DESCRIPTION

Title of Invention: COMPOSITE BEAM

Technical Field

[0001]

The present invention relates to a composite beam including: an H-beam; and a composite slab formed by pouring concrete on a steel deck disposed on the upper surface of the H-beam such that the H-beam and the composite slab form an integral structure.

Background Art

[0002]

One known composite beam including H-beams and a slab integrally connected to the H-beams uses, as the H-beams, vertically asymmetric H-beams described in, for example, Patent Literature 1.

[0003]

When a bending force acts on a composite beam because of its dead load and live loads, almost only bottom flanges of the H-beams resist tensile stress on the lower side of the composite beam, and the slab having a relatively large cross-sectional area and top flanges of the H-beams resist compressive stress on the upper side of the composite beam. Therefore, even when the cross-sectional area of each of the top flanges of the H-beams is set to be smaller than the cross-sectional area of each of the bottom flanges, the composite beam as a whole can have the same level of bending resistance. Therefore, when vertically asymmetric

H-beams are used as the H-beams of the composite beam, the composite beam can have a rational structure, and this is technologically advantageous because the material cost of the steel material and the weight of the steel material can be reduced.

Citation List

Patent Literature

[0004]

PTL 1: Japanese Unexamined Patent Application Publication No. 49-130862

Summary of Invention

Technical Problem

[0005]

The above-described composite beam includes the vertically asymmetric H-beams and the slab that forms an integral structure together with the H-beams. It is expected that, even when this composite beam is applied not only to civil engineering structures such as composite girder bridges but also to floor structures of buildings such as steel-frame buildings, the effects such as material savings and a reduction in steel material weight will be obtained.

[0006]

However, the floor structure of a building needs to have structural performance including resistance to stress due to the dead load of the floor and live loads and also needs to satisfy a deflection limit from the viewpoint of

the comfortability of the building. Specifically, in the floor structure of a building, the deflection limit is generally about 1/300 to about 1/400 of the span L of the floor or H-beams.

[0007]

In many cases, the frames of buildings have a multilayer structure. Therefore, when the composite beam described above is used for a floor structure, it is necessary that the above deflection limit be satisfied while the beam depth of the H-beams in the composite beam forming the floor structure is reduced so that the available floor height is not limited.

[0008]

When the above-described composite beam including the vertically asymmetric H-beams and the slab integrally connected to the H-beams is applied to the floor structure of, for example, a steel-framed building, there is a problem in use because the cross-sectional stiffness of the vertically asymmetric H-beams themselves is lower than the cross-sectional stiffness of vertically symmetric H-beams having the same cross-sectional area as that of the vertically asymmetric H-beams.

[0009]

Specifically, a construction process of a building having a floor structure including the above-described composite beam is performed as follows. First, a plurality of H-beams are placed between columns or girders, and a

steel deck is placed on the plurality of H-beams. Then concrete is poured on the steel deck. In the course of the construction process, it is necessary for the H-beams alone to support the load of the steel deck and the concrete while the deflection limit described above is satisfied. Most of the total deflection when the floor structure including the composite beam is in service is due to the deflection of the H-beams themselves that has occurred during the construction process.

[0010]

Fig. 7 is a graph conceptually showing the relation between the deviation β between the cross-sectional areas of top and bottom flanges of vertically asymmetric H-beams and the deflection δconst of the vertically asymmetric H-beams themselves during the construction process and the relation between the deviation β and the total deflection δtot when the composite beam is in service. The deviation β is given by $\beta = (A - At)/A = (Ab - A))/A$, where At is the cross-sectional area of the top flange of the vertically asymmetric H-beams, Ab is the cross-sectional area of the bottom flange, and A is the average value of the cross-sectional area At of the top flange and the cross-sectional area Ab of the bottom flange.

[0011]

As shown in Fig. 7, when the vertically asymmetric H-beams are used for the floor structure including the composite beam, the deflection of the H-beams themselves

during the construction process increases as the deviation β between the cross-sectional areas of the top and bottom flanges increases. Therefore, the composite beam that uses the vertically asymmetric H-beams has not been widely used for the floor structures of buildings.

[0012]

Accordingly, an object of the present invention is to provide a composite beam that uses vertically asymmetric H-beams and can be preferably used for the floor structure of a building. Even when this composite beam is applied to the floor structure of a building, the deflection of the vertically asymmetric H-beams themselves during the construction process of the floor structure is small, so that the total deflection when the floor structure is in service can be reduced.

Solution to Problem

[0013]

In view of the foregoing problem, the composite beam of the present invention has the following structure.

[1] A composite beam including: an H-beam; and a composite slab including a steel deck disposed on an upper surface of the H-beam and concrete poured on the steel deck, the composite slab and the H-beam forming an integral structure, wherein a width of an upper flange of the steel deck is equal to or larger than a width of a lower flange of the steel deck, wherein the steel deck has a height of from 25 mm to 100 mm inclusive, wherein the composite slab

has a thickness of from 50 mm to 150 mm inclusive, and wherein the ratio At/Ab of a cross-sectional area At of a top flange of the H-beam to a cross-sectional area Ab of a bottom flange of the H-beam is 0.7/1.3 or more and less than 1.0.

[0014]

The H-beam may be a rolled H-beam or a welded H-section steel.

[2] The composite beam according to [1], wherein the H-beam has a yield strength of 235 N/mm^2 or more, and wherein the ratio H/L of an outside height H of the H-beam to a beam span L is 1/20.9 or more.

[3] The composite beam according to [1], wherein the H-beam has a yield strength of 325 N/mm^2 or more, and wherein the ratio H/L of an outside height H of the H-beam to a beam span L is 1/15.1 or more.

Advantageous Effects of Invention

[0015]

With the composite beam of the present invention that uses the vertically asymmetric H-beam, when the composite beam is applied to the floor structure of a building, the deflection of the vertically asymmetric H-beam itself during the construction process of the floor structure can be reduced to the same level as or lower than the deflection of a floor structure formed of a composite beam that uses a vertically symmetric H-beam, so that the total deflection of the floor structure in service can be

reduced. Therefore, when the composite beam using the vertically asymmetric H-beam is used for the floor structure of a building, a rational structure can be obtained, and the material cost of the H-beam of the composite beam and the weight of the H-beam can be reduced.

[0016]

When the yield strength of the H-beam is 235 N/mm^2 or more and the ratio H/L of the outside height H of the H-beam to the beam span L is 1/20.9 or more, the effect of reducing the total deflection of the floor structure formed from the composite beam of the present invention when the floor structure is in service to equal to or less than a deflection limit of about L/300 that is required for the floor structure of the building can be obtained reliably.

[0017]

Alternatively, when the yield strength of the H-beam is 325 N/mm^2 or more and the ratio H/L of the outside height H of the H-beam to the beam span L is 1/15.1 or more, the effect of reducing the total deflection of the floor structure formed from the composite beam when the floor structure is in service to equal to or less than a deflection limit of about L/300 that is required for the floor structure of the building can be obtained reliably.

Brief Description of Drawings

[0018]

[Fig. 1] A cross-sectional view of the composite beam of the present invention.

[Fig. 2] A cross-sectional view when the composite beam of the present invention is viewed from a side.

[Fig. 3] An enlarged view of an H-beam portion of the composite beam of the present invention.

[Fig. 4] A graph showing examples of the deflection of the composite beam of the present invention during construction.

[Fig. 5] A graph showing examples of the deflection of the composite beam of the present invention during construction.

[Fig. 6] A graph showing examples of the deflection of the composite beam of the present invention during construction.

[Fig. 7] A graph conceptually showing the deflection of a composite beam using vertically asymmetric H-beams during construction and the total deflection of the composite beam in service.

Description of Embodiments

[0019]

Embodiments of the composite beam of the present invention will be specifically described with reference to the drawings. Fig. 1 is a cross-sectional view of a composite beam 1 in an embodiment. Fig. 2 is a cross-sectional view when the composite beam 1 is viewed from a side.

[0020]

As shown in Figs. 1 and 2, the composite beam 1 of the

present invention includes H-beams 10 and a composite slab 20 disposed on the H-beams 10. Each of the H-beams 10 is a vertically asymmetric H-beam including a top flange 11 and a bottom flange 12 whose cross-sectional area differs from that of the top flange 11. Each H-beam 10 may be a rolled H-beam obtained by roll forming. When roll-formed vertically asymmetric H-beams are not available, welded H-section steels each formed by welding steel plates serving as the top flange 11 and the bottom flange 12 to a steel plate serving as a web 13 may be used. Shear studs 30 are welded to the upper surfaces of the H-beams 10 at prescribed intervals.

[0021]

The dimensions of each H-beam 10 as shown in Fig. 3 are as follows. Their outside height is denoted by H, and the average value of the width of the top flange 11 and the width of the bottom flange 12 is denoted by B. The width of the top flange 11 is $(1 - \beta) \times B$, and the width of the bottom flange 12 is $(1 + \beta) \times B$. The thickness of the web 13 is denoted by tw. The thickness of the top flange 11 is denoted by ttf, and the thickness of the bottom flange 12 is denoted by tbf. Therefore, the cross-sectional area At of the top flange 11 of each H-beam 10 and the cross-sectional area Ab of the bottom flange 12 are $At = (1 - \beta) \times B \times ttf$ and $Ab = (1 + \beta) \times B \times tbf$, respectively. In the composite beam 1 of the present invention, the ratio At/Ab of the cross-sectional area At of the top flange 11 of the

H-beam to the cross-sectional area Ab of the bottom flange 12 is set to 0.7/1.3 or more and less than 1.0.

[0022]

In the present embodiment, the thickness ttf of the top flange 11 and the thickness tbf of the bottom flange 12 are set to be equal to each other. Therefore, the numerical range of the ratio At/Ab, $0.7/1.3 \leq At/Ab < 1$, corresponds to the numerical range of the above parameter β, $0 < \beta \leq 0.3$, (hereinafter, β is referred to as the "deviation between the cross-sectional areas of the top and bottom flanges").

[0023]

The composite slab 20 is formed by placing a steel deck 21 on the upper surfaces of the H-beams 10, placing a welded wire mesh or reinforcing steel bars serving as crack prevention reinforcements on the steel deck 21 with spacers therebetween, and pouring concrete 22 on the steel deck 21 to a prescribed thickness.

[0024]

As shown in Fig. 2, the steel deck 21 has a substantially vertically symmetric corrugated cross-sectional shape including ridge portions and valley portions arranged continuously, and the width of upper flanges 211 is substantially the same as the width of the lower flanges 212. The groove top width of the steel deck 21 is set to be larger than its groove bottom width, and therefore webs 213 between the upper flanges 211 and the

lower flanges 212 are inclined. However, the webs 213 may extend vertically, or the groove top width may be set to be smaller than the groove bottom width, so that the webs 213 may be inclined opposite to those described above. The upper flanges 211 are embossed and prevented from being displaced from the concrete 22.

[0025]

In the composite beam 1 of the present invention, the height hd of the steel deck 21 is set to from 25 mm to 100 mm inclusive and is preferably set to about 50 mm or about 75 mm that are the heights of steel decks widely distributed in the market.

[0026]

In the present invention, no particular limitation is imposed on the thickness of the steel deck 21, and any steel deck can be used so long as it can serve as a formwork when the concrete 22 is poured thereon. For example, the steel deck may have a thickness selected from standard nominal thicknesses defined in Japanese Industrial Standards JIS G3352 "Steel decks." Specifically, the thickness is preferably set to 1.0 mm, 1.2 mm, 1.6 mm, etc.

[0027]

In the present invention, the thickness of the composite slab, that is, the thickness of the concrete 22, is set to from 50 mm to 150 mm inclusive.

[0028]

The heads of the shear studs 30 welded to the top

surfaces of the H-beams 10 at prescribed intervals protrude upward from the steel deck 21 through holes disposed in the lower flanges 212 of the steel deck 21 and are embedded in the concrete 22 poured on the steel deck 21. The composite slab 20 and the H-beams 10 form an integral structure with the shear studs 30 embedded therein.

[0029]

With the composite beam 1 in the present embodiment that uses the vertically asymmetric H-beams, when the composite beam 1 is applied to the floor structure of a building, the deflection of the vertically asymmetric H-beams 10 themselves during a construction process of the floor structure can be reduced to the same level as or lower than the deflection of a floor structure formed from a composite beam 1 that uses vertically symmetric H-beams 10, so that the total deflection of the floor structure in service can be reduced. Therefore, when the composite beam using the vertically asymmetric H-beams is used for the floor structure of a building, a rational structure can be obtained, and the material cost of the H-beams of the composite beam and the weight of the H-beams can be reduced.

[0030]

When the yield strength of the H-beams 10 is 235 N/mm^2 or more and the ratio H/L of the outside height H of the H-beams 10 to the beam span L is 1/20.9 or more, the effect of reducing the total deflection of the floor structure

formed from the composite beam when the floor structure is in service to equal to or less than a deflection limit of about L/300 that is required for the floor structure of the building can be obtained more reliably.

[0031]

Alternatively, when the yield strength of the H-beams 10 is 325 N/mm^2 or more and the ratio H/L of the outside height H of the H-beams 10 to the beam span L is 1/15.1 or more, the effect of reducing the total deflection of the floor structure formed from the composite beam when the floor structure is in service to equal to or less than a deflection limit of about L/300 that is required for the floor structure of the building can be obtained more reliably.

[0032]

In the description of the above embodiment, the steel deck 21 used has the substantially vertically symmetric corrugated cross-sectional shape including the ridge portions and the valley portions arranged continuously, and the width of the upper flanges 211 is substantially the same as the width of the lower flanges 212. Instead of the above steel deck, a steel deck including upper flanges having a width larger than the width of lower flanges may be used. When the steel deck has such a shape, the dead load of the concrete poured on the steel deck is reduced, and the same effect as that described above can be obtained.

EXAMPLE 1

[0033]

In the composite beam of the present invention, the ratio At/Ab of the cross-sectional area At of the top flange of each vertically asymmetric H-beam to the cross-sectional area Ab of its bottom flange is in a specific numerical range ($0.7/1.3 \leq At/Ab < 1.0$), and this allows the total deflection at the center of the beam span of the composite beam in service to be reduced. The effect of reducing the total deflection was examined by numerical analysis.

[0034]

In Example 1, composite beam analysis models Nos .1 to 32 and Nos. 1A to 32A shown in Table 1 were prepared, each of which was used as a composite beam for numerical analysis of the total deflection at the center of the beam span of the composite beam in service. Analysis models Nos. 1 to 32 and Nos. 1A to 32A differ from each other in the dimensions of the vertically asymmetric H-beams (H×B×tw×tf (where B is the average value of the top flange width and the bottom flange width), the height hd of the steel deck, the thickness Ts of the composite slab, and the equivalent width B_{CB}/n of the composite beam (the details will be described later).

[0035]

Analysis models Nos. 1A to 32A differ from analysis models Nos. 1 to 32 shown in Table 1 in that the height hd

of the steel deck is changed from 50 mm to 75 mm.

[0036]

In each of analysis models Nos. 1 to 32 and Nos. 1A to 32A, the thicknesses ttf and tbf of the top and bottom flanges are set to the same value tf. Therefore, the above-described numerical range of the ratio At/Ab, $0.7/1.3 \leq At/Ab < 1$, corresponds to the numerical range of the deviation β between the cross-sectional areas of the top and bottom flanges, $0 < \beta \leq 0.3$.

[0037]

In the following description, the average of the cross-sectional area At of the top flange and the cross-sectional area Ab of the bottom flange 12 is denoted by A. Therefore, the cross-sectional area At of the top flange of each H-beam and the cross-sectional area Ab of the bottom flange are given by $At = (1 - \beta) \times A$ and $Ab = (1 + \beta) \times A$, respectively.

[0038]

The center-to-center distance h between the top and bottom flanges is $h = H - (ttf + tbf)/2 = H - tf$.

[0039]

[Table 1]

No.	Dimensions of H-beams H × B × tw × tf [mm]	Web ratio ξ=(h × tw)/A	Deck height hd [mm]	Slab thickness Ts [mm]	Equivalent width of composite beam B_{CB}/n [mm]
1	400×200×4.7×13.5	0.67	50	60	100
2	400×200×4.7×13.5	0.67	50	100	100
3	400×200×4.7×13.5	0.67	50	60	420
4	400×200×4.7×13.5	0.67	50	100	420
5	400×100×4.8×4.7	4.0	50	60	100
6	400×100×4.8×4.7	4.0	50	100	100
7	400×100×4.8×4.7	4.0	50	60	420
8	400×100×4.8×4.7	4.0	50	100	420
9	600×300×7×20.3	0.67	50	60	150
10	600×300×7×20.3	0.67	50	100	150
11	600×300×7×20.3	0.67	50	60	630
12	600×300×7×20.3	0.67	50	100	630
13	600×150×7.1×7	4.0	50	60	150
14	600×150×7.1×7	4.0	50	100	150
15	600×150×7.1×7	4.0	50	60	630
16	600×150×7.1×7	4.0	50	100	630
17	800×400×9.3×27	0.67	50	60	200
18	800×400×9.3×27	0.67	50	100	200
19	800×400×9.3×27	0.67	50	60	840
20	800×400×9.3×27	0.67	50	100	840
21	800×200×9.5×9.5	4.0	50	60	200
22	800×200×9.5×9.5	4.0	50	100	200
23	800×200×9.5×9.5	4.0	50	60	840
24	800×200×9.5×9.5	4.0	50	100	840
25	1000×500×11.6×33.5	0.67	50	60	250
26	1000×500×11.6×33.5	0.67	50	100	250
27	1000×500×11.6×33.5	0.67	50	60	1050
28	1000×500×11.6×33.5	0.67	50	100	1050
29	1000×250×11.6×11.4	4.0	50	60	250
30	1000×250×11.6×11.4	4.0	50	100	250
31	1000×250×11.6×11.4	4.0	50	60	1050
32	1000×250×11.6×11.4	4.0	50	100	1050

In each of analysis models Nos. 1 to 32 and Nos. 1A to 32A, the dimensions of a vertically symmetric H-beam used as the reference dimensions of the vertically asymmetric H-beams were set according to the dimensions of an H-beam defined in Japanese Industrial Standards JIS G3192

"Dimensions, shape, mass and permissible variations of hot rolled steel sections" such that the web ratio $\xi = (h \times tw)/A$ was 0.67 to 4.0. The outside height H of the H-beams was set to 400 to 1000 mm, and the width B of the H-beams B (the average of the width of the top flange of each vertically asymmetric H-beam and the width of the bottom flange) was set to h/4 to h/2. The web thickness ratio h/tw of the H-beams was set to about 83 in consideration of the lower limit of the plate thickness that was set so as not to allow local buckling to occur and such that the H-beams were designed to be usable.

[0040]

The thickness Ts of the slab in each of analysis models Nos. 1 to 32 and Nos. 1A to 32A was set to 60 to 100 mm, which is a standard dimension when a steel deck including ridge and valley portions having a substantially vertically symmetric shape is used. A deck floor thickness ratio γ described later is a value computed as $\gamma = (ttf/2 + hd)/h$.

[0041]

The equivalent width B_{CB}/n of the composite beam in each of analysis models Nos. 1 to 32 and Nos. 1A to 32A was set in the range of 0.25h to 1.13h. The numerical range of the equivalent width B_{CB}/n of the composite beam, that is, 0.25h to 1.05h, was computed under the following conditions. The beam span L of the composite beam was set to 8h to 21h, which is a standard value, and the effective

width B_{CB} of the composite beam was set to L/4, which is an evaluation value ordinary used. A steel-concrete stiffness ratio (the Young's modulus of the steel/the Young's modulus of the concrete) was set to 5 to 8.

[0042]

For each of the composite beams in analysis models Nos. 1 to 32 and Nos. 1A to 32A, how the total deflection $\delta tot(\beta)$ at the center of the beam span of the composite beam in service changes with the deviation β between the cross-sectional areas of the top and bottom flanges of the vertically asymmetric H-beams was analyzed numerically. Then the feature of the composite beam of the present invention was checked. Specifically, whether or not the total deflection $\delta tot(\beta)$ at the center of the beam span of the composite beam in service was reduced to the same level as or lower than the total deflection $\delta tot(0)$ at a deviation β of 0 when the composite beam was in service was checked in the numerical range of the ratio At/Ab of the cross-sectional area At of the top flange of each vertically asymmetric H-beam to the cross-sectional area Ab of the bottom flange ($0.7/1.3 \leq At/Ab < 1.0$), that is, in the numerical range of the deviation β between the cross-sectional areas of the top and bottom flanges ($0 < \beta \leq 0.3$).

[0043]

For each of the composite beams in analysis models Nos. 1 to 32 and Nos. 1A to 32A, the total deflection

δtot(β) at the center of the beam span in service was computed under the following conditions.

[0044]

First, for each of the composite beams in analysis models Nos. 1 to 32 and Nos. 1A to 32A, the H-beams and the composite slab connected to the H-beams were assumed to form a fully composite beam having a fully integral structure.

[0045]

Then a load Wsust on the composite beam in service (the total load on the floor when the floor structure formed from the composite beam was in service such as the sum of finishing loads applied by a floor, a ceiling, and partitions and live loads applied by appliances placed on the floor, i.e., the total load on the floor in service such as the finishing loads, the appliance loads, and the floor live loads borne by the beam-floor frame and excluding the dead load Wconst of the beam-floor frame) was set to a relatively small value of 5 kN/m^2 on the assumption that the composite beam was applied to a general building such as an office building or a commercial or public facility.

[0046]

The dead load Wconst of the composite beam during construction was set based on the dimensions and unit weights of the H-beams, the steel deck, and the concrete and the width of the slab borne per composite beam in each

of analysis models Nos. 1 to 32 and Nos. 1A to 32A.

[0047]

The load Wsust when the composite beam is in service does not include the dead load Wconst during construction of the composite beam.

[0048]

A floor load ratio α described later is a value computed as α = Wsust/Wconst, where Wconst is the dead load during construction of the composite beam (the load applied by the own weights of the H-beams, the steel deck, the concrete, etc. forming the composite beam). A slab contribution ratio η described later is a value computed as $\eta = (Ts \times B_{CB}/n)/(h \times tw)$.

[0049]

Specifically, the total deflection δtot(β) at the center of the beam span of each of the composite beams in analysis models Nos .1 to 32 and Nos. 1A to 32A in service was computed from the following formula (1) using deflection δconst(β) during construction and deflection δsust(β) caused by the load Wsust in service.

[0050]

[Math. 1]

$$\delta_{tot}(\beta) = \delta_{const}(\beta) + \delta_{sust}(\beta)$$
$$= 5 \times L^4/(384 \times E) \times (W_{const}/I_H(\beta) + \alpha \times W_{const}/I_{CB}(\beta))$$
$$= 5 \times L^4/(384 \times E) \times W_{const} \times (1/I_H(\beta) + \alpha/I_{CB}(\beta)) \quad \ldots\ldots \quad (1)$$

Here, E is the Young's modulus of the steel material, I_H is the second moment of area of each H-beam, and I_{CB} is

the second moment of area of the composite beam. The positions (estimated values) of the centers of gravity of the H-beam and the composite beam are denoted by y_{cg} and Y_{cg}, respectively. Then I_H, y_{cg}, I_{CB}, and Y_{cg} are obtained by the following formulas (2) to (5), respectively.

[0051]

[Math. 2]

$$\begin{aligned} I_H(\beta) &= t_w \times h^3/12 + H \times t_w \times (h/2 - y_{cg})^2 \\ &\quad + (1 - \beta) \times A \times y_{cg}^2 + (1 + \beta) \times A \times (h - y_{cg})^2 \\ &= a \times h^2 \times [\xi/12 + \xi \times (0.5 - F(\beta, \xi))^2 \\ &\quad + (1 - \beta) \times F(\beta, \xi)^2 + (1 + \beta) \times (1 - F(\beta, \xi))^2] \quad \ldots\ldots \quad (2) \end{aligned}$$

Here,

[0052]

[Math. 3]

$$\begin{aligned} y_{cg} &= (h \times t_w \times h/2 + (1 + \beta) \times a \times h)/(h \times t_w + 2a) \\ &= h \times [0.5 + \beta/(2 + \xi)] = h \times F(\beta, \xi) \quad \ldots\ldots \quad (3) \end{aligned}$$

[0053]

[Math. 4]

$$\begin{aligned} I_{CB}(\beta) &= I_H(\beta) + (B_{CB}/n) \times Ts^3/12 \\ &\quad + A \times (y_{cg} + Ts + \gamma \times h - Y_{cg})^2 \\ &\quad + (Ts \times B_{CB}/n) \times (Y_{cg} - Ts/2)^2 \\ &= I_H(\beta) + a \times h^2 \times (\eta \times \xi \times \gamma^2)/12 \\ &\quad + a \times h^2 \times (\xi + 2) \times (F(\beta, \xi) + \lambda + \gamma - G(\beta, \gamma, \lambda, \eta, \xi))^2 \\ &\quad + a \times h^2 \times (\xi \times \eta) \times (G(\beta, \gamma, \lambda, \eta, \xi) - \lambda/2)^2 \\ &= a \times h^2 \times [\xi/12 + \xi \times (0.5 - F(\beta, \xi))^2 + (1 - \beta) \times F(\beta, \xi))^2 + (1 + \beta) \times (1 - F(\beta, \xi))^2] \\ &\quad + a \times h^2 \times (\eta \times \xi \times \gamma^2)/12 + a \times h^2 \times (\xi + 2) \times (F(\beta, \xi) + \lambda + \gamma - G(\beta, \gamma, \lambda, \eta, \xi))^2 \\ &\quad + a \times h^2 \times (\xi \times \eta) \times (G(\beta, \gamma, \lambda, \eta, \xi) - \lambda/2)^2 \quad \ldots\ldots \quad (4) \end{aligned}$$

[0054]

[Math. 5]

$$Y_{cg} = [Ts \times (B_{CB}/n) \times Ts/2 + A \times (Ts + \gamma \times h + y_{cg}]/(Ts \times B_{CB}/n + A)$$
$$= h \times [0.5 \times \lambda \times \eta \times \xi + (2 + \xi) \times (\lambda + \gamma + F(\beta, \xi))]/(\xi \times \eta + 2 + \xi)$$
$$= h \times G(\beta, \gamma, \lambda, \eta, \xi) \quad \ldots\ldots \quad (5)$$

Fig. 4 is a graph showing the relation between the total deflection δtot(β) at the center of the beam span of each of the composite beams in analysis models Nos. 1 to 32 in service and the deviation β between the cross-sectional areas of the top and bottom flanges of the vertically asymmetric H-beam, the total deflection δtot(β) being computed using formulas (1) to (5) above. Fig. 5 is a graph showing the relation between the total deflection δtot(β) at the center of the beam span of each of the composite beams in analysis models Nos. 1A to 32A in service and the deviation β between the cross-sectional areas of the top and bottom flanges of the vertically asymmetric H-beam, the total deflection δtot(β) being computed using formulas (1) to (5) above. Fig. 6 is a graph showing the total deflection δtot(β) at the center of the beam span of each of the composite beams in analysis models Nos. 1 to 8 and Nos. 1A to 8A in service.

[0055]

In Figs. 4 to 6, the total deflection δtot(β) at the center of the beam span in service is represented as a deflection indicator δtot(β)/δtot(0) that is a value relative to the total deflection δtot(0) in service when the deviation is 0 (i.e., each H-beam is a vertically symmetric H-beam).

[0056]

As can be seen from Fig. 4, in any of the composite beams in analysis models Nos. 1 to 32, the deflection indicator δtot(β)/δtot(0) first decreases from 1.0 as the deviation β between the cross-sectional areas of the top and bottom flanges increases. Then the deflection indicator δtot(β)/δtot(0) increases, exceeds 1.0, and continues increasing. It can be seen that, in a region in which the deviation β between the cross-sectional areas of the top and bottom flanges is 0.3 or less, the deflection indicator δtot(β)/δtot(0) is less than 1.0 for any of analysis models Nos. 1 to 32.

[0057]

As can be seen from Fig. 5, in any of the composite beams in analysis models Nos. 1A to 32A, the deflection indicator δtot(β)/δtot(0) first decreases from 1.0 as the deviation β between the cross-sectional areas of the top and bottom flanges increases. Then the deflection indicator δtot(β)/δtot(0) increases, exceeds 1.0, and continues increasing. It can be seen that, in a region in which the deviation β between the cross-sectional areas of the top and bottom flanges is 0.25 or less, the deflection indicator δtot(β)/δtot(0) is less than 1.0 for any of analysis models Nos. 1A to 32A. Even in a region in which the deviation β is from 0.25 to 0.3 inclusive, the deflection indicator δtot(β)/δtot(0) is suppressed to a level slightly larger than 1.0.

[0058]

As can be seen from Fig. 6, in analysis models Nos. 1A to 8A in which the height hd of the steel deck is 75 mm, the upper limits of the ranges of the deviation β in which the deflection indicator δtot(β)/δtot(0) is suppressed to less than 1.0 are relatively smaller than those for analysis model Nos. 1 to 8 in which the height hd of the steel deck is 50 mm.

[0059]

As can be seen from the results of the numerical analysis on the composite beams in analysis models Nos. 1 to 32 and Nos. 1A to 32A, when the deviation β between the cross-sectional areas of the top and bottom flanges is 0.3 or less, that is , when the ratio At/Ab of the cross-sectional area At of the top flange of each H-beam to the cross-sectional area Ab of the bottom flange is in the range of $0.7/1.3 \leq At/Ab < 1.0$ as defined in the present invention, the total deflection δtot(β) at the center of the beam span of the composite beam in service is reduced to the same level as or lower than the total deflection δtot(0) in service when the deviation β is 0, and the cross-sectional shape is rational.

[0060]

In particular, it can be seen that, when the deviation β between the cross-sectional areas of the top and bottom flanges is 0.25 or less, that is, the ratio At/Ab of the cross-sectional area At of the top flange of each H-beam to

the cross-sectional area Ab of the bottom flange is in the range of $0.75/1.25 \leq At/Ab < 1.0$, the total deflection $\delta tot(\beta)$ at the center of the beam span of the composite beam in service is reliably reduced to the same level as or lower than the total deflection $\delta tot(0)$ in service when the deviation β is 0 even when the height hd of the steel deck is about 75 mm.

[0061]

As the deviation β between the cross-sectional areas of the top and bottom flanges increases, the second moment I_H of area of each H-beam decreases. Therefore, the ratio of the deflection $\delta const(\beta)$ during construction to the total deflection $\delta tot(\beta)$ at the center of the beam span of the composite beam in service increases.

[0062]

As the thickness tw of the web of each H-beam increases, the web ratio $\xi = (h \times tw)/A$ increases, and the influence of the increase in the deviation β on the increase in the total deflection $\delta tot(\beta)$ in service tends to decrease. In analysis models Nos. 1 to 32 and Nos. 1A to 32A, the web thickness ratio h/tw is about 83. However, in a cross section in which the web thickness ratio h/tw is smaller than 83, the web ratio ξ is small, and therefore the upper limit of the range of the deviation β in which the total deflection $\delta tot(\beta)$ in service can be reduced further increases.

[0063]

As the construction load ratio 1/α of the dead load Wconst during construction to the load Wsust when the composite beam is in service (1/α is the inverse of the floor load ratio α = Wsust/Wconst) increases, the ratio of the deflection δconst(β) during construction to the total deflection δtot(β) at the center of the beam span of the composite beam in service increases, and the total deflection δtot(β) in service is likely to increase as the deviation β increases. Specifically, the load Wsust in service is large in a warehouse or a distribution facility. In this case, the construction load ratio 1/α is small, and the tendency of the total deflection δtot(β) in service to increase due to the increase in the deviation β decreases, so that the effect of reducing the total deflection δtot(β) in service is more significant.

EXAMPLE 2

[0064]

In Example 2, the degree of reduction in weight of the H-beams achieved by the composite beam of the present invention was verified by numerical computations.

[0065]

Specifically, a composite beam in a Conventional Example was assumed to include vertically symmetric H-beams having dimensions of H-450×200×9×14 [mm]. A plurality of composite beams having the same level of bending performance (design strength and design deflection) as that of the composite beam in the Conventional Example and

satisfying the requirements of the present invention were used as Inventive Examples 1 to 3, and computations were performed for the cross sections of the composite beams. Then the weight per unit length of the vertically asymmetric H-beams in each of the composite beams in Inventive Examples 1 to 3 was compared with the weight per unit length of the vertically symmetric H-beams in the composite beam in the Conventional Example.

[0066]

In the numerical computations, the beam span L of the composite beam was 9.5 m, the spacing of the composite beam was 2.25 m, the height hd of the steel deck was 50 mm, and the thickness Ts of the composite slab was 80 mm in each of Inventive Examples 1 to 3 and Conventional Example, as shown in Table 2. In the composite beams in Inventive Examples 1 and 2 and the Conventional Example, the yield strength of the H-beams was 235 N/mm^2 (corresponding to that of steel type SN400 defined in Japanese Industrial Standards JIS G3136 "Rolled steels for building structure", reference strength F = 235 N/mm^2). In Inventive Example 3, the yield strength of the H-beams was 325 N/mm^2 (corresponding to that of steel type SN490, reference strength F = 325 N/mm^2).

[0067]

In the computation of the cross section of the composite beam in each of Inventive Example 1 and the Conventional Example, the ratio H/L of the outside height H

of the H-beams to the beam span L was set to 1/21.1. In the computation of the cross section of the composite beam in Inventive Example 2, the ratio H/L was set to 1/19.0. In the computation of the cross section of the composite beam in Inventive Example 3, the ratio H/L was set to 1/14.6.

[0068]

The computation was performed for each of the cross sections of the composite beams in Inventive Examples 1 to 3 such that the same level of design strength as that of the composite beam in the Conventional Example and the same level of design deflection as that in the Conventional Example were obtained under the conditions that the ratio At/Ab of the cross-sectional area At of the top flange of each H-beam to the cross-sectional area Ab of the bottom flange was 0.7/1.3 or more and less than 1.0, as defined in the present invention.

[0069]

As shown in Table 2, in the composite beams in Inventive Examples 1 to 3, the cross-sectional shapes of the asymmetric H-beams computed were BH-450×150×255×6×14 [mm], BH-500×125×255×6×14 [mm], and BH-650×60×110×9×8 [mm], respectively.

[0070]

[Table 2]

	Inventive Example 1	Inventive Example 2	Inventive Example 3	Conventional Example
H-beam	BH-450×150×255×6×14	BH-500×125×255×6×14	RH-650×60×110×9×8	RH-450×200×9×14
Unit weight	64.4	59.6	54.1	73.8
Steel type (JIS G3136)	SN400 (reference strength F=235 N/mm^2)	SN400 (reference strength F=235 N/mm^2)	SN490 (reference strength F=325 N/mm^2)	SN400 (reference strength F=235 N/mm^2)
Imposed load	7.5 kN/m^2	7.5 kN/m^2	7.5 kN/m^2	7.5 kN/m^2
Steel deck	Height 50 mm - Thickness 1 mm	Height 50 mm - Thickness 1 mm	Height 50 mm - Thickness 1 mm	Height 50 mm - Thickness 1 mm
Effective thickness of concrete slab	80 mm	80 mm	80 mm	80 mm
Beam span L/beam spacing	9.5 m / 2.25 m	9.5 m / 2.25 m	9.5 m / 2.25 m	9.5 m / 2.25 m
H/L	1/21.1	1/19.0	1/14.6	1/21.1
Design deflection ≤ L/300	21.9 mm	21.9 mm	21.5 mm	22.2 mm
Design strength	690 kN·m	690 kN·m	938 kN·m	690 kN·m
Weight ratio	0.87	0.81	0.73	1.0

In the vertically symmetric H-beams in the composite beam in the Conventional Example, the weight per unit length was 73.8 kg/m. However, in the vertically asymmetric H-beams in the composite beams in Inventive Examples 1 to 3, the weights per unit length were 64.4 kg/m, 59.6 kg/m, and 54.1 kg/m, respectively.

[0071]

Specifically, in Inventive Examples 1 to 3, the steel material weights of the H-beams were reduced to about 87%,

about 81%, and about 73%, respectively, of that of the composite beam in the Conventional Example having the same level of bending strength. It was therefore found that the effect of reducing the weight of the H-beams by more than 10% was obtained while the bending performance equivalent to that of the composite beam having the vertically symmetric H-beams in the Conventional Example was maintained.

[0072]

In particular, it can be seen that, in the composite beam in Inventive Example 2 in which the yield strength of the H-beams is 235 N/mm^2 or more and in which the ratio H/L of the outside height H of the H-beams to the beam span L is 1/20.9 or more, the effect of reducing the weight of the H-beams is higher than that in Inventive Example 1.

[0073]

Moreover, it can also be seen that, in the composite beam in Inventive Example 3 in which the yield strength of the H-beams is 325 N/mm^2 or more and in which the ratio H/L of the outside height H of the H-beams to the beam span L is 1/15.1 or more, the effect of reducing the weight of the H-beams is higher than that in Inventive Example 1. In addition, as shown in Table 2, in Inventive Example 3, the design strength is higher than that in Inventive Examples 1 and 2. It can be seen that, by applying the H-beams having high yield strength, design strength that allows the H-beams to withstand a larger live load can be obtained.

Reference Signs List

[0074]

1	composite beam
10	H-beam
11	top flange of H-beam
12	bottom flange of H-beam
13	web of H-beam
20	composite slab
21	steel deck
211	upper flange of steel deck
212	lower flange of steel deck
213	web of steel deck
22	concrete
H	outside height of H-beam
At	cross-sectional area of top flange of H-beam
Ab	cross-sectional area of bottom flange of H-beam
hd	height of steel deck
L	beam span