

[Document Type] Specification

[Title of the Invention] BEAM JOINING STRUCTURE, DESIGNING METHOD
OF BEAM JOINING STRUCTURE, AND MANUFACTURING METHOD OF
BEAM JOINING STRUCTURE

[Technical Field of the Invention]

[0001]

The present invention relates to a beam joining structure, a designing method of a beam joining structure, and a manufacturing method of beam joining structure.

Priority is claimed on Japanese Patent Application No. 2017-046780, filed on March 10, 2017, the content of which is incorporated herein by reference.

[Related Art]

[0002]

In the related art, for example, continuous girders described in Patent Documents 1 and 2 are known.

The continuous girder described in Patent Document 1 is a continuous girder reinforced with prestressed steel, and the prestressed steel extending from both end portions of the girder toward a fulcrum is disposed to reach the vicinity of a boundary between hogging bending and sagging bending situated opposite each other with the fulcrum therebetween.

In the continuous girder described in Patent Document 2, the hogging bending section is formed by a steel floor plate and the sagging bending section is formed by a concrete floor plate.

In any of the continuous girders of Patent Documents 1 and 2, a hogging bending region based on a rigid joint is reinforced by the prestressed steel material and the steel floor plate. Accordingly, the prestressed steel and the steel floor plate

withstand the tensile stress generated in the hogging bending region.

[0003]

However, in general, referring to Non-Patent Document 1, a hogging bending reinforcement of a beam of a reinforced concrete structure is set to have a length of “(1/4 of the beam span) + (15 times the diameter of the reinforcing bar)” from the end portion of the beam. The reinforcement is disposed in a range obtained by adding the fixing length of the reinforcing bar and concrete to the length of a hogging bending region present along the length direction of the beam from the end portion of the beam in the beam in a case where the flexural stiffness against sagging bending (hereinafter, referred to as “flexural stiffness against sagging bending”) and the flexural stiffness against hogging bending (hereinafter, referred to as “flexural stiffness against hogging bending”) are the same and the joint at the end portion of the beam is regarded as a rigid joint.

[Prior Art Document]

[Patent Document]

[0004]

[Patent Document 1] Japanese Unexamined Patent Application, First
Publication No. 2003-293323

[Patent Document 2] Japanese Unexamined Patent Application, First
Publication No. H11-222817

[Non-Patent Document]

[0005]

[Non-Patent Document 1] Architectural Institute of Japan, Recommendation
for Detailing and Placing of Concrete Reinforcement, Second Edition, Japan,
Architectural Institute of Japan, September 1986, p.28, 33, 42

[Disclosure of the Invention]

[0006]

In the related art, even in a case where a beam is joined to a support member in a semi-rigid manner regardless of the flexural stiffness and in a case where a beam having flexural stiffness against sagging bending and flexural stiffness against hogging bending different from each other is joined to a support member in a rigid manner, a reinforcing member is disposed over a hogging bending region in a case where a beam having flexural stiffness against sagging bending and flexural stiffness against hogging bending which are the same is regarded as being joined to a support member in a rigid manner. Therefore, the optimization of the arrangement of the reinforcing member is not achieved.

[0007]

The present invention has been made in view of the above circumstances, and an object thereof is to achieve the optimization of the arrangement of a reinforcing member in a beam joining structure in which both ends of a beam is joined to a pair of support members in a semi-rigid manner or a rigid manner.

[Means for Solving the Problem]

[0008]

The summary of the present invention is as follows.

(1) A first aspect of the present invention is a beam joining structure including: a first support member and a second support member forming a pair; a beam which includes a first joint portion and a second joint portion respectively joined to the first support member and the second support member at both end portions, and is spanned between the first support member and the second support member by being joined via the first joint portion and the second joint portion in a semi-rigid manner or

a rigid manner; and a reinforcing member which is disposed to protrude in a direction from the first support member toward the second support member and reinforces the beam by withstanding at least a part of tensile stress generated in the beam by hogging bending of the beam.

A protruding length x of the reinforcing member from a virtual plane which is perpendicular to a member axis direction of the beam and includes the first joint portion is equal to or more than a first distance and equal to or less than a second distance, the first distance is a distance from the first joint portion to an inflection point at which a bending moment distribution of the beam changes from hogging bending to sagging bending in a case where a two-point concentrated load acts on the beam, and the second distance is, on an assumption that a reference beam in which both end portions are joined to the first support member and the second support member in a rigid manner and flexural stiffness against hogging bending and flexural stiffness against sagging bending are the same is used as the beam, a distance from the first joint portion to an inflection point at which a bending moment distribution of the reference beam changes from the hogging bending to the sagging bending in a case where a two-point concentrated load acts on the reference beam.

[0009]

(2) In the beam joining structure according to (1), both the end portions of the beam may be respectively joined to the first support member and the second support member in a semi-rigid manner.

(3) In the beam joining structure according to (2), both the end portions of the beam may be joined to the first support member and the second support member in a semi-rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are different from each other,

and the protruding length x of the reinforcing member may satisfy Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2A),

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ - \left(\frac{l}{2EI_s} + \frac{1}{K} \right) + \sqrt{\left(\frac{l}{2EI_s} + \frac{1}{K} \right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right)} \right\} \quad \dots \quad (2A)$$

here, each of variables is as follows,

EI_h : the flexural stiffness against the hogging bending of the beam (kNm^2)

EI_s : the flexural stiffness against the sagging bending of the beam (kNm^2)

l : a length of the beam (m)

K : a rotational stiffness of the first joint portion of the end portion of the beam (kNm/rad).

(4) In the beam joining structure according to (2), both the end portions of the beam may be joined to the first support member and the second support member in a semi-rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are the same, and the protruding length x of the reinforcing member may satisfy Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2B),

$$x_h = \frac{2l}{9 \left(1 + \frac{2EI}{KI} \right)} \quad \dots \quad (2B)$$

here, each of variables is as follows,

EI : the flexural stiffness against the hogging bending or the sagging bending of the beam (kNm^2)

l : a length of the beam (m)

K: a rotational stiffness of the first joint portion of the end portion of the beam (kNm/rad).

[0010]

(5) In the beam joining structure according to (1), both the end portions of the beam may be joined to the first support member and the second support member in a rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are different from each other.

(6) In the beam joining structure according to (5), the protruding length x of the reinforcing member may satisfy Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2A'),

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ -\frac{l}{2EI_s} + \sqrt{\left(\frac{l}{2EI_s}\right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s}\right)} \right\} \quad \dots \quad (2A')$$

here, each of variables is as follows,

EI_h : the flexural stiffness against the hogging bending of the beam (kNm²)

EI_s : the flexural stiffness against the sagging bending of the beam (kNm²)

l : a length of the beam (m).

[0011]

(7) A second aspect of the present invention is a designing method of a beam joining structure, the beam joining structure including a first support member and a second support member forming a pair, a beam which includes a first joint portion and a second joint portion respectively joined to the first support member and the second support member at both end portions, and is spanned between the first support member and the second support member by being joined via the first joint portion and the second joint portion in a semi-rigid manner or a rigid manner, and a reinforcing

member which is disposed to protrude in a direction from the first support member toward the second support member and reinforces the beam by withstanding at least a part of tensile stress generated in the beam by hogging bending of the beam.

The designing method includes: calculating a first distance which is a distance from the first joint portion to an inflection point at which a bending moment distribution of the beam changes from hogging bending to sagging bending in a case where a two-point concentrated load acts on the beam; calculating, on an assumption that a reference beam in which both end portions are joined to the first support member and the second support member in a rigid manner and flexural stiffness against hogging bending and flexural stiffness against sagging bending are the same is used as the beam, a second distance which is the distance from the first joint portion to an inflection point at which a bending moment distribution of the reference beam changes from the hogging bending to the sagging bending in a case where a two-point concentrated load acts on the reference beam; and setting a protruding length x of the reinforcing member from a virtual plane which is perpendicular to a member axis direction of the beam and includes the first joint portion to be equal to or more than the first distance and equal to or less than the second distance.

[0012]

(8) In the designing method of a beam joining structure according to (7), both the end portions of the beam may be respectively joined to the first support member and the second support member in a semi-rigid manner.

(9) In the designing method of a beam joining structure according to (8), both the end portions of the beam may be joined to the first support member and the second support member in a semi-rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are different

from each other, and the protruding length x of the reinforcing member may satisfy

Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2A),

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ \left(\frac{l}{2EI_s} + \frac{1}{K} \right) + \sqrt{\left(\frac{l}{2EI_s} + \frac{1}{K} \right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right)} \right\} \quad \dots \quad (2A)$$

here, each of variables is as follows,

EI_h : the flexural stiffness against the hogging bending of the beam (kNm^2)

EI_s : the flexural stiffness against the sagging bending of the beam (kNm^2)

l : a length of the beam (m)

K : a rotational stiffness of the first joint portion of the end portion of the beam (kNm/rad).

(10) In the designing method of a beam joining structure according to (8), both the end portions of the beam may be joined to the first support member and the second support member in a semi-rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are the same, and the protruding length x of the reinforcing member may satisfy Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2B),

$$x_h = \frac{2l}{9 \left(1 + \frac{2EI}{KI} \right)} \quad \dots \quad (2B)$$

here, each of variables is as follows,

EI : the flexural stiffness against the hogging bending or the sagging bending of the beam (kNm^2)

l: a length of the beam (m)

K: a rotational stiffness of the first joint portion of the end portion of the beam (kNm/rad).

[0013]

(11) In the designing method of a beam joining structure according to (7), both the end portions of the beam may be joined to the first support member and the second support member in a rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are different from each other.

(12) In the designing method of a beam joining structure according to (11), the protruding length x of the reinforcing member may satisfy Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2A'),

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ -\frac{l}{2EI_s} + \sqrt{\left(\frac{l}{2EI_s}\right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s}\right)} \right\} \quad \dots \quad (2A')$$

here, each of variables is as follows,

EI_h : the flexural stiffness against the hogging bending of the beam (kNm²)

EI_s : the flexural stiffness against the sagging bending of the beam (kNm²)

l: a length of the beam (m).

[0014]

(13) A third aspect of the present invention is a manufacturing method of a beam joining structure designed based on the designing method of a beam joining structure according to any one of (7) to (12), the manufacturing method including:

joining the beam to the first support member and the second support member; and arranging the reinforcing member to have the set protruding length x .

[Effects of the Invention]

[0015]

According to the invention, optimization of an arrangement of a reinforcing member can be achieved in a beam joining structure in which both ends of a beam are joined to a pair of support members in a semi-rigid manner or a rigid manner.

[Brief Description of the Drawings]

[0016]

FIG. 1 is a plan view showing a part of a building in which a beam joining structure according to an embodiment of the present invention is used.

FIG. 2 is a perspective view of a structure corresponding to the part enclosed by A in FIG. 1.

FIG. 3 is a plan view of the structure corresponding to the part enclosed by A in FIG. 1.

FIG. 4 is a sectional view taken along the line IV-IV shown in FIG. 3.

FIG. 5 is a view modeling a beam joining structure applied to the building shown in FIG. 1, and is a view showing a case where an equally distributed load acts on a beam joined in a semi-rigid manner.

FIG. 6 is a view modeling a beam joining structure applied to the building shown in FIG. 1, and is a view showing a case where a two-point concentrated load acts on the beam joined in a semi-rigid manner.

FIG. 7 is a view showing the difference in joint portion in a case of different rigid zones in the structure shown in FIG. 4.

FIG. 8 is a view showing a case where a reference beam is adopted as the

beam in the model shown in FIG. 6.

FIG. 9 is a view modeling a beam joining structure applied to the building shown in FIG. 1, and is a view showing a case where an equally distributed load acts on the beam joined in a rigid manner.

FIG. 10 is a view modeling a beam joining structure applied to the building shown in FIG. 1, and is a view showing a case where a two-point concentrated load acts on the beam joined in a rigid manner.

FIG. 11 is a plan view of a structure corresponding to the part enclosed by B in FIG. 1.

FIG. 12 is a sectional view taken along the line VI-VI shown in FIG. 11.

FIG. 13 is a flowchart showing a designing method of a beam joining structure according to a second embodiment of the present invention.

FIG. 14 is a view showing a modification example of a column included in a building in which the beam joining structure according to the present invention is used.

[Embodiments of the Invention]

[0017]

(First Embodiment)

Hereinafter, a beam joining structure according to a first embodiment of the present invention will be described.

FIG. 1 shows an example of a building to which the beam joining structure according to this embodiment is applied. Examples of the building include a house, a school, an office, and a hospital facility.

FIGS. 2 to 4 show a first structure 61 as a beam joining structure 60 corresponding to the part enclosed by A in FIG. 1.

As shown in FIGS. 1 to 4, the building 1 includes a plurality of columns 11

extending along a vertical direction, primary beams 21 spanned between pairs of the columns 11, and secondary beams 31 spanned between pairs of the primary beams 21, and floor slabs 41 joined to the upper sides of the primary beams 21 and the secondary beams 31. The primary beams 21, the secondary beams 31, and the floor slabs 41 constitute a composite beam.

[0018]

As shown in FIG. 2, the column 11 is a steel framed reinforced concrete (SRC) structure. The column 11 includes concrete 12 formed in a substantially rectangular cross section, and steel frames 13 and reinforcing bars 14 disposed inside the concrete 12. In the shown example, the steel frames 13 are formed of H-section steel. As the reinforcing bars 14, a plurality of main bars 14a extending in an up-down direction and hoops 14b arranged to surround the plurality of main bars 14a in a plurality of stages in the up-down direction are provided.

[0019]

Four primary beams 21 extend from one column 11 so as to form a cross shape in a plan view. In addition, the primary beams 21 can also be appropriately changed into another form spanned between a pair of the columns 11. For example, three primary beams 21 may extend from one column 11 so as to form a T-shape in the plan view. Furthermore, for example, two primary beams 21 may extend from one column 11 so as to form an I-shape in plan view.

[0020]

The primary beam 21 is formed of an H-section steel including a web and flanges respectively disposed on and under the web. An end portion of the primary beam 21 is fixed to the column 11 via a first shear plate 22. The first shear plate 22 is fixed to the column 11 (the steel frame 13 in the shown example) by welding or the

like. The first shear plate 22 extends parallel to the web of the primary beam 21. The primary beam 21 and the first shear plate 22 are joined to each other by a plurality of first bolts 23. The plurality of first bolts 23 join the web of the primary beam 21 and the first shear plate 22 at a plurality of portions in the up-down direction.

[0021]

In the building 1 shown in FIG. 1, two secondary beams 31 are provided between the pair of primary beams 21 at equal intervals in the member axis direction. Therefore, it can be assumed that a two-point concentrated load acts on one primary beam 21 spanned between the pair of columns 11 from the two secondary beams 31. In addition, the assumption here does not limit the application range of the present invention. One or more secondary beams 31 may be spanned between the pair primary beams 21 extending parallel to each other in a direction intersecting the primary beams 21 at any given intervals in the member axis direction of both the primary beams 21.

[0022]

Like the primary beam 21, the secondary beam 31 is formed of H-section steel, and the end portion thereof is joined to the primary beam 21.

[0023]

As shown in FIGS. 2 and 4, the floor slab 41 includes a deck plate (not shown) disposed on the primary beam 21 and the secondary beam 31 and concrete 42 placed on the deck plate. In FIG. 4, hatching of the concrete 42 is omitted for ease of viewing of the drawing.

The primary beam 21 and the secondary beam 31 are provided with studs 51 (tensile stress transmitting members) which protrude upward and are embedded in the concrete 42. A plurality of the studs 51 are provided at intervals in the member axis

direction of the primary beam 21 or the secondary beam 31. The studs 51 transmit the tensile force acting on the primary beam 21 or the secondary beam 31 to the floor slab 41.

[0024]

The beam joining structure 60 according to this embodiment includes a pair of support members 71 (a first support member and a second support member forming a pair), a beam 72 joined to the pair of support members 71, and a reinforcing member 73 which reinforces the beam 72.

Both end portions of the beam 72 are respectively joined to the pair of support members 71 in a semi-rigid manner so that the beam 72 is spanned between the pair of support members 71.

The reinforcing member 73 is disposed so as to protrude in a direction from one support member 71 toward the other support member, and withstands at least a part of the tensile stress generated in the beam 72 due to hogging bending of the beam 72.

[0025]

In a rigid joint, the rotational stiffness of the joint portion is infinite and in a pin joint, the rotational stiffness of the joint portion is 0, whereas in a semi-rigid joint, the rotational stiffness of the joint portion is finite. The semi-rigid joint refers to a joint type in which the bending moment transmitted between the support member 71 and the beam 72 is small and the rotational movement of the beam 72 with respect to the support member 71 is restricted to some extent. In addition, the pin joint refers to a joint type in which there is no or minimal bending moment transmitted between the support member 71 and the beam 72, and the rotational movement of the beam 72 with respect to the support member 71 is not restricted.

The semi-rigid joint, pin joint, and rigid joint can be defined based on European Design Standards (Eurocode 3-Part 1-8).

[0026]

As shown in FIGS. 2 to 4, in the first structure 61, the primary beam 21 as the beam 72 is joined to the column 11 as the support member 71, and a first reinforcing member 73a as the reinforcing member 73 reinforces the primary beam 21.

[0027]

Specifically, the first structure 61 includes the pair of columns 11, the primary beam 21 spanned between the pair of columns 11, and the first reinforcing member 73a that reinforces the primary beam 21.

Both end portions of the primary beam 21 are respectively joined to the pair of columns 11 in a semi-rigid manner. In this embodiment, both end portions of the primary beam 21 are joined to the columns 11 in a semi-rigid manner by being fixed to the columns 11 via the first shear plates 22.

[0028]

The first reinforcing member 73a withstands at least a part of the tensile stress generated in the primary beam 21 by the hogging bending of the primary beam 21. The first reinforcing member 73a is formed of a reinforcing bar and is embedded in the floor slab 41. The first reinforcing member 73a is embedded in the floor slab 41 so as to be located above the studs 51 provided on the primary beam 21. The first reinforcing member 73a extends along the member axis direction of the primary beam 21 to be reinforced.

[0029]

In this embodiment, the first reinforcing member 73a reinforces, among the four primary beams 21 extending from one column 11, two primary beams 21

extending toward opposite directions across the column 11 therebetween. The first reinforcing member 73a extends along the member axis direction (hereinafter, referred to as “first member axis direction X1”) of the two primary beams 21. The first reinforcing member 73a is disposed to avoid the column 11.

[0030]

A plurality of the first reinforcing members 73a are arranged at intervals in a direction orthogonal to the first member axis direction X1 in the horizontal direction. The column 11 is disposed between the first reinforcing members 73a adjacent to each other in the orthogonal direction. The size (length) of the first reinforcing member 73a along the first member axis direction X1 of the primary beam 21 is larger than the size (width) of the column 11 along the first member axis direction X1 of the primary beam 21, and the first reinforcing member 73a extends beyond the column 11 toward both sides in the first member axis direction X1.

In FIGS. 2 and 3, the two primary beams 21 to which the first structure 61 is not applied are indicated by the two-dot chain lines.

[0031]

In the first structure 61, when a load is applied to the primary beam 21 from above, a bending moment acts on the end portion of the primary beam 21. In addition, the tensile force on the upper flange of the primary beam 21 and the compressive force on the lower flange of the primary beam 21 simultaneously act on the respective end portions. The tensile force is transmitted to the first reinforcing member 73a via the studs 51 and the floor slab 41. Accordingly, at least a part of the tensile force is withstood by the first reinforcing member 73a. The compressive force is transmitted to the column 11 via the web of the primary beam 21 and the first shear plate 22.

[0032]

In the first structure 61, as shown in FIGS. 5 and 6, a coordinate system in which an X axis is directed along the member axis direction X (the first member axis direction X1 in the first structure 61) of the beam 72 (the primary beam 21 in the first structure 61) can be defined. In this coordinate system, a joint portion O between any first support member 71a of the pair of support members 71 (the columns 11 in the first structure 61) and the end portion of the beam 72 can be used as the origin of an X coordinate. Furthermore, in this coordinate system, the direction from the first support member 71a toward a second support member 71b can be used as a positive direction X+ of the X axis. At this time, the reinforcing member 73 (the first reinforcing member 73a in the first structure 61) extends from the origin (the joint portion O between the first support member 71a and the end portion of the beam 72) parallel to a direction along the positive direction X+.

In other words, the reinforcing member 73 protrudes from a virtual plane which is perpendicular to the member axis direction X of the beam 72 and includes the joint portion O, in a direction parallel to the member axis direction X of the beam 72.

[0033]

Any support member 71 of the pair of support members 71 may be used as the first support member 71a (or the second support member 71b). In addition, as shown in FIG. 4, the joint portion O between the first support member 71a or the second support member 71b and the end portion of the beam 72 can be used as the center of the support member 71 in the member axis direction X. However, in a case where a part or the entirety of the support member 71 is a rigid zone, the joint portion O between the first support member 71a or the second support member 71b and the end portion of the beam 72 is used as the end edge of the rigid zone along the member axis direction X. That is, by appropriately setting the rigid zone, for example, as shown in

FIG. 7, in the first structure 61, the center of the support member 71 in the member axis direction X can be used as the joint portion O, and the position at which the first bolt 23 is disposed can be used as the joint portion O.

[0034]

In this embodiment, the upper limit and the lower limit of the protruding length x of the reinforcing member 73 from the joint portion O between one support member 71 and the end portion of the beam 72 are set as follows.

[0035]

(Setting of Lower Limit)

In a case where a two-point concentrated load acts on the beam 72, the distance from the joint portion O to the inflection point at which the bending moment distribution of the beam 72 changes from hogging bending to sagging bending is used as the lower limit of the protruding length x.

[0036]

(Setting of Upper Limit)

Assuming that as the beam 72, a reference beam 72A is used in which both end portions are joined to the pair of support members 71 in a rigid manner and the flexural stiffness against hogging bending and the flexural stiffness against sagging bending are the same, in a case where a two-point concentrated load acts on the reference beam 72A, the distance from the joint portion O to the inflection point at which the bending moment distribution of the reference beam 72A changes from hogging bending to sagging bending is used as the upper limit of the protruding length x.

[0037]

In other words, in this embodiment, the X coordinate of the end portion of the

reinforcing member 73 in the positive direction X+ (hereinafter referred to as “end portion X coordinate of the reinforcing member 73”) is equal to or more than a lower limit X coordinate described below and equal to or less than an upper limit X coordinate.

[0038]

(Lower Limit X Coordinate)

The lower limit X coordinate is, as shown in FIG. 6, the X coordinate of the inflection point at which the bending moment distribution of the beam 72 changes from hogging bending to sagging bending in a case where a two-point concentrated load acts on the beam 72. The two-point concentrated load refers to a situation in which the same load acts on only two points that trisect the beam 72 in the member axis direction X.

[0039]

By causing the end portion X coordinate of the reinforcing member 73 to be equal to or more than the lower limit X coordinate, the hogging bending region in the member axis direction in the case where a two-point concentrated load acts on the beam 72 is longer than, for example, that, in a case where an equally distributed load acts on the beam 72. Therefore, the reinforcing member 73 can be located not only in the hogging bending region when the two-point concentrated load acts on the beam 72, but also in the hogging bending region when the equally distributed load acts on the beam 72. As a result, the beam 72 can be reliably reinforced by the reinforcing member 73. That is, the lower limit X coordinate defined here can be applied to any other load condition such as an equally distributed load, in which a live load due to gravity is the main external force.

[0040]

The upper limit X coordinate is the X coordinate of the inflection point at which the bending moment distribution of the reference beam 72A changes from hogging bending to sagging bending in a case where a two-point concentrated load acts on the reference beam 72A as shown in FIG. 8. The reference beam 72A is a beam assumed to have end portions joined to the pair of support members 71 in a rigid manner instead of a semi-rigid manner and have flexural stiffness against hogging bending (hereinafter, referred to as “flexural stiffness against hogging bending”) and flexural stiffness against sagging bending (hereinafter, referred to as “flexural stiffness against sagging bending”) which are the same. For example, “being the same” refers to a case where the value of $|(flexural\ stiffness\ against\ hogging\ bending - flexural\ stiffness\ against\ sagging\ bending) / flexural\ stiffness\ against\ hogging\ bending|$ is preferably within $\pm 5\%$, and more preferably within $\pm 2\%$.

[0041]

As in the reference beam 72A, the hogging bending region in the member axis direction in the case where the end portions are joined to the support members 71 in a rigid manner (in the case where the rotational stiffness is infinite) is longer than that in the case where the end portions are joined to the support members 71 in a semi-rigid manner (in the case where the rotational stiffness is finite). Furthermore, as in the reference beam 72A, the hogging bending region in the member axis direction in the case where the end portions are joined to the support members 71 in a rigid manner and in the case where the flexural stiffness against hogging bending (hereinafter, referred to as “flexural stiffness against hogging bending”) and flexural stiffness against sagging bending (hereinafter, referred to as “flexural stiffness against sagging bending”) are the same is also longer than that in the case where the flexural stiffness against hogging bending is smaller than the flexural stiffness against sagging bending.

That is, considering that the flexural stiffness against hogging bending is generally equal to or smaller than the flexural stiffness against sagging bending, it can be said that the upper limit X coordinate set based on the reference beam 72A is calculated assuming a case where the hogging bending region is longest in the member axis direction. Therefore, by causing the end portion X coordinate of the reinforcing member 73 to be equal to or less than the upper limit X coordinate, the reinforcing member 73 can be prevented from becoming excessively long.

[0042]

As described above, by causing the end portion X coordinate of the reinforcing member 73 to be equal to or more than the lower limit X coordinate and equal to or less than the upper limit X coordinate, it is possible to reliably reinforce the beam using the reinforcing member 73 while preventing excessive arrangement of the reinforcing member 73, so that the optimization of the arrangement of the reinforcing member 73 can be achieved. In the related art, in a case where the flexural stiffness against sagging bending and the flexural stiffness against hogging bending of the beam 72 are different from each other, or even in a case where the rotational stiffness of the joint portion of the end portion of the beam 72 is finite (semi-rigid joint), the reinforcing member 73 is disposed in the entire hogging bending region set based on the reference beam 72A. Therefore, the reinforcing member becomes heavy, the burden on an operator is large during construction, and a large amount of materials is required, resulting in inefficiency. According to the present invention, in the case where the flexural stiffness against sagging bending and the flexural stiffness against hogging bending of the beam 72 are different from each other, or even in the case where the rotational stiffness of the joint portion of the end portion of the beam 72 is finite (semi-rigid joint), the length of the hogging bending region can be calculated by

appropriately considering these cases, and the amount of the reinforcing member 73 can be reduced. Therefore, a reduction in the burden on the operator and a reduction in the amount of materials used can be achieved by the reduction in weight.

[0043]

More specifically, the end portion X coordinate x (that is, protruding length x (m)) of the reinforcing member 73 satisfies Formula (1).

$$x_h \leq x \leq \frac{2l}{9} \quad \cdots \quad (1)$$

[0044]

Here, x_h representing the lower limit of the end portion X coordinate x of the reinforcing member 73 is obtained by Formula (2A) in a case where the flexural stiffness against sagging bending of the beam 72 and the flexural stiffness against hogging bending of the beam 72 are different from each other ($EI_s \neq EI_h$), and is obtained by Formula (2B) in a case where the flexural stiffness against sagging bending of the beam 72 and the flexural stiffness against hogging bending of the beam 72 are the same ($EI_s = EI_h = EI$).

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left[- \left(\frac{l}{2EI_s} + \frac{1}{K} \right) + \sqrt{\left(\frac{l}{2EI_s} + \frac{1}{K} \right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right)} \right] \quad \cdots \quad (2A)$$

$$x_h = \frac{2l}{9 \left(1 + \frac{2EI}{KI} \right)} \quad \cdots \quad (2B)$$

Here, each of the variables is as follows.

EI_h : the flexural stiffness against hogging bending of the beam 72 (kNm^2)

EI_s : the flexural stiffness against sagging bending of the beam 72 (kNm^2)

l: the length of the beam 72 (m)

K: the rotational stiffness of the joint portion of the end portion of the beam 72 (kNm/rad)

[0045]

In Formula (1), (21/9) representing the upper limit of the end portion X coordinate x of the reinforcing member 73 is a value when K is infinite in Formula (2B), that is, when the end portions of the beam are joined to the support members 71 in a rigid manner.

[0046]

As described above, by causing the end portion X coordinate x of the reinforcing member 73 to satisfy Formula (1), the end portion X coordinate x of the reinforcing member 73 can be reliably caused to be equal to or more than the lower limit X coordinate and equal to or less than the upper limit X coordinate.

[0047]

As shown in FIG. 7, the length l of the beam 72 can be set to, for example, the distance (span) between a first joint portion Oa between the first support member 71a and the end portion of the beam 72 and a second joint portion Ob between the second support member 71b and the end portion of the beam 72, in the member axis direction X .

[0048]

(Application to Rigid Joint)

In the beam joining structure 60, the beam 72 is joined to the support member 71 in a semi-rigid manner. However, the technical scope of the present invention can also be applied to a beam joining structure in which the beam 72 in which the flexural stiffness against sagging bending and the flexural stiffness against hogging bending are different from each other is joined to the support members 71 in a rigid manner.

In this case, as shown in FIGS. 9 and 10, a coordinate system in which an X axis is directed along the member axis direction X (the first member axis direction $X1$

in the first structure 61) of the beam 72 (the primary beam 21 in the first structure 61) can be defined.

In such a rigid joint type beam joining structure, x_h is obtained by setting the rotational stiffness K in Formula (2A) to be infinite (that is, the beam 72 is assumed to be joined to the support members 71 in a rigid manner). That is, x_h is obtained by Formula (2A').

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ -\frac{l}{2EI_s} + \sqrt{\left(\frac{l}{2EI_s}\right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s}\right)} \right\} \quad \dots \quad (2A')$$

[0049]

In the above description, the beam joining structure 60 is an exemplary example of the first structure 61 shown in FIGS. 2 to 4.

However, as shown in FIGS. 11 and 12, the beam joining structure 60 may be a second structure 62 in which the secondary beams 31 as the beam 72 are joined to the primary beams 21 as the support member 71, and second reinforcing members 73b as the reinforcing member 73 reinforce the secondary beams 31.

FIGS. 11 and 12 show the second structure 62 as the beam joining structure 60 corresponding to the part enclosed by B in FIG. 1.

As shown in FIGS. 11 and 12, the second structure 62 includes a pair of the primary beams 21, the secondary beam 31 spanned between the pair of primary beams 21, and the second reinforcing members 73b that reinforce the secondary beams 31.

The end portions of the secondary beam 31 are respectively joined to the pair of primary beams 21 in a semi-rigid manner. In this embodiment, the end portions of the secondary beam 31 are joined to the primary beams 21 in a semi-rigid manner by being fixed to the primary beams 21 via second shear plates 32.

Specifically, the end portions of the secondary beam 31 are fixed to the pair of

primary beams 21 via the second shear plate 32. The second shear plate 32 is fixed to the primary beam 21 by welding or the like. The second shear plate 32 extends parallel to the web of the secondary beam 31. The secondary beam 31 and the second shear plate 32 are joined to each other by a plurality of second bolts 33. The plurality of second bolts 33 join the web of the secondary beam 31 and the second shear plate 32 at a plurality of portions in the up-down direction.

[0050]

The second reinforcing member 73b withstands at least a part of the tensile stress generated in the secondary beam 31 by the hogging bending of the secondary beam 31. The second reinforcing member 73b is formed of a reinforcing bar and is embedded in the floor slab 41. The second reinforcing member 73b is embedded in the floor slab 41 so as to be located above the studs 51 provided on the secondary beam 31. The second reinforcing member 73b extends along the member axis direction of the secondary beam 31 to be reinforced.

[0051]

In this embodiment, the second reinforcing member 73b reinforces two secondary beams 31 extending toward opposite directions across one primary beam 21 therebetween. The second reinforcing member 73b extends along the member axis direction (hereinafter, referred to as “second member axis direction X2”) of the two secondary beams 31. A plurality of the second reinforcing members 73b are arranged at intervals in a direction orthogonal to the first member axis direction X2 in the horizontal direction. The size (length) of the second reinforcing member 73b along the second member axis direction X2 of the secondary beam 31 is larger than the size (width) of the primary beam 21 along the second member axis direction X2 of the secondary beam 31, and the second reinforcing member 73b extends beyond the

primary beam 21 toward both sides in the second member axis direction X2.

[0052]

In the second structure 62, when a load is applied to the secondary beam 31 from above, a bending moment acts on the end portion of the secondary beam 31. In addition, the tensile force on the upper flange of the secondary beam 31 and the compressive force on the lower flange of the secondary beam 31 simultaneously act on the respective end portions. The tensile force is transmitted to the second reinforcing member 73b via the studs 51 and the floor slab 41. Accordingly, at least a part of the tensile force is withstood by the second reinforcing member 73b. The compressive force is transmitted to the primary beam 21 via the web of the secondary beam 31 and the second shear plate 32.

[0053]

(Formula Derivation Process 1: Derivation of Lower Limit X Coordinate)

Hereinafter, a process of deriving Formulas (1), (2A), and (2B) will be described.

In this process, assuming two conditions of (i) equally distributed load and (ii) two-point concentrated load as representative load conditions acting on the beam 72, the X coordinate x_h of a point at which the bending moment of the beam 72 becomes zero is obtained for each of the two load conditions. The position of x_h is the boundary between a hogging bending region R1 and a sagging bending region R2 under each load condition.

[0054]

In addition, x_h is situated at each of both ends of the beam 72, and is present at two points. In the following description, of the two x_h , the smaller one is referred to as x_{h1} , and the larger one is referred to as x_{h2} . That is, both ranges of $0 \leq x \leq x_{h1}$ and

$x_{h2} \leq x \leq l$ become the hogging bending region R1. In this embodiment, x_{h1} of the two x_h is derived. x_{h1} is the X coordinate of the inflection point at which the bending moment distribution of the beam 72 changes from hogging bending to sagging bending in a case where a two-point concentrated load acts on the beam 72. x_{h2} is the X coordinate of the inflection point at which the bending moment distribution of the beam 72 changes from sagging bending to hogging bending in the case where the two-point concentrated load acts on the beam 72. x_{h1} is smaller than x_{h2} .

Regarding x_{h1} under the two conditions of (i) equally distributed load and (ii) two-point concentrated load, one having a larger value is used as the lower limit X coordinate.

[0055]

In a front view of the beam 72 viewed such that the first support member 71a is located on the left and the second support member 71b is located on the right, the rotation angle at the joint portion O between the first support member 71a and the end portion of the beam 72 in is θ_a (rad) assuming that clockwise is positive, the absolute value M_a (Nmm) of the bending moment at the end portion of the beam 72 is expressed by Formula (11) regardless of the load conditions.

$$M_a = K|\theta_a| \quad \cdots \quad (11)$$

[0056]

(i) In Case of Equally Distributed Load

In this case, as shown in FIG. 5, it is assumed that a load w (Nmm²) acts on the beam 72 uniformly over the entire length in the X-axis direction (the member axis direction X).

The bending moment distribution of the beam 72 in the X-axis direction is expressed by Formula (12) from the force balance condition, assuming that positive is

taken when the lower flange is in tension.

$$M(x) = \frac{wl}{2}x - \frac{w}{2}x^2 - M_a \quad \dots \quad (12)$$

[0057]

The curvature ϕ (rad/m) of the beam 72 is categorized into ($x_{h1} \leq x \leq x_{h2}$) in the case of the sagging bending region R2 and ($0 \leq x \leq x_{h1}$, $x_{h2} \leq x \leq l$) in the case of the hogging bending region R1 using the bending moment M_a , and the flexural stiffness against hogging bending EI_h and the flexural stiffness against sagging bending EI_s of the beam 72, and is expressed by Formulas (13) and (14). In each of the following formulas, the formula in parentheses described in parallel represents the range of the variable x to which the corresponding formula is applied.

$$\phi(x) = \frac{1}{EI_s} \left(\frac{wl}{2}x - \frac{w}{2}x^2 - M_a \right) \quad (x_{h1} \leq x \leq x_{h2}) \quad \dots \quad (13)$$

$$\phi(x) = \frac{1}{EI_h} \left(\frac{wl}{2}x - \frac{w}{2}x^2 - M_a \right) \quad (0 \leq x \leq x_{h1}, x_{h2} \leq x \leq l) \quad \dots \quad (14)$$

[0058]

Here, the value of the X coordinate when the value of the bending moment $M(x)$ becomes zero is the boundaries x_{h1} and x_{h2} between the hogging bending region R1 and the sagging bending region R2. That is, in Formula (12), when $x = x_{h1}$ and $x = x_{h2}$, $M(x)$ becomes zero. Therefore, Formulas (15) and (16) are obtained from Formula (12).

$$x_{h1} = \frac{l}{2} \left(1 - \sqrt{1 - \frac{8M_a}{wl^2}} \right) \quad \dots \quad (15)$$

$$x_{h2} = \frac{l}{2} \left(1 + \sqrt{1 - \frac{8M_a}{wl^2}} \right) \quad \dots \quad (16)$$

[0059]

Next, the distribution $\theta(x)$ of the rotation angle θ (rad) of the beam 72 is expressed by Formulas (17) to (19) according to the position of the X coordinate by integrating the curvature ϕ of Formulas (13) and (14) with x , in consideration of the

boundary condition $\theta(0) = \theta_a$ at $x = 0$.

$$\theta(x) = \frac{1}{EI_h} A(x)_{x=0} + \theta_a \quad (0 \leq x \leq x_{h1}) \quad \dots \quad (17)$$

$$\theta(x) = \frac{1}{EI_s} A(x)_{x=x} + \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) A(x)_{x=x_{h1}} + \theta_a \quad (x_{h1} \leq x \leq x_{h2}) \quad \dots \quad (18)$$

$$\theta(x) = \frac{1}{EI_h} A(x)_{x=x} + \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) \{ A(x)_{x=x_{h1}} - A(x)_{x=x_{h2}} \} + \theta_a \quad (x_{h2} \leq x \leq l) \quad \dots \quad (19)$$

[0060]

Here, $A(x)$ in Formulas (17) to (19) is expressed by Formula (20).

$$A(x) = \frac{w}{6} x^3 - \frac{wl}{4} x^2 + M_a x \quad \dots \quad (20)$$

[0061]

(i-i) In Case of Flexural stiffness against hogging bending $EI_h \neq$ Flexural stiffness against sagging bending EI_s

Using the compatibility conditions for deformation at $x = (l/2)$, that is, the fact that the rotation angle becomes zero at the center of the beam 72 in the X-axis direction ($\theta(l/2) = 0$), the relationship between the rotational stiffness K and the rotation angle θ_a is expressed by Formula (21) from Formulas (11), (18), and (20).

$$\theta(x) \Big|_{x=l/2} = \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) \left(\frac{wl^3}{24} - \frac{l}{3} K \theta_a \right) \sqrt{1 - \frac{8K\theta_a}{wl^2}} - \frac{1}{EI_h} \left(\frac{wl^3}{24} - \frac{l}{2} K \theta_a \right) + \theta_a = 0 \quad \dots \quad (21)$$

[0062]

By taking K on both sides of Formula (21) and substituting Formula (11) into Formula (21) considering that $\theta(x) \geq 0$ in the range of $0 \leq x \leq (l/2)$, Formula (22) is obtained.

$$\left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) \left(\frac{l}{3} M_a - \frac{wl^3}{24} \right) K \sqrt{1 - \frac{8M_a}{wl^2}} + \frac{K}{EI_h} \left(\frac{wl^3}{24} - \frac{l}{2} M_a \right) = M_a \quad \dots \quad (22)$$

[0063]

M_a is obtained from Formula (22), and by substituting the value into Formula (15), X_h is obtained.

[0064]

(i-ii) In Case of flexural stiffness against hogging bending EI_h = flexural stiffness against sagging bending EI_s (= EI)

By substituting Formula (20) and $EI_h = EI_s = EI$ into Formula (17) and further substituting Formula (11) considering that $\theta(x) \geq 0$ in the range of $0 \leq x \leq (l/2)$,

Formula (23) is obtained.

$$\theta(x) = \frac{1}{EI} \left(\frac{w}{6} x^3 - \frac{wl}{4} x^2 + K\theta_a x \right) + \theta_a \quad (x_{h1} \leq x \leq x_{h2}) \quad \dots \quad (23)$$

[0065]

Here, when Formula (23) is solved for θ_a using the compatibility conditions ($\theta(l/2) = 0$) for deformation at $x = (l/2)$, Formula (24) is obtained.

$$\theta_a = -\frac{wl^2}{12 \left(K + \frac{2EI}{l} \right)} \quad \dots \quad (24)$$

[0066]

By substituting Formulas (11) and (24) into Formula (12) considering that $\theta(x) \geq 0$ in the range of $0 \leq x \leq (l/2)$, Formula (25) is obtained.

$$M(x) = \frac{wl}{2} x - \frac{w}{2} x^2 - \frac{wl^2}{12 \left(1 + \frac{2EI}{KI} \right)} \quad \dots \quad (25)$$

[0067]

Since x is x_h in a case where the value of the bending moment $M(x)$ becomes zero in Formula (25), Formula (26) is obtained based on Formula (25).

$$x_h = \frac{l}{2} \left\{ 1 \pm \sqrt{1 - \frac{2K}{3 \left(K + \frac{2EI}{l} \right)}} \right\} \quad \dots \quad (26)$$

[0068]

Here, since $x_{h1} \leq x_{h2}$, x_{h1} is expressed by Formula (27).

$$x_{h1} = \frac{l}{2} \left\{ 1 - \sqrt{1 - \frac{2K}{3 \left(K + \frac{2EI}{l} \right)}} \right\} \quad \dots \quad (27)$$

[0069]

(i-iii) Summary in Case of Equally Distributed Load

In a case on the assumption of an equally distributed load, x_h is obtained by Formula (28) (when $EI_s \neq EI_h$) or by Formula (30) (when $EI_s = EI_h = EI$).

[0070]

(when $EI_s \neq EI_h$)

$$x_h = \frac{l}{2} \left(1 - \sqrt{1 - \frac{8M_a}{wl^2}} \right) \quad \dots \quad (28)$$

However, M_a satisfies Formula (29).

$$\left(\frac{1}{EI_s} - \frac{1}{EI_h} \right) \left(\frac{l}{3} M_a - \frac{wl^3}{24} \right) K \sqrt{1 - \frac{8M_a}{wl^2}} + \frac{K}{EI_h} \left(\frac{wl^3}{24} - \frac{l}{2} M_a \right) = M_a \quad \dots \quad (29)$$

[0071]

(when $EI_s = EI_h = EI$)

$$x_h = \frac{l}{2} \left\{ 1 - \sqrt{1 - \frac{2K}{3 \left(K + \frac{2EI}{l} \right)}} \right\} \quad \dots \quad (30)$$

[0072]

(ii) In Case of Two-Point Concentrated Load

In this case, as shown in FIG. 6, it is assumed that the same load P (N) acts on only two points that trisect the beam 72 in the X-axis direction (the member axis direction X).

The bending moment distribution of the beam 72 in the X-axis direction is expressed by Formulas (31) to (33) from the force balance condition, assuming that positive is taken when the lower flange is in tension.

$$M(x) = Px - M_a \quad \left(0 \leq x \leq \frac{l}{3}\right) \quad \dots \quad (31)$$

$$M(x) = \frac{Pl}{3} - M_a \quad \left(\frac{l}{3} \leq x \leq \frac{2l}{3}\right) \quad \dots \quad (32)$$

$$M(x) = Pl - M_a - Px \quad \left(\frac{2l}{3} \leq x \leq l\right) \quad \dots \quad (33)$$

[0073]

The curvature ϕ (rad/m) of the beam 72 is categorized into cases of ($x_{h1} \leq x \leq x_{h2}$) in the case of the sagging bending region R2, ($0 \leq x \leq x_{h1}$, $x_{h2} \leq x \leq l$) in the case of the hogging bending region R1, and a region having a discontinuous bending moment distribution, using the bending moment M_a , and the flexural stiffness against hogging bending EI_h and the flexural stiffness against sagging bending EI_s of the beam 72, and is expressed by Formulas (34) to (38).

$$\phi(x) = \frac{1}{EI_h}(Px - M_a) \quad (0 \leq x \leq x_{h1}) \quad \dots \quad (34)$$

$$\phi(x) = \frac{1}{EI_s}(Px - M_a) \quad \left(x_{h1} \leq x \leq \frac{l}{3}\right) \quad \dots \quad (35)$$

$$\phi(x) = \frac{1}{EI_s}\left(\frac{Pl}{3} - M_a\right) \quad \left(\frac{l}{3} \leq x \leq \frac{2l}{3}\right) \quad \dots \quad (36)$$

$$\phi(x) = \frac{1}{EI_s}(Pl - Px - M_a) \quad \left(\frac{2l}{3} \leq x \leq x_{h2}\right) \quad \dots \quad (37)$$

$$\phi(x) = \frac{1}{EI_h}(Pl - Px - M_a) \quad (x_{h2} \leq x \leq l) \quad \dots \quad (38)$$

[0074]

Here, the value of the X coordinate when the value of the bending moment $M(x)$ becomes zero is the boundaries x_{h1} and x_{h2} between the hogging bending region R1 and the sagging bending region R2. That is, in Formula (31), when $x = x_{h1}$ in Formula (31) and when $x = x_{h2}$ in Formula (33), $M(x)$ becomes zero. Therefore, Formulas (39) and (40) are obtained from Formulas (31) and (33).

$$x_{h1} = \frac{M_a}{P} \quad \dots \quad (39)$$

$$x_{h2} = l - \frac{M_a}{P} \quad \dots \quad (40)$$

[0075]

Next, the distribution $\theta(x)$ of the rotation angle θ (rad) of the beam 72 is

expressed by Formulas (41) to (45) according to the position of the X coordinate by integrating the curvature ϕ of Formulas (34) to (38) with x, in consideration of the boundary condition $\theta(0) = \theta_a$ at $x = 0$.

$$\theta(x) = \frac{1}{EI_h} A(x)_{x=0} + \theta_a \quad (0 \leq x \leq x_{h1}) \quad \dots \quad (41)$$

$$\theta(x) = \frac{1}{EI_s} A(x)_{x=x_1} + \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) \frac{M_a^2}{2P} + \theta_a \quad \left(x_{h1} \leq x \leq \frac{l}{3} \right) \quad \dots \quad (42)$$

$$\theta(x) = \frac{1}{EI_s} \left(-\frac{Pl}{3} + M_a \right) x + \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) \frac{M_a^2}{2P} + \frac{Pl^2}{18EI_s} + \theta_a \quad \left(\frac{l}{3} \leq x \leq \frac{2l}{3} \right) \quad \dots \quad (43)$$

$$\theta(x) = \frac{1}{EI_s} B(x)_{x=x_2} + \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) \frac{M_a^2}{2P} + \frac{5Pl^2}{18EI_s} + \theta_a \quad \left(\frac{2l}{3} \leq x \leq x_{h2} \right) \quad \dots \quad (44)$$

$$\theta(x) = \frac{1}{EI_h} B(x)_{x=l} + \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) \left(\frac{Pl^2}{2} - M_a l + \frac{M_a^2}{P} \right) + \frac{5Pl^2}{18EI_s} + \theta_a \quad (x_{h2} \leq x \leq l) \quad \dots \quad (45)$$

[0076]

Here, A(x) and B(x) in Formulas (41) to (45) are expressed by Formulas (46) and (47).

$$A(x) = -\frac{P}{2} x^2 + M_a x \quad \dots \quad (46)$$

$$B(x) = \frac{P}{2} x^2 + (-Pl + M_a)x \quad \dots \quad (47)$$

[0077]

(ii-i) In Case of Flexural stiffness against hogging bending $EI_h \neq$ Flexural stiffness against sagging bending EI_s

Using the compatibility conditions for deformation at $x = (l/2)$, that is, the fact that the rotation angle becomes zero at the center of the beam 72 in the X-axis direction ($\theta(l/2) = 0$), the relationship between the rotational stiffness K and the rotation angle θ_a is expressed by Formula (48) from Formulas (11) and (43).

$$\theta_a = \frac{P}{\left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) K^2} \left\{ -\left(\frac{Kl}{2EI_s} + 1 \right) + \sqrt{\left(\frac{Kl}{2EI_s} + 1 \right)^2 + \frac{2K^2 l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right)} \right\} \quad \dots \quad (48)$$

[0078]

By taking K on both sides of Formula (48) and substituting Formula (11) into

$$M_a = \frac{P}{\left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) K} \left\{ -\left(\frac{Kl}{2EI_s} + 1 \right) + \sqrt{\left(\frac{Kl}{2EI_s} + 1 \right)^2 + \frac{2K^2 l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right)} \right\} \quad \dots \quad (49)$$

Formula (48) considering that $\theta(x) \geq 0$ in the range of $0 \leq x \leq (l/2)$, Formula (49) is obtained.

[0079]

By substituting Formula (49) into Formula (39), X_h is obtained by Formula (50).

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ -\left(\frac{l}{2EI_s} + \frac{1}{K} \right) + \sqrt{\left(\frac{l}{2EI_s} + \frac{1}{K} \right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right)} \right\} \quad \dots (50)$$

[0080]

(ii-ii) In Case of flexural stiffness against hogging bending EI_h = flexural stiffness against sagging bending EI_s (= EI)

By substituting $EI_h = EI_s = EI$ into Formula (43) and further substituting Formula (11) considering that $\theta(x) \geq 0$ in the range of $0 \leq x \leq (l/3)$, Formula (51) is obtained.

$$\theta(x) = \frac{1}{EI} \left\{ \left(-\frac{Pl}{3} + K\theta_a \right) x + \frac{Pl^2}{18} \right\} + \theta_a \quad \left(\frac{l}{3} \leq x \leq \frac{2l}{3} \right) \quad \dots (51)$$

[0081]

Here, when Formula (51) is solved for θ_a using the compatibility conditions ($\theta(l/2) = 0$) for deformation at $x = (l/2)$, Formula (52) is obtained.

$$\theta_a = \frac{2Pl}{9 \left(K + \frac{2EI}{l} \right)} \quad \dots (52)$$

[0082]

By substituting Formulas (11) and (52) into Formula (31) considering that $\theta(x) \geq 0$ in the range of $0 \leq x \leq (l/3)$, Formula (53) is obtained.

$$M(x) = Px - \frac{2Pl}{9 \left(1 + \frac{2EI}{KI} \right)} \quad \left(0 \leq x \leq \frac{l}{3} \right) \quad \dots (53)$$

[0083]

Since x is x_h in a case where the value of the bending moment $M(x)$ becomes

zero in Formula (53), Formula (54) is obtained.

$$x_{h1} = \frac{2l}{9\left(1 + \frac{2EI}{KI}\right)} \quad \dots \quad (54)$$

[0084]

From the symmetry condition, x_{h2} is obtained as Formula (55).

$$x_{h2} = l - \frac{2l}{9\left(1 + \frac{2EI}{KI}\right)} \quad \dots \quad (55)$$

[0085]

(ii-iii) Summary in Case of Two-Point Concentrated Load

In a case on the assumption of a two-point concentrated load, x_h is obtained by Formula (56) (when $EI_s \neq EI_h$) or by Formula (57) (when $EI_s = EI_h = EI$).

[0086]

(when $EI_s \neq EI_h$)

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ -\left(\frac{l}{2EI_s} + \frac{1}{K}\right) + \sqrt{\left(\frac{l}{2EI_s} + \frac{1}{K}\right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s}\right)} \right\} \quad \dots \quad (56)$$

[0087]

(when $EI_s = EI_h = EI$)

$$x_h = \frac{2l}{9\left(1 + \frac{2EI}{KI}\right)} \quad \dots \quad (57)$$

[0088]

Formulas (28), (29), (30), (56), and (57) are rearranged in Table 1 shown below.

[Table 1]

LOAD CONDITION	IN CASE OF FLEXURAL STIFFNESS AGAINST HOGGING BENDING EI _h ≠ FLEXURAL STIFFNESS AGAINST SAGGING BENDING EI _s	IN CASE OF FLEXURAL STIFFNESS AGAINST HOGGING BENDING EI _h = FLEXURAL STIFFNESS AGAINST SAGGING BENDING EI _s (EI)
(i) EQUALLY DISTRIBUTED LOAD	$x_h = \frac{l}{2} \left(1 - \sqrt{1 - \frac{8M_a}{wl^2}} \right)$ HERE, M_a SATISFIES THE FOLLOWING FORMULA. $\left(\frac{1}{EI_h} - \frac{1}{EI_s} \right) \left(\frac{l}{3} M_a - \frac{wl^3}{24} \right) K \sqrt{1 - \frac{8M_a}{wl^2}} + \frac{K}{EI_h} \left(\frac{wl^3}{24} - \frac{l}{2} M_a \right) = M_a$	$x_h = \frac{l}{2} \left\{ 1 - \sqrt{1 - \frac{2K}{3 \left(K + \frac{2EI}{l} \right)}} \right\}$
(ii) TWO-POINT CONCENTRATED LOAD	$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ - \left(\frac{l}{2EI_s} + \frac{1}{K} \right) + \sqrt{\left(\frac{l}{2EI_s} + \frac{1}{K} \right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right)} \right\}$	$x_h = \frac{2l}{9 \left(1 + \frac{2EI}{KI} \right)}$

[0089]

Here, the hogging bending region R1 in the member axis direction X in the case where the two-point concentrated load acts on the beam 72 is longer than, for example, that in the case where the equally distributed load acts on the beam 72. Therefore, by causing the end portion X coordinate of the reinforcing member 73 to be equal to or more than the lower limit X coordinate, the reinforcing member 73 can be located not only in the hogging bending region R1 when the two-point concentrated load acts on the beam 72, but also in the hogging bending region R1 when the equally distributed load acts on the beam 72. As a result, the beam 72 can be reliably reinforced by the reinforcing member 73.

Therefore, in this embodiment, as the lower limit X coordinate, the X coordinate of the inflection point at which the bending moment distribution of the beam 72 changes from hogging bending to sagging bending in the case where the two-point concentrated load acts on the beam 72 is adopted, and the X coordinate is obtained by Formula (2A) or (2B).

[0090]

(Formula Derivation Process 2: Derivation of Upper Limit X Coordinate)

As in the reference beam 72A, the hogging bending region R1 in the member axis direction X in the case where the end portions are joined to the support members 71 in a rigid manner (in the case where the rotational stiffness is infinite) is longer than that in the case where the end portions are joined to the support members 71 in a semi-rigid manner (in the case where the rotational stiffness is finite). Furthermore, as in the reference beam 72A, the hogging bending region R1 in the member axis direction X in the case where the end portions are joined to the support members 71 in a rigid manner and in the case where the flexural stiffness against hogging bending and the

flexural stiffness against sagging bending are the same is also longer than, for example, that in the case where the flexural stiffness against hogging bending is smaller than the flexural stiffness against sagging bending. That is, considering that the flexural stiffness against hogging bending is generally equal to or smaller than the flexural stiffness against sagging bending, it can be said that the upper limit X coordinate set based on the reference beam 72A is calculated assuming a case where the hogging bending region R1 is longest in the member axis direction X. Therefore, by causing the end portion X coordinate of the reinforcing member 73 to be equal to or less than the upper limit X coordinate, the reinforcing member 73 can be prevented from becoming excessively long.

Here, the length of the hogging bending region R1 when the two-point concentrated load acts on the reference beam 72A is obtained by Formula (57) because flexural stiffness against hogging bending EI_h = flexural stiffness against hogging bending EI_s = EI is satisfied, and by setting K to be infinite in this formula, the left side becomes $(2l/9)$. Accordingly, the upper limit X coordinate can be set to $(2l/9)$ as shown in Formula (1).

[0091]

(Second Embodiment)

Hereinafter, a designing method of a beam joining structure according to a second embodiment of the present invention (hereinafter, referred to as a designing method according to this embodiment) will be described.

[0092]

The designing method according to this embodiment is preferably realized by a computer device (not shown) that executes a program recorded on a non-temporary, tangible recording medium (not shown) by a CPU (not shown). In this case, it is

preferable that the computer device executes the following designing method in response to a command from an input device operated by an operator, and outputs the design result in a visible manner via an output device.

Hereinafter, the designing method according to this embodiment will be described in detail with reference to the flowchart of FIG. 13. The description of the beam joining structure described in the first embodiment is omitted.

[0093]

The designing method according to this embodiment includes a structure planning step S1, a proof stress calculating step S2, a proof stress examining step S3, a first distance calculating step S4a, a second distance calculating step S4b, and a reinforcing member designing step S5.

[0094]

In the structure planning step S1, based on the application of the structure, a live load, and external force factors (earthquake, wind, fire), structure planning is performed to temporarily determine the arrangement of structural members (columns, beams, walls, floors, braces, and the like), the cross-sectional dimensions of the structural members, reinforcing members, and floor slabs, material strengths, and the like.

[0095]

In the proof stress calculating step S2, based on the structure plan temporarily determined in the structure planning step S1, the proof stress (required proof stress) required for each structural member and the proof stress (ultimate proof stress) held by each structural member are calculated.

[0096]

In the proof stress examining step S3, the validity of the proof stress

calculated in the proof stress calculating step S2 is examined. That is, it is examined whether or not the ultimate proof stress of each structural member is equal to or more than the required proof stress of the structural member. In a case where the ultimate proof stress is smaller than the required proof stress, the process returns to the structure planning step S1, and the proof stress calculating step S2 and the proof stress examining step S3 are performed again by correcting the arrangement of structural members (columns, beams, walls, floors, braces, and the like), the cross-sectional dimensions of the structural members, reinforcing members, and floor slabs, material strengths, and the like. In a case where the ultimate proof stress is equal to or more than the required proof stress, the process proceeds to the first distance calculating step S4a and the second distance calculating step S4b.

[0097]

In the first distance calculating step S4a, a first distance, which is the distance from the joint portion between a first support member and the end portion of a beam to the inflection point at which the bending moment distribution of the beam changes from hogging bending to sagging bending in a case where a two-point concentrated load acts on the beam, is calculated.

[0098]

In the second distance calculating step S4b, assuming that as a beam, a reference beam is used in which both end portions are joined to a pair of support members in a rigid manner and the flexural stiffness against hogging bending and the flexural stiffness against sagging bending are the same, a second distance, which is the distance from the joint portion to the inflection point at which the bending moment distribution of the reference beam changes from hogging bending to sagging bending in a case where a two-point concentrated load acts on the reference beam, is calculated.

[0099]

In the first distance calculating step S4a and the second distance calculating step S4b, Formulas (1), (2A), (2B), and (2A') described in the first embodiment may be used.

[0100]

In the reinforcing member designing step S5, the protruding length x of a reinforcing member is set to be equal to or more than the first distance calculated in the first distance calculating step S4a and equal to or less than the second distance calculated in the second distance calculating step S4b.

[0101]

According to the designing method according to this embodiment, it is possible to optimize the arrangement of the reinforcing members in the beam joining structure joined to the support members in a semi-rigid manner or a rigid manner.

[0102]

By executing the designing method described above, the final output values become the design values, and the design values are used in a manufacturing method of a beam joining structure. For example, by performing the above-described steps, the sizes and arrangement positions of columns, beams, and floor slabs, the lengths and arrangement positions of reinforcing members are output as design results. When a beam structure is manufactured, the beam joining structure 60 described above is manufactured by performing a step of arranging columns, primary beams, and secondary beams and a step of placing a floor slab including a step of arranging reinforcing members using columns, beams, and reinforcing members according to the design results. Accordingly, it is possible to manufacture a beam joining structure in which the arrangement of reinforcing members is optimized. That is, the

manufacturing method of a beam joining structure designed based on the designing method of the beam joining structure includes a joining step of joining a first support member, a second support member, and a beam, and an arrangement step of arranging a reinforcing member to have a set protruding length x .

[0103]

(Examples)

Based on each formula of the derivation results, the length of the beam 72, the flexural stiffness against sagging bending, the flexural stiffness against hogging bending, and the rotational stiffness are set to the values of Examples 1 to 4 shown in Table 2 below, and the length x_h of the hogging bending region R1 in each of a case of an equally distributed load and a case of a two-point concentrated load is obtained as shown in Table 2 below. Comparative Example 1 in the table shows the length x_h of the hogging bending region R1 in each of a case of an equally distributed load and a case of a two-point concentrated load on the assumption of the reference beam 72A. Example 2 in the table is on the assumption of a case where the beam 72 is joined to the support members 71 in a rigid manner, and the rotational stiffness is infinite.

[Table 2]

	Length of beam of beam	Sagging flexural stiffness	Hogging flexural stiffness	Rotational stiffness of end portion of beam	Length of hogging bending region, x_h [m]		Ratio of length of hogging bending region to related art	
					(i) Equally distributed load	(ii) Two-point concentrated load	(i) Equally distributed load	(ii) Two-point concentrated load
	1	EI_s	EI_h	K				
	[m]	[kNm ²]	[kNm ²]	[kNm/rad]				
Comparative Example 1	8.4	-	-	-	1.78	1.87	100%	100%
Example 1	8.4	276924	109858	75287	0.76	0.91	43%	49%
Example 2	8.4	276924	109858	∞	1.36	1.47	76%	79%
Example 3	8.4	76821	76821	32315	1.02	1.19	57%	64%
Example 4	8.4	276924	136537	80718	0.80	1.03	45%	55%

[0104]

From the above, it is confirmed that the length x_h of the hogging bending region R1 is shorter in Examples 1 to 4 than in Comparative Example 1.

[0105]

As described above, according to the beam joining structure 60 according to this embodiment, by causing the end portion X coordinate of the reinforcing member 73 to be equal to or more than the lower limit X coordinate and equal to or less than the upper limit X coordinate, it is possible to reliably reinforce the beam 72 by the reinforcing member 73 while preventing excessive arrangement of the reinforcing member 73, so that the optimization of the arrangement of the reinforcing member 73 can be achieved.

[0106]

The technical scope of the present invention is not limited to the above embodiments, and various modifications can be made without departing from the spirit of the present invention.

[0107]

For example, in addition to the reinforcing members 73 (reinforcements) arranged in the range specified above, other reinforcing bars (reinforcements and reinforcing members) may be arranged at any positions, for example, by arranging crack preventing bars over the entire region of the floor slab 41 including the joint portion.

[0108]

In the embodiment, the first structure 61 is applied to the two primary beams 21 extending toward opposite directions across the column 11 therebetween among the four primary beams 21 extending from one column 11, but the present invention is not

limited thereto. For example, the first structure 61 may be applied to all the four primary beams 21, or the first structure 61 may be applied to only one primary beam 21. In a case where the first structure 61 is applied to all the four primary beams 21, for example, a configuration in which the first reinforcing members 73a are arranged in a lattice pattern can be adopted.

[0109]

The column 11 may be a reinforced concrete (RC) structure in which no steel frame is disposed inside of concrete. Furthermore, as shown in FIG. 14, the column 11 may have a CFT structure in which a steel pipe is filled with concrete.

[0110]

In addition, it is possible to substitute the constituent elements in the embodiments with known constituent elements as appropriate without departing from the spirit of the present invention, and the modification examples described above may be combined as appropriate.

[Industrial Applicability]

[0111]

According to the present invention, the optimization of the arrangement of a reinforcing member can be achieved in a beam joining structure in which a beam is joined to support members in a semi-rigid manner or a rigid manner.

[Brief Description of the Reference Symbols]

[0112]

60: beam joining structure

71: support member

71a: first support member

71b: second support member

72: beam

72A: reference beam

73: reinforcing member

O: joint portion

R1: hogging bending region

X+: positive direction

X: member axis direction

1. A beam joining structure comprising:

a first support member and a second support member forming a pair;

a beam which includes a first joint portion and a second joint portion

respectively joined to the first support member and the second support member at both end portions, and is spanned between the first support member and the second support member by being joined via the first joint portion and the second joint portion in a semi-rigid manner or a rigid manner; and

a reinforcing member which is disposed to protrude in a direction from the first support member toward the second support member and reinforces the beam by withstanding at least a part of tensile stress generated in the beam by hogging bending of the beam,

wherein a protruding length x of the reinforcing member from a virtual plane which is perpendicular to a member axis direction of the beam and includes the first joint portion is equal to or more than a first distance and equal to or less than a second distance,

the first distance is a distance from the first joint portion to an inflection point at which a bending moment distribution of the beam changes from hogging bending to sagging bending in a case where a two-point concentrated load acts on the beam, and

the second distance is, on an assumption that a reference beam in which both end portions are joined to the first support member and the second support member in a rigid manner and flexural stiffness against hogging bending and flexural stiffness against sagging bending are the same is used as the beam, a distance from the first joint portion to an inflection point at which a bending moment distribution of the reference beam changes from the hogging bending to the sagging bending in a case where a two-

point concentrated load acts on the reference beam.

2. The beam joining structure according to claim 1,

wherein both the end portions of the beam are respectively joined to the first support member and the second support member in the semi-rigid manner.

3. The beam joining structure according to claim 2,

wherein both the end portions of the beam are joined to the first support member and the second support member in the semi-rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are different from each other, and

the protruding length x of the reinforcing member satisfies Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2A),

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ - \left(\frac{l}{2EI_s} + \frac{1}{K} \right) + \sqrt{\left(\frac{l}{2EI_s} + \frac{1}{K} \right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right)} \right\} \quad \dots \quad (2A)$$

here, each of variables is as follows,

EI_h : the flexural stiffness against the hogging bending of the beam (kNm^2)

EI_s : the flexural stiffness against the sagging bending of the beam (kNm^2)

l : a length of the beam (m)

K : a rotational stiffness of the first joint portion of the end portion of the beam (kNm/rad).

4. The beam joining structure according to claim 2,
wherein both the end portions of the beam are joined to the first support member and the second support member in the semi-rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are the same, and

the protruding length x of the reinforcing member satisfies Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2B),

$$x_h = \frac{2l}{9 \left(1 + \frac{2EI}{KI} \right)} \quad \dots \quad (2B)$$

here, each of variables is as follows,

EI: the flexural stiffness against the hogging bending or the sagging bending of the beam (kNm²)

l: a length of the beam (m)

K: a rotational stiffness of the first joint portion of the end portion of the beam (kNm/rad).

5. The beam joining structure according to claim 1,
wherein both the end portions of the beam are joined to the first support member and the second support member in the rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are different from each other.

6. The beam joining structure according to claim 5,

wherein the protruding length x of the reinforcing member satisfies Formula

(1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2A'),

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ -\frac{l}{2EI_s} + \sqrt{\left(\frac{l}{2EI_s}\right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s}\right)} \right\} \quad \dots \quad (2A')$$

here, each of variables is as follows,

EI_h : the flexural stiffness against the hogging bending of the beam (kNm^2)

EI_s : the flexural stiffness against the sagging bending of the beam (kNm^2)

l : a length of the beam (m).

7. A designing method of a beam joining structure,

the beam joining structure including

a first support member and a second support member forming a pair,

a beam which includes a first joint portion and a second joint portion respectively joined to the first support member and the second support member at both end portions, and is spanned between the first support member and the second support member by being joined via the first joint portion and the second joint portion in a semi-rigid manner or a rigid manner, and

a reinforcing member which is disposed to protrude in a direction from the first support member toward the second support member and reinforces the beam by withstanding at least a part of tensile stress generated in the beam by hogging bending of the beam,

the designing method comprising:

calculating a first distance which is a distance from the first joint portion to an inflection point at which a bending moment distribution of the beam changes from hogging bending to sagging bending in a case where a two-point concentrated load acts on the beam;

calculating, on an assumption that a reference beam in which both end portions are joined to the first support member and the second support member in a rigid manner and flexural stiffness against hogging bending and flexural stiffness against sagging bending are the same is used as the beam, a second distance which is the distance from the first joint portion to an inflection point at which a bending moment distribution of the reference beam changes from the hogging bending to the sagging bending in a case where a two-point concentrated load acts on the reference beam; and

setting a protruding length x of the reinforcing member from a virtual plane which is perpendicular to a member axis direction of the beam and includes the first joint portion to be equal to or more than the first distance and equal to or less than the second distance.

8. The designing method of a beam joining structure according to claim 7, wherein both the end portions of the beam are respectively joined to the first support member and the second support member in the semi-rigid manner.

9. The designing method of a beam joining structure according to claim 8, wherein both the end portions of the beam are joined to the first support member and the second support member in the semi-rigid manner in a state where the

flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are different from each other, and

the protruding length x of the reinforcing member satisfies Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2A),

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ - \left(\frac{l}{2EI_s} + \frac{1}{K} \right) + \sqrt{\left(\frac{l}{2EI_s} + \frac{1}{K} \right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right)} \right\} \quad \dots \quad (2A)$$

here, each of variables is as follows,

EI_h : the flexural stiffness against the hogging bending of the beam (kNm^2)

EI_s : the flexural stiffness against the sagging bending of the beam (kNm^2)

l : a length of the beam (m)

K : a rotational stiffness of the first joint portion of the end portion of the beam (kNm/rad).

10. The designing method of a beam joining structure according to claim 8, wherein both the end portions of the beam are joined to the first support member and the second support member in the semi-rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are the same, and

the protruding length x of the reinforcing member satisfies Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2B),

$$x_h = \frac{2l}{9 \left(1 + \frac{2EI}{KI} \right)} \quad \dots \quad (2B)$$

here, each of variables is as follows,

EI: the flexural stiffness against the hogging bending or the sagging bending of the beam (kNm²)

l: a length of the beam (m)

K: a rotational stiffness of the first joint portion of the end portion of the beam (kNm/rad).

11. The designing method of a beam joining structure according to claim 7, wherein both the end portions of the beam are joined to the first support member and the second support member in the rigid manner in a state where the flexural stiffness against the sagging bending and the flexural stiffness against the hogging bending are different from each other.

12. The designing method of a beam joining structure according to claim 11, wherein the protruding length x of the reinforcing member satisfies Formula (1) in the unit of m,

$$x_h \leq x \leq \frac{2l}{9} \quad \dots \quad (1)$$

here, x_h is obtained by Formula (2A'),

$$x_h = \frac{1}{\frac{1}{EI_h} - \frac{1}{EI_s}} \left\{ -\frac{l}{2EI_s} + \sqrt{\left(\frac{l}{2EI_s} \right)^2 + \frac{2l^2}{9EI_s} \left(\frac{1}{EI_h} - \frac{1}{EI_s} \right)} \right\} \quad \dots \quad (2A')$$

here, each of variables is as follows,

EI_h : the flexural stiffness against the hogging bending of the beam (kNm^2)

EI_s : the flexural stiffness against the sagging bending of the beam (kNm^2)

l : a length of the beam (m).

13. A manufacturing method of a beam joining structure designed based on the designing method of a beam joining structure according to any one of claims 7 to 12, the manufacturing method comprising:

joining the beam to the first support member and the second support member;

and

arranging the reinforcing member to have the set protruding length x .