure resistance at an interface between a face bearing plate and the concrete of the column, the reaction force due to pull-out resistance of a stud in the column, and the reaction force due to resistance of a reinforcement bar in the slab.

Fig. 7 is a perspective view for explaining conical fracture of the concrete of the column by pulling out the stud in the column when the stud in the column is installed as an additional member in the portion embedded in the column concrete of the steel beam.

Fig. 8A is a side view illustrating a model for calculating resistance of the joint between the column and the beam, and a side view schematically illustrating a situation in which a maximum reaction force due to the bearing pressure resistance in a vertical direction of the interface between the concrete and the upper and lower flanges of the column in the portion embedded in the column concrete of the steel beam acts on the steel beam.

Fig. 8B is a side view illustrating a model for calculating moment resistance moment resistance of the joint between the column and the beam, and a side view for explaining an actual stress distribution and conversion into a stress block when the maximum reaction force due to the bearing pressure resistance acts on the interface between the concrete and the upper and lower flanges of the column in the portion embedded in the column concrete of the steel beam.

Fig. 9A is an explanatory view for explaining an effective bearing pressure area and a maximum bearing pressure distribution area, and illustrates a case where the entire projection surface is in the concrete.

Fig. 9B is an explanatory view for explaining the effective bearing pressure area and the maximum bearing pressure distribution area, and illustrates a case where a portion of the projection surface is outside the concrete.

Fig. 10A is a side view illustrating the model for calculating the moment resistance moment resistance of the joint between the column and the beam, and a side view schematically illustrating a situation in which a maximum reaction force due to horizontal resistance of the portion embedded in the column concrete of the steel beam and an additional member provided at a peripheral edge thereof acts on the steel beam. The additional members are the face bearing plate, the stud in the column, and the reinforcement bar in the slab.

Fig. 10B is a side view illustrating the model for calculating the moment resistance of the joint between the column and the beam, and a side view for explaining a maximum stress distribution of the effective bearing pressure area at the interface between the face bearing plate and the concrete of the column, a maximum reaction force due to the pull-out resistance of the stud in the column, and a maximum reaction force due to the resistance of the reinforcement bar in the slab.

Fig. 11 is an explanatory view for explaining the effective bearing pressure area and the maximum bearing pressure stress distribution area at the interface between the face bearing plate and the concrete of the column.

Fig. 12 is a view for explaining a relationship between a moment and a rotation angle of the joint, and the rotational rigidity and the moment resistance of the joint.

Fig. 13A is a side view illustrating the model for calculating the rotational rigidity of

the joint between the column and the beam, and a side view illustrating the stress distribution of the reaction force due to the bearing pressure resistance at an interface between the portion embedded in the column concrete of the steel beam and the column concrete.

Fig. 13B is a side view illustrating the model for calculating the resistance of the joint between the column and the beam, and a side view illustrating an effective region of the bearing pressure resistance stress obtained when the maximum reaction force due to the bearing pressure resistance at the interface between the concrete and the upper and lower flanges of the column in a portion embedded in the column concrete of a column steel beam acts on the steel beam, the actual stress distribution, and conversion into the stress block.

Fig. 14 is a graph illustrating the relationship between the moment and the rotation angle at a column face position of the joint, and illustrates both an experimental result and a calculation result according to the present disclosure.

Fig. 15 is a graph illustrating comparison between an experimental result of the rotational rigidity of the joint against repeatedly acting a load and a calculation result according to the present disclosure.

Fig. 16 is a view illustrating a calculation result of a fixation degree α_{rig} according to the present disclosure.

Fig. 17 is a view illustrating a ratio between a generated moment $M_{j,Ed}$ of the joint calculated according to the present disclosure and resistance $M_{j,Rd}$ of the joint.

DESCRIPTION OF EMBODIMENTS

[0019] A column-beam joint structure according to an embodiment of the present disclosure will be described with reference to Figs. 1 and 2. In the following description of the drawings, the same or similar components are denoted by the same or similar reference numerals. However, a relation between a thickness and a plane size in the drawings, a ratio of thickness of each device and each member, etc. differ from actual ones. Accordingly, specific thicknesses and dimensions should be determined by taking the following description into consideration. A relationship or a ratio of mutual dimensions may differ among the drawings.

[0020] As illustrated in Figs. 1 and 2, the column-beam joint structure of the present embodiment is applied to a joint 14 between a column 10 and a beam 12. A vertical direction of a building is indicated by an arrow Z direction, and one side in a direction in which the beam 12 extends and one direction in a horizontal direction of the building are indicated by an arrow X direction. The arrow Z direction is a vertical direction in Fig. 1, and the arrow X direction is a horizontal direction in Fig. 1.

[0021] In the following description of the directions X, Y and Z, signs “positive (+)” and

"negative (-)" are reversed between one direction and the other direction extending opposite to each other. For example, in the vertical direction in Fig. 1, when the vertical direction is simply explained as a whole without distinguishing a +Z direction on an upper side and a -Z direction on a lower side, description will be made without adding the signs "positive (+)" and "negative (-)" like the "Z direction".

[0022] The column 10 is formed in a substantially rectangular shape in a cross-sectional view taken along the horizontal direction (plane parallel to XY plane) of the building. The column 10 is realized as a column made of steel reinforced concrete (SRC) by arranging a reinforcement bar 16 (see Fig. 2) and a steel frame 18 inside concrete 32. The present disclosure can also be applied to a joint between a column made of reinforced concrete (RC) and a steel beam.

[0023] In the present embodiment, H-shaped steel is used as the steel frame 18. The H-shaped steel is formed to have an H-shaped cross section in a cross-sectional view taken along the horizontal direction of the building. Furthermore, in the present embodiment, as illustrated in Fig. 2, a plurality of the reinforcement bars 16 extending in the vertical direction of the building are provided as main reinforcements 16A. The reinforcement bar 16 surrounding the plurality of main reinforcements 16A are provided as hoops 16B over a plurality of stages in the vertical direction of the building, above, below and on the side of the beam 12.

[0024] In the present embodiment, the four beams 12 are joined to the column 10 at the same position in the vertical direction of the building. For example, the four beams 12 are arranged around the column 10 at intervals of 90° from each other when viewed from the upper side of the building. Since the four beams 12 have the same configuration, one of the four beams 12 will be exemplarily described in the following description.

[0025] The beam 12 is a composite beam including a steel beam 20 and a slab 22 of reinforced concrete. The steel beam 20 is formed to have an H-shaped cross section in a cross-sectional view taken along the vertical direction. The vertical direction is a direction orthogonal to a longitudinal direction of the beam 12. That is, the steel beam 20 is cut along a plane parallel to a YZ plane. The slab 22 extends horizontally above the steel beam 20 and is integrated with the steel beam 20. The horizontal direction is parallel to the XY plane. The present disclosure can also be applied to a beam (that is, steel beam) that is not integrated with the slab 22.

[0026] As illustrated in Figs. 1 and 2, the steel beam 20 includes a rectangular plate-like upper flange 20A whose thickness direction is the vertical direction (that is, Z direction) of the building, and a lower flange 20B expanding in parallel with the upper flange 20A below the upper flange 20A. The steel beam 20 includes a web 20C. The web 20C connects a central portion in a width direction of the upper flange 20A and a central portion in a width direction of the lower flange 20B to each other in the vertical direction of the building. The width

direction in the upper flange 20A and the lower flange 20B is one direction in the horizontal direction of the building and is the Y direction orthogonal to the X direction. The web 20C is formed in a rectangular plate shape with the Y direction as the thickness direction.

[0027] A beam end 24 which is an end of the steel beam 20 in the longitudinal direction is joined to the steel frame 18 of the column 10 via a fastening member such as a bolt 34 and a fin plate 36. The "beam end 24" means a portion of the steel beam 20 embedded in the concrete 32 of the column 10. In the steel beam 20, the beam end 24 of the steel beam 20 is embedded in the concrete 32 of the column 10. In the present embodiment, the steel beam 20 is joined to the column 10 in a semi-rigid joint state.

[0028] The steel beam 20 includes an upper flange end 20Aa, a lower flange end 20Ba, and a web end 20Ca at the beam end 24. The upper flange end 20Aa refers to a region of the upper flange 20A embedded in the concrete 32 of the column 10. The lower flange end 20Ba refers to a region of the lower flange 20B embedded in the concrete 32 of the column 10. The web end 20Ca refers to a region of the web 20C embedded in the concrete 32 of the column 10.

[0029] The upper flange end 20Aa is in contact with the concrete 32 of the column 10 on each of an outer surface 24A of the upper flange 20A located on the +Z direction side in Fig. 1 and an inner surface 24B of the upper flange 20A located on the -Z direction side in Fig. 1.

[0030] The lower flange end 20Ba is in contact with the concrete 32 of the column 10 on each of an inner surface 24C of the lower flange 20B located on the +Z direction side in Fig. 1 and an outer surface 24D of the lower flange 20B located on the -Z direction side in Fig. 1.

[0031] As illustrated in Fig. 7, the web end 20Ca is in contact with the concrete 32 of the column 10 on each of a web surface on the +Y direction side and a web surface on the -Y direction side.

[0032] The steel beam 20 of the present embodiment includes a plurality of studs 26 fixed to the upper flange 20A constituting the upper portion of the steel beam 20. The plurality of studs 26 protrude from the upper flange 20A toward the upper side of the building, and are arranged at intervals along the longitudinal direction of the steel beam 20. In Fig. 1, only two studs 26A at the beam end 24 are exemplarily illustrated. The stud 26A at the beam end 24 is an additional member that acts as a "resistance element" against rotation when the beam end 24 rotates about a rotation center 24E to be described later.

[0033] In the present embodiment, a joint reinforcement bar 28 is provided along the longitudinal direction of the steel beam 20 and an upper end of the stud 26 so as to penetrate the column 10 in the X direction for a portion included in a diameter of the column 10 on a Y axis. Among the joint reinforcement bar 28 and the stud 26 arranged, a part of the joint reinforcement bar 28 other than a portion located at the beam end 24 and the stud 26B are

embedded inside the slab 22. The stud 26B in the slab 22 connects the steel beam 20 and the slab 22. The joint reinforcement bar 28 is an additional member that acts as a "resistance element" against rotation when the beam end 24 rotates about the rotation center 24E.

[0034] In addition, the steel beam 20 includes a face bearing plate 30 formed in a rectangular plate shape whose thickness direction is the longitudinal direction of the steel beam 20. In the present embodiment, the two face bearing plates 30 are fixed respectively to the +Y direction side and the -Y direction side with the web 20C interposed therebetween at the same position in the longitudinal direction of the steel beam 20.

[0035] A dimension measured along the +Y direction of the face bearing plate 30 is set to a dimension within a range in which the face bearing plate 30 does not protrude from a region surrounded by the upper flange 20A, the lower flange 20B, and the web 20C to the +Y direction side or the -Y direction side. In a state where the steel beam 20 is embedded in the concrete 32 of the column 10, a surface of the face bearing plate 30 on a side opposite to an axial center side of the column 10 in the X direction is substantially flush with the outer surface of the column 10. The axial center side of the column 10 is the right side in Fig. 1, and the side opposite to the axial center side of the column 10 is a surface on an outer side of the column 10.

[0036] On the other hand, an inner surface 30A of the face bearing plate 30 located on the axial center side of the column 10 is in contact with the concrete 32 of the column 10.

[0037] As illustrated in Fig. 1, when a vertical load in the -Z direction acts on the steel beam 20, the steel beam 20 rotates the steel beam 20 counterclockwise by φ_j in Fig. 1 about the rotation center 24E of the beam end 24 in an XZ plane, and the steel beam 20 displaced to a position of a steel beam 20a indicated by a broken line in Fig. 1.

[0038] Here, a first shaft 24F that passes through the rotation center 24E and is parallel to the Z direction and a second shaft 24G that passes through the rotation center 24E and is parallel to the X direction are set. When the beam end 24 rotates about the rotation center 24E, a portion of the inner surface 30A of the face bearing plate 30 in the -Z direction across the second shaft 24G is defined as a first inner surface 30Aa of the face bearing plate.

[0039] When the steel beam 20 rotates toward the position of the steel beam 20a, a reaction force due to bearing pressure acts from the concrete 32 of the column 10, so that the first inner surface 30Aa of the face bearing plate 30 generates rotational resistance against the rotation of the beam end 24. That is, the first inner surface 30Aa of the face bearing plate 30 is an additional member that acts as a "resistance element" against rotation when the beam end 24 disposed inside the concrete 32 of the column 10 in the steel beam 20 rotates about the rotation center 24E.

[0040] When the vertical load in the -Z direction acts on the steel beam 20 and the steel beam

20a rotates about the rotation center 24E, the reaction force due to the bearing pressure acts from the concrete 32 of the column 10. For this reason, rotational resistance against rotation of the beam end 24 is generated on the outer surface 24A and the inner surface 24B of the upper flange 20A at the upper flange end 20Aa. The rotational resistance against the rotation of the beam end 24 is also generated on the inner surface 24C and the outer surface 24D of the lower flange 20B at the lower flange end 20Ba.

[0041] That is, the outer surface 24A of the upper flange end 20Aa serves as a "resistance element", which resists the rotation of the beam end 24, while serving as an upper flange end outer surface resistance element 24Aa. The inner surface 24B of the upper flange end 20Aa serves as a "resistance element", which resists the rotation of the beam end 24, while serving as an upper flange end inner surface resistance element 24Ba.

[0042] The inner surface 24C of the lower flange end 20Ba serves as a "resistance element", which resists the rotation of the beam end 24, while serving as a lower flange end inner surface resistance element 24Ca. The outer surface 24D of the lower flange end 20Ba serves as a "resistance element", which resists the rotation of the beam end 24, while serving as a lower flange end outer surface resistance element 24Da.

[0043] More specifically, a portion of the outer surface 24A of the upper flange end 20Aa on the +X direction side with respect to the first shaft 24F is set as the upper flange end outer surface resistance element 24Aa. A portion of the inner surface 24B of the upper flange end 20Aa on the -X direction side with respect to the first shaft 24F is set as the upper flange end inner surface resistance element 24Ba.

[0044] A portion of the inner surface 24C of the lower flange end 20Ba on the +X direction side with respect to the first shaft 24F is set as the lower flange end inner surface resistance element 24Ca. A portion of the outer surface 24D of the lower flange end 20Ba on the -X direction side with respect to the first shaft 24F is set as the lower flange end outer surface resistance element 24Da.

[0045] The upper flange end outer surface resistance element 24Aa, the upper flange end inner surface resistance element 24Ba, the lower flange end inner surface resistance element 24Ca, and the lower flange end outer surface resistance element 24Da are four "resistance elements" that generate the reaction force against rotation when the beam end 24 disposed inside the concrete 32 of the column 10 in the steel beam 20 rotates about the rotation center 24E.

[0046] In addition, in the present embodiment, when the steel beam 20 rotates to the position of the steel beam 20a, the stud 26A, which is one of the additional members, is displaced in the -X direction on the left side in Fig. 1, and receives the reaction force from the concrete 32 of the column 10 according to the displacement amount. That is, the stud 26A is a "resistance

element" that generates the reaction force against rotation when the beam end 24 disposed inside the concrete 32 of the column 10 in the steel beam 20 rotates about the rotation center 24E.

[0047] In the present embodiment, when the steel beam 20 rotates to the position of the steel beam 20a, the first inner surface 30Aa of the face bearing plate 30, which is one of the additional members, is displaced to the +X direction side that is the right side in Fig. 1. The displaced first inner surface 30Aa receives the reaction force from the concrete 32 of the column 10 and the facing joint 14 on the +X direction side across the column 10 according to the displacement amount. That is, the first inner surface 30Aa of the face bearing plate 30 is a "resistance element" that generates the reaction force against rotation when the beam end 24 disposed inside the concrete 32 of the column 10 in the steel beam 20 rotates about the rotation center 24E.

[0048] In addition, in the present embodiment, when the steel beam 20 rotates to the position of the steel beam 20a, the joint reinforcement bar 28, which is one of the additional members, is stretched and displaced in the -X direction on the left side in Fig. 1. The displaced joint reinforcement bar 28 receives the reaction force (in other words, tensile force) from the concrete 32 of the column 10 and the joint reinforcement bar 28 of the joint 14 on the opposite side existing in the +X direction according to the displacement amount. That is, the joint reinforcement bar 28 is a "resistance element" that generates the reaction force against rotation when the beam end 24 disposed inside the concrete 32 of the column 10 in the steel beam 20 rotates about the rotation center 24E.

[0049] As described above, in the present embodiment, the seven "resistance elements" including the upper flange end outer surface resistance element 24Aa, the upper flange end inner surface resistance element 24Ba, the lower flange end inner surface resistance element 24Ca, the lower flange end outer surface resistance element 24Da, the stud 26A, the first inner surface 30Aa of the face bearing plate 30, and the joint reinforcement bar 28 are set. Thus, in the present embodiment, a total number "n" of the resistance elements is n = 7.

[0050] Here, "i" is defined as a natural number of from 1 to n. In the present embodiment, a resistance element 1 (i = 1) is the upper flange end outer surface resistance element 24Aa. A resistance element 2 (i = 2) is the upper flange end inner surface resistance element 24Ba. A resistance element 3 (i = 3) is the lower flange end inner surface resistance element 24Ca. A resistance element 4 (i = 4) is the lower flange end outer surface resistance element 24Da. A resistance element 5 (i = 5) is the stud 26A. A resistance element 6 (i = 6) is the first inner surface 30Aa of the face bearing plate. A resistance element 7 (i = 7) is the joint reinforcement bar 28. These resistance elements are collectively referred to as "resistance element i".

[0051] In the present embodiment, the reaction force of the resistance element i is defined as

a product of rigidity k_i of the resistance element i and a deformation amount. An elastic rotation center 24Ea of the beam end 24 disposed inside the concrete 32 of the column 10 can be obtained as a point at which a sum, obtained by accumulating the reaction force of the resistance element i for i = 1 to 7 in consideration of its direction of action, and a shearing force (that is, external force) acting on the joint by the vertical load in the -Z direction supported by the steel beam 20 are balanced.

[0052] When an axial force in the X direction as the external force acts on the beam, the elastic rotation center 24Ea can be obtained such that the axial force and a sum of X-direction components of the reaction force of the resistance element i satisfy a balance of forces. The "elastic rotation center 24Ea" means the rotation center 24E in a state where a balance between the reaction force of the resistance element i and the external force is established.

[0053] In the present embodiment, the elastic rotation center 24Ea is set as a point at which the following two types of balance are simultaneously realized.

[0054] Specifically, first, at the elastic rotation center 24Ea, with respect to the upper flange end outer surface resistance element 24Aa, the upper flange end inner surface resistance element 24Ba, the lower flange end inner surface resistance element 24Ca, and the lower flange end outer surface resistance element 24Da, a sum of the reaction force in the Z direction due to the bearing pressure acting from the concrete 32 of the column 10 is balanced with the shearing force acting on the joint due to the vertical load in the -Z direction acting on the steel beam 20. The vertical load is an external force.

[0055] At the same time, at the elastic rotation center 24Ea, a sum of the reaction force in the X direction due to the bearing pressure acting from the concrete 32 of the column 10 with respect to the stud 26A and the reaction force of the joint reinforcement bar 28 is balanced with the reaction force in the X direction due to the bearing pressure acting from the concrete 32 of the column 10 with respect to the first inner surface 30Aa of the face bearing plate 30.

[0056] A distance between a point of action of a representative displacement of the resistance element i and the elastic rotation center 24Ea is set to "$x_{d,i}$". Although the distance $x_{d,i}$ is not illustrated in Figs. 1 to 17, a specific setting will be described in detail in Fig. 6 and Formula 2.31 that will appear later.

[0057] The "representative displacement" will be described later. As the "point of action of the representative displacement", although not illustrated, it is possible to adopt central points in the X direction of each of the upper flange end outer surface resistance element 24Aa, the upper flange end inner surface resistance element 24Ba, the lower flange end inner surface resistance element 24Ca, and the lower flange end outer surface resistance element 24Da.

[0058] For example, when the entire length of the upper flange end outer surface resistance

element 24Aa illustrated in Fig. 1 in the X direction is 200 mm, a central point 100 mm away from respective ends in the X direction can be adopted as the "point of action of the representative displacement" of the upper flange end outer surface resistance element 24Aa.

[0059] A distance between a center of gravity of the reaction force of the resistance element i and the elastic rotation center 24Ea is set to "$x_{l,i}$". In the present embodiment, the rotational rigidity of the joint 14 is calculated by the following Formula 1.

[Expression 3]

$$S_j = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 1}$$

[0060] Here, the "center of gravity of the reaction force" in the setting of the distance $x_{l,i}$ refers to a line of action of a virtual concentrated load p that gives a moment equivalent to a moment acting on the rotation center by a distributed load w acting on a region s having a certain constant length or a constant area. However, for the virtual concentrated load p, a distance from the rotation center to the line of action is set assuming that the value is the same as the value obtained by integrating the distributed load w by the region s. For example, in the joint reinforcement bar 28 as the resistance element i, an intersection line with a plane at a position shifted by dr in the -Z direction from an upper surface of the slab 22 in a plane parallel to the XY plane in the XZ plane illustrated in Fig. 1 can be set as the center of gravity of the reaction force. Formula 1 allows characteristics of each resistance element and the rotational rigidity of the joint to be uniquely associated with each other for joints having a plurality of resistance elements and any details. The distance $x_{l,i}$ will be specifically described later with reference to Fig. 1 and Formula 1.21.

[0061] According to the above procedure, the rotational rigidity S_j of the joint can be obtained from the characteristics of each resistance element of the joint. A bending moment acting on the joint is uniquely determined from the obtained rotational rigidity of the joint, bending rigidity of the beam, span of the beam, and a load supported by the beam. The bending moment acting on the joint is defined as required moment resistance $M_{j,Ed}$ of the joint. In order to prevent the joint from being damaged, it is necessary to prevent the required moment resistance $M_{j,Ed}$ from exceeding a maximum moment resistance $M_{j,Rd}$ possessed by the joint to be described later. Here, the rotational rigidity S_j of the joint can be adjusted by adjusting a cross-sectional shape of the beam and each resistance element of the joint, and the required moment resistance $M_{j,Ed}$ of the joint can be adjusted by adjusting the rotational rigidity S_j of the joint and the span of the beam.

[0062] In addition, in the present embodiment, the reaction force of the resistance element i is regarded as a maximum reaction force $F_{i,Rd}$ that can be borne by the resistance element i. The moment resistance of the joint 14 is expressed as "$M_{j,Rd}$". An arbitrary rotation center 24E is assumed, and a distance between the assumed rotation center 24E and the point of action of the reaction force is set to "$x_{u,i}$". "$M_{j,Rd}$" is calculated using the following Formula 2 such that the X coordinate and the Y coordinate which are the positions of the rotation center 24E are two variables.

[0063] The moment resistance of the joint 14 is established to be the same as a minimum value of the maximum moment resistance $M_{j,Rd}$ calculated by the following Formula 2. In the calculation of Formula 2, the X coordinate and the Y coordinate of the rotation center 24E are used as two variables, so that one or more values of the resistance $M_{j,Rd}$ are calculated. Finally, the minimum value is selected from the calculated values of the maximum moment resistance $M_{j,Rd}$. Thus, in the calculation, the rotation center 24E can be arbitrarily assumed as described above.

[Expression 4]

$$M_{j,Rd} = \sum_{i} F_{i,Rd} \cdot x_{u,i} \qquad \text{Formula 2}$$

[0064] Formula 2 allows maximum resistance of each resistance element and the maximum moment resistance of the joint to be uniquely associated with each other for joints having a plurality of resistance elements and any details.

[0065] The rotation center 24E at a position where the value of the maximum moment resistance $M_{j,Rd}$ is minimized in Formula 2 is defined as a "final rotation center 24Eb". That is, in the process of calculation of Formula 2, the rotation center 24E shifts from the state of the "elastic rotation center 24Ea" to the state of the "final rotation center 24Eb". At the "final rotation center 24Eb", the balance between the reaction force of the resistance element i and the external force is not necessarily established.

[0066] As in the joint 14 between the column 10 and the beam 12 described above, when the steel beam 20 is joined to the column 10 in the semi-rigid joint state, and the additional member including the resistance element, a cross-sectional dimension of the beam 12, and a length of the beam 12 are suitably set, suitable rotational rigidity and resistance can be imparted to the beam end 24. Next, a method of designing a column-beam joint will be described. The column-beam joint is the joint 14 between the column 10 and the beam 12.

[0067] (Method of evaluating rotational rigidity of joint 14)

First, a method of quantitatively evaluating the rotational rigidity of the joint 14 will be described. A dimension of each portion of the steel beam 20, the additional member, and the like can be designed based on the evaluation of the rotational rigidity of the joint 14. The rotational rigidity of the joint 14 can be determined to a desired value by forming the joint 14 using the dimension of each portion of the steel beam 20, the additional member, and the like, which are designed.

[0068] Here, when the rotational rigidity S_j (Nmm/rad) of the joint 14 is defined as the rotational resistance (Nmm) per unit rotation angle (rad) of the beam end 24 in the joint 14, the rotational rigidity S_j is expressed by the following Formula 1.1. In Formula 1.1, "M_j" is the rotational resistance (Nmm) of the beam end 24. "φ_j" in Formula 1.1 is the rotation angle (rad) of the beam end 24.

[Expression 5]

$$S_j = \frac{M_j}{\phi_j} \qquad \text{Formula 1.1}$$

[0069] As illustrated in Fig. 1, assuming that a deformation state of the joint 14 includes rigid rotation of the beam end 24 of the steel beam 20 and deformation of each resistance element that constrains (that is, resists) the rotation of the steel beam 20, a deformation amount δ_i (mm) of the resistance element i is expressed by the following Formula 1.2.

[Expression 6]

$$\delta_i = x_{d,i} \cdot \phi_j \qquad \text{Formula 1.2}$$

[0070] "$x_{d,i}$" in Formula 1.2 is a distance (mm) from the line of action of the representative displacement of the resistance element i to the elastic rotation center of the beam end 24, that is, a distance between the line of action of the representative displacement of the resistance element i and the elastic rotation center of a portion of the steel beam disposed inside the concrete of the column. Here, the representative displacement represents the displacement at the point of action of the reaction force when the reaction force of the resistance element acts on one point. In a case where the reaction force of the resistance element is distributed and acts as stress in a linear shape or a planar shape, the representative displacement represents a virtual displacement at the center of action of a uniform stress distribution when the uniform stress distribution equivalent to a value obtained by line integral or surface integral of each distributed reaction force is assumed.

[0071] Reaction force F_i of the resistance element i can be calculated by the product of the deformation amount δ_i and the rigidity k_i (N/mm) of the resistance element i, and is expressed by the following Formula 1.3.

[Expression 7]

$$F_i = k_i \cdot \delta_i \qquad \text{Formula 1.3}$$

[0072] A sum of products of the reaction force F_i in all the resistance elements and the distance $x_{l,i}$ (mm) from the center of gravity of the reaction force of the resistance element i to be described later to the elastic rotation center of the beam end 24 is obtained as rotational resistance M_j (Nmm) of the joint and is expressed by the following Formula 1.4. The distance $x_{l,i}$ is a distance between the center of gravity of the reaction force of the resistance element i and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column.

[Expression 8]

$$M_j = \sum_i (F_i \cdot x_{l,i}) \qquad \text{Formula 1.4}$$

[0073] The following Formula 1.5 is obtained by substituting Formulas 1.2 and 1.3 into Formula 1.4.

[Expression 9]

$$M_j = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i})\phi_j \qquad \text{Formula 1.5}$$

[0074] The following Formula 1.6 (that is, Formula 1) holds from a relationship between Formula 1.5 and Formula 1.1.

[Expression 10]

$$S_j = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 1.6}$$

[0075] In order to obtain the rotational rigidity of the joint 14 by the above method, it is necessary to specify a position of the elastic rotation center of the rigid rotation of the beam end 24 of the steel beam 20 in the model. Since an object is an elastic behavior, it is assumed that, for an arbitrary rotation angle, each resistance element of the joint 14 undergoes reversible

deformation having a linear load-deformation relationship. Then, the elastic rotation center can be obtained from a balance condition between a sum of internal force F_i of the joint 14 and the external force. As the external force, at least one of beam axial force N (N) or beam shearing force V (N) can be applied.

[0076] The resistance element in the joint 14 is an element that generates the reaction force against the rotation of the beam end 24 of the steel beam 20. Specifically, as described above, as the resistance element, the tensile resistance of the joint reinforcement bar 28 disposed in the slab 22 or the concrete 32 of the column 10, pull-out resistance of the stud 26 in the joint 14 (in the column), bearing pressure resistance stress between the upper and lower surfaces of the upper flange 20A and the lower flange 20B of the steel beam 20 and the concrete 32 of the column 10, and the bearing pressure resistance stress between the face bearing plate 30 and the concrete 32 of the column 10 can be set.

[0077] In addition, sliding resistance due to friction of a bolt joint connecting the web 20C of the steel beam 20 and the fin plate 36 of the column 10, shearing deformation resistance of the bolt 34 due to bearing pressure, local deformation resistance of a bolt hole through which the bolt 34 is inserted, shearing resistance of the fin plate 36, and the like can also be set. In the present embodiment, an elastic load deformation relationship (elastic rigidity) is assumed for each resistance element.

[0078] In the present embodiment, among the above, the tensile resistance of each of the joint reinforcement bars 28 arranged in the slab 22 and the concrete 32 of the column 10, the pull-out resistance of the stud 26 in the joint 14 (in the column), the bearing pressure resistance between the upper and lower surfaces of the upper flange 20A of the steel beam 20 and the concrete 32 of the column 10, the bearing pressure resistance between the upper and lower surfaces of the lower flange 20B and the concrete 32 of the column 10, and the bearing pressure resistance between the face bearing plate 30 and the concrete 32 of the column 10 are set as main resistance elements. Hereinafter, the elastic rigidity of each resistance element will be described.

[0079] (Elastic rigidity of joint reinforcement bar 28)

The elastic rigidity with respect to the tensile resistance of the joint reinforcement bar 28 disposed in the slab 22 or the concrete 32, that is, the elastic rigidity k_r (N/mm) of the joint reinforcement bar 28 can be expressed by the following Formula 1.7 using the elongation u_r (mm), tensile force T_r (N), and k_{slip}, which will be described later, of the joint reinforcement bar 28. In Fig. 1, the elongation u_r of the joint reinforcement bar 28 is illustrated.

[Expression 11]

$$k_r = \frac{T_r}{u_r} \cdot k_{slip}$$ Formula 1.7

[0080] When a total cross-sectional area of the joint reinforcement bar 28 within an effective width of the slab 22 is set to a_r (mm^2), a Young's modulus of the joint reinforcement bar 28 is set to E_r, a stress degree of the reinforcement bar corresponding to the elongation u_r is set to σ_r (N/mm^2), and strain is set to ε_r, the following Formulas 1.8 and 1.9 are further satisfied.

[Expression 12]

$$T_r = a_r \cdot \sigma_r$$ Formula 1.8

[Expression 13]

$$\sigma_r = E_r \cdot \varepsilon_r$$ Formula 1.9

[0081] Here, within the effective width of the joint reinforcement bar 28, the strain ε_r and the elongation u_r are assumed to be constant regardless of the position in the width direction. Thus, an effective length h_r of the joint reinforcement bar 28 is similarly defined to be constant regardless of the position in the width direction of the slab 22. By this definition, the elongation u_r and the strain ε_r are related by the following Formula 1.10.

[Expression 14]

$$\varepsilon_r = \frac{u_r}{\alpha \cdot h_r}$$ Formula 1.10

[0082] In Formula 1.10, it is assumed that the strain of the joint reinforcement bar 28 is uniform in a range of the effective length h_r around a core of the column 10. "α" in Formula 1.10 is a correction coefficient of a joint length according to the moments on both sides.

[0083] The value of the correction coefficient α is set based on "Appendix A.2" of the known document 1 "EN1994-1-1: 2004 Eurocode 4: Design of composite steel and concrete structures Part 1-1: General rules and rules for buildings". For example, when symmetrical negative bending moments ($M_{j,Ed1} = M_{j,Ed2}$) act on both sides, the value of the correction coefficient α is 0.5. When the moment on one side is 0 ($M_{j,Ed1} > M_{j,Ed2} = 0$), the value of the correction coefficient α is 3.6. 0.5 is adopted as a lower limit value of the correction coefficient α, and 3.6 is adopted as an upper limit value of the correction coefficient α. Then, calculation is performed

by the following Formulas 1.11 to 1.15 according to a ratio of the moments on both sides ($M_{j,Ed1} > M_{j,Ed2}$).

[0084] (i) Correction coefficient α for $M_{j,Ed1}$

[Expression 15]

$$\alpha = \frac{1+\beta}{2} + K_{\beta} \qquad \text{Formula 1.11}$$

[Expression 16]

$$K_{\beta} = \beta(4.3\beta^2 - 8.9\beta + 7.2) \qquad \text{Formula 1.12}$$

[Expression 17]

$$\beta = \left|1 - M_{j,Ed2} / M_{j,Ed1}\right| \leq 2 \qquad \text{Formula 1.13}$$

[0085] (ii) Correction coefficient α for $M_{j,Ed2}$

[Expression 18]

$$\alpha = \frac{1-\beta}{2} \qquad \text{Formula 1.14}$$

[Expression 19]

$$\beta = \left|1 - M_{j,Ed1} / M_{j,Ed2}\right| \leq 2 \qquad \text{Formula 1.15}$$

Here, in the moment, a negative bending direction (that is, direction in which the beam has an upward convex) is positive.

[0086] As illustrated in Fig. 2, in a history of the strain of the joint reinforcement bar 28, among the studs 26 connecting the steel beams 20 on both sides sandwiching the joint 14 and the slab 22, a distance between the studs 26 closest to the column 10 is set to be equal to the effective length h_r. Since substantially symmetrical negative bending moments act on the both sides sandwiching the joint 14, the correction coefficient α is set to 0.5. As a result, it has been confirmed that a strain $\varepsilon_{r,calc}$ of the joint reinforcement bar 28 calculated under Navier Hypothesis and the strain in an experiment in a range in which a relationship between the moment and the rotation angle the joint 14 exhibits elastic behavior substantially coincide with

each other. Based on this result, the effective length h_r can be set as the distance between the studs 26 closest to the column among the studs 26 connecting the steel beam 20 and the slab 22.

[0087] From the above, the elastic rigidity k_r can be calculated by the following Formula 1.16 by substituting Formulas 1.8 to 1.10 into Formula 1.7.

[Expression 20]

$$k_r = \frac{E_r \cdot \alpha_r}{\alpha \cdot h_r} \cdot k_{slip} \qquad \text{Formula 1.16}$$

[0088] "k_{slip}" in Formula 1.16 is a reduction coefficient ($0 \leq k_{slip} \leq 1$) of the rigidity of the joint reinforcement bar 28 in consideration of the deformation of the stud 26, and the larger a relative deviation between the slab 22 and the steel beam 20 due to the deformation of the stud 26, the smaller the value. The reduction coefficient k_{slip} can be calculated by the following Formulas 1.17 to 1.20 based on "Appendix A.2" of the known document 1 "EN1994-1-1: 2004 Eurocode 4: Design of composite steel and concrete structures Part 1-1: General rules and rules for buildings".

[Expression 21]

$$k_{slip} = \frac{1}{1 + \dfrac{E_r \cdot a_r}{\alpha \cdot h_r \cdot K_{sc}}} \qquad \text{Formula 1.17}$$

[Expression 22]

$$k_{sc} = \frac{N \cdot k_{sc}}{\nu - \left(\dfrac{\nu - 1}{1 + \xi} \right) \dfrac{h_s}{d_s}} \qquad \text{Formula 1.18}$$

[Expression 23]

$$\nu = \sqrt{\frac{(1 + \xi) N \cdot k_{sc} \cdot l_h \cdot d_s^{\,2}}{E_a I_a}} \qquad \text{Formula 1.19}$$

[Expression 24]

$$\xi = \frac{E_a I_a}{d_s^{\,2} \cdot E_r \cdot a_r} \qquad \text{Formula 1.20}$$

[0089] Here, in Formulas 1.17 to 1.20, "l_h" is a length of a section (negative bending section) from the joint 14 to an inflection point in the length direction of the steel beam 20. "N" is the number of studs 26 (shear connectors) included in the concrete 32a of the slab 22 in l_h. "k_{sc}" is the shearing rigidity (N/mm) per stud 26.

[0090] "h_s" is a distance (mm) from the center of action of compressive force (compression force due to the bearing pressure between the face bearing plate 30 and the concrete 32 of the column 10 to be described later) balanced with the tensile force of the reinforcement bar to the joint reinforcement bar 28. "d_s" is a distance (mm) from the joint reinforcement bar 28 to the center of gravity of a cross section of the steel beam 20. "I_a" is a cross-sectional secondary moment (mm^4) of the steel beam 20. "E_a" is the Young's modulus (N/mm^2) of the steel beam 20.

[0091] The distance $x_{d,i}$ used to calculate the displacement of the joint reinforcement bar 28, that is, the distance between the line of action of the representative displacement of the resistance element i and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is expressed by the following Formula 1.21. An arm length used to calculate the moment resistance due to the reaction force, that is, the distance $x_{l,i}$ between the center of gravity of the reaction force of the resistance element i and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is similarly expressed by the following Formula 1.21.

[Expression 25]

$$x_{d,i} = x_{l,i} = x_r = x_n - d_r \qquad \text{Formula 1.21}$$

[0092] Here, as illustrated in Fig. 1, "x_n" in Formula 1.21 is a component (mm) parallel to a vertical axis (Z axis) in a distance between the elastic rotation center of the joint 14 and the surface of the slab 22 (that is, the upper surface of the slab 22 in Fig. 1). "d_r" in Formula 1.21 is a component (mm) parallel to the vertical axis (Z axis) in a distance from the center (in the case of a multilayer reinforcing member, the centers of gravity thereof) of a cross section of the joint reinforcement bar 28 to the surface of the slab 22. As can be seen from Formula 1.21, in the present embodiment, the distance $x_{d,i}$ and the distance $x_{l,i}$ are equal.

[0093] (Elastic rigidity against shearing of stud in column)

The elastic rigidity with respect to the pull-out resistance of the stud 26 in the joint 14 (in the column), that is, the elastic rigidity k_{st} (N/mm) against shearing of the stud in the column can be obtained based on the pull-out resistance T_{st} (N) of the stud 26 and a deviation u_{st} (mm) of the stud 26. The pull-out resistance T_{st} of the stud 26 is expressed by the following Formula 1.22, and the deviation u_{st} of the stud 26 is expressed by the following Formula 1.23.

[Expression 26]

$$T_{st} = \phi_{st} \cdot 9.8 \cdot 10^3 \cdot n_{st} \cdot u_{st} \qquad \text{Formula 1.22}$$

[Expression 27]

$$u_{st} = \left(x_n - D_s\right)\phi_j \qquad \text{Formula 1.23}$$

[0094] Here, "T_{st}" in Formula 1.22 represents the pull-out resistance (N) of the stud 26 (see Fig. 1). "φ_{st}" in Formula 1.22 represents the diameter of the stud 26 (a diameter (mm) of a shaft portion in the case of a headed stud) (see Fig. 1). "n_{st}" in Formula 1.22 represents the number of studs 26 (see Fig. 1). "u_{st}" in Formula 1.22 represents the displacement (mm) of the stud 26 (see Fig. 1). "D_s" in Formula 1.23 represents a total thickness (mm) of the slab 22 including a deck (see Fig. 1).

[0095] Formula 1.22 relating to the shearing rigidity of the stud 26 is an experimental formula shown by Inoue et al., in the known document 2 "Kazuo Inoue: The Present Technical Level and the Reviews of Headed Stud, Concrete Technology, Vol. 34, No. 4, 1996.4". The shearing rigidity of the stud 26 is proportional to the diameter of the stud 26. "9.8" of the coefficient in Formula 1.22 has a dimension of "N/mm^2".

[0096] As the shearing rigidity k_{sc} used in Formulas 1.18 and 1.19, a value (100 kN/mm with respect to φ 19 stud) described in "Appendix A.3" of the known document 1 "EN1994-1-1: 2004 Eurocode 4: Design of composite steel and concrete structures Part 1-1: General rules and rules for buildings" may be used.

[0097] From Formula 1.22, the elastic rigidity k_{st} (N/mm) due to shearing of the stud 26 in the column 10 is expressed by the following Formula 1.24.

[Expression 28]

$$k_{st} = \frac{T_{st}}{u_{st}} = \phi_{st} \cdot 9.8 \cdot 10^3 \cdot n_{st} \qquad \text{Formula 1.24}$$

[0098] A value used to calculate the displacement of the stud 26 in the column 10, that is, the distance $x_{d,i}$ between the line of action of the representative displacement of the resistance element and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is expressed by the following Formula 1.25. The arm length used to calculate the moment resistance due to the reaction force of the stud 26 in the column 10, that is, the distance $x_{l,i}$ between the center of gravity of the reaction force of the resistance element and the elastic rotation center of the steel beam disposed inside the concrete of the column is similarly expressed by the following Formula 1.25.

[Expression 29]

$$x_{d,i} = x_{l,i} = x_{st} = x_n - D_s \qquad \text{Formula 1.25}$$

[0099] (Elastic rigidity due to beam flange surface and bearing pressure of concrete)

Next, the elastic rigidity with respect to the bearing pressure between the upper and lower surfaces of the upper flange 20A of the steel beam 20 and the concrete 32 of the column 10 and the elastic rigidity with respect to the bearing pressure between the upper and lower surfaces of the lower flange 20B and the concrete 32 of the column 10 will be described. That is, the elastic rigidity due to a beam flange surface and the bearing pressure of the concrete will be described.

[0100] First, the reaction force of a bearing pressure surface and displacement of the bearing pressure surface in a compression direction when a steel plate and the concrete are under uniform bearing pressure stress are formulated.

[0101] In the known document 3 "EN1993-1-8: 2005 Eurocode 3: Design of steel structures Part 1-8: Design of joints, BSI, 2010", the elastic rigidity k_c (N/mm) due to the bearing pressure between a surface of the steel plate and the concrete when the steel sheet and the concrete are under uniform bearing pressure stress is given by the following Formula 2.1.

[Expression 30]

$$k_c = \frac{E_c \sqrt{b_{eff}\, l_{eff}}}{\alpha_c \sqrt{b_{eff} / l_{eff}}} = \frac{E_c \cdot l_{eff}}{\alpha_c} \qquad \text{Formula 2.1}$$

[0102] Here, "b_{eff}" in Formula 2.1 is a width (mm) of an effective bearing pressure region. "l_{eff}" in Formula 2.1 is a distance (length (mm) of the effective bearing pressure region) from the elastic rotation center to an edge end of the effective bearing pressure region. "$b_{eff} \times l_{eff}$" in Formula 2.1 represents an effective bearing pressure area (mm^2) of the concrete 32 (see Fig. 5).

"E_c" in Formula 2.1 is the Young's modulus (N/mm^2) of the concrete.

[0103] "α_c" in Formula 2.1 is, for example, a value depending on a Poisson's ratio in the known document 4 "Lambe T.W., Whitman R.V.: Soil Mechanics, MIT, John Wiley & Sons, Inc., New York, 1969". Further, "α_c" is disclosed as a value of the following Formula 2.2 in, for example, the known document 5 "Martin Steenhuis et al.: Concrete in compression and base plate in bending, HERON Vol. 53, No. 1/2, 2008". Furthermore, as "α_c", for example, a value calculated by the following Formula 2.3 can be adopted in consideration of a rigidity reduction rate 1.5 due to a filling property of mortar between a steel material and the concrete.

[Expression 31]

$$0.85\sqrt{l_{eff}/b_{eff}} \qquad \text{Formula 2.2}$$

[Expression 32]

$$0.85\sqrt{l_{eff}/b_{eff}} \times 1.5 = 1.275\sqrt{l_{eff}/b_{eff}} \qquad \text{Formula 2.3}$$

[0104] When Formula 2.3 is transformed into a general hook equation: P=kδ, the following Formula 2.4 holds.

[Expression 33]

$$P_{c1} = k_c \cdot \delta_c = E_c \frac{\delta_c}{\alpha_c \cdot b_{eff}} \cdot b_{eff} \cdot l_{eff} \qquad \text{Formula 2.4}$$

[0105] Here, "P_{cl}" in Formula 2.4 is a sum of the reaction force due to the bearing pressure (value (N) obtained by integrating the reaction force in the effective bearing pressure region with the effective bearing pressure area). "δ_c" in Formula 2.4 is displacement (mm) of a bearing pressure interface in the compression direction. When uniform average bearing pressure stress of the effective bearing pressure area is set to σ_c (N/mm^2), Formula 2.4 can be further transformed into the form of the following Formula 2.5.

[Expression 34]

$$\sigma_c = \frac{P_{c1}}{b_{eff} l_{eff}} = E_c \cdot \frac{\delta_c}{\alpha_c \cdot b_{eff}} \qquad \text{Formula 2.5}$$

[0106] In a half space of the concrete 32 receiving the bearing pressure, an actual strain of the concrete 32 with respect to the displacement δ_c is 0 at infinity from the bearing pressure surface

of the concrete 32. On the other hand, it is assumed that a constant strain acts in a range of an effective depth $D_{c,eff}$ (mm) equivalent thereto. Then, a strain $\varepsilon_{c,eff}$ and the displacement δ_c of the concrete 32 are associated with each other by the following Formula 2.6.

[Expression 35]

$$\varepsilon_{c,eff} = \frac{\delta_c}{D_{c,eff}} \qquad \text{Formula 2.6}$$

[0107] Then, from Formulas 2.5 and 2.6, the effective depth $D_{c,eff}$ can be defined by the following Formula 2.7 that does not depend on a magnitude of strain.

[Expression 36]

$$D_{c,eff} = \alpha_c \cdot b_{eff} \qquad \text{Formula 2.7}$$

[0108] As for the bearing pressure between the steel beam 20 (beam end 24) embedded in the concrete 32 of the column 10 in the joint 14 and the concrete 32, sinking (displacement of the bearing pressure interface) due to the bearing pressure becomes larger as a distance from the elastic rotation center of the beam end 24 is longer. For this reason, it is not possible to directly use the formula of the aforementioned known document 3 "EN1993-1-8: 2005 Eurocode 3: Design of steel structures Part 1-8: Design of joints, BSI, 2010". In this case, a method of calculating the rigidity using formula 2.1 is derived for a case where the bearing pressure surface has a linear stress gradient as illustrated in Figs. 3 and 4.

[0109] When the bearing pressure interface has a displacement distribution shown in Figs. 3 and 4, a sum P_{c2} (N) of the reaction force received by the bearing pressure surface can be calculated by the following Formula 2.8. In Fig. 3, "$P_{c2,t}$" is the sum of the reaction force on the upper flange side, and can be calculated by replacing "P_{c2}" in the following Formula 2.8 with "$P_{c2,t}$". In addition, "$P_{c2,b}$" in Fig. 3 is the sum of the reaction force on the lower flange side, and can be similarly calculated by replacing "P_{c2}" in the following Formula 2.8 with "$P_{c2,b}$".

[Expression 37]

$$P_{c2} = \int_0^{l_{eff}} \sigma_c(y) \cdot b_{eff} \cdot dy \qquad \text{Formula 2.8}$$

[0110] "$\sigma_c(y)$" in Formula 2.8 is a reaction force distribution (N/mm^2) per unit area of the concrete on the bearing pressure surface.

[0111] It is assumed that the following Formulas 2.9 to 2.11 are satisfied from Fig. 4.

[Expression 38]

$$\sigma_c(y) = E_c \cdot \varepsilon_c(y) \qquad \text{Formula 2.9}$$

[Expression 39]

$$\varepsilon_c(y) = \frac{\delta_c(y)}{\alpha_c \cdot b_{eff}} \qquad \text{Formula 2.10}$$

[Expression 40]

$$\delta_c(y) = \phi_j \cdot y \qquad \text{Formula 2.11}$$

[0112] Here, "$\varepsilon_c(y)$" in Formulas 2.9 to 2.11 is a strain distribution of the concrete on the bearing pressure surface. "$\delta_c(y)$" in Formulas 2.9 and 2.10 is a displacement distribution (mm) of the bearing pressure surface in the compression direction.

[0113] When Formulas 2.9 to 2.11 are substituted into Formula 2.8, the following Formula 2.12 is satisfied.

[Expression 41]

$$P_{c2} = E_c \cdot \frac{\phi_j}{\alpha_c} \int_0^{l_{eff}} y dy = \frac{1}{2} \cdot E_c \cdot \frac{l_{eff} \cdot \phi_j}{\alpha_c \cdot b_{eff}} \cdot l_{eff} \cdot b_{eff} \qquad \text{Formula 2.12}$$

[0114] Assuming that the reaction force according to Formula 2.12 is equivalent to the reaction force according to Formula 2.4, the following Formula 2.13 is established.

[Expression 42]

$$\delta_c = \frac{l_{eff}}{2} \cdot \phi_j = \delta_{cP,eff} \qquad \text{Formula 2.13}$$

[0115] "$\delta_{cP,eff}$" in Formula 2.13 is a representative displacement (mm) of the concrete on the bearing pressure surface.

[0116] Therefore, even when the bearing pressure surface has the linear stress gradient, the reaction force can be obtained by applying Formula 2.4 in a uniform bearing pressure state using the displacement calculated by Formula 2.13.

[0117] Next, the moment (rotational resistance) M_{c2} (Nmm) due to the bearing pressure reaction force when the bearing pressure surface has the linear stress gradient can be calculated by the following Formula 2.14.

[Expression 43]

$$M_{c2} = \int_0^{l_{eff}} \sigma_c(y) \cdot b_{eff} \cdot y dy = E_c \cdot \frac{l_{eff} \cdot \phi_j}{\alpha_c \cdot b_{eff}} \cdot \frac{l_{eff}^3}{3} = P_{c2} \cdot \frac{2l_{eff}}{3}$$

Formula 2.14

[0118] When the uniform stress distribution is assumed on the bearing pressure surface, the moment (rotational resistance) M_{c1} (Nmm) can be calculated by the following Formula 2.15.

[Expression 44]

$$M_{c1} = \int_0^{l_{eff}} \sigma_c \cdot b_{eff} \cdot y dy = E_c \cdot \frac{\delta_c}{\alpha_c \cdot b_{eff}} \cdot b_{eff} \cdot \frac{l_{eff}^2}{2}$$

Formula 2.15

[0119] Assuming that the moment according to Formula 2.14 is equivalent to the moment according to Formula 2.15, the following Formula 2.16 is satisfied.

[Expression 45]

$$\delta_c = \frac{2l_{eff}}{3} \cdot \phi_j = \delta_{cM,eff}$$

Formula 2.16

[0120] "$\delta_{cM,eff}$" in Formula 2.16 is a displacement (mm) of the bearing pressure surface in the compression direction at a distance for moment calculation.

[0121] Therefore, even when the bearing pressure surface has the linear stress gradient, Formula 2.15 in the uniform bearing pressure state can be applied using the displacement calculated by Formula 2.16. From the above, the rigidity k_c of the bearing pressure surface can be finally evaluated by the following Formula 2.17 that is the same as Formula 2.1 from Formulas 2.12 and 2.13.

[Expression 46]

$$k_c = \frac{P_{c2}}{\delta_{cP,eff}} = \cdot \frac{E_c \cdot l_{eff}}{\alpha_c}$$

Formula 2.17

[0122] The width b_{eff} of the effective bearing pressure region is set in consideration of the fact that the reaction force due to the bearing pressure attenuates toward an edge end of the bearing pressure surface due to plate bending. Regarding the flange of the steel beam 20 (beam end 24) embedded in the column 10, when the concrete 32 is filled between the upper and lower flanges 20A and 20B, the entire width of the upper and lower flanges 20A and 20B is considered to be

effective by assuming that the plate bending of the upper and lower flanges 20A and 20B is constrained by the concrete 32.

[0123] A value used to calculate the representative displacement due to the bearing pressure between the upper and lower flanges 20A and 20B of the steel beam 20 (beam end 24) embedded inside the column 10 and the concrete 32, that is, the distance $x_{d,i}$ between the line of action of the representative displacement of the resistance element i and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is expressed by the following Formula 2.18 using the distance l_{eff} from the elastic rotation center to the edge end of the effective bearing pressure region from Formulas 2.13 and 2.14.

[0124] The arm length used to calculate the moment resistance, that is, the distance $x_{l,i}$ between the center of gravity of the reaction force of the resistance element and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is expressed by the following Formula 2.19 using the distance l_{eff} from the elastic rotation center to the edge end of the effective bearing pressure region from Formulas 2.13 and 2.14.

[Expression 47]

$$x_{d,i} = x_{d,c} = \frac{l_{eff}}{2} \qquad \text{Formula 2.18}$$

[Expression 48]

$$x_{l,i} = x_{l,c} = \frac{2}{3} l_{eff} \qquad \text{Formula 2.19}$$

[0125] In the case of Fig. 3, the length of the effective bearing pressure region of the upper flange end outer surface resistance element 24Aa of the upper flange 20A is exemplified by "$l_{eff,t}$". The length of the effective bearing pressure region of the upper flange end inner surface resistance element 24Ba of the upper flange 20A is exemplified by "$l_{eff,b}$". The length of the effective bearing pressure region of the lower flange end inner surface resistance element 24Ca of the lower flange 20B is exemplified by "$l_{eff,t}$". The length of the effective bearing pressure region of the lower flange end outer surface resistance element 24Da of the lower flange 20B is exemplified by "$l_{eff,b}$". Each width of the effective bearing pressure region is exemplified by b_{eff}".

[0126] (Elastic rigidity by bearing pressure of face bearing plate and concrete)

Next, the elastic rigidity regarding the bearing pressure resistance between the face

bearing plate 30 and the concrete 32 of the column 10 will be described.

[0127] For the face bearing plate 30, constraint conditions around the bearing pressure surface need to be suitably considered. In this case, out-of-plane deformation constraint of the face bearing plate 30 by the web 20C is ignored. Referring to the aforementioned known document 3 "EN1993-1-8: 2005 Eurocode 3: Design of steel structures Part 1-8: Design of joints, BSI, 2010", as illustrated in Fig. 6, it is assumed that the compressive force acting on an axis of the lower flange 20B is transmitted to the concrete 32 through the effective bearing pressure region of the face bearing plate 30.

[0128] The length l_{eff} and the width b_{eff} of the effective bearing pressure region are calculated by the following Formulas 2.20 and 2.21 using a width B_f (mm) of the lower flange 20B of the steel beam 20, a thickness t_w (mm) of the web 20C, a plate thickness t_{fb} (mm) of the face bearing plate 30, compressive strength f_{jd} (N/mm^2) of the concrete 32 against local bearing pressure, and yield stress f_y (N/mm^2) of the face bearing plate 30.

[Expression 49]

$$b_{eff} = B_f - t_w \qquad \text{Formula 2.20}$$

[Expression 50]

$$l_{eff} = t_{fb}\sqrt{\frac{f_y}{3\gamma_{M0} \cdot f_{jd}}} \qquad \text{Formula 2.21}$$

[0129] "γ_{M0}" in Formula 2.21 is a reduction coefficient in consideration of variation in strength of the steel material. In this case, a value of the reduction coefficient γ_{M0} is set to "1.0".

[0130] According to the aforementioned known document 4 "Lambe T.W., Whitman R.V.: Soil Mechanics, MIT, John Wiley & Sons, Inc., New York, 1969", Formula 2.21 is obtained by back calculating a beam length when a maximum bending moment of a cantilever beam reaches an elastic limit bending moment. Bending of the steel plate having a bearing pressure surface of a T stub with the concrete is considered, and a model in which the T stub receives a uniformly distributed load equal to bearing pressure strength of the concrete as a cantilever beam is assumed. That is, Formula 2.21 represents the length of the effective bearing pressure region used to calculate the bearing pressure strength.

[0131] On the other hand, in the aforementioned known document 4 "Lambe T.W., Whitman R.V.: Soil Mechanics, MIT, John Wiley & Sons, Inc., New York, 1969", regarding a dimension of the effective bearing pressure region used to calculate the rigidity of the bearing pressure

surface, a net length C_{fl} (mm) of the bearing pressure region considering bending deformation (sinusoidal waveform) of the steel plate is expressed by the following Formula 2.23. A length C_r(mm) = l_{eff} of the effective bearing pressure region converted into a uniform bearing pressure deformed state equivalent to the length C_{fl} is expressed by the following Formula 2.22. An effective depth h_{eq} (mm) that defines a strain against a bearing pressure deformation is expressed by the following Formula 2.24.

[Expression 51]

$$C_r = C_{fl} \cdot \frac{2}{\pi} \qquad \text{Formula 2.22}$$

[Expression 52]

$$C_{fl} = t\sqrt{\frac{(\pi/2)^4}{12} \cdot \xi \cdot \frac{E}{E_c}} \qquad \text{Formula 2.23}$$

[Expression 53]

$$h_{eq} = \xi \cdot C_{fl} = \alpha_c \cdot \alpha_{rig} = \alpha_c \cdot b_{eff} \qquad \text{Formula 2.24}$$

[0132] Here, "ξ" in Formulas 2.23 and 2.24 is a ratio of the effective depth h_{eq} to a length C_{fl}. In addition, "α_c" in Formula 2.24 is expressed by the following Formula 2.25 with a coefficient set to α, with reference to the aforementioned known document 3 "EN1993-1-8: 2005 Eurocode 3: Design of steel structures Part 1-8: Design of joints, BSI, 2010" and the aforementioned known document 5 "Martin Steenhuis et al.: Concrete in compression and base plate in bending, HERON Vol. 53, No. 1/2, 2008".

[Expression 54]

$$\alpha_c = \alpha \cdot \sqrt{C_r / b_{eff}} \qquad \text{Formula 2.25}$$

[0133] Thus, Formula 2.24 is expressed by the following Formula 2.26.

[Expression 55]

$$\xi = \frac{\alpha\sqrt{C_r \cdot b_{eff}}}{C_{fl}} \qquad \text{Formula 2.26}$$

[0134] When Formulas 2.23 and 2.26 are substituted into Formula 2.22, the following Formula 2.27 is satisfied.

[Expression 56]

$$C_r = t^{6/7} \cdot \left(\frac{\alpha}{12} \cdot \frac{E}{E_c} \right)^{2/7} \cdot b_{eff}{}^{1/7} = l_{eff} \qquad \text{Formula 2.27}$$

[0135] On the other hand, in the aforementioned known document 3 "EN1993-1-8: 2005 Eurocode 3: Design of steel structures Part 1-8: Design of joints, BSI, 2010", Formula 2.21 may be used for both strength calculation and rigidity calculation. This is because the value of Formula 2.21 and the value of Formula 2.27 are substantially the same in the aforementioned known document 4 "Lambe T.W., Whitman R.V.: Soil Mechanics, MIT, John Wiley & Sons, Inc., New York, 1969".

[0136] From the above, similarly to Formulas 2.1 and 2.4, the rigidity $k_{c,fb}$ (N/mm) and the reaction force $P_{c,fb}$ (N) of the bearing pressure surface between the face bearing plate 30 and the concrete 32 can be calculated by the following Formulas 2.28, 2.29, and 2.30.

[Expression 57]

$$k_{c,fb} = \frac{E_c \sqrt{b_{eff} \cdot C_r}}{\alpha} = \frac{E_c \sqrt{b_{eff} \cdot C_r}}{\alpha_c \sqrt{b_{eff} / C_r}} = \frac{E_c \cdot C_r}{\alpha_c} \qquad \text{Formula 2.28}$$

[Expression 58]

$$P_{c,fb} = k_{c,fb} \cdot \delta_{c,fb} \qquad \text{Formula 2.29}$$

"$\delta_{c,fb}$" in Formula 2.29 means displacement of the face bearing plate 30.

[Expression 59]

$$\delta_{c,fb} = x_{c,fb} \cdot \phi_j \qquad \text{Formula 2.30}$$

"$x_{c,fb}$" in Formula 2.30 means a distance between the face bearing plate 30 and the concrete 32.

[0137] A value used to calculate the representative displacement due to the bearing pressure force between the face bearing plate 30 and the concrete 32, that is, the distance $x_{d,i}$ between the line of action of the representative displacement of the resistance element i and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is

expressed by the following Formula 2.31 from Fig. 6, using a thickness D_s (mm) of the slab 22, a height H (mm) of the steel beam 20, a thickness t_f (mm) of the lower flange 20B of the steel beam 20, and a distance x_n (mm) measured along the Z direction from the upper surface of the slab 22 to the elastic rotation center.

[0138] The arm length used to calculate the moment resistance, that is, the distance $x_{l,i}$ between the center of gravity of the reaction force of the resistance element and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is similarly expressed by Formula 2.31 that is equal to or less than the distance measured along the thickness of 20B.

[Expression 60]

$$x_{d,i} = x_{l,i} = x_{c,fb} = D_s + H - x_n - t_f - \frac{C_r}{2} \qquad \text{Formula 2.31}$$

[0139] In the above description, the method of calculating the elastic rigidity (that is, rotational rigidity) regarding a bearing pressure portion between steel and concrete in which the deformation state of the joint 14 between the column 10 and the beam 12 is modeled by the rigid rotation of the beam end 24 of the steel beam 20 which is a steel frame portion to generate the moment resistance is described.

[0140] (Method of evaluating resistance of joint 14)

Next, a case where the column-beam joint is designed by evaluating the resistance of the joint 14 will be described. The resistance $M_{j,Rd}$ of the joint 14 is obtained as a sum of a product of a distance $x_{u,i}$ (mm) from the resistance element i to the rotation center of the beam end 24 and the maximum reaction force $F_{i,Rd}$ (N) of the resistance element i by the following Formula. In the present embodiment, the distance $x_{u,i}$ from the resistance element i to the rotation center of the beam end 24 is the distance $x_{u,i}$ from the center of gravity of the reaction force of the resistance element i to the rotation center of the beam end 24. In a final state of the joint 14 between the column 10 and the beam 12, it is assumed that all the reaction force of each resistance element constraining the rotation of the beam end 24 of the steel beam 20 reaches the maximum resistance due to the rigid rotation of the beam end 24 of the steel beam 20.

[Expression 61]

$$M_{j,Rd} = \sum_i F_{i,Rd} \cdot x_{u,i} \qquad \text{Formula 3.1}$$

[0141] In Formula 3.1, each resistance element in the joint 14 is set to have a completely rigid plastic load deformation relationship. It is assumed that all resistance elements are in a state (that is, mechanism) in which a plastic flow occurs. Due to the moment resistance determined by this assumption, a value larger than a true collapse load is obtained as an upper bound. Thus, calculation for obtaining the moment resistance using Formula 3.1 is executed for an arbitrary rotation center. In the calculation, the rotation center that minimizes the collapse load is obtained as the final rotation center. The moment resistance when the final rotation center is obtained is set as the moment resistance (that is, the maximum moment resistance $M_{j,Rd}$ of the joint 14) of the joint 14.

[0142] As the resistance element in the joint 14, the tensile resistance of the joint reinforcement bar 28 disposed in the slab 22, the pull-out resistance of the stud 26 in the joint 14, the bearing pressure resistance between the face bearing plate 30 and the concrete 32 of the column 10, the bearing pressure resistance between the upper flange 20A of the steel beam 20 and the concrete 32 of the column 10, and the bearing pressure resistance between the lower flange 20B and the concrete 32 of the column 10 can be set.

[0143] In addition, as the resistance element, the sliding resistance due to friction of the bolt joint connecting the web 20C of the steel beam 20 and the fin plate 36 of the column 10, the shearing deformation resistance of the bolt 34 due to the bearing pressure, the local deformation resistance of the bolt hole, and the shearing resistance of the fin plate 36 can be set.

[0144] For each resistance element, resistance $F_{i,Rd}$ as the reaction force that generates a plastic flow is required, however, in this case, among the resistance elements described above, each resistance in consideration of the tensile resistance of the joint reinforcement bar 28 disposed in the slab 22, the pull-out resistance of the stud 26 in the joint 14, the bearing pressure resistance between the face bearing plate 30 and the concrete 32 of the column 10, the bearing pressure resistance between the upper flange 20A of the steel beam 20 and the concrete 32 of the column 10, and the bearing pressure resistance between the lower flange 20B and the concrete 32 of the column 10 will be described, assuming that the resistance is relatively large and cannot be ignored in calculation of the moment resistance. The moment resistance may be obtained by suitably considering other resistance elements.

[0145] (Resistance of joint reinforcement bar)

As illustrated in Fig. 10A, the resistance for the tensile resistance of the joint reinforcement bar 28 disposed in the slab 22, corresponding to the reaction force $F_{i,Rd}$, that is, resistance $F_{r,Rd}$ (N) of the joint reinforcement bar 28 can be expressed by the following Formula 3.2 using a total cross-sectional area a_r (mm^2) of the joint reinforcement bar 28 and yield stress $f_{r,y}$ (N/mm^2) within the effective width of the slab 22.

[Expression 62]

$$F_{r,Rd} = a_r \cdot f_{r,y} \qquad \text{Formula 3.2}$$

[0146] Alternatively, tensile strength $f_{r,u}$ may be used instead of the yield stress $f_{r,y}$.

[0147] The arm length used to calculate the moment resistance due to the reaction force of the joint reinforcement bar 28, that is, the distance $x_{u,i}$ between the rotation center of the portion of the steel beam disposed inside the concrete of the column and the line of action of the reaction force is expressed by the following Formula 3.3. The distance $x_{u,i}$ is the distance from the center of gravity of the reaction force of the resistance element i to the rotation center of the beam end 24.

[Expression 63]

$$x_{u,i} = x_{u,r} = x_{u,n} - d_r \qquad \text{Formula 3.3}$$

[0148] "$x_{u,n}$" in Formula 3.3 is a component (mm) parallel to the vertical axis (Z axis) of a distance between the rotation center of the joint 14 and the surface of the slab 22. "d_r" in Formula 3.3 is a component (mm) parallel to the vertical axis (Z axis) in the distance from the center (a center of gravity of a multilayer reinforcing member when the joint reinforcement bar 28 is the multilayer reinforcing member) of the cross section of the joint reinforcement bar 28 to the surface of the slab 22.

[0149] (Shear resistance of stud in column)

Next, as illustrated in Fig. 10A, the shear resistance for the pull-out resistance of the stud 26 in the joint 14 (in the column), corresponding to the reaction force $F_{i,Rd}$, that is, maximum resistance $F_{st,Rd}$ (N) of the stud 26 in the column will be described. As for the maximum resistance $F_{st,Rd}$ (N), the calculation formula of the shear resistance of a headed anchor bolt described in "Vol. 4, Section 4.2, 4.2" of the known document 6 "Architectural Institute of Japan: Design Recommendations for Composite Constructions, 2nd Edition, 2010.11" is cited.

[0150] As the maximum resistance $F_{st,Rd}$, any smaller value of resistance T_{st1} determined by shear strength of the stud 26, resistance T_{st2} determined by the bearing pressure strength of the concrete 32, and resistance T_{st3} determined by conical fracture of the concrete 32 of the column 10 on a front surface of the stud 26 is adopted.

[0151] (i) Shear resistance determined by shear strength of stud

The resistance T_{st1} (N) is given by the following Formula 3.4 using the number n_{st} of the studs 26 and shear resistance q_{a1} (N) per one stud 26.

[Expression 64]

$$T_{st1} = n_{st} \cdot q_{a1} = n_{st} \cdot \phi_1 \cdot_s \sigma_{qa} \cdot_{sc} a \qquad \text{Formula 3.4}$$

[0152] "φ_1" in Formula 3.4 is a reduction coefficient. In this case, a value of the reduction coefficient φ_1 is set to "1.0". "${}_s\sigma_{qa}$" in Formula 3.4 is the shear strength (N/mm^2) of the stud 26. As the value of the shear strength ${}_s\sigma_{qa}$, a value of $1/3^{1/2}$ of 0.2% yield resistance of a material test is used. "${}_{sc}a$" in Formula 3.4 is a cross-sectional area (mm^2) of a shaft portion of the stud 26.

[0153] (ii) Shear resistance determined by bearing pressure strength of concrete

The resistance T_{st2} (N) is given by the following Formula 3.5 using the number n_{st} of the studs 26 and bearing resistance q_{a2} (N) with the concrete 32 per one stud 26.

[Expression 65]

$$T_{st2} = n_{st} \cdot q_{a2} = n_{st} \cdot \phi_2 \cdot 0.5\sqrt{f_{cd} \cdot E_c} \cdot_{sc} a$$

Formula 3.5

[0154] "φ_2" in Formula 3.5 is a reduction coefficient of concrete resistance, and the value of the reduction coefficient φ_2 is set to "1.0" in this case. "f_{cd}" in Formula 3.5 is compressive strength (N/mm^2) of the concrete 32 of the column 10. "E_c" in Formula 3.5 is the Young's modulus (N/mm^2) of the concrete. Both the value of the compressive strength f_{cd} and the value of the Young's modulus E_c are values obtained by a material test.

[0155] (iii) Shear resistance determined by conical fracture of column concrete

The resistance T_{st3} (N) is given by the following Formula 3.6 using resistance q_{a3} (N) of the conical fracture.

[Expression 66]

$$T_{st3} = q_{a3} = \phi_2 \cdot_c \sigma_t \cdot A_{qc} \qquad \text{Formula 3.6}$$

[0156] "${}_c\sigma_t$" in Formula 3.6 is the tensile strength (N/mm^2) of the concrete 32 against the conical fracture. In the setting of the tensile strength ${}_c\sigma_t$, the following Formula 3.7 given in the known document 6 "Architectural Institute of Japan: Design Recommendations for Composite Constructions, 2nd Edition, 2010.11" is used.

[Expression 67]

$$_c\sigma_t = 0.31\sqrt{f_{cd}} \qquad \text{Formula 3.7}$$

[0157] "A_{qc}" in Formula 3.6 is an effective projected area (mm^2) of a conical fracture surface,

and is obtained by the following Formula 3.8.

[Expression 68]

$$A_{qc} = \min\left\{0.5\pi c^2 \cdot n_r, 0.5\pi c^2 + sc\left(n_r - 1\right)\right\}$$

Formula 3.8

[0158] "c" in Formula 3.8 is a distance (mm) from a shaft core of the stud 26 at the most back side from a surface of the concrete 32 of the column 10 to the surface of the concrete 32 of the column 10 (see Fig. 7). "s" in Formula 3.8 is an interval (mm) between the studs 26 in a row having the same depth (see Fig. 7). "n_r" in Formula 3.8 is the number of studs 26 in the row having the same depth (see Fig. 7).

[0159] The arm length used to calculate the moment resistance due to the reaction force of the stud 26 in the column 10, that is, the distance $x_{u,i}$ between the rotation center of the portion of the steel beam disposed inside the concrete of the column and the line of action of the reaction force is expressed by the following Formula 3.9.

[Expression 69]

$$x_{u,i} = x_{u,st} = x_{u,n} - D_s$$

Formula 3.9

[0160] (Bearing resistance of beam flange surface and concrete)

Next, the bearing resistance for the bearing pressure resistance between the upper flange 20A and the lower flange 20B of the steel beam 20 and the concrete 32 of the column 10, that is, bearing resistance $F_{c,Rd}$ (N) of the beam flange surface and the concrete will be described. In the aforementioned known document 3 "EN1993-1-8: 2005 Eurocode 3: Design of steel structures Part 1-8: Design of joints, BSI, 2010", when a base plate and the concrete are in the uniform bearing pressure state, the bearing resistance $F_{c,Rd}$ is given by the following Formula 3.10.

[Expression 70]

$$F_{c,Rd} = f_{id} \cdot b_{eff} \cdot \beta \cdot l_{eff}$$

Formula 3.10

[0161] Here, "b_{eff}" in Formula 3.10 represents the width (mm) of the effective bearing pressure region of the concrete. "l_{eff}" in Formula 3.10 represents the length (mm) of the effective bearing pressure region of the concrete. As in the case of calculation rigidity of the elastic rigidity, the width b_{eff} is the entire width of the upper and lower flanges 20A and 20B in consideration of the constraint of the out-of-plane deformation of the upper and lower flanges 20A and 20B by the concrete 32 on the bearing pressure surface between the upper and lower flanges 20A and 20B of the steel beam 20 and the concrete 32 of the column 10.

[0162] Since uniform bearing pressure deformation is assumed in the aforementioned known document 3 "EN1993-1-8: 2005 Eurocode 3: Design of steel structures Part 1-8: Design of joints, BSI, 2010", the length l_{eff} is a length of the entire bearing pressure surface ($\beta = 1$).

[0163] On the other hand, in the case of rotational deformation as illustrated in Fig. 8A, a stress block in which stress is uniform is assumed with respect to a state in which there is a stress gradient. Thus, as illustrated in Figs. 8A and 8B, the length l_{eff} is converted into the bearing pressure surface equivalent to an actual stress distribution using a reduction coefficient β. On the other hand, for example, in the known document 7 "EN1992-1-1: 2004 Eurocode 2: Design of concrete structures Part 1-1: General rules and rules for buildings", the reduction coefficient β is determined by the following Formula 3.11 corresponding to the compressive strength f_{cd} of the concrete 32.

[Expression 71]

$$\beta = 0.8 - \left(f_{cd} - 50\right) / 400 \leq 0.8 \qquad \text{Formula 3.11}$$

[0164] The known document 8 "Architectural Institute of Japan: Design and Construction of Mixed Structures Composed of Reinforced Concrete Columns and Steel Beams, 1st Edition, 2001.1" describes that the reduction coefficient β is in a range of 0.6 to 0.85.

[0165] In addition, "f_{jd}" in Formula 3.10 is the compressive strength of the concrete 32 against the local bearing pressure and is defined by the following Formula 3.12.

[Expression 72]

$$f_{jd} = \beta_j \cdot f_{cd} \cdot \lambda_c \qquad \text{Formula 3.12}$$

[0166] Here, "λ_c" in Formula 3.12 is a strength magnification factor with respect to the local bearing pressure. The strength magnification factor λ_c is obtained in accordance with the aforementioned known document 7 "EN1992-1-1: 2004 Eurocode 2: Design of concrete structures Part 1-1: General rules and rules for buildings" and known document 8 "Architectural Institute of Japan: Design and Construction of Mixed Structures Composed of Reinforced Concrete Columns and Steel Beams, 1st Edition, 2001.1". For example, according to the known document 7, the calculation can be performed by the following Formula 3.13.

[Expression 73]

$$\lambda_c = \sqrt{A_{c1} / A_{c0}} \leq 3 \qquad \text{Formula 3.13}$$

[0167] Here, "A_{c0}" in Formula 3.12 is a local effective bearing pressure area (mm^2). "A_{c1}" in Formula 3.12 is a maximum bearing pressure stress distribution area (mm^2). In the half space,

a projection surface having a similar shape of the effective bearing pressure area A_{c0} and having the same normal line at a surface center is assumed (see Figs. 9A and 9B). When there is an outer portion from an edge of the concrete 32 in the projection surface, an area obtained by subtracting the outer portion is set as the maximum bearing pressure stress distribution area A_{c1} (see, for example, the model of Fig. 9B).

[0168] "β_j" in Formula 3.12 is a reduction coefficient depending on the material of the bearing pressure surface. In this case, a value of the reduction coefficient β_j is set to "1.0". When mortar to be laid or the like is used, the value of the reduction coefficient β_j can be set to, for example, "2/3".

[0169] The distance $x_{u,i}$ as the arm length used to calculate the moment resistance due to the stress block is expressed by the following Formula 3.14 using the distance l_{eff} from the rotation center to the line of action of a resultant force due to the bearing pressure stress from the models of Figs. 8A and 8B.

[Expression 74]

$$x_{u,i} = x_{u,c} = l_{eff}\left(1 - \frac{\beta}{2}\right) \qquad \text{Formula 3.14}$$

[0170] In Figs. 8A and 8B, the length of the effective bearing pressure region of the upper flange end outer surface resistance element 24Aa of the upper flange 20A is exemplified by "$l_{eff,t}$". The length of the effective bearing pressure region of the lower flange end outer surface resistance element 24Da of the lower flange 20B is exemplified by "$l_{eff,b}$". The width of the effective bearing pressure region of the upper flange end outer surface resistance element 24Aa and the width of the effective bearing pressure region of the lower flange end outer surface resistance element 24Da are both exemplified by "b_{eff}".

[0171] With respect to initial rigidity, in the concrete 32 of the column 10, integrity between the concrete 32 inside the upper and lower flanges 20A and 20B and the concrete 32 outside the upper and lower flanges 20A and 20B is maintained, and the inside of the upper and lower flanges 20A and 20B also has the bearing pressure resistance.

[0172] However, at the time of ultimate resistance, it is set that the upper flange end inner surface resistance element 24Ba of the upper flange 20A and the lower flange end inner surface resistance element 24Ca of the lower flange 20B are not considered in deriving the ultimate resistance.

[0173] This is based on the idea that, at the time of ultimate resistance, the concrete 32 is destroyed by torsion between a rectangular portion enveloping the steel beam 20 and the outside

of the rectangular portion, and the integrity with the concrete 32 inside the upper and lower flanges 20A and 20B of the column 10 cannot be maintained. The outside of the rectangular portion is a width direction end of the upper and lower flanges 20A and 20B. Furthermore, this is based on the idea that the inside of the upper and lower flanges 20A and 20B is not effective as the resistance element.

[0174] In Figs. 8A and 8B, a length corresponding to the distance $x_{u,i}$ is exemplified by "$x_{u,ct}$" for the upper flange end outer surface resistance element 24Aa of the upper flange 20A. For the lower flange end outer surface resistance element 24Da of the lower flange 20B, the length corresponding to the distance $x_{u,i}$ is exemplified by "$x_{u,cb}$".

[0175] Similarly, in Figs. 8A and 8B, the resistance corresponding to the reaction force $F_{i,Rd}$ is exemplified by "bearing resistance $F_{ct,Rd}$" for the upper flange end outer surface resistance element 24Aa of the upper flange 20A. The bearing resistance of the lower flange end outer surface resistance element 24Da of the lower flange 20B is exemplified by "$F_{cb,Rd}$".

[0176] (Bearing resistance of face bearing plate and concrete of column)

Next, bearing resistance $F_{c,fb,Rd}$ (N) for the bearing pressure resistance between the face bearing plate 30 and the concrete 32 of the column 10 corresponding to the reaction force $F_{i,Rd}$ will be described. As in the case of the bearing resistance of the beam flange surface and the concrete, the bearing resistance $F_{c,fb,Rd}$ is set using the following Formula 3.15 of the aforementioned known document 3 "EN1993-1-8: 2005 Eurocode 3: Design of steel structures Part 1-8: Design of joints, BSI, 2010". As illustrated in Figs. 10A and 10B, it is assumed that the face bearing plate 30 and the concrete 32 are in the uniform bearing pressure state.

[Expression 75]

$$F_{c,fb,Rd} = f_{jd} \cdot b_{eff} \cdot l_{eff} \qquad \text{Formula 3.15}$$

[0177] Here, "b_{eff}" in Formula 3.15 is a width (mm) of an effective bearing pressure surface of the concrete 32. "l_{eff}" in Formula 3.15 is a length (mm) of the effective bearing pressure surface of the concrete 32. As in the calculation rigidity of the elastic rigidity, in the setting of the width b_{eff}, the entire width of the upper and lower flanges 20A and 20B is adopted in consideration of the constraint of the out-of-plane deformation of the upper and lower flanges 20A and 20B by the concrete 32 on the bearing pressure surface between the upper and lower flanges 20A and 20B and the concrete 32 of the column 10.

[0178] The length l_{eff} can be set by using the following Formula 3.16 of the aforementioned known document 3 "EN1993-1-8: 2005 Eurocode 3: Design of steel structures Part 1-8: Design of joints, BSI, 2010" and the aforementioned known document 5 "Martin Steenhuis et al.:

Concrete in compression and base plate in bending, HERON Vol. 53, No. 1/2, 2008".

[Expression 76]

$$l_{eff} = t_{fb}\sqrt{\frac{f_y}{3\gamma_{M0} \cdot f_{jd}}} \qquad \text{Formula 3.16}$$

[0179] Here, "t_{fb}" in Formula 3.16 is the plate thickness (mm) of the face bearing plate 30. "f_{jd}" in Formula 3.16 is the compressive strength (N/mm^2) of the concrete 32 against the local bearing pressure. The compressive strength m f_{jd} is similar to that described by Formulas 3.12 and 3.13. "f_y" in Formula 3.16 is the yield stress (N/mm^2) of the face bearing plate 30.

[0180] "γ_{M0}" in Formula 3.16 is a reduction coefficient for considering the variation in strength of the steel material, and the value of the reduction coefficient γ_{M0} is set to "1.0" in this case. For the effective bearing pressure area A_{c0} (mm^2) and the maximum bearing pressure stress distribution area A_{c1} (mm^2) described in Formula 3.13, the projection surface illustrated in Fig. 11 is assumed. The value of the reduction coefficient β_j is set to "1.0".

[0181] The distance $x_{u,i}$ as the arm length used to calculate the moment resistance due to the stress block is expressed by the following Formula 3.17 using the distance l_{eff} from the rotation center to the line of action of the resultant force due to the bearing pressure stress from the models of Figs. 10A and 10B.

[Expression 77]

$$x_{u,i} = x_{u,c,fb} = D_s + H - x_{u,n} - t_f - \frac{l_{eff}}{2} \qquad \text{Formula 3.17}$$

[0182] In the above description, the method of predicting the moment resistance in the final state of the joint 14 from the upper bound by adding the maximum resistance of each resistance element is described. The moment resistance of the joint 14 between the column 10 and the beam 12 can be set to a desired moment resistance by setting the dimension of each portion of the steel beam 20, the number of resistance elements (the presence or absence, and the number if the resistance element exists), and the position based on this method. That is, the moment resistance can be adjusted to equal to or more than the required moment resistance $M_{j,Ed}$.

[0183] (Example 1)

(Comparison between calculation result and experimental result)

In order to confirm the effect of the column-beam joint of the present disclosure, for

the column-beam joint of the embodiment illustrated in Figs. 1 and 2 of the present disclosure, a load was applied to the beam in the -Z direction downward in the vertical direction, and a relationship between the rotation angle of the joint and the moment was acquired. Then, the results of calculating the rotational rigidity and the moment resistance of the joint using Formulas 1 to 3.17 were compared with experimental results.

[0184] The relationship between the moment and the rotation angle of the beam end 24 of the steel beam 20 in the joint 14 can be defined by a bilinear model by obtaining an initial rotational rigidity $S_{j,ini}$ (Nmm/rad) and the maximum moment resistance $M_{j,Rd}$ (Nmm) according to the procedures of Formulas 1 to 3.17. In this case, 2/3 times the maximum moment resistance $M_{j,Rd}$ was established as the elastic limit. When a moment exceeding the set elastic limit was applied, it was defined that the rotational rigidity was lower than the initial rotational rigidity $S_{j,ini}$.

[0185] When the maximum moment resistance $M_{j,Rd}$ (Nmm) was satisfied, secant rigidity S_j (Nmm/rad) was defined by a trilinear model determined by a value obtained by dividing $S_{j,ini}$ by a rigidity reduction rate η (> 1) (see Fig. 12). When the trilinear model is applied, an acting moment of the joint is calculated with the rotational rigidity $S_{j,ini}$ as elastic rotational rigidity. When a moment equal to or less than 2/3 times the maximum moment resistance $M_{j,Rd}$ was applied, the process could be performed as it is.

[0186] Then, the acting moment of the joint was calculated with the rotational rigidity $S_{j,ini}$ as the elastic rotational rigidity, and when a moment exceeding 2/3 times the maximum moment resistance $M_{j,Rd}$ was applied, the acting moment of the joint was newly calculated with the secant rigidity S_j as the elastic rotational rigidity. If the calculated acting moment was equal to or less than the maximum moment resistance $M_{j,Rd}$, it was determined that implementation was possible, that is, this fell within the scope of claims of the present disclosure. If the calculated acting moment exceeded the maximum moment resistance $M_{j,Rd}$, it was determined that implementation was impossible, that is, this was outside the scope of claims of the present disclosure. The rotational rigidity $S_{j,ini}$, the maximum moment resistance $M_{j,Rd}$, and η are determined by the following Formulas 4.1, 4.2, and 4.3.

[Expression 78]

$$S_j = S_{j,ini} = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 4.1}$$

$$\left(\text{When } M_{j,Ed} \leqq \frac{2}{3} M_{j,Rd}\right)$$

[Expression 79]

$$M_{j,Rd} = \sum_i (F_{i,Rd} \cdot x_{u,i})$$ Formula 4.2

[Expression 80]

$$S_j = S_{j,ini} / \eta$$ Formula 4.3

(When $M_{j,Ed} > \frac{2}{3} M_{j,Rd}$)

[0187] Deformation performance φ_{cd} illustrated in Fig. 12 is a minimum value (rad) of a rotation angle $\varphi_{cd,i}$ when each resistance element reaches a limit of the deformation amount. In a case where a product of the distance $x_{u,i}$ from the final rotation center to each resistance element and the rotation angle φ_j is equal to a limit $\delta_{u,i}$ (mm) of the deformation amount of each resistance element, when the rotation angle φ_j is solved, a minimum rotation angle $\varphi_{cd,i}$ can be obtained by $\varphi_{cd,i}=\delta_{u,i}/x_{u,i}$.

[0188] (Elastic rigidity and resistance of joint reinforcement bar)

In Example 1, when the joint reinforcement bar 28 was set as i = the first resistance element, the elastic rigidity k_r (N/mm), a distance (arm length) x_r (= $x_{d,1}$, $x_{l,1}$ (mm)) from the elastic rotation center satisfying the balance of forces at the time of elasticity to the reinforcement bar, a distance (arm length) $x_{u,r}$ (= $x_{u,1}$ (mm)) from the rotation center at the time of the ultimate resistance to the reinforcement bar, and the resistance $F_{r,Rd}$ (N) were obtained using the following Formulas 4.4 to 4.11.

[0189] The definition of each parameter in the formula is the same as that described in Formulas 1 to 3.17. The following Table 1 shows each parameter used to calculate the rigidity and the resistance of the reinforcement bar. In the experiment in Example 1, "k_r, k_{slip}, K_{sc}, ν, ξ, $x_{d,1}$, $F_{r,Rd}$, $x_{u,1}$" in Formulas 4.4 to 4.11 were calculated using the conditions (E_r, a_r, h_r, α, N, k_{sc}, h_s, d_s, l_h, E_a, I_a, ξ, d_r, $f_{r,y}$, x_n, $x_{u,n}$) shown in Table 1.

[Table 1]

[Expression 81]

(i=1)Rebar

i	Parameters for rebar calculation											
	Specification of reinforcement bar											
1	k_r	[N/mm]	3.42	E_r	[N/mm^2]	210000						
				a_r	[mm^2]	1608						
				h_r	[mm]	940						
				α	[-]	0.5						
	k_{slip}	[-]	0.50	K_{sc}	[N/mm]	726688	N	[-]	16			
							k_{sc}	[N/mm]	100			
							h_s	[mm]	644			
							d_s	[mm]	402			
							ν	[-]	3.85	l_h	[mm]	2000
										E_a	[N/mm^2]	210000
										I_a	[mm^4]	460000000
							ξ	[-]	1.77			
	$x_{d,1}$	[mm]	470	x_n	[mm]	508						
				d_r	[mm]	38						
	$F_{r,Rd}$	[kN]	661	$f_{r,y}$	[N/mm^2]	411						
	$x_{u,1}$	[mm]	0	$x_{u,n}$	[mm]	38						

$$k_1 = k_r = \frac{E_r \cdot a_r}{\alpha \cdot h_r} \cdot k_{slip}$$ Formula 4.4

[Expression 82]

$$k_{slip} = \frac{1}{1 + \frac{E_r \cdot a_r}{\alpha \cdot h_r \cdot k_{sc}}}$$ Formula 4.5

[Expression 83]

$$K_{sc} = \frac{N \cdot k_{sc}}{\nu - \left(\frac{\nu - 1}{1 + \xi}\right)\frac{h_s}{d_s}}$$ Formula 4.6

[Expression 84]

$$\nu = \sqrt{\frac{(1+\xi) N \cdot k_{sc} \cdot l_h \cdot d_s^{\,2}}{E_a I_a}}$$ Formula 4.7

[Expression 85]

$$\xi = \frac{E_a I_a}{d_s^{\,2} \cdot E_r \cdot a_r}$$ Formula 4.8

[Expression 86]

$$x_{d,1} = x_{l,1} = x_r = x_n - d_r$$ Formula 4.9

[Expression 87]

$$F_{1,Rd} = F_{r,Rd} = a_r \cdot f_{r,y}$$ Formula 4.10

[Expression 88]

$$x_{u,1} = x_{u,r} = x_{u,n} - d_r \qquad \text{Formula 4.11}$$

[0190] (Elastic rigidity and resistance against shearing of stud in column)

In Example 1, when the stud 26 in the column 10 was set as i = the second resistance element, the elastic rigidity k_{st} (N/mm) due to shearing, a distance (that is, arm length) x_{st} (= $x_{d,2}$, $x_{l,2}$ (mm)) from the final rotation center satisfying the balance of forces at the time of elasticity to a root of the stud, a distance (that is, arm length) $x_{u,st}$ (= $x_{u,2}$ (mm)) from the rotation center at the time of the ultimate resistance to the reinforcement bar, and the resistance $F_{st,Rd}$ (N) can be obtained using the following Formulas 4.12 to 4.20.

[0191] The definition of each parameter in the formula is the same as that described in Formulas 1 to 3.17. Table 2 shows each parameter used to calculate the rigidity and the resistance of the stud in the column. In the experiment in Example 1, "k_2, $x_{d,2}$, $F_{2,Rd}$, $x_{u,2}$, T_{st1}, T_{st2}, T_{st3}, ${}_c\sigma_t$, A_{qc}" in Formulas 4.12 to 4.20 were calculated using the conditions (φ_{st}, n_{st}, x_n, D_s, φ_1, ${}_s\sigma_{qa}$, ${}_{sc}a$, φ_2, f_{cd}, E_c, c, s, n_r) shown in Table 2.

[Table 2]

[Expression 89]

(i=2)Inner Studs

i	Parameter for inner studs calculation											
	Specification of stud embedded in column											
2	k_{st}	[N/mm]	3.55	ϕ_{st}	[mm]	19						
				n_{st}	[-]	4						
	$x_{d,1}$	[mm]	318	x_n	[mm]	508						
				D_s	[mm]	190						
	$F_{st,Rd}$	[kN]	980	T_{st1}	[kN]	980	ϕ_1	[-]	1			
							${}_s\sigma_{qa}$	[N/mm^2]	216			
							${}_{sc}a$	[mm^2]	1134			
				T_{st2}	[kN]	3608	ϕ_2	[-]	1			
							f_{cd}	[N/mm^2]	65			
							E_c	[N/mm^2]	38916			
				T_{st3}	[kN]	1525	${}_c\sigma_t$	[N/mm^2]	20			
							A_{qc}	[mm^2]	75706	c	[mm]	100
										s	[mm]	100
										n_r	[Number]	2

$$k_2 = k_{st} = \phi_{st} \cdot 9.8 \cdot 10^3 \cdot n_{st}$$ Formula 4.12

[Expression 90]

$$x_{d,2} = x_{l,2} = x_{st} = x_n - D_s$$ Formula 4.13

[Expression 91]

$$F_{2,Rd} = F_{st,Rd} = \min(T_{st1,} T_{st2,} T_{st3})$$ Formula 4.14

[Expression 92]

$$x_{u,2} = x_{u,st} = x_{u,n} - D_s$$ Formula 4.15

[Expression 93]

$$T_{st1} = n_{st} \cdot q_{a1} = n_{st} \cdot \phi_1 \cdot_s \sigma_{qa} \cdot_{sc} a$$ Formula 4.16

[Expression 94]

$$T_{st2} = n_{st} \cdot q_{a2} = n_{st} \cdot \phi_2 \cdot 0.5\sqrt{f_{cd} \cdot E_c} \cdot_{sc} a$$

Formula 4.17

[Expression 95]

$$T_{st3} = q_{a3} = \phi_2 \cdot_c \sigma_t \cdot A_{qc}$$ Formula 4.18

[Expression 96]

$$_c\sigma_t = 0.31\sqrt{f_{cd}}$$ Formula 4.19

[Expression 97]

$$A_{qc} = \min\left\{0.5\pi c^2 \cdot n_r, 0.5\pi c^2 + sc(n_r - 1)\right\}$$

Formula 4.20

[0192] (Elastic rigidity and resistance against flange surface of beam body and bearing pressure of concrete)

As shown in Figs. 13A and 13B, in Example 1, it was assumed that, with respect to the initial rigidity, the bearing pressure resistance was generated at all four locations (that is, i = 3,

4, 5, 6) on the inner and outer surfaces of the upper and lower flanges 20A and 20B. In addition, it was assumed that, with respect to the maximum resistance, the bearing pressure resistance was generated at all two locations (that is, i = 3, 6) only on the outer surfaces of the upper and lower flanges 20A and 20B.

[0193] This is based on the idea that, with respect to the initial rigidity, the integrity between the concrete 32 inside the upper and lower flanges 20A and 20B and the concrete 32 outside the upper and lower flanges 20A and 20B is maintained, and the inside of the upper and lower flanges 20A and 20B also has the bearing pressure resistance. However, this is based on the idea that, in the final state, the concrete 32 is destroyed by the torsion between the rectangular portion enveloping the steel beam 20 and the outside of the rectangular portion (that is, the width direction end of the upper and lower flanges 20A and 20B) and the inside of the upper and lower flanges 20A and 20B is not effective as the resistance element.

[0194] The elastic rigidity k_c (N/mm) of the bearing pressure between the surfaces of the upper and lower flanges 20A and 20B and the concrete 32, a distance $x_{d,c,i}$ (mm) from a representative point of bearing pressure displacement of the resistance element i at the time of elasticity to the rotation center, a distance (that is, arm length) $x_{l,c,i}$ (mm) from the rotation center satisfying the balance of forces at the time of elasticity to the center of gravity of the bearing pressure force, a distance (that is, arm length) $x_{u,c,i}$ (mm) from the rotation center at the time of the ultimate resistance to the center of gravity of the bearing pressure force, and resistance $F_{c,i,Rd}$ (N) can be set using the following Formulas 4.21 to 4.35. The resistance elements i are provided at all four locations (that is, i = 3, 4, 5, 6) including the inner and outer surfaces of the upper and lower flanges 20A and 20B.

[0195] Table 3 shows each parameter used to calculate the rigidity and the resistance by the bearing pressure resistance of the interface between the portion embedded in the column concrete of the steel beam and the column concrete. The values shown in Table 3 were used as the parameters in Formulas 4.21 to 4.35.

[Table 3]

[Expression 98]

(i=3～6)Flange bearing

i	Parameter for flange bearing Specification for bearing pressure resistance element between beam flange and column concrete											
3	$k_{c,i}$	[N/mm]	31.80	E_c	[N/mm^2]	38916						
				$\alpha_{c,i}$	[-]	0.62	$b_{eff,i}$	[mm]	200	B_f	[mm]	200
							$l_{eff,el,i}$	[mm]	106	L_{em}	[mm]	240
	$x_{d,c,i}$	[mm]	53.2							y_n	[mm]	134
	$x_{l,c,i}$	[mm]	70.9									
	$F_{c,i,Rd}$	[kN]	3821	$f_{j,d}$	[N/mm^2]	159	β_j	[-]	1			
							f_{cd}	[N/mm^2]	65			
							λ_c	[-]	2.45	A_{c0}	[mm^2]	24000
										A_{c1}	[mm^2]	144000
				β	[-]	0.7625						
				$l_{eff,u,i}$	[mm]	120				$y_{u,n}$	[mm]	120
4	$k_{c,i}$	[N/mm]	32.68	E_c	[N/mm^2]	38916						
				$\alpha_{c,i}$	[-]	0.67	$b_{eff,i}$	[mm]	191	B_f	[mm]	200
										t_w	[mm]	9
							$l_{eff,el,i}$	[mm]	118	L_{em}	[mm]	240
	$x_{d,c,i}$	[mm]	58.8							y_n	[mm]	134
	$x_{l,c,i}$	[mm]	78.4									
5	$k_{c,i}$	[N/mm]	31.07	E_c	[N/mm^2]	38916						
				$\alpha_{c,i}$	[-]	0.63	$b_{eff,i}$	[mm]	191	B_f	[mm]	200
										t_w	[mm]	9
							$l_{eff,el,i}$	[mm]	106	L_{em}	[mm]	240
	$x_{d,c,i}$	[mm]	53.2							y_n	[mm]	134
	$x_{l,c,i}$	[mm]	70.9									
6	$k_{c,i}$	[N/mm]	35.64	E_c	[N/mm^2]	38916						
				$\alpha_{c,i}$	[-]	0.69	$b_{eff,i}$	[mm]	200	B_f	[mm]	200
							$l_{eff,el,i}$	[mm]	134	L_{em}	[mm]	240
	$x_{d,c,i}$	[mm]	66.8							y_n	[mm]	134
	$x_{l,c,i}$	[mm]	89.1									
	$F_{c,i,Rd}$	[kN]	3821	$f_{j,d}$	[N/mm^2]	159	β_j	[-]	1			
							f_{cd}	[N/mm^2]	65			
							λ_c	[-]	2.45	A_{c0}	[mm^2]	24000
										A_{c1}	[mm^2]	144000
				β	[-]	0.7625						
				$l_{eff,u,i}$	[mm]	120				$y_{u,n}$	[mm]	120

$$k_{c,i} = \frac{E_c \sqrt{b_{eff,i} \cdot l_{eff,el,i}}}{\alpha_{c,i} \sqrt{b_{eff,i} / l_{eff,el,i}}} = \frac{E_c \cdot l_{eff,el,i}}{\alpha_{c,i}} (i = 3,4,5,6)$$ Formula 4.21

[Expression 99]

$$\alpha_{c,i} = 0.85 \sqrt{l_{eff,el,i} / b_{eff,i}} \quad (i = 3,4,5,6)$$ Formula 4.22

[Expression 100]

$$l_{eff,el,i} = L_{em} - y_n \quad (i = 3,5)$$ Formula 4.23

[Expression 101]

$$l_{eff,el,i} = y_n - t_{fb} \quad (i = 4)$$ Formula 4.24

[Expression 102]

$$l_{eff,el,i} = y_n \quad (i = 6)$$ Formula 4.25

[Expression 103]

$$b_{eff,i} = B_f \quad (i = 3,6)$$ Formula 4.26

[Expression 104]

$$b_{eff,i} = B_f - t_w \quad (i = 4,5)$$ Formula 4.27

[Expression 105]

$$x_{d,c,i} = \frac{l_{eff,el,i}}{2} \quad (i = 3,4,5,6)$$ Formula 4.28

[Expression 106]

$$x_{l,c,i} = \frac{2}{3} l_{eff,el,i} \quad (i = 3,4,5,6)$$ Formula 4.29

[Expression 107]

$$F_{c,i,Rd} = f_{jd} \cdot b_{eff,i} \cdot \beta \cdot l_{eff,u,i} \quad (i = 3,4,5,6)$$

Formula 4.30

[Expression 108]

$$f_{jd} = \beta_j \cdot f_{cd} \cdot \lambda_c$$

Formula 4.31

[Expression 109]

$$\lambda_c = \sqrt{A_{c1} / A_{c0}} \leq 3$$

Formula 4.32

[Expression 110]

$$x_{u,c,i} = l_{eff,u,i} \left(1 - \frac{\beta}{2} \right) \quad (i = 3,4,5,6)$$

Formula 4.33

[Expression 111]

$$l_{eff,u,i} = L_{em} - y_{u,n} \quad (i = 3)$$

Formula 4.34

[Expression 112]

$$l_{eff,u,i} = y_{u,n} \quad (i = 6)$$

Formula 4.35

[0196] Here, in Formulas 4.21 to 4.35, "B_f" is the width (mm) of the upper and lower flanges 20A and 20B of the steel beam 20. "t_w" is the plate thickness (mm) of the web 20C of the steel beam 20. "t_{fb}" is the plate thickness (mm) of the face bearing plate 30. "L_{em}" is an embedded length (mm) of the column 10 of the steel beam 20 in the concrete 32.

[0197] "y_n" in Formulas 4.21 to 4.35 is a horizontal distance (mm) in a direction parallel to an x axis from the outer surface (face bearing plate 30 side) of the concrete 32 of the column 10 to the elastic rotation center satisfying the balance of forces at the time of elasticity. The "$y_{u,n}$" is a horizontal distance (mm) from an outer surface of the concrete 32 of the column 10 to the final rotation center. The outer surface of the concrete 32 of the column 10 is a surface on the face bearing plate 30 side.

[0198] (Elastic rigidity and resistance against bearing pressure of face bearing plate and concrete)

In Example 1, the out-of-plane deformation constraint of the face bearing plate 30 by

the web 20C was ignored. The compressive force acting on the axis of the lower flange 20B is set to be transmitted, to the concrete 32, as a uniform bearing pressure force in the plane via the effective bearing pressure region of the face bearing plate 30. The bearing pressure of the face bearing plate 30 and the concrete 32 was set as i = seventh resistance element.

[0199] The elastic rigidity $k_{c,fb}$ (N/mm), a distance $x_{d,c,fb}$ (= $x_{d,7}$ (mm)) from the line of action of the representative displacement in the bearing pressure region at the time of elasticity to the elastic rotation center, a distance (that is, arm length) $x_{l,c,fb}$ (= $x_{l,7}$ (mm)) from the elastic rotation center satisfying the balance of forces at the time of elasticity to the center of gravity of the bearing pressure force, a distance (that is, arm length) $x_{u,c,fb}$ (mm) from the rotation center at the time of the ultimate resistance to the center of gravity of the bearing pressure force, and resistance $F_{c,fb,Rd}$ (N) were set using the following Formulas 4.36 to 4.43.

[0200] The definition of each parameter in the formula is the same as that described in Formulas 1 to 3.17. Table 4 shows parameters used to calculate the rigidity and the resistance by the bearing pressure between the face bearing plate and the concrete. In the experiment in Example 1, "$k_{c,fb}$, $x_{d,c,fb}$, $x_{l,c,fb}$, $F_{c,fb,Rd}$" was calculated from Formulas 4.36 to 4.43 using the conditions (E_c, B_f, t_w, t_{fb}, f_y, γ_{M0}, β_j, $f_{cd,fb}$, A_{c0}, A_{c1}) shown in Table 4.

[Table 4]

[Expression 113]

(i=7)Face plate bearing

i	Parameter for face plate bearing											
	Specification for bearing pressure resistance element between face bearing plate provided in beam and column concrete											
7	$k_{c,fb}$	[N/mm]	11.71	E_c	[N/mm^2]	0						
				$\alpha_{c,fb}$	[-]	0.24	$b_{eff,fb}$	[mm]	191	B_f	[mm]	200
										t_w	[mm]	9
							$l_{eff,fb}$	[mm]	15	t_{fb}	[mm]	16
										f_y	[N/mm^2]	347
	$x_{d,c,fb}$	[mm]	165.6							γ_{M0}	[-]	1
	$x_{l,c,fb}$	[mm]	158.1									
	$F_{c,fb,Rd}$	[kN]	375	$f_{j,d}$	[N/mm^2]	130	β_j	[-]	0			
							$f_{cd,fb}$	[N/mm^2]	0			
							λ_c	[-]	2.00	A_{c0}	[mm^2]	2883
										A_{c1}	[mm^2]	11530

$$k_{c,fb} = \frac{E_c \sqrt{b_{eff,fb} \cdot l_{eff,fb}}}{\alpha_c \sqrt{b_{eff,fb} / l_{eff,fb}}} = \frac{E_c \cdot l_{eff,fb}}{\alpha_{c,fb}}$$ Formula 4.36

[Expression 114]

$$\alpha_{c,fb} = 0.85 \sqrt{l_{eff,fb} / b_{eff,fb}}$$ Formula 4.37

[Expression 115]

$$b_{eff,fb} = B_f - t_w$$ Formula 4.38

[Expression 116]

$$l_{eff,fb} = t_{fb} \sqrt{\frac{f_y}{3\gamma_{M0} \cdot f_{jd,fb}}}$$ Formula 4.39

[Expression 117]

$$x_{d,c,fb} = x_{d,7} = D_s + H - x_n - t_f - l_{eff,fb}$$ Formula 4.40

[Expression 118]

$$x_{l,c,fb} = x_{l,7} = D_s + H - x_n - t_f - \frac{l_{eff,fb}}{2}$$ Formula 4.41

[Expression 119]

$$F_{c,fb,Rd} = f_{jd,fb} \cdot b_{eff,fb} \cdot l_{eff,fb}$$ Formula 4.42

[Expression 120]

$$x_{u,c,fb} = D_s + H - x_{u,n} - t_f - \frac{l_{eff,fb}}{2}$$ Formula 4.43

[0201] (Comparison of elastic rigidity and resistance between experiment and evaluation model)

In Example 1, with respect to the elastic rigidity, "x_n" and "y_n" indicating the position of the elastic rotation center of the beam end 24 were obtained from the balance condition of the external force and the internal force in the vertical direction and the horizontal direction, and the initial rotational rigidity $S_{j,ini}$ was obtained using Formula 4.1.

[0202] Regarding the final moment resistance, "$x_{u,n}$" and "$y_{u,n}$" representing the position of the final rotation center at which the maximum moment resistance $M_{j,Rd}$ was minimized were obtained from simple superposed strength of all resistance elements and the upper bound theorem. When the rigidity reduction rate η was about 3.0, the rigidity reduction rate η well corresponded to the rigidity after nonlinearization of the experiment, and therefore, the value of the rigidity reduction rate η was set to "3.0" in this case.

[0203] The experimental results and the trilinear by an evaluation model are compared and shown in Fig. 14. In Fig. 14, the vertical axis represents the moment of the joint, and the horizontal axis represents the rotation angle of the joint. A solid line in Fig. 14 represents a history of the experimental results, and a dotted line represents the trilinear by the evaluation model. The moment of the joint 14 in the experiment was defined in a face position of the concrete 32 of the column 10. The face position of the concrete 32 of the column 10 is a surface opposite to the X axis among side surfaces of the concrete 32 of the column 10 orthogonal to the X axis direction in Fig. 1.

[0204] As can be seen from Fig. 14, the experiment and the evaluation model are in close agreement.

[0205] Fig. 15 shows a comparison between the rotational rigidity of an unloading cycle for repeated loading in an elastic range and the evaluation model. In Fig. 15, the vertical axis represents the rotational rigidity of the joint in the unloading cycle, and the horizontal axis represents the number of cycles (that is, the number of repetitions). A plot points in Fig. 15 represents the experimental result, and a dotted line represents the evaluation model. Regarding the rotational rigidity of the evaluation model, an experimental lower limit value can be generally evaluated. Table 5 shows specific numerical values in the above comparison results.

[0206] Table 5 shows experimental results of the rotational rigidity and the moment resistance of the joint and calculation results according to the present disclosure. With respect to the average value of the experiments, the final moment resistance has an evaluation accuracy of 93%. The rotational rigidity has an evaluation accuracy of 76 to 77%. The moment resistance is a calculation result on a safety side that is not overestimated.

[0207] With respect to the rotational rigidity, an evaluation error of about 20% hardly affects

an evaluation error of the moment acting on the joint. Thus, it can be said that the evaluation model in the present disclosure has accuracy with no practical problem.

[Table 5]

		Rotational rigidity of joint	Maximum resistance of joint	Secant rigidity in 2/3 $M_{j,Rd}$	Secant rigidity in $M_{j,Rd}$	Rigidity reduction rate
		$S_{j,ini}$	$M_{j,Rd}$	S_j	$S_{j,ini}/\eta$	η
		[kNm/rad]	[kNm]	[kNm/rad]	[kNm/rad]	[-]
Experimental result	1	446096	904	338760	55226	6.1
	2	455718	822	555850	130283	4.3
	Average	450907	863	447305	92754	4.8
Evaluation model	Calculation	342876	803	342876	114292	3.0
	Accuracy	76%	93%	77%	123%	-

[0208] As described above, the trilinear model according to the method of designing a column-beam joint of the present disclosure well corresponded to the present experimental

results in both the elastic rigidity and the maximum moment resistance. Therefore, it could be confirmed that the rotational rigidity S_j and the maximum moment resistance $M_{j,Rd}$ of the joint could be accurately evaluated using the calculation method described in the present disclosure.

[0209] As a result, it is possible to accurately compare an estimated value of the moment acting on the column from the steel beam by the load supported by the steel beam and the rotational rigidity S_j of the portion of the steel beam disposed inside the concrete of the column with the maximum moment resistance that can be resisted by the joint between the column and the beam. As a result, in the column-beam joint of the present disclosure, it is possible to prevent significant irreversible deformation (that is, plastification) from occurring in the joint between the column and the beam, and to ensure stability of deflection of the steel beam and soundness of the column.

[0210] (Example 2)

Also in Example 2, the column-beam joint was designed, and the rotational rigidity and the moment resistance of the joint were evaluated. The rotational rigidity and the moment resistance of the joint were evaluated based on the method of evaluating the rotational rigidity and the moment resistance of the joint described in Example 1 above. Examples of the present disclosure that satisfy the conditions of the present disclosure are shown as Examples. Examples are examples in which the moment (required moment resistance) $M_{j,Ed}$ acting on the joint and estimated from the rotational rigidity S_j calculated according to the evaluation method of the present disclosure and the load supported by the steel beam does not exceed the maximum moment resistance (holding moment resistance) $M_{j,Rd}$ of the joint.

[0211] Examples that do not satisfy the conditions of the present disclosure are shown as comparative examples. Comparative Examples are examples in which the moment $M_{j,Ed}$ acting on the joint and estimated from the rotational rigidity S_j calculated according to the evaluation method of the present disclosure and the load supported by the steel beam is equal to or more than the maximum moment resistance $M_{j,Rd}$ of the joint.

[0212] The design conditions are the materials shown in Table 6, the load conditions shown in Table 7, a distance between respective ends of the steel beam (that is, beam length), and a dominant width at which the steel beam bears the load. Tables 8, 9, 10, and 11 show the design results. As shown in Tables 8 to 11, 101 samples of No. 1 to No. 101 were designed. Table 8 shows design conditions of 48 samples of No. 1 to No. 48, and Table 9 shows design conditions of 53 samples of No. 49 to No. 101. Table 10 shows the design results of 48 samples of No. 1 to No. 48 are shown, and Table 11 shows the design results of 53 samples of No. 49 to No. 101.

[0213] In Example 2, a case where a value ($M_{j,Ed}/M_{j,Rd}$) obtained by dividing the moment, generated in the joint when the elastic rotational rigidity of the joint was assumed, by the

moment resistance held by the joint exceeded 1.00 in the comparison between the maximum (holding) moment resistance and the required moment resistance of the joint was set as a comparative example.

[0214]

[Table 6]

Steel frame		Concrete	
Young's modulus	Yield stress	Young's modulus	Compressive strength
Ea	*fy*	*Ec*	*fcd*
[N/mm ^{2}]	[N/mm ^{2}]	[N/mm ^{2}]	[N/mm ^{2}]
210000	355	39000	60

[0215]

[Table 7]

Fixed loading load	Variable load	Beam length	Dominant width
[kN/m^2]	[kN/m^2]	[m]	[m]
1.0	3.0	12.0	10.0

[0216]

[Table 8]

No.	Design condition													
	Floor slab	Dimension of steel beam					Load supported by steel beam		Dimension of embedded portion		Stud in column			Face bearing plate
	Thickness of floor slab	Height of cross section	Width of flange	Plate thickness of web	Plate thickness of flange	Cross-sectional secondary moment	Own weight of structure	Loading load	Embedded length of steel beam with respect to column concrete	Embedded length ratio	Diameter	Distance from shaft core of stud at the most back side from concrete surface of column to concrete surface of column	Number	Plate thickness
	D_s	H	B_f	t_w	t_f	I_a	S_w	w	L_{em}	L_{em}/H	ϕ_{st}	c	n_r	t_{fb}
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm4]	[kN/m2]	[kN/m]	[mm]	[-]	[mm]	[mm]	[本]	[mm]
1	150	700	200	9	12	830000000	4.1	40	100	0.14	Nothing	Nothing	Nothing	Nothing
2	150	700	200	9	12	830000000	4.1	40	150	0.21	Nothing	Nothing	Nothing	Nothing
3	150	700	200	9	12	830000000	4.1	40	200	0.29	Nothing	Nothing	Nothing	Nothing
4	150	700	200	9	12	830000000	4.1	40	250	0.36	Nothing	Nothing	Nothing	Nothing
5	150	700	200	9	12	830000000	4.1	40	300	0.43	Nothing	Nothing	Nothing	Nothing
6	150	700	200	9	12	830000000	4.1	40	350	0.50	Nothing	Nothing	Nothing	Nothing
7	150	700	200	9	12	830000000	4.1	40	400	0.57	Nothing	Nothing	Nothing	Nothing
8	150	700	200	9	12	830000000	4.1	40	450	0.64	Nothing	Nothing	Nothing	Nothing
9	150	700	200	9	12	830000000	4.1	40	500	0.71	Nothing	Nothing	Nothing	Nothing
10	150	700	200	9	12	830000000	4.1	40	550	0.79	Nothing	Nothing	Nothing	Nothing
11	150	700	200	9	12	830000000	4.1	40	600	0.86	Nothing	Nothing	Nothing	Nothing
12	150	700	200	9	12	830000000	4.1	40	650	0.93	Nothing	Nothing	Nothing	Nothing
13	150	700	200	9	12	830000000	4.1	40	700	1.00	Nothing	Nothing	Nothing	Nothing
14	150	700	200	9	12	830000000	4.1	40	100	0.14	19	150	2	12
15	150	700	200	9	12	830000000	4.1	40	150	0.21	19	150	2	12
16	150	700	200	9	12	830000000	4.1	40	200	0.29	19	150	2	12
17	150	700	200	9	12	830000000	4.1	40	250	0.36	19	150	2	12
18	150	700	200	9	12	830000000	4.1	40	300	0.43	19	150	2	12
19	150	700	200	9	12	830000000	4.1	40	350	0.50	19	150	2	12
20	150	700	200	9	12	830000000	4.1	40	400	0.57	19	150	2	12
21	150	700	200	9	12	830000000	4.1	40	450	0.64	19	150	2	12
22	150	700	200	9	12	830000000	4.1	40	500	0.71	19	150	2	12
23	150	700	200	9	12	830000000	4.1	40	550	0.79	19	150	2	12
24	150	700	200	9	12	830000000	4.1	40	600	0.86	19	150	2	12
25	150	700	200	9	12	830000000	4.1	40	650	0.93	19	150	2	12
26	150	700	200	9	12	830000000	4.1	40	700	1.00	19	150	2	12
27	150	600	200	9	12	570000000	4.1	40	100	0.17	Nothing	Nothing	Nothing	Nothing
28	150	600	200	9	12	570000000	4.1	40	150	0.25	Nothing	Nothing	Nothing	Nothing
29	150	600	200	9	12	570000000	4.1	40	200	0.33	Nothing	Nothing	Nothing	Nothing
30	150	600	200	9	12	570000000	4.1	40	250	0.42	Nothing	Nothing	Nothing	Nothing
31	150	600	200	9	12	570000000	4.1	40	300	0.50	Nothing	Nothing	Nothing	Nothing
32	150	600	200	9	12	570000000	4.1	40	350	0.58	Nothing	Nothing	Nothing	Nothing
33	150	600	200	9	12	570000000	4.1	40	400	0.67	Nothing	Nothing	Nothing	Nothing
34	150	600	200	9	12	570000000	4.1	40	450	0.75	Nothing	Nothing	Nothing	Nothing
35	150	600	200	9	12	570000000	4.1	40	500	0.83	Nothing	Nothing	Nothing	Nothing
36	150	600	200	9	12	570000000	4.1	40	550	0.92	Nothing	Nothing	Nothing	Nothing
37	150	600	200	9	12	570000000	4.1	40	600	1.00	Nothing	Nothing	Nothing	Nothing
38	150	600	200	9	12	570000000	4.1	40	100	0.17	19	150	2	12
39	150	600	200	9	12	570000000	4.1	40	150	0.25	19	150	2	12
40	150	600	200	9	12	570000000	4.1	40	200	0.33	19	150	2	12
41	150	600	200	9	12	570000000	4.1	40	250	0.42	19	150	2	12
42	150	600	200	9	12	570000000	4.1	40	300	0.50	19	150	2	12
43	150	600	200	9	12	570000000	4.1	40	350	0.58	19	150	2	12
44	150	600	200	9	12	570000000	4.1	40	400	0.67	19	150	2	12
45	150	600	200	9	12	570000000	4.1	40	450	0.75	19	150	2	12
46	150	600	200	9	12	570000000	4.1	40	500	0.83	19	150	2	12
47	150	600	200	9	12	570000000	4.1	40	550	0.92	19	150	2	12
48	150	600	200	9	12	570000000	4.1	40	600	1.00	19	150	2	12

[0217]

[Table 9]

No.	Design condition													
	Floor slab	Dimension of steel beam					Load supported by steel beam		Dimension of embedded portion		Stud in column			Face bearing plate
	Thickness of floor slab	Height of cross section	Width of flange	Plate thickness of web	Plate thickness of flange	Cross-sectional secondary moment	Own weight of structure	Loading load	Embedded length of steel beam with respect to column concrete	Embedded length ratio	Diameter	Distance from shaft core of stud at the most back side from concrete surface of column to concrete surface of column	Number	Plate thickness
	D_s	H	B_f	t_w	t_f	I_a	S_w	w	L_{em}	L_{em}/H	ϕ_{st}	c	n_r	t_{fb}
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm4]	[kN/m2]	[kN/m]	[mm]	[-]	[mm]	[mm]	[本]	[mm]
49	150	500	200	9	12	370000000	4.1	40	100	0.20	Nothing	Nothing	Nothing	Nothing
50	150	500	200	9	12	370000000	4.1	40	150	0.30	Nothing	Nothing	Nothing	Nothing
51	150	500	200	9	12	370000000	4.1	40	200	0.40	Nothing	Nothing	Nothing	Nothing
52	150	500	200	9	12	370000000	4.1	40	250	0.50	Nothing	Nothing	Nothing	Nothing
53	150	500	200	9	12	370000000	4.1	40	300	0.60	Nothing	Nothing	Nothing	Nothing
54	150	500	200	9	12	370000000	4.1	40	350	0.70	Nothing	Nothing	Nothing	Nothing
55	150	500	200	9	12	370000000	4.1	40	400	0.80	Nothing	Nothing	Nothing	Nothing
56	150	500	200	9	12	370000000	4.1	40	450	0.90	Nothing	Nothing	Nothing	Nothing
57	150	500	200	9	12	370000000	4.1	40	500	1.00	Nothing	Nothing	Nothing	Nothing
58	150	500	200	9	12	370000000	4.1	40	550	1.10	Nothing	Nothing	Nothing	Nothing
59	150	500	200	9	12	370000000	4.1	40	600	1.20	Nothing	Nothing	Nothing	Nothing
60	150	500	200	9	12	370000000	4.1	40	650	1.30	Nothing	Nothing	Nothing	Nothing
61	150	500	200	9	12	370000000	4.1	40	700	1.40	Nothing	Nothing	Nothing	Nothing
62	150	500	200	9	12	370000000	4.1	40	100	0.20	19	150	2	12
63	150	500	200	9	12	370000000	4.1	40	150	0.30	19	150	2	12
64	150	500	200	9	12	370000000	4.1	40	200	0.40	19	150	2	12
65	150	500	200	9	12	370000000	4.1	40	250	0.50	19	150	2	12
66	150	500	200	9	12	370000000	4.1	40	300	0.60	19	150	2	12
67	150	500	200	9	12	370000000	4.1	40	350	0.70	19	150	2	12
68	150	500	200	9	12	370000000	4.1	40	400	0.80	19	150	2	12
69	150	500	200	9	12	370000000	4.1	40	450	0.90	19	150	2	12
70	150	500	200	9	12	370000000	4.1	40	500	1.00	19	150	2	12
71	150	500	200	9	12	370000000	4.1	40	550	1.10	19	150	2	12
72	150	500	200	9	12	370000000	4.1	40	650	1.30	19	150	2	12
73	150	500	200	9	12	370000000	4.1	40	700	1.40	19	150	2	12
74	150	800	250	12	22	2.14E+09	4.2	40	100	0.13	Nothing	Nothing	Nothing	Nothing
75	150	800	250	12	22	2.14E+09	4.2	40	150	0.19	Nothing	Nothing	Nothing	Nothing
76	150	800	250	12	22	2.14E+09	4.2	40	200	0.25	Nothing	Nothing	Nothing	Nothing
77	150	800	250	12	22	2.14E+09	4.2	40	250	0.31	Nothing	Nothing	Nothing	Nothing
78	150	800	250	12	22	2.14E+09	4.2	40	300	0.38	Nothing	Nothing	Nothing	Nothing
79	150	800	250	12	22	2.14E+09	4.2	40	350	0.44	Nothing	Nothing	Nothing	Nothing
80	150	800	250	12	22	2.14E+09	4.2	40	400	0.50	Nothing	Nothing	Nothing	Nothing
81	150	800	250	12	22	2.14E+09	4.2	40	450	0.56	Nothing	Nothing	Nothing	Nothing
82	150	800	250	12	22	2.14E+09	4.2	40	500	0.63	Nothing	Nothing	Nothing	Nothing
83	150	800	250	12	22	2.14E+09	4.2	40	550	0.69	Nothing	Nothing	Nothing	Nothing
84	150	800	250	12	22	2.14E+09	4.2	40	600	0.75	Nothing	Nothing	Nothing	Nothing
85	150	800	250	12	22	2.14E+09	4.2	40	650	0.81	Nothing	Nothing	Nothing	Nothing
86	150	800	250	12	22	2.14E+09	4.2	40	700	0.88	Nothing	Nothing	Nothing	Nothing
87	150	800	250	12	22	2.14E+09	4.2	40	750	0.94	Nothing	Nothing	Nothing	Nothing
88	150	800	250	12	22	2.14E+09	4.2	40	100	0.13	19	150	2	12
89	150	800	250	12	22	2.14E+09	4.2	40	150	0.19	19	150	2	12
90	150	800	250	12	22	2.14E+09	4.2	40	200	0.25	19	150	2	12
91	150	800	250	12	22	2.14E+09	4.2	40	250	0.31	19	150	2	12
92	150	800	250	12	22	2.14E+09	4.2	40	300	0.38	19	150	2	12
93	150	800	250	12	22	2.14E+09	4.2	40	350	0.44	19	150	2	12
94	150	800	250	12	22	2.14E+09	4.2	40	400	0.50	19	150	2	12
95	150	800	250	12	22	2.14E+09	4.2	40	450	0.56	19	150	2	12
96	150	800	250	12	22	2.14E+09	4.2	40	500	0.63	19	150	2	12
97	150	800	250	12	22	2.14E+09	4.2	40	550	0.69	19	150	2	12
98	150	800	250	12	22	2.14E+09	4.2	40	600	0.75	19	150	2	12
99	150	800	250	12	22	2.14E+09	4.2	40	650	0.81	19	150	2	12
100	150	800	250	12	22	2.14E+09	4.2	40	700	0.88	19	150	2	12
101	150	800	250	12	22	2.14E+09	4.2	40	750	0.94	19	150	2	12

[0218]

[Table 10]

No.	Design result								Section
	Evaluation model of joint								
	Maximum resistance	Rigidity reduction rate	Fixation degree	Rotational rigidity	Acting moment of joint of rigid joint calculated from load supported by steel beam	Acting moment of joint calculated from load supported by steel beam and rotational rigidity	$M_{j,Ed}/M_{j,Rd}$	Implementation propriety	
	$M_{j,Rd}$	η	α_{rig}	S_j	$M_{j,Ed,rigid}$	$M_{j,Ed}$ by S_j		$C_{ompatibility}$	
	[kNm]	[-]	[-]	[kNm/rad]	[kNm]	[kNm]	[-]		
1	92	3	0.12	5927	720	86	0.94	OK	Example
2	207	3	0.28	16954	720	202	0.98	OK	Example
3	367	3	0.45	35569	720	324	0.88	OK	Example
4	574	3	0.59	63034	720	426	0.74	OK	Example
5	827	3	0.70	100475	720	502	0.61	OK	Example
6	1125	1	0.91	446799	720	656	0.58	OK	Example
7	1470	1	0.94	628172	720	673	0.46	OK	Example
8	1860	1	0.95	848487	720	685	0.37	OK	Example
9	2296	1	0.96	1110542	720	693	0.30	OK	Example
10	2779	1	0.97	1416961	720	699	0.25	OK	Example
11	3307	1	0.98	1770594	720	703	0.21	OK	Example
12	3881	1	0.98	2174241	720	706	0.18	OK	Example
13	4501	1	0.98	2630750	720	708	0.16	OK	Example
14	259	3	0.56	55683	720	404	1.56	Not Okay	Comparative Example
15	374	3	0.60	66700	720	435	1.17	Not Okay	Comparative Example
16	534	3	0.66	85365	720	477	0.89	OK	Example
17	741	3	0.72	112916	720	520	0.70	OK	Example
18	994	1	0.91	451442	720	657	0.66	OK	Example
19	1292	1	0.93	597270	720	671	0.52	OK	Example
20	1637	1	0.95	779195	720	682	0.42	OK	Example
21	2027	1	0.96	1000303	720	690	0.34	OK	Example
22	2463	1	0.97	1263039	720	696	0.28	OK	Example
23	2946	1	0.97	1570320	720	701	0.24	OK	Example
24	3474	1	0.98	1924922	720	704	0.20	OK	Example
25	4048	1	0.98	2329648	720	707	0.17	OK	Example
26	4668	1	0.98	2787351	720	709	0.15	OK	Example
27	92	3	0.16	5898	720	119	1.29	Not Okay	Comparative Example
28	207	3	0.36	16922	720	260	1.26	Not Okay	Comparative Example
29	367	3	0.54	35531	720	391	1.06	Not Okay	Comparative Example
30	574	3	0.68	62986	720	488	0.85	OK	Example
31	827	3	0.77	100413	720	555	0.67	OK	Example
32	1125	1	0.94	446561	720	675	0.60	OK	Example
33	1470	1	0.95	627879	720	687	0.47	OK	Example
34	1860	1	0.97	848219	720	695	0.37	OK	Example
35	2296	1	0.97	1110137	720	701	0.31	OK	Example
36	2779	1	0.98	1416500	720	705	0.25	OK	Example
37	3307	1	0.98	1770081	720	708	0.21	OK	Example
38	234	3	0.58	42061	720	421	1.79	Not Okay	Comparative Example
39	349	3	0.64	53092	720	460	1.32	Not Okay	Comparative Example
40	510	3	0.71	71745	720	508	1.00	OK	Example
41	717	3	0.77	99270	720	553	0.77	OK	Example
42	969	3	0.82	136796	720	591	0.61	OK	Example
43	1268	1	0.95	556034	720	683	0.54	OK	Example
44	1612	1	0.96	737896	720	692	0.43	OK	Example
45	2003	1	0.97	958630	720	698	0.35	OK	Example
46	2439	1	0.98	1221108	720	703	0.29	OK	Example
47	2921	1	0.98	1528107	720	706	0.24	OK	Example
48	3449	1	0.98	1882399	720	709	0.21	OK	Example

[0219]

[Table 11]

No.	Design result								Section
	Evaluation model of joint								
	Maximum resistance	Rigidity reduction rate	Fixation degree	Rotational rigidity	Acting moment of joint of rigid joint calculated from load supported by steel beam	Acting moment of joint calculated from load supported by steel beam and rotational rigidity	$M_{j,Ed}/M_{j,Rd}$	Implementation propriety	
	$M_{j,Rd}$	η	α_{rig}	S_j	$M_{j,Ed,rigid}$	$M_{j,Ed}$ by S_j		Compatibility	
	[kNm]	[-]	[-]	[kNm/rad]	[kNm]	[kNm]	[-]		
49	92	3	0.23	5881	720	167	1.82	Not Okay	Comparative Example
50	207	3	0.47	16902	720	335	1.62	Not Okay	Comparative Example
51	367	3	0.65	35504	720	465	1.27	Not Okay	Comparative Example
52	574	3	0.76	62951	720	550	0.96	OK	Example
53	827	3	0.84	100368	720	603	0.73	OK	Example
54	1125	1	0.96	446392	720	690	0.61	OK	Example
55	1470	1	0.97	627728	720	698	0.48	OK	Example
56	1860	1	0.98	847988	720	704	0.38	OK	Example
57	2296	1	0.98	1109883	720	708	0.31	OK	Example
58	2779	1	0.99	1416234	720	710	0.26	OK	Example
59	3307	1	0.99	1769826	720	712	0.22	OK	Example
60	3881	1	0.99	2173471	720	714	0.18	OK	Example
61	4501	1	0.99	2630033	720	715	0.16	OK	Example
62	210	3	0.61	30645	720	441	2.10	Not Okay	Comparative Example
63	325	3	0.68	41680	720	491	1.51	Not Okay	Comparative Example
64	485	3	0.76	60317	720	545	1.12	Not Okay	Comparative Example
65	692	3	0.82	87815	720	590	0.85	OK	Example
66	945	3	0.87	125297	720	623	0.66	OK	Example
67	1243	1	0.96	521422	720	694	0.56	OK	Example
68	1588	1	0.97	703118	720	701	0.44	OK	Example
69	1978	1	0.98	923673	720	705	0.36	OK	Example
70	2414	1	0.98	1185957	720	708	0.29	OK	Example
71	2897	1	0.99	1492751	720	711	0.25	OK	Example
72	3999	1	0.99	2251004	720	714	0.18	OK	Example
73	4619	1	0.99	2708203	720	715	0.15	OK	Example
74	115	3	0.06	6774	720	41	0.36	OK	Example
75	258	3	0.15	19089	720	105	0.40	OK	Example
76	459	3	0.26	39903	720	189	0.41	OK	Example
77	718	1	0.65	211844	720	470	0.66	OK	Example
78	1033	1	0.75	337433	720	540	0.52	OK	Example
79	1407	1	0.82	499965	720	588	0.42	OK	Example
80	1837	1	0.86	702708	720	621	0.34	OK	Example
81	2325	1	0.89	948971	720	644	0.28	OK	Example
82	2870	1	0.92	1241667	720	660	0.23	OK	Example
83	3473	1	0.93	1584075	720	672	0.19	OK	Example
84	4134	1	0.95	1979047	720	681	0.16	OK	Example
85	4851	1	0.96	2429762	720	688	0.14	OK	Example
86	5626	1	0.96	2939524	720	693	0.12	OK	Example
87	6459	1	0.97	3511088	720	698	0.11	OK	Example
88	304	3	0.39	71717	720	281	0.92	OK	Example
89	447	3	0.43	83974	720	308	0.69	OK	Example
90	648	3	0.48	104823	720	348	0.54	OK	Example
91	907	1	0.78	406879	720	564	0.62	OK	Example
92	1222	1	0.83	532904	720	595	0.49	OK	Example
93	1596	1	0.86	695976	720	620	0.39	OK	Example
94	2026	1	0.89	899417	720	640	0.32	OK	Example
95	2514	1	0.91	1146508	720	656	0.26	OK	Example
96	3060	1	0.93	1440134	720	668	0.22	OK	Example
97	3662	1	0.94	1783647	720	677	0.18	OK	Example
98	4323	1	0.95	2179819	720	685	0.16	OK	Example
99	5040	1	0.96	2631874	720	691	0.14	OK	Example
100	5815	1	0.97	3142967	720	695	0.12	OK	Example
101	6648	1	0.97	3716327	720	699	0.11	OK	Example

[0220] A fixed loading load (SDL) in Table 7 is a load that constantly acts on the beam except for an own weight Sw of a structure. A variable load (LL) is a maximum load that is considered

to act during a common use period of a building except for the own weight Sw of the structure and the fixed loading load. A product of a sum of the fixed loading load, the variable load, and the own weight of the structure and the dominant width is set as a loading load w (see Tables 8 and 9) of a uniform distribution.

[0221] "L_{em}" in Tables 8 and 9 is the embedded length of the beam with respect to the column concrete. "D_s" represents a thickness of a floor slab. "H, B_f, t_w, t_f" represents the height of the cross section of the steel beam, a width of the flange, a plate thickness of the web, and a plate thickness of the flange, respectively. "I_a" represents a cross-sectional secondary moment of the steel beam. "t_{fb}" represents the plate thickness of the face bearing plate.

[0222] The design conditions shown in Tables 6 and 7 were set to be unchanged. With the cross-sectional dimension (H, B_f, t_w, t_f) of the steel beam, the embedded length L_{em} of the beam with respect to the column concrete, and the presence or absence of the additional member (that is, the stud in the column and the face bearing plate) as parameters, the rotational rigidity S_j of the joint, the maximum moment resistance $M_{j,Rd}$ of the joint, and the moment $M_{j,Ed}$ generated in the joint were calculated using the method of designing a joint, which was proposed in the present disclosure. The embedded length L_{em} was set to a maximum embeddable dimension limited by the diameter of the column and the steel frame of the column.

[0223] In the case where the additional member was provided, the diameter φ_{st} of the stud was set to 19 mm. An embedded depth c from the surface of the column to the shaft core of the stud in the length direction of the steel beam was set to 150 mm. The number of studs was two, and the two studs were arranged in a row in the Y-axis direction. An interval between the two studs was unified to 100 mm. The plate thickness t_{fb} of the face bearing plate was unified to 12 mm. No joint reinforcement bar was provided.

[0224] Fig. 16 is a graph in which data points are plotted for the design results shown in Tables 8, 9, 10, and 11. In Fig. 16, an embedded length ratio L_{em}/H (= embedded length ÷ beam depth) is set on the horizontal axis, and a fixation degree α_{rig} (= moment generated at the joint in each design example ÷ moment generated at the joint when the joint is rigid joint) is set on the vertical axis.

[0225] Fig. 17 is a graph in which data points are plotted for the design results shown in Tables 8, 9, 10, and 11. In Fig. 17, the embedded length ratio L_{em}/H (= embedded length ÷ beam depth) is set on the horizontal axis, and the bending moment ratio (= moment $M_{j,Ed}$ generated at the joint in each design example ÷ maximum moment resistance $M_{j,Rd}$ of the joint in each design example) is set on the vertical axis.

[0226] In Example of the present disclosure in Fig. 17, when the bending moment ratio $M_{j,Ed}/M_{j,Rd}$ is 1.00 or less, the maximum moment resistance $M_{j,Rd}$ of the joint exceeds the

moment $M_{j,Ed}$ of the joint generated by the rotational rigidity of the joint, and it is shown that design requirements are satisfied. The case where the bending moment ratio $M_{j,Ed}/M_{j,Rd}$ is 1.00 or less means a state where the moment $M_{j,Ed}$ of the joint calculated using the load supported by the steel beam and the rotational rigidity S_j does not exceed the maximum moment resistance $M_{j,Rd}$ that the joint can resist.

[0227] On the other hand, in Comparative Example, when the bending moment ratio exceeds 1.00, it indicates that the moment resistance of the joint is insufficient with respect to the moment of the joint generated by the rotational rigidity of the joint, and the design requirements are not satisfied.

[0228] As illustrated in Fig. 17, in particular, when the embedded length ratio L_{em}/H is 0.6 or less, the moment resistance of the joint is insufficient as in Comparative Example, and if the additional member, the span of the beam, the cross-sectional shape, and the like are not adjusted, there is a high possibility that the moment resistance is insufficient. For this reason, by setting the bending moment ratio $M_{j,Ed}/M_{j,Rd}$ to 1.00 or less using the method of designing a column-beam joint according to the present embodiment, the maximum moment resistance $M_{j,Rd}$ of the joint exceed the moment $M_{j,Ed}$ of the joint, and it is possible to suppress occurrence of Comparative Example and to satisfy the design requirements as in Example.

[0229] In addition, in the region where the embedded length ratio L_{em}/H is 0.5 or less in Fig. 17, a probability of occurrence of Comparative Example in which the moment resistance of the joint is insufficient further increases. Thus, the present embodiment is more advantageous in the region where the embedded length ratio L_{em}/H is 0.5 or less.

[0230] As shown in Tables 8, 9, 10, and 11, and Fig. 17, in the joint in which the steel beam is simply embedded in the column concrete without the additional member, in a case where the height of the cross section of the beam is 500 mm (about 1/24 of a beam length of 12 m) or less, when the embedded length ratio L_{em}/H is 0.4 or less, the moment resistance of the joint is insufficient, and the joint cannot be adopted as the column-beam joint (Nos. 49, 50, 51).

[0231] As shown in Nos. 27, 28, and 29 in Tables 8, 9, 10, and 11, and Fig. 17, in the joint in which the steel beam is simply embedded in the column concrete without the additional member, in a case where the height of the cross section of the beam is 600 mm or less, when the embedded length ratio L_{em}/H is 0.33 or less, the moment resistance of the joint is insufficient, and the joint cannot be adopted as the column-beam joint. The height 600 mm of the cross section of the beam is about 1/20 of the length 12 m of the beam. However, while No. 29 in which the embedded length ratio L_{em}/H was 0.33 was Comparative Example, in No. 40 in which the cross section of the steel beam and the embedded length were the same and the additional member was provided, the moment resistance of the joint by adjusting the additional member

satisfied a required value. The additional members of No. 40 are the stud in the column and the face bearing plate. For this reason, No. 40 can be adopted as the column-beam joint, and is Example of the present disclosure.

[0232] As can be seen from Figs. 16 and 17, the fixation degree α_{rig} and the bending moment ratio change depending on not only the embedded length ratio L_{em}/H but also the cross-sectional shape of the beam and the presence or absence of the stud. That is, even when the embedded length ratio L_{em}/H is the same and the load condition is the same, depending on the cross-sectional shape of the beam and the presence or absence of the additional member such as the stud, the moment resistance of the joint may or may not satisfy the condition of the present disclosure.

[0233] In the above embodiment, the example in which the total number n of resistance elements is n = 7 has been described, however, the value of the total number n can be appropriately set by adjusting the number of additional members or the like to increase or decrease the number of resistance elements. For example, when the reinforcement bar, the stud, and the face bearing plate, which are additional members, are omitted in the column-beam joint described in the above embodiment, the total number of resistance elements is n = 4. In this case, the elastic rotation center of the beam end of the steel beam disposed inside the concrete of the column can be obtained as a point at which the sum, obtained by accumulating the reaction force of the resistance element i for i = 1 to 4, and the vertical load in the –Z direction acting on the steel beam are balanced.

[0234] In the above embodiment, the rotational rigidity and the moment resistance of the joint are mainly adjusted by the additional member of the steel beam. However, the rotational rigidity and the moment resistance of the joint may be adjusted only by adjusting the distance (that is, the beam length) between respective ends of the steel beam or only by adjusting the cross-sectional shape of the beam end in the longitudinal direction in the steel beam.

[0235] In addition, for the additional member provided as the resistance element, at least one of an arrangement, shape, dimension, or number of the additional members is adjusted. For example, the arrangement, shape, dimension, number, or the like of each of the reinforcement bar and the stud can be adjusted, or the position, shape, dimension, number, or the like of the face bearing plate can be adjusted. The required moment resistance and the maximum moment resistance are changed and adjusted depending on the presence or absence and amount of the additional member.

[0236] As described above, in the state where the resistance element designed using the method of designing a column-beam joint of the present disclosure is provided, at least one end in the longitudinal direction of the steel beam is embedded in the concrete of the column in the

semi-rigid joint state, whereby the method of manufacturing a column-beam joint according to the present disclosure can be achieved. Although one embodiment of the present disclosure has been described above, the present disclosure is not limited to the above embodiment, and it is a matter of course that various other modifications can be made without departing from the gist of the present disclosure.

[0237]

10 column

12 beam

16 reinforcement bar

18 steel frame

20A upper flange (resistance element)

20B lower flange (resistance element)

26 stud (resistance element)

28 joint reinforcement bar (resistance element)

30 face bearing plate (resistance element)

32 concrete

32a slab concrete

34 bolt (resistance element)

36 fin plate (resistance element)

[0238] <<Additional remarks>>

From the present specification, the following aspects are conceptualized.

[0239] That is, a first aspect is

a method of designing a column-beam joint including a concrete column, a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state, and a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam, and the method includes

defining rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint as a rotational rigidity S_j,

calculating a required moment resistance, acting on the column-beam joint from the steel beam, using a load supported by the steel beam and the rotational rigidity S_j, and

adjusting at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam so that the required moment resistance calculated does not exceed a maximum moment resistance that can be resisted by the column-beam joint.

[0240] A second aspect is

a method of designing a column-beam joint including a concrete column, a steel beam

in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state, and a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam, and the method includes

defining rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint as a rotational rigidity S_j, and

calculating a required moment resistance, acting on the column-beam joint from the steel beam, using a load supported by the steel beam and the rotational rigidity S_j, which is determined by the following process A.

<Process A>

A total number of the resistance elements is denoted by n, i is a given natural number from 1 to n, and the resistance elements are denoted as resistance element i,

the reaction force of the resistance element i is represented by a product of rigidity k_i of the resistance element i and a deformation amount,

a rotation center of the portion of the steel beam inside the concrete of the column is denoted by a point at which the reaction force of the resistance element i and an external force are balanced,

a distance between a line of action of a representative displacement of the resistance element i and the rotation center is denoted by $x_{d,i}$,

a distance between a center of gravity of the reaction force of the resistance element i and the rotation center is denoted by $x_{l,i}$, and

the rotational rigidity S_j is determined based on evaluation of a value obtained by the following Formula 1.

[Expression 121]

$$S_j = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 1}$$

[0241] A third aspect is

the method of designing a column-beam joint according to the second aspect, and

the method further includes

adjusting at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam such that the required moment resistance does not exceed a maximum moment resistance that can be resisted by the column-beam joint.

[0242] A fourth aspect is

the method of designing a column-beam joint according to the first or third aspect, in which

the resistance element includes an additional member provided at the portion of the steel beam inside the concrete and at a peripheral edge of the portion, and

the required moment resistance or the maximum moment resistance of the column-beam joint is established by adjusting at least one of an arrangement, shape, or dimension of the additional member.

[0243] A fifth aspect is

the method of designing a column-beam joint according to any one of the first, third, and fourth aspects, in which

a maximum reaction force borne by a resistance element i of the portion of the steel beam inside the concrete is denoted by $F_{i,Rd}$,

the maximum moment resistance of the column-beam joint is denoted by $M_{j,Rd}$,

a distance between a rotation center of the steel beam and a line of action of the reaction force is denoted by $x_{u,i}$, and

a minimum value of $M_{j,Rd}$ calculated using the following Formula 2 is established as the maximum moment resistance with a position of the rotation center as a variable.

[Expression 122]

$$M_{j,Rd} = \sum_{i} F_{i,Rd} \cdot x_{u,i} \qquad \text{Formula 2}$$

[0244] A sixth aspect is

the method of designing a column-beam joint according to any one of the first to fifth aspects, in which

an embedded length ratio obtained by dividing an embedded length of the end of the steel beam in the concrete of the column by a beam depth of the steel beam is 0.6 or less.

[0245] A seventh aspect is

a method of manufacturing a column-beam joint, the method including

embedding at least one end in a longitudinal direction of a steel beam inside concrete of a column in a semi-rigid joint state, in a state in which a resistance element designed using the method of designing a column-beam joint according to any one of the first to sixth aspects is provided.

[0246] An eight aspect is

a column-beam joint structure including

a concrete column,

a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state, and

a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam, in which

when rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint is defined as a rotational rigidity S_j and a moment generated by a maximum resistance that can be resisted by the resistance element is defined as a maximum moment resistance that can be resisted by the column-beam joint,

as a required moment resistance acting on the column-beam joint from the steel beam, at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam is adjusted so that the required moment resistance calculated using a load supported by the steel beam and the rotational rigidity S_j does not exceed the maximum moment resistance.

[0247] A ninth aspect is

a column-beam joint structure including

a concrete column,

a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state, and

a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam, in which

when rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint is defined as a rotational rigidity S_j, as a required moment resistance acting on the column-beam joint from the steel beam, the required moment resistance is set using a load supported by the steel beam and the rotational rigidity S_j, which is determined by the following process B.

<Process B>

A total number of the resistance elements is denoted by n, i is a given natural number from 1 to n, and the resistance elements are denoted as resistance element i,

the reaction force of the resistance element i is represented by a product of rigidity k_i of the resistance element i and a deformation amount,

a rotation center of the portion of the steel beam inside the concrete of the column is denoted by a point at which the reaction force of the resistance element i and an external force are balanced,

a distance between a line of action of a representative displacement of the resistance element i and the rotation center is denoted by $x_{d,i}$,

a distance between a center of gravity of the reaction force of the resistance element i and the rotation center is denoted by $x_{l,i}$, and

the rotational rigidity S_j is determined as a value satisfying the following Formula 3.

[Expression 123]

$$S_j = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 3}$$

[0248] A tenth aspect is

the column-beam joint structure according to the ninth aspect, in which

at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam is adjusted so that the required moment resistance does not exceed a maximum moment resistance that can be resisted by the column-beam joint.

[0249] An eleventh aspect is

the column-beam joint structure according to the eighth or tenth aspect, in which

at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam is adjusted so that the required moment resistance does not exceed a maximum moment resistance that can be resisted by the column-beam joint.

[0250] A twelfth aspect is

the column-beam joint structure according to any one of the eighth, tenth, and eleventh aspects, in which

the resistance element includes an additional member provided at the portion of the steel beam inside the concrete and at a peripheral edge of the portion, and

the required moment resistance or the maximum moment resistance of the column-beam joint is established by adjusting at least one of an arrangement, shape, or dimension of the additional member.

[Expression 124]

$$M_{j,Rd} = \sum_i F_{i,Rd} \cdot x_{u,i} \qquad \text{Formula 4}$$

[0251] A thirteenth aspect is

the column-beam joint structure according to any one of the eighth to twelfth aspects, in which

an embedded length ratio obtained by dividing an embedded length of the end of the steel beam in the concrete of the column by a beam depth of the steel beam is 0.6 or less.

[0252] <<Other aspects>>

From the present specification, the following other aspects are conceptualized.

[0253] That is, another first aspect is

a column-beam joint structure including a concrete column, and a steel beam in which at least one end in a longitudinal direction is disposed in concrete of the column, in which

when rotational resistance per unit rotation angle of a portion of the steel beam disposed inside the concrete of the column is a rotational rigidity S_j, a force acting on the column from the steel beam is estimated by a load supported by the steel beam and the rotational rigidity S_j of the portion of the steel beam disposed inside the concrete of the column, the steel beam has a resistance element that generates a reaction force against rotation of the portion of the steel beam disposed inside the concrete of the column so that the force acting on the column from the steel beam does not exceed maximum resistance that can be resisted by the concrete of the column, and

the reaction force of the resistance element is adjusted by adjusting, at least, a distance between respective ends of the steel beam and/or a cross-sectional shape of the steel beam.

[0254] Another second aspect is

the column-beam joint structure according to another first aspect, in which

the resistance element includes the portion of the steel beam disposed inside the concrete of the column, and an additional member provided at a peripheral edge of the portion, and the reaction force of the resistance element is adjusted by adjusting at least one of an arrangement, shape, or dimension of the additional member.

[0255] Another third aspect is

the column-beam joint structure according to another first or second aspect, in which

when a total number of the resistance elements is n, i is a given natural number from 1 to n, and the resistance element provided in the steel beam is a resistance element i,

the reaction force of the resistance element i is represented by a product of rigidity k_i of the resistance element i and a deformation amount,

an elastic rotation center of a portion disposed inside the concrete of the column is denoted by a point at which the reaction force of the resistance element i and an external force are balanced,

a distance between a line of action of a representative displacement of the resistance element i and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is denoted by $x_{d,i}$,

a distance between a center of gravity of the reaction force of the resistance element i and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is denoted by $x_{l,i}$, and

the rotational rigidity S_j is determined as a value satisfying the following Formula 1.

[Expression 125]

$$S_j = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 1}$$

[0256] Another fourth aspect is

the column-beam joint structure according to any one of another first to third aspects, in which a reaction force of the resistance element i of the portion of the steel beam disposed inside the concrete of the column and a maximum reaction force that can be borne by the resistance element are denoted by $F_{i,Rd}$,

resistance of the joint is denoted by $M_{j,Rd}$,

a distance between a rotation center of the portion of the steel beam disposed inside the concrete of the column and a line of action of the reaction force is denoted by $x_{u,i}$, and

$M_{j,Rd}$ is calculated using the following Formula 2 with a position of the rotation center as a variable, and

the resistance of the joint is set to a minimum value of $M_{j,Rd}$ calculated by the following Formula 2.

[Expression 126]

$$M_{j,Rd} = \sum_i F_{i,Rd} \cdot x_{u,i} \qquad \text{Formula 2}$$

[0257] Another fifth aspect is

a method of designing a column-beam joint including a concrete column, and a steel beam in which at least one end in a longitudinal direction is disposed in concrete of the column, in which

when rotational resistance per unit rotation angle of a portion of the steel beam disposed inside the concrete of the column is a rotational rigidity S_j, a force acting on the column from the steel beam is estimated by a load supported by the steel beam and the rotational rigidity S_j of the portion of the steel beam disposed inside the concrete of the column, the steel beam includes a resistance element that generates a reaction force against rotation of the portion of the steel beam disposed inside the concrete of the column so that the force acting on the column from the steel beam does not exceed maximum resistance that can be resisted by the concrete of the column, and

the reaction force of the resistance element is adjusted by adjusting, at least, a distance between the respective ends of the steel beam and/or a cross-sectional shape of the steel beam.

[0258] Another sixth aspect is

the method of designing a column-beam joint according to another fifth aspect, in

which the resistance element includes the portion of the steel beam disposed inside the concrete of the column, and an additional member provided at a peripheral edge of the portion, and the reaction force of the resistance element is adjusted by adjusting at least one of an arrangement, shape, or dimension of the additional member.

[0259] Another seventh aspect is the method of designing a column-beam joint according to another fifth or sixth aspect, in which

when a total number of the resistance elements is n, i is a given natural number from 1 to n, and the resistance element provided in the steel beam is a resistance element i,

the reaction force of the resistance element i is represented by a product of rigidity k_i of the resistance element i and a deformation amount,

an elastic rotation center of a portion disposed inside the concrete of the column is denoted by a point at which the reaction force of the resistance element i and an external force are balanced,

a distance between a line of action of a representative displacement of the resistance element i and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is denoted by $x_{d,i}$,

a distance between a center of gravity of the reaction force of the resistance element i and the elastic rotation center of the portion of the steel beam disposed inside the concrete of the column is denoted by $x_{l,i}$, and

rotational rigidity of the joint is evaluated by a value obtained by the following Formula 3.

[Expression 127]

$$S_j = \sum_i (k_i^i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 3}$$

[0260] Another eighth aspect is

the method of designing a column-beam joint according to any one of another fifth to seventh aspects, in which

a reaction force of the resistance element i of the portion of the steel beam disposed inside the concrete of the column and a maximum reaction force that can be borne by the resistance element i are denoted by $F_{i,Rd}$,

resistance of the joint is denoted by $M_{j,Rd}$,

a distance between a rotation center of the portion of the steel beam disposed inside the concrete of the column and a line of action of the reaction force is denoted by $x_{u,i}$,

$M_{j,Rd}$ is calculated using the following Formula 4 with a position of the rotation center

as a variable, and the resistance of the joint is a minimum value of $M_{j,Rd}$ calculated by the following Formula 4.

[Expression 128]

$$M_{j,Rd} = \sum F_{i,Rd} \cdot x_{u,i} \qquad \text{Formula 4}$$

[0261] In the other aspects described above, the following effects are obtained.

[0262] According to the column-beam joint structure and the method of designing a column-beam joint according to another aspect, an estimated value of the moment acting on the column from the steel beam by the load supported by the steel beam and the rotational rigidity S_j of the portion of the steel beam disposed inside the concrete of the column does not exceed the maximum moment resistance that can be resisted by the joint between the column and the beam. As a result, it is possible to prevent significant irreversible deformation (plastification) from occurring in the joint between the column and the beam, to ensure stability of deflection of the steel beam and soundness of the column, and to satisfy required performance.

[0263] The disclosure of Japanese Patent Application No. 2019-103652, filed on June. 3, 2019, is incorporated herein by reference in its entirety.

[0264] All publications, patent applications, and technical standards mentioned in this description are incorporated herein by reference to the same extent as if each individual publication, patent application, or technical standard was specifically and individually indicated to be incorporated by reference.

CLAIMS

1. A method of designing a column-beam joint comprising a concrete column, a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state, and a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam, the method comprising:

defining rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint as a rotational rigidity S_j;

calculating a required moment resistance, acting on the column-beam joint from the steel beam, using a load supported by the steel beam and the rotational rigidity S_j; and

adjusting at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam, such that the required moment resistance calculated does not exceed a maximum moment resistance that can be resisted by the column-beam joint.

2. A method of designing a column-beam joint comprising a concrete column, a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state, and a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam, the method comprising:

defining rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint as a rotational rigidity S_j; and

calculating a required moment resistance, acting on the column-beam joint from the steel beam, using a load supported by the steel beam and the rotational rigidity S_j, which is determined by the following process A.

<Process A>

A total number of the resistance elements is denoted by n, i is a given natural number from 1 to n, and the resistance elements are denoted as resistance element i,

the reaction force of the resistance element i is represented by a product of rigidity k_i of the resistance element i and a deformation amount,

a rotation center of the portion of the steel beam inside the concrete of the column is denoted by a point at which the reaction force of the resistance element i and an external force are balanced,

a distance between a line of action of a representative displacement of the resistance element i and the rotation center is denoted by $x_{d,i}$,

a distance between a center of gravity of the reaction force of the resistance element i and the rotation center is denoted by $x_{l,i}$, and

the rotational rigidity S_j is determined based on evaluation of a value obtained by the following Formula 1.

[Expression 1]

$$S_j = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 1}$$

3. The method of designing a column-beam joint according to claim 2, further comprising

adjusting at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam, such that the required moment resistance does not exceed a maximum moment resistance that can be resisted by the column-beam joint.

4. The method of designing a column-beam joint according to claim 1 or claim 3, wherein

the resistance element includes an additional member provided at the portion of the steel beam inside the concrete and at a peripheral edge of the portion, and

the required moment resistance or the maximum moment resistance of the column-beam joint is established by adjusting at least one of an arrangement, shape, or dimension of the additional member.

5. The method of designing a column-beam joint according to any one of claims 1, 3 and 4, wherein

a maximum reaction force borne by a resistance element i of the portion of the steel beam inside the concrete is denoted by $F_{i,Rd}$,

the maximum moment resistance of the column-beam joint is denoted by $M_{j,Rd}$,

a distance between a rotation center of the steel beam and a line of action of the reaction force is denoted by $x_{u,i}$, and

a minimum value of $M_{j,Rd}$ calculated using the following Formula 2 is established as the maximum moment resistance with a position of the rotation center as a variable.

[Expression 2]

$$M_{j,Rd} = \sum_i F_{i,Rd} \cdot x_{u,i} \qquad \text{Formula 2}$$

6. The method of designing a column-beam joint according to any one of claims 1 to 5, wherein

an embedded length ratio obtained by dividing an embedded length of the end of the steel beam in the concrete of the column by a beam depth of the steel beam is 0.6 or less.

7. A method of manufacturing a column-beam joint, the method comprising

embedding at least one end in a longitudinal direction of a steel beam inside concrete of a column in a semi-rigid joint state, in a state in which a resistance element designed using the method of designing a column-beam joint according to any one of claims 1 to 6 is provided.

8. A column-beam joint structure comprising:

a concrete column;

a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state; and

a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam, wherein

when rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint is defined as a rotational rigidity S_j and a moment generated by a maximum resistance that can be resisted by the resistance element is defined as a maximum moment resistance that can be resisted by the column-beam joint,

as a required moment resistance acting on the column-beam joint from the steel beam, at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam is adjusted, such that the required moment resistance calculated using a load supported by the steel beam and the rotational rigidity S_j does not exceed the maximum moment resistance.

9. A column-beam joint structure comprising:

a concrete column;

a steel beam in which at least one end in a longitudinal direction is embedded inside concrete of the column in a semi-rigid joint state; and

a resistance element that is provided in the steel beam and that generates a reaction force against rotation of the steel beam, wherein

when rotational resistance per unit rotation angle of a portion of the steel beam inside the concrete in the column-beam joint is defined as a rotational rigidity S_j, as a required moment resistance acting on the column-beam joint from the steel beam, the required moment resistance

is set using a load supported by the steel beam and the rotational rigidity S_j, which is determined by the following process B.

<Process B>

A total number of the resistance elements is denoted by n, i is a given natural number from 1 to n, and the resistance elements are denoted as resistance element i,

the reaction force of the resistance element i is represented by a product of rigidity k_i of the resistance element i and a deformation amount,

a rotation center of the portion of the steel beam inside the concrete of the column is denoted by a point at which the reaction force of the resistance element i and an external force are balanced,

a distance between a line of action of a representative displacement of the resistance element i and the rotation center is denoted by $x_{d,i}$,

a distance between a center of gravity of the reaction force of the resistance element i and the rotation center is denoted by $x_{l,i}$, and

the rotational rigidity S_j is determined as a value satisfying the following Formula 3.

[Expression 3]

$$S_j = \sum_i (k_i \cdot x_{d,i} \cdot x_{l,i}) \qquad \text{Formula 3}$$

10. The column-beam joint structure according to claim 9, wherein

at least one of a distance between respective ends of the steel beam or a cross-sectional shape of the steel beam is adjusted, such that the required moment resistance does not exceed a maximum moment resistance that can be resisted by the column-beam joint.

11. The column-beam joint structure according to claim 8 or 10, wherein

the resistance element includes an additional member provided at the portion of the steel beam inside the concrete and at a peripheral edge of the portion, and

the required moment resistance or the maximum moment resistance of the column-beam joint is established by adjusting at least one of an arrangement, shape, or dimension of the additional member.

12. The column-beam joint structure according to any one of claims 8, 10 and 11, wherein

a maximum reaction force borne by a resistance element i of the portion of the steel beam inside the concrete is denoted by $F_{i,Rd}$,

the maximum moment resistance of the column-beam joint is denoted by $M_{j,Rd}$,

a distance between a rotation center of the steel beam and a line of action of the reaction force is denoted by $x_{u,i}$, and

a minimum value of $M_{j,Rd}$ calculated using the following Formula 4 is established as the maximum moment resistance with a position of the rotation center as a variable.

[Expression 4]

$$M_{j,Rd} = \sum_{i} F_{i,Rd} \cdot x_{u,i} \qquad \text{Formula 4}$$

13. The column-beam joint structure according to any one of claims 8 to 12, wherein

an embedded length ratio obtained by dividing an embedded length of the end of the steel beam in the concrete of the column by a beam depth of the steel beam is 0.6 or less.