

DESCRIPTION

TITLE OF INVENTION: JOINING STRUCTURE

TECHNICAL FIELD

5 [0001]

The present invention relates to a joint structure.

BACKGROUND ART

[0002]

Secondary beams supporting floors in steel or composite structures are
10 treated as non-seismic members. Typically, a joint portion at an end of the secondary
beam is a bolt joint where a web of the secondary beam is bolted to a gusset plate
(also called a fin plate) attached to a primary beam, and top and bottom flanges of
the secondary beam are joined by pins without being joined to the primary beam.
When a vertical load acts on the secondary beam supported by such pinned joints,
15 additional bending occurs in the secondary beam web and gusset plate. This is
because the center of action of the force acting mainly on the secondary beam (the
thickness center of the secondary beam web) and the center of action of the reaction
force from the gusset plate (the thickness center of the gusset plate) are eccentric.
The out-of-plane bending stiffness of the secondary beam web and the gusset plate
20 is normally small. The above-described additional bending thus causes the out-of-
plane deformation of the secondary beam web, which in turn displaces the bottom
flange of the secondary beam, reducing the transmission efficiency of the
compressive force acting on the end of the secondary beam. As a result, the joint
portion fails to have sufficient rotational stiffness or resistance to reduce the deflection
25 of the secondary beam.

[0003]

In order to solve the above problem, there are known a rigid joint in which not
only the secondary beam web but also the top and bottom flanges are joined to the
primary beam by bolting or welding, and a semi-rigid joint in which only the bottom
30 flange is joined as described, for example, in Patent Literatures 1, 2 and 3. These
joints reduce the deflection and moment in the center portion of the secondary beam
compared to pinned joints, enabling reduction in size and weight of a cross-section

of the secondary beam, and are therefore used in large span structures.

CITATION LIST

PATENT LITERATURE(S)

[0004]

5 Patent Literature 1: JP 2022-069006 A

Patent Literature 2: JP 2021-156116 A

Patent Literature 2: JP 2021-156115A

SUMMARY OF THE INVENTION

PROBLEM(S) TO BE SOLVED BY THE INVENTION

10 [0005]

However, in the rigid joint mentioned above, for example, the flanges of the secondary beam are joined in-situ to the primary beam or to brackets attached to the primary beam. Therefore, welding requires processes such as groove preparation at flange ends and site welding, while bolted joints require processes such as drilling
15 holes at flange ends, treating friction surfaces, and installing splice plates. Also in the semi-rigid joint, processes such as welding and installation of contact members are required. That is, the pinned joint is advantageous in terms of reducing labor in the process.

[0006]

20 In view of the above, an object of the invention is to provide a joint structure that ensures rotational stiffness and resistance of a joint portion by inhibiting out-of-plane deformation of a secondary beam web without compromising workability of a pinned joint, and enables reduction in size and weight of a cross-section of the secondary beam by inhibiting deflection and moment in a center portion of the
25 secondary beam.

MEANS FOR SOLVING THE PROBLEM(S)

[0007]

[1] A joint structure connecting a primary beam having an H-shaped cross-section and an end in an axial direction of a secondary beam having an H-shaped cross-section and extending in a direction intersecting the primary beam, the joint structure
30 including: a gusset plate joined at least to a web and a top flange of the primary beam; and a row of bolts arranged in a beam height direction of the secondary beam and

joining the gusset plate to a web of the secondary beam, in which a distance from an axial center of a bottom bolt in the row of bolts to a bottom surface of a bottom flange of the secondary beam is less than $1/5$ of a beam height of the secondary beam.

[2] The joint structure according to [1], further including a reinforcing rib disposed to intersect a plate-shaped body of the gusset plate and the web of the primary beam, the reinforcing rib being joined at least to the gusset plate.

[3] The joint structure according to [1] or [2], further including at least one reinforcing plate disposed below a height center line of the web of the secondary beam and in contact with a side end surface of the gusset plate, in which the reinforcing plate is bolted to the web of the secondary beam.

[4] The joint structure according to [3], in which the reinforcing plate is joined to the web of the secondary beam through a high-strength bolt friction joint.

[5] The joint structure according to any of [1] to [4], in which the gusset plate is joined to the web of the secondary beam through a high-strength bolt friction joint.

[6] The joint structure according to any of [1] to [5], further including a concrete floor slab constructed on the primary beam and the secondary beam, in which a top flange of the secondary beam is joined to the concrete floor slab.

[0008]

In the above configuration, the bottom bolt in the row of bolts joining the gusset plate and the secondary beam web is disposed close to the bottom flange of the secondary beam. This enhances the effect of the gusset plate in restraining the out-of-plane deformation of the secondary beam web, thus inhibiting the displacement of the bottom flange of the secondary beam and ensuring the rotational stiffness and resistance of the joint portion. Accordingly, it is possible to inhibit the deflection and moment in a center portion of the secondary beam, thus enabling reduction in size and weight of the cross-section of the secondary beam.

BRIEF DESCRIPTION OF DRAWINGS

[0009]

Fig. 1 is a perspective view of a joint structure according to a first exemplary embodiment of the invention.

Fig. 2 illustrates a first example of the exemplary embodiment, including (A) and (B) that correspond to arrow views taken along a line A-A and a line B-B in Fig.

1.

Fig. 3 illustrates a second example of the exemplary embodiment including a reinforcing rib and a reinforcing plate, Fig. 3 including (A) and (B) that correspond to arrow views taken along the line A-A and the line B-B in Fig. 1.

5 Fig. 4 illustrates a third example of the exemplary embodiment including a reinforcing plate different in shape from Fig. 3, Fig. 4 including (A) and (B) that correspond to arrow views taken along the line A-A and the line B-B in Fig. 1.

Fig. 5 illustrates how to determine a distance e_v illustrated in Figs. 2 to 4.

Fig. 6 illustrates how to determine the distance e_v illustrated in Figs. 2 to 4.

10 Fig. 7 illustrates a method for calculating a rotation angle of a joint portion in analysis of Examples.

Fig. 8 illustrates a method for calculating a displacement of a bottom flange of a secondary beam in the analysis of Examples.

15 Fig. 9 is a graph showing the relationship between the joint portion moment and the rotation angle at cross-section No. 1 of the secondary beam in Examples and Comparatives.

Fig. 10 is a graph showing the relationship between the joint portion moment and the rotation angle at cross-section No. 2 of the secondary beam in Examples and Comparatives.

20 Fig. 11 is a graph showing the relationship between the joint portion moment and the rotation angle at cross-section No. 3 of the secondary beam in Examples and Comparatives.

Fig. 12 is a graph showing the initial stiffness and the maximum joint portion moment value at cross-section No. 1 of the secondary beam in Examples and
25 Comparatives, expressed as a ratio assuming that a reference case is 1.

Fig. 13 is a graph showing the initial stiffness and the maximum joint portion moment value at cross-section No. 2 of the secondary beam in Examples and Comparatives, expressed as a ratio assuming that a reference case is 1.

30 Fig. 14 is a graph showing the initial stiffness and the maximum joint portion moment value at cross-section No. 3 of the secondary beam in Examples and Comparatives, expressed as a ratio assuming that a reference case is 1.

Fig. 15 is a graph showing the relationship between the bottom flange

displacement and the rotation angle at cross-section No. 1 of the secondary beam in Examples and Comparatives.

Fig. 16 is a graph showing the relationship between the bottom flange displacement and the rotation angle at cross-section No. 2 of the secondary beam in
5 Examples and Comparatives.

Fig. 17 is a graph showing the relationship between the bottom flange displacement and the rotation angle at cross-section No. 3 of the secondary beam in Examples and Comparatives.

Fig. 18A illustrates a deformation state and equivalent plastic strain contour
10 at maximum resistance in Example.

Fig. 18B illustrates a deformation state and equivalent plastic strain contour at maximum resistance in Example.

Fig. 18C illustrates a deformation state and equivalent plastic strain contour at maximum resistance in Example.

Fig. 19A illustrates a deformation state and equivalent plastic strain contour
15 at maximum resistance in Comparative.

Fig. 19B illustrates a deformation state and equivalent plastic strain contour at maximum resistance in Comparative.

Fig. 19C illustrates a deformation state and equivalent plastic strain contour
20 at maximum resistance in Comparative.

Fig. 20 is a graph showing the relationship between e_v/H and the ratio of the rotational stiffness at the joint portion to the reference case in Examples and Comparatives.

Fig. 21 is a graph showing the relationship between e_v/H and the ratio of
25 maximum resistance at the joint portion to the reference case in Examples and Comparatives.

Fig. 22 is a graph showing the relationship between the design load capacity supported by the concrete floor slab when the joint portion at cross-section No. 1 of the secondary beam has the maximum moment and the deflection reduction ratio for the secondary beam supported by pinned joints at both ends, in Examples and
30 Comparatives.

Fig. 23 is a graph showing the relationship between the design load capacity

supported by the concrete floor slab when the joint portion at cross-section No. 2 of the secondary beam has the maximum moment and the deflection reduction ratio for the secondary beam supported by pinned joints at both ends, in Examples and Comparatives.

Fig. 24 is a graph showing the relationship between the design load capacity supported by the concrete floor slab when the joint portion at cross-section No. 3 of the secondary beam has the maximum moment and the deflection reduction ratio for the secondary beam supported by pinned joints at both ends, in Examples and Comparatives.

DESCRIPTION OF EMBODIMENT(S)

[0010]

Referring to the accompanying drawings, preferred embodiments of the invention will be described in detail below. In the specification and the drawings, components having substantially the same functional configuration are denoted by the same reference numeral, and redundant explanations are omitted.

[0011]

Fig. 1 is a perspective view of a joint structure according to an exemplary embodiment of the invention. Figs. 2 to 4 include arrow views, illustrated as (A), taken along a line A-A of Fig. 1. Figs. 2 to 4 include arrow views, illustrated as (B), taken along a line B-B of Fig. 1. As illustrated in Fig. 1, the joint structure according to the exemplary embodiment is formed between a gusset plate 2 joined to a primary beam 1 and a secondary beam 3 extending in a direction intersecting the primary beam 1. In the drawings, a longitudinal direction of the secondary beam is indicated as an X direction, a beam height direction of the secondary beam is indicated as a Y direction, and a longitudinal direction of the primary beam is indicated as a Z direction. The primary beam 1 and the secondary beam 3 are each composed of an H-shaped steel. The primary beam 1 includes a web 11, a top flange 12, and a bottom flange 13. The secondary beam 3 includes a web 31, a top flange 32, and a bottom flange 33. The gusset plate 2 is welded to the web 11, the top flange 12, and the bottom flange 13 of the primary beam 1. The gusset plate 2 is bolted to the web 31 of the secondary beam 3 using bolts 41. The primary beam 1 and the secondary beam 3 are not limited to the H-shaped steel as long as they have an H-shaped cross-section. The primary

beam 1 and the secondary beam 3 may be formed from, for example, a welding member having an H-shaped cross-section.

[0012]

As illustrated in Figs. 2 to 4, a concrete floor slab 5 is constructed on the primary beam 1 and the secondary beam 3. In the illustrated examples, the concrete floor slab 5 is a composite deck slab. The concrete floor slab 5 includes concrete 51, rebar 52, and a steel deck profile 53. Studs 6 are erected on the top flanges 12 and 32 of the primary beam 1 and the secondary beam 3 to penetrate the steel deck profile 53. The studs 6 are fixed to the concrete 51. That is, in the illustrated examples, the secondary beam 3 is joined to the concrete floor slab 5, whereby a tensile force acting on the top flange of the secondary beam 3 is transmitted to the concrete floor slab 5. On the other hand, the bottom flange 33 of the secondary beam 3 is not directly joined to the primary beam 1 or the gusset plate 2.

[0013]

Of Figs. 2 to 4, Fig. 2 illustrates the simplest example including the above-described components. Figs. 3 and 4 each illustrate an exemplary joint structure including additional components not illustrated in Fig. 1, as described below. Figs. 2 to 4 also indicate dimensions that will be referred to in Examples described later. In the example illustrated in each of Figs. 2 to 4, the bolts 41 joining the gusset plate 2 to the web 31 of the secondary beam 3 form a row of bolts arranged in the beam height direction of the secondary beam 3. A distance e_v from an axial center of the bolt 41 located at a bottom of the row of bolts to a bottom surface of the bottom flange 33 of the secondary beam 3 is less than $1/5$ of a beam height H of the secondary beam 3. This enhances the effect of the gusset plate 2 in restraining the out-of-plane deformation of the web 31 of the secondary beam 3, thereby inhibiting the displacement of the bottom flange 33 and maintaining the efficiency of transmission of a compressive force acting on the end of the secondary beam. The ratio e_v/H of the distance e_v to the beam height H is preferably less than 0.18, and more preferably 0.16 or less. For simplicity, dimensions other than the distance e_v are indicated only in Fig. 3, but the same applies to the examples of Figs. 2 and 4.

[0014]

In the examples illustrated in Figs. 3 and 4, in addition to the components

described with reference to Fig. 1, a reinforcing rib 21 and a reinforcing plate 7 are provided. The reinforcing rib 21 is a plate-shaped portion. The reinforcing rib 21 is disposed to intersect a plate-shaped body of the gusset plate 2 that is disposed along the web 31 of the secondary beam 3 and to intersect the web 11 of the primary beam 1. The reinforcing rib 21 may be formed, for example, by fillet welding another plate-shaped member different from the gusset plate 2 to the gusset plate 2, or by molding in advance the gusset plate 2 to have an L-shaped cross-section. The reinforcing rib 21 may be joined also to the web 11 of the primary beam 1 by fillet welding or the like. In the examples illustrated in Figs. 3 and 4, there is no portion of the gusset plate 2 below the reinforcing rib 21, and the gusset plate 2 is not welded to the bottom flange 13 of the primary beam 1, unlike the example in Fig. 1. However, in another example, the gusset plate 2 may have a portion below the reinforcing rib 21 and be welded to the bottom flange 13. In this case, the reinforcing rib 21 may be attached to a middle part of the gusset plate 2, and a cutout may be formed in a part of the reinforcing rib 21 that comes into contact with the web 11 of the primary beam 1 to avoid interference with a welded part for the gusset plate 2 and the web 11.

[0015]

Providing the reinforcing rib 21 inhibits the out-of-plane deformation of the gusset plate 2 due to additional bending caused by, for example, that the thickness center of the web 31 of the secondary beam 3 and the thickness center of the gusset plate 2 are eccentric. Since the gusset plate 2 is joined to only one side of the web 31 of the secondary beam 3 (one-sided friction), the reinforcing rib 21 is also formed on only one side of the web 31. Thus, the compressive force generated by the bending of the secondary beam 3 can be reliably transmitted from the web 31 through the gusset plate 2 to the primary beam 1. In order to transmit the compressive force, the gusset plate 2 is provided to extend below a height center line C of the web 31 of the secondary beam 3, and the reinforcing rib 21 is provided in a region below the height center of the web 31. The reinforcing rib 21 is different from a rib provided, for example, to abut against an end surface of the bottom flange 33 of the secondary beam 3. The reinforcing rib 21 is located at a height different from that of the bottom flange 33 of the secondary beam 3, more specifically, above the bottom flange 33 of the secondary beam 3. When viewed in an axial direction of the secondary beam 3,

providing the reinforcing rib 21 over almost the entire length of the gusset plate 2 to overlap with the bottom flange 33 of the secondary beam 3 can further enhance the effect of the reinforcing rib 21 in inhibiting the out-of-plane deformation of the gusset plate 2.

5 [0016]

The reinforcing plate 7 is provided in contact with a side end surface of the gusset plate 2 below the height center line C of the web 31, and is bolted to the web 31 of the secondary beam 3 with additional bolts 71. As in the example of Fig. 3, the reinforcing plate 7 having a size equivalent to two rows of additional bolts may be provided, or as in the example of Fig. 4, a reinforcing plate 7A having a size equivalent to one row of additional bolts may be provided. In addition, for example, a further reinforcing plate may be disposed adjacent to the reinforcing plate 7A. Here, the side end surfaces of the gusset plate 2 and the reinforcing plates 7 and 7A are end surfaces facing the axial direction of the secondary beam 3. Unlike the gusset plate 2, no reinforcing ribs are provided for the reinforcing plates 7 and 7A.

[0017]

In the configuration provided with the reinforcing plate 7, 7A, when the number of bolts 41 and the number of additional bolts 71 are included, the number of bolts located below the height center line C of the web 31 is greater than the number of bolts located above the height center line C. With this configuration, the compressive force, which is a couple to the tensile force borne by the rebar 52 of the concrete floor slab 5, can be borne more at a lower side of a joint portion. The additional bolts 71 may also be high-strength bolts like the bolts 41. In this case, the behavior of the joint structure can be further stabilized through the high-strength bolt friction joint. As in the examples of Figs. 3 and 4, the reinforcing plate 7, 7A may be provided in addition to the reinforcing rib 21. Or, as in the example of Fig. 2 where no reinforcing rib is provided, the reinforcing plate 7, 7A may be placed in contact with the side end surface of the gusset plate 2.

[0018]

30 When the reinforcing plate 7, 7A is joined to the web 31 using the additional bolts 71 through the high-strength bolt friction joint, the reinforcing plate 7, 7A may be installed after the construction of the concrete floor slab 5. This prevents the

reinforcing plate 7, 7A from being involved in the bending moment caused by the weight of the concrete floor slab 5, so that the number of additional bolts 71 required to maintain the friction joint between the reinforcing plate 7, 7A and the web 31 can be reduced.

5 [0019]

In the exemplary embodiment of the invention as described above, it can be said that a pinned joint at the end of the secondary beam is a semi-rigid joint without any additional process (the example of Fig. 2) or with only simple reinforcement (the examples of Figs. 3 and 4). When the pinned joint has a large out-of-plane deformation of the gusset plate due to the additional bending caused by the eccentricity of the gusset plate and the secondary beam web, the stiffness and resistance of the joint decrease rapidly. Therefore, the degree of fixation of the joint portion could not be taken into consideration in the design. However, in the exemplary embodiment, the bottom end of the gusset plate is positioned close to the bottom end of the secondary beam web, so that the gusset plate is used not only as a member for transmitting shear force but also as a reinforcing member for the out-of-plane stiffness of the secondary beam web, thereby inhibiting the out-of-plane deformation of the web. By making the distance e_v from the axial center of the bottom bolt to the bottom surface of the bottom flange of the secondary beam less than $1/5$ of the beam height H of the secondary beam as described above, the bottom end position of the gusset plate is close to the bottom end of the secondary beam web (close to the fillet of a rolled H-section steel or the top end of the weld fillet of a welded assembled H-section steel), which results in a sufficient effect to prevent the out-of-plane deformation of the secondary beam web as described above. Furthermore, the effect of inhibiting a horizontal displacement of the bottom flange of the secondary beam and rotational deformation (twist) around the axis of the secondary beam may be enhanced by disposing a horizontal rib for inhibiting out-of-plane bending of the gusset plate close to the bottom flange of the secondary beam. Moreover, the stability of the joint portion may be increased by placing the reinforcing plate so that more bolts are arranged on the bottom flange side of the secondary beam web, and causing the lower part of the joint portion at the end of the secondary beam to greatly bear the compressive force, which is a couple to tensile force borne by the rebar in

the floor slab after the concrete floor slab is constructed. The rotational deformation (twist) of the secondary beam about its axis is inhibited also by causing the concrete floor slab to restrain the horizontal movement of the top flange of the secondary beam, which makes it possible to stably transmit the compressive force from the bottom flange of the secondary beam to the primary beam. The above configuration in the exemplary embodiment significantly improves the resistance at which the joint portion exhibits nonlinear behavior compared to typical pinned joints, while also obtaining higher rotational stiffness of the joint portion, resulting in a deflection reduction effect reflecting the degree of fixation of the joint portion in the design.

[0020]

Figs. 5 and 6 illustrate how to determine the distance e_v illustrated in Figs. 2 to 4. In the example illustrated in Fig. 5, the reinforcing plate 7 on the right side of the figure is disposed shifting upward, so that the bottom bolts among the additional bolts 71 joining the reinforcing plate 7 to the web 31 are positioned above the bottom bolt 41 in the row of bolts joining the gusset plate 2 to the web 31. On the other hand, in the example illustrated in Fig. 6, the reinforcing plate 7 on the right side of the figure is disposed shifting downward. The bottom bolts among the additional bolts 71 joining the reinforcing plate 7 to the web 31 are thus positioned below the bottom bolt 41 in the row of bolts joining the gusset plate 2 to the web 31. In both cases of Fig. 5 and Fig. 6, the distance e_v is a distance from the axial center of the bottom bolt 41 in the row of bolts to the bottom surface of the bottom flange of the secondary beam. The additional bolts 71 may be positioned at the same height as the bottom bolt 41 in the row of bolts as in the examples of Figs. 2 to 4, or may be positioned above the bottom bolt 41 as in the example of Fig. 5, or may be positioned below the bottom bolt 41 as in the example of Fig. 6. In such cases, the distance e_v is not affected by the arrangement of the additional bolts 71.

Examples

[0021]

In the following, the results of FEM analysis for verifying the effects of the exemplary embodiment of the invention as described above will be described. The initial stiffness and resistance of the joint portion between the primary beam and the secondary beam were calculated for the conventional technology and Examples of

the invention. The shapes of the joint portions of respective examples are illustrated in Figs. 2 to 4, and the dimensional parameters are mainly indicated in Fig. 3 (the same applies to Figs. 2 and 4). The main parameters are: three types of cross-sections (No.1 to No.3) defined by the beam height H , flange width B_f , web thickness t_w , and flange thickness t_f of the secondary beam; the distance e_v from the axial center of the bottom bolt to the bottom surface of the bottom flange of the secondary beam that is determined by the number n_b in the beam height direction of the bolts joining the secondary beam web and gusset plate, the interval p_v therebetween, and the height h_{fin} of the gusset plate, the distance e_v being changed in a range of $e_v/H =$ 0.125 to 0.286; and the presence or absence of the reinforcing rib and the reinforcing plate.

[0022]

Cross-Section of Secondary Beam

No.1: $H = 700$ mm, $B_f = 200$ mm, $t_w = 9$ mm, $t_f = 16$ mm

No.2: $H = 450$ mm, $B_f = 150$ mm, $t_w = 3.6$ mm, $t_f = 6$ mm

No.3: $H = 500$ mm, $B_f = 200$ mm, $t_w = 5.5$ mm, $t_f = 9$ mm

[0023]

Table 1 shows the conditions of each of the examples. Each number "1" to "3" at the beginning of the analytical model name indicates which of the above No. 1 to No. 3 the cross-section of the secondary beam corresponds to. "R" indicates that the concrete floor slab is constructed and the studs erected on the top flange of the secondary beam are fixed to the concrete, thereby restraining the top flange from moving in the horizontal plane (applies to all examples). "MG", "TG" and "HG" indicate that the height h_{fin} of the gusset plate is higher than normal, and therefore the bottom position of the gusset plate is closer to the bottom of the secondary beam web (height h_{fin} increases in the order of "MG", "TG" and "HG"). "EXC2" and "EXC" indicate that the reinforcing plate and additional bolts are arranged as in the examples of Figs. 3 and 4. "EXC2" indicates that two rows of additional bolts are arranged as in the example in Fig. 3, and "EXC" indicates that one row of additional bolts is arranged as in the example in Fig. 4. (t6) indicates that the thickness of the gusset plate is 6 mm, and (t9) indicates that the thickness of the gusset plate is 9mm. In Examples, the distance e_v from the bottom surface of the bottom flange of the

secondary beam to the axial center of the bottom bolt is smaller than $1/5$ of the beam height H as in the examples of Figs. 2 to 4 above, satisfying $e_v/H < 0.2$. Comparatives include examples where $e_v/H \geq 0.2$, and examples where the top and bottom flanges of the secondary beam are rigidly welded to the primary beam.

5

[0024]

Table 1

Analytical model name	Cross section	t_{fin} [mm]	h_{fin} [mm]	p_v [mm]	n_b [pieces]	e_v [mm]	e_v/H	End Margin [mm]	Rib	Plate	Additional bolts	
1-R(t9)	No.1	9	380	60	6	200	0.286	40	—	—	—	Comp.
1-TG-R(t9)	No.1	9	605	105	6	87.5	0.125	40	—	—	—	Ex.
1EXC2-R(t9)	No.1	9	380	60	6	200	0.286	40	O	O	2×2	Comp.
1EXC2-TG-R(t9)	No.1	9	605	105	6	87.5	0.125	40	O	O	2×2	Ex.
1Rigid	No.1	* Rigid joint										
2-R(t6)	No.2	6	320	60	5	105	0.233	40	—	—	—	Comp.
2-TG-R(t6)	No.2	6	400	80	5	65	0.144	40	—	—	—	Ex.
2EXC-R(t6)	No.2	6	320	60	5	105	0.233	40	O	O	2×1	Comp.
2EXC2-R(t6)	No.2	6	320	60	5	105	0.233	40	O	O	2×2	Comp.
2EXC2-TG-R(t6)	No.2	6	400	80	5	65	0.144	40	O	O	2×2	Ex.
2Rigid	No.2	* Rigid joint										
3-R(t6)	No.3	9	320	60	5	130	0.26	40	—	—	—	Comp.
3-MG-R(t6)	No.3	9	400	80	5	90	0.18	40	—	—	—	Ex.
3-TG-R(t6)	No.3	9	420	85	5	80	0.16	40	—	—	—	Ex.
3-HG-R(t6)	No.3	9	440	90	5	70	0.14	40	—	—	—	Ex.
3EXC2-R(t6)	No.3	9	320	60	5	130	0.26	40	O	O	2×2	Comp.
3EXC2-MG-R(t6)	No.3	9	400	80	5	90	0.18	40	O	O	2×2	Ex.
3EXC2-TG-R(t6)	No.3	9	420	85	5	80	0.16	40	O	O	2×2	Ex.
3EXC2-HG-R(t6)	No.3	9	440	90	5	70	0.14	40	O	O	2×2	Ex.
3Rigid	No.3	* Rigid joint										

Table 1: Conditions of Examples and Comparatives

[0025]

In the analysis, a predetermined initial introducing tension was first applied to the bolts joining the secondary beam web and the gusset plate. More specifically, in the examples of the secondary beam cross-sections No. 1 and No. 3, an initial
5 introducing tension of 180 kN was applied to F10T-M20 bolts, and in the examples of the secondary beam cross-section No. 2, an initial introducing tension of 110 kN was applied to F10T-M16 bolts. Next, a forced displacement by up to 20 mm was applied to an end of the secondary beam opposite the joint portion in a cantilever beam configuration, and a joint portion moment M_j [kNm] and a rotation angle ϕ_j [rad],
10 as well as a displacement [mm] of the bottom flange of the secondary beam in a direction (Z direction) orthogonal to the secondary beam were calculated.

[0026]

Fig. 7 illustrates a method for calculating the rotation angle ϕ_j of the joint portion in the analysis. The rotation angle ϕ_j is obtained by dividing a difference
15 between longitudinal displacements δ_{ft} , δ_{fb} of the secondary beam at two points where an intersection line of the vertical center of the bolts joining the secondary beam web and the gusset plate with the thickness center of the secondary beam web intersects with the thickness centers of the top and bottom flanges of the secondary beam, by a vertical distance $H - t_f$ (t_f is a flange thickness) between these two points.
20 Fig. 8 illustrates a method for calculating the displacement of the bottom flange of the secondary beam in the analysis. The displacement z_{fb} in a direction (-Z direction) orthogonal to the secondary beam in a horizontal plane of the bottom flange of the secondary beam is a displacement in the Z direction of the position on the bottom flange side of the above two points.

25 [0027]

The primary beam had a beam height of 800 mm, a flange width of 300 mm, a web thickness of 12 mm, and a flange thickness of 25 mm. The friction coefficient between the gusset plate and the secondary beam web that were joined by the bolts and the friction coefficient between the reinforcing plate and the secondary beam
30 web that were joined by additional bolts were set to 0.6 based on the slip coefficient obtained in the experiment. The friction coefficient of all the other contact surfaces was set to 0.2, which corresponded to the friction coefficient between mill scale

surfaces. In all models, the length from the center of the web thickness of the primary beam to a forced displacement point of the secondary beam was set to 1.5 m (nominal length of the secondary beam). The joint portion moment M_j was calculated by multiplying the reaction force at the forced displacement point by the arm length of 1.3 m (a value obtained by subtracting the distance of 0.2 m from the vertical center of the bolts joining the secondary beam web and gusset plate to the center of the web thickness of the primary beam, from the nominal length of the secondary beam of 1.5 m).

[0028]

The analysis results of Examples and Comparatives are shown in Table 2, and the relationship between the joint portion moment M_j and the rotation angle ϕ_j is shown in Figs. 9 to 11. In Table 2, the initial stiffness $S_{j,ini}$ [kNm/rad] is a secant stiffness at 1/3 of the maximum resistance, and $M_{j,max}$ [kNm] is a maximum value of the joint portion moment. Figs. 12 to 14 are graphs showing $S_{j,ini}$ and $M_{j,max}$ at the secondary beam cross-sections No. 1, No. 2 and No. 3 in Examples and Comparatives, as a ratio assuming that the analytical models 1-R(t9), 2-R(t6) and 3-R(t6) used as the reference cases is 1. Comparing Examples with Comparatives, it can be seen that in Examples where $e_v/H < 0.2$ is satisfied by increasing the height of the gusset plate (TG, MG), $S_{j,ini}$ is improved for the same $M_{j,max}$ value compared to Comparatives where $e_v/H \geq 0.2$ is satisfied. Furthermore, in cases in which the reinforcing rib and reinforcing plate are arranged (1EXC2-TG-R, 2EXC2-TG-R, 3EXC2-TG-R, and 3EXC2-MG-R), there are obtained $S_{j,ini}$ and $M_{j,max}$ exceeding the values of $S_{j,ini}$ and $M_{j,max}$ that are linearly predicted from the results of Examples in which neither the reinforcing rib nor the reinforcing plate are arranged and Comparatives in which the reinforcing rib and the reinforcing plate are arranged but $e_v/H \geq 0.2$ is satisfied. These results show that a synergistic effect can be obtained by setting $e_v/H < 0.2$ and by arranging the reinforcing rib and the reinforcing plate.

[0029]

Table 2

Analytical model name	$S_{j,ini}$ [kNm/rad]	$M_{j,y}$ at $S_{j,ini}/3$ [kNm]	$M_{j,max}$ [kNm]	Ratio to Reference Cases		
				Ratio of $S_{j,ini}$	Ratio of $M_{j,y}$	Ratio of $M_{j,max}$
1-R(t9) (Comp.)	111251	179.8	205.8	1.00	1.00	1.00
1-TG-R(t9) (Ex.)	243266	210.8	322.7	2.19	1.17	1.57
1EXC2-R(t9) (Comp.)	157138	280.7	312.7	1.41	1.56	1.52
1EXC2-TG-R(t9) (Ex.)	341527	437.7	511.3	3.07	2.43	2.48
1Rigid (Comp.)	3973352	-	711.4	35.72	-	3.46
2-R(t6) (Comp.)	27222	24.0	38.4	1.00	1.00	1.00
2-TG-R(t6) (Ex.)	43333	35.6	48.3	1.59	1.49	1.26
2EXC-R(t6) (Comp.)	40340	55.4	56.8	1.48	2.31	1.48
2EXC2-R(t6) (Comp.)	45184	65.1	67.7	1.66	2.72	1.76
2EXC2-TG-R(t6) (Ex.)	72316	105.0	110.6	2.66	4.38	2.88
2Rigid (Comp.)	1543872	-	129.9	56.71	-	3.38
3-R(t6) (Comp.)	47968	76.9	94.2	1.00	1.00	1.00
3-MG-R(t6) (Ex.)	72197	84.6	114.0	1.51	1.10	1.21
3-TG-R(t6) (Ex.)	82278	90.8	121.0	1.72	1.18	1.28
3-HG-R(t6) (Ex.)	95362	94.0	131.1	1.99	1.22	1.39
3EXC2-R(t6) (Comp.)	71844	141.6	150.5	1.50	1.84	1.60
3EXC2-MG-R(t6) (Ex.)	108994	192.7	206.4	2.27	2.50	2.19
3EXC2-TG-R(t6) (Ex.)	122608	211.7	227.9	2.56	2.75	2.42
3EXC2-HG-R(t6) (Ex.)	140163	228.1	252.9	2.92	2.96	2.69
3Rigid (Comp.)	2338325	-	287.2	48.75	-	3.05

Table 2: Stiffness and Moment of Examples and Comparatives

[0030]

Figs. 15 to 17 are graphs showing the relationships between the displacement (z) in the Z direction of the bottom flange and the rotation angle ϕ_j at

the secondary beam cross-sections No. 1, No. 2, and No. 3 in Examples and Comparatives. As described above, when the displacement (z) in the Z direction of the bottom flange increases, the eccentric distance in the plate thickness direction between the compressive force transmitted from the bottom flange of the secondary beam through the web to the gusset plate and the reaction force on the gusset plate side increases. This promotes the out-of-plane deformation of the secondary beam web and the gusset plate, reducing the efficiency of transmission of the compressive force from the bottom flange. Figs. 15 to 17 show that in Examples satisfying $e_v/H < 0.2$, the displacement in the Z direction of the bottom flange before reaching the maximum resistance is restrained compared to Examples having a similar configuration and $e_v/H \geq 0.2$. Providing the reinforcing rib and reinforcing plate further reduces the displacement in the Z direction of the bottom flange.

[0031]

Figs. 18A to 18C illustrate a deformation state at the maximum resistance and equivalent plastic strain contour of Example (3-TG-R(t6)). Similarly, Figs. 19A to 19C illustrate a deformation state at the maximum resistance and equivalent plastic strain contour of Comparative (3-R(t6)). In the Example (3-TG-R(t6)), compared to the Comparative (3-R(t6)), the web has a smaller region of large equivalent plastic strain, and this region tends to be closer to the bottom flange side. This shows that out-of-plane bending deformation of the web is inhibited over a wide area in the Example.

[0032]

Fig. 20 is a graph showing the relationship between e_v/H and the ratio of the rotational stiffness $R_{S_{j,ini}}$ at the joint portion to the reference case in Examples and Comparatives. Similarly, Fig. 21 is a graph showing the relationship between e_v/H and the ratio of the maximum resistance $R_{M_{j,max}}$ at the joint portion to the reference case. Figs. 20 and 21 show that setting $e_v/H < 0.2$ significantly increases $S_{j,ini}$ and $M_{j,max}$ compared to the reference cases. It is further shown that setting $e_v/H < 0.18$, more preferably $e_v/H \leq 0.16$ more significantly increases $S_{j,ini}$ and $M_{j,max}$ compared to the reference cases.

[0033]

Table 3 and Figs. 22 to 24 show the relationship between the design load

capacity supported by the concrete floor slab when the joint portion is at $M_{j,max}$ and the deflection reduction ratio $((\delta_{pin} - \delta)/\delta_{pin} \text{ by } S_{j,ini})$ for the secondary beam supported by pinned joints at both ends in Examples and Comparatives. The preconditions for the analysis are as below.

5 [0034]

- Examine the third span of a five-span continuous beam (approximately equivalent to any span of an infinite continuous beam) of the secondary beam supported at an intermediate supporting point by the joint portion having the initial stiffness $S_{j,ini}$ obtained in the analysis.
- 10 • Set a span L of the secondary beam at 15m for cross-section No. 1, and at 7.5m for cross-sections No. 2 and 3.
- Set a dominant width B of the secondary beam (a distance between the secondary beams in a direction orthogonal to the longitudinal direction of the secondary beam) to 3 m.
- 15 • Set the concrete floor slab to have a thickness of 180 mm and joining it to the top flange of the secondary beam with headed studs having a diameter of 19 mm and a pitch of 200 mm.
- Reinforce the concrete floor slab throughout with a D10@200 reinforcement arrangement, and place D10@100 reinforcement bars in negative bending regions.
- 20 • Calculate the bending stiffness of the secondary beam as the stiffness of a fully composite beam, calculate the negative bending stiffness by ignoring the concrete of the floor slab and considering the stiffness of the rebar of the floor slab, and calculate the positive bending stiffness by taking the Young's modulus of the concrete of the floor slab as 1/15 of the Young's modulus of the steel frame, 210,000 N/mm².
- 25 • Perform no FEM analysis for the rigid joints (1Rigid, 2Rigid, 3Rigid) in Comparatives, and perform the calculation assuming that the joint portion has a rotational stiffness 100 times the value obtained by dividing the positive bending stiffness of the secondary beam by the span length (composite beam bending stiffness per unit length), and assuming that the full plastic bending resistance of the two-flange model
- 30 with a yield stress of 325 N/mm² is the maximum resistance.

[0035]

Table 3

Analytical model name	L [m]	B [m]	$(\delta_{pin}-\delta)/\delta_{pin}$ by $S_{j,ini}$ [-]	$M_{j,max}$ [kNm]	Distributed load [kN/m]	Design load capacity [kN/m ²]
1-R(t9) (Comp.)	15	3	44%	205.8	20.2	6.7
1-TG-R(t9) (Ex.)	15	3	55%	322.7	25.7	8.6
1EXC2-R(t9) (Comp.)	15	3	49%	312.7	27.6	9.2
1EXC2-TG-R(t9) (Ex.)	15	3	58%	511.3	38.5	12.8
1Rigid (Comp.)	15	3	67%	711.4	46.8	15.6
2-R(t6) (Comp.)	7.5	3	35%	38.4	18.7	6.2
2-TG-R(t6) (Ex.)	7.5	3	43%	48.3	19.5	6.5
2EXC-R(t6) (Comp.)	7.5	3	42%	56.8	23.6	7.9
2EXC2-R(t6) (Comp.)	7.5	3	44%	67.7	27.0	9.0
2EXC2-TG-R(t6) (Ex.)	7.5	3	50%	110.6	38.9	13.0
2Rigid (Comp.)	7.5	3	64%	129.9	36.3	12.1
3-R(t6) (Comp.)	7.5	3	39%	94.2	42.1	14.0
3-MG-R(t6) (Ex.)	7.5	3	45%	114.0	43.6	14.5
3-TG-R(t6)(Ex.)	7.5	3	47%	121.0	44.4	14.8
3-HG-R(t6) (Ex.)	7.5	3	50%	131.1	46.1	15.4
3EXC2-R(t6) (Comp.)	7.5	3	45%	150.5	57.6	19.2
3EXC2-MG-R(t6) (Ex.)	7.5	3	51%	206.4	70.2	23.4
3EXC2-TG-R(t6) (Ex.)	7.5	3	53%	227.9	75.5	25.2
3EXC2-HG-R(t6) (Ex.)	7.5	3	54%	252.9	81.5	27.2
3Rigid (Comp.)	7.5	3	67%	287.2	76.3	25.4

Table 3: Design load capacity and deflection reduction ratio of Examples and Comparatives

[0036]

Table 3 and Figs. 22 to 24 show that, in Examples satisfying $e_v/H < 0.2$, the deflection reduction effect is greater and the upper limit value of the design load capacity is higher than in Examples with a similar configuration and $e_v/H \geq 0.2$. Arranging the reinforcing rib and reinforcing plate further improves the deflection reduction effect and the upper limit value of the design load capacity.

[0037]

Although the preferred exemplary embodiment of the invention is described in detail above with reference to the accompanying drawings, the invention is not limited thereto. It will be appreciated that a person skilled in the art to which the invention pertains can arrive at various modifications and alterations within the scope of the technical concept set forth in the Claims, and such modifications and alterations are also naturally included within the technical scope of the invention.

EXPLANATION OF CODES

[0038]

1...primary beam, 11...web, 12...top flange, 13...bottom flange, 2...gusset plate, 21...reinforcing rib, 3...secondary beam, 31...web, 32...top flange, 33...bottom flange, 41...bolt, 5...concrete floor slab, 51...concrete, 52...rebar, 53...steel deck profile, 6...stud, 7,7A...reinforcing plate, 71...additional bolt.

15

CLAIM(S)

[Claim 1]

A joint structure connecting a primary beam having an H-shaped cross-section and an end in an axial direction of a secondary beam having an H-shaped cross-section and extending in a direction intersecting the primary beam, the joint
5 structure comprising:

a gusset plate joined at least to a web and a top flange of the primary beam;
and

a row of bolts arranged in a beam height direction of the secondary beam
10 and joining the gusset plate to a web of the secondary beam, wherein

a distance from an axial center of a bottom bolt in the row of bolts to a bottom surface of a bottom flange of the secondary beam is less than $1/5$ of a beam height of the secondary beam.

[Claim 2]

15 The joint structure according to claim 1, further comprising a reinforcing rib disposed to intersect a plate-shaped body of the gusset plate and the web of the primary beam, the reinforcing rib being joined at least to the gusset plate.

[Claim 3]

The joint structure according to claim 1 or 2, further comprising at least one
20 reinforcing plate disposed below a height center line of the web of the secondary beam and in contact with a side end surface of the gusset plate, wherein

the reinforcing plate is bolted to the web of the secondary beam.

[Claim 4]

The joint structure according to claim 3, wherein the reinforcing plate is joined
25 to the web of the secondary beam through a high-strength bolt friction joint.

[Claim 5]

The joint structure according to claim 1, wherein the gusset plate is joined to the web of the secondary beam through a high-strength bolt friction joint.

[Claim 6]

30 The joint structure according to claim 1, further comprising a concrete floor slab constructed on the primary beam and the secondary beam, wherein

a top flange of the secondary beam is joined to the concrete floor slab.