(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 584 384 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
25.12.2019 Bulletin 2019/52

(21) Application number: **18754414.3**

(22) Date of filing: **19.02.2018**

(51) Int Cl.:
E04C 3/06 *(2006.01)*

(86) International application number:
PCT/JP2018/005763

(87) International publication number:
WO 2018/151297 (23.08.2018 Gazette 2018/34)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD TN

(30) Priority: **17.02.2017 JP 2017028465**

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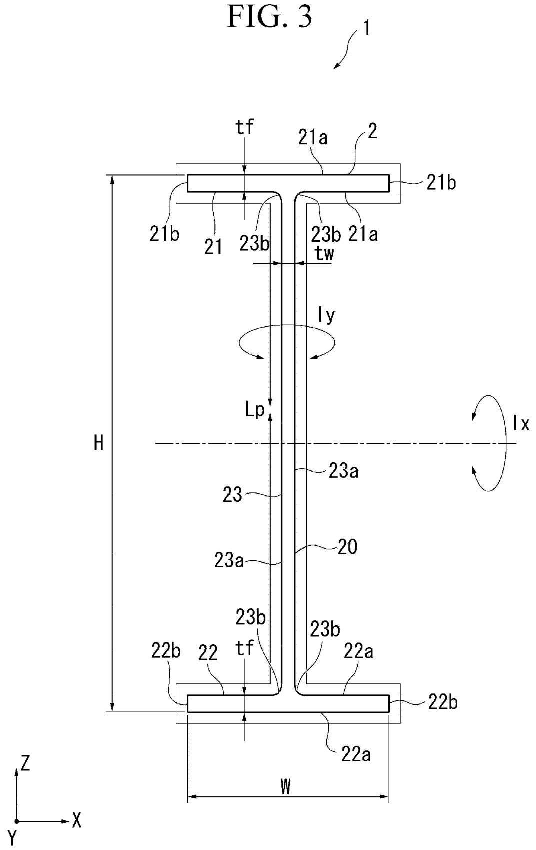
(54) METHOD FOR DESIGNING ROLLED H-SHAPED STEEL, ROLLED H-SHAPED STEEL, AND METHOD FOR MANUFACTURING ROLLED H-SHAPED STEEL

(57) A method of designing a rolled H-section steel includes: setting a height dimension H from an upper flange to a lower flange, a width dimension W of each of the upper flange and the lower flange, a plate thickness tw of a web, and a plate thickness tf of each of the upper flange and the lower flange so that, when it is assumed that a value obtained by dividing a second moment of area Ix about a strong axis by an outer circumferential length Lp in a cross-sectional shape when viewed in a cross section perpendicular to a member axis direction is a surface treatment economy Ix/Lp and an area of the cross-sectional shape is S, a predetermined relational formula is satisfied.

FIG. 3



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Description

[Technical Field of the Invention]

[0001] The present invention relates to a method of designing a rolled H-section steel, a rolled H-section steel, and a method of manufacturing a rolled H-section steel.

[0002] Priority is claimed on Japanese Patent Application No. 2017-028465, filed on February 17, 2017, the content of which is incorporated herein by reference.

[Related Art]

[0003] Patent Document 1 discloses a steel framed beam for the purpose of providing an economical and reliable structural system for deformably resisting temporary loads caused by earthquakes, impacts, and other severe temporary causes.

[0004] In the steel framed beam disclosed in Patent Document 1, deformability is enhanced by the use of multiple distributed regions determined by one or more voids provided in a web of a support member which is to be the steel framed beam. The voids have sizes, shapes, and configurations that guarantee that the distributed regions will deform inelastically when critical stress is reached, allowing mechanical equipment, electric wires, and the like to pass through the voids.

[Prior Art Document]

[Patent Document]

[0005] [Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2008-175056

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0006] Here, in the steel framed beam disclosed in Patent Document 1, since the voids are formed in the web of the support member which is to be the steel framed beam, for example, in a case where the outer circumferential surface of the web is coated or painted, the paint amount of the web, the refractory coating amount of the web, the plating amount of the web, and the like can be reduced by the voids formed in the web.

[0007] However, in the steel framed beam disclosed in Patent Document 1, since the voids are formed in the web of the support member which is to be the steel framed beam and the loss of cross section occurs in the void parts in the web, the strength and rigidity of the web decrease. Therefore, in the steel framed beam disclosed in Patent Document 1, there is a problem that in the web of the support member which is to be the steel framed beam, local fracture phenomena are likely to occur due to local buckling, shear buckling, crippling buckling, or the like.

[0008] The present invention has been made in view of the above circumstances, and an object thereof is to provide a method of designing a rolled H-section steel, a rolled H-section steel, and a method of manufacturing a rolled H-section steel with reduced costs for surface treatments, such as coating or painting while suppressing local fracture phenomena caused by local buckling or the like.

[Means for Solving the Problem]

[0009] The present invention adopts the following in order to solve the above problems.

(1) A first aspect of the present invention is a method of designing a rolled H-section steel, the rolled H-section steel including an upper flange, a lower flange, and a web connecting the upper flange to the lower flange, an outer circumferential surface of each of the upper flange, the lower flange, and the web being subjected to a surface treatment, the method including: setting a height dimension H from the upper flange to the lower flange, a width dimension Wof each of the upper flange and the lower flang, a plate thickness tw of the web, and a plate thickness tf of each of the upper flange and the lower flange so that, when it is assumed that a value obtained by dividing a second moment of area Ix about a strong axis by an outer circumferential length Lp in a cross-sectional shape when viewed in a cross section perpendicular to a member axis direction is a surface treatment economy Ix/Lp and an area of the cross-sectional shape is S, Formulas (35) to (38) are satisfied, the height dimension H is 700 mm or more, the width dimension W e is 1/5 or more and 1/2 or less of the height dimension H, the plate thickness tw is 9

mm or more and 32 mm or less, and the plate thickness tf is 12 mm or more and 40 mm or less.

(2) In the aspect according to (1), the following configuration may be adopted: under a condition that the rolled H-section steel is used as a beam extending in the member axis direction and both end portions of the rolled H-section steel in the member axis direction are fixed, a condition that lateral movement of the rolled H-section steel in a width direction in a middle portion in the member axis direction is restricted, and a condition in which an intermediate load acts on the upper flange from above and end loads act on both end portions in the member axis direction, using an elastic lateral buckling moment M_{cr} of the beam calculated from Formulas (12) to (16), the height dimension H, the width dimension W, the plate thickness tw, and the plate thickness tf are set so that lateral buckling does not occur in the beam,

in which, V_{cr}: a shear force acting on the end portions of the beam in the member axis direction, W_{cr}: the intermediate load acting on the middle portion of the beam in the member axis direction, β and γ: coefficients determined from Formulas (1) and (2) depending on loads V_{cr} and W_{cr}, 1: a length of the beam in the member axis direction, E: a Young's modulus, I: a second moment of area about a weak axis of the lower flange, G: a shear elastic modulus, J: a Saint-Venant's torsion constant, d_b: a plate thickness center-to-center distance between the upper flange and the lower flange, y: a length from one end portion of the beam in the member axis direction as a reference to any point of the beam in the member axis direction, θ_y: a torsion angle generated in the beam due to lateral buckling, θ'_y: a first order derivative of θ_y, θ'_y: a second order derivative of θ_y, and a: a parameter for integration.

(3) In the aspect according to (2), the height dimension H, the width dimension W, the plate thickness tw, and the plate thickness tf may be set so that a square root of a value obtained by dividing a full plastic moment Mp of the rolled H-section steel by the elastic lateral buckling moment M_{cr} becomes 0.6 or less.

[Math 1]

$$Ix / Lp = C_{k1} \cdot \exp(C_{k2} \cdot H / S) \quad \cdot\cdot\cdot \quad (35)$$

$$C_{k1} = 120 + 100 \cdot k \quad \cdot\cdot\cdot \quad (36)$$

$$C_{k2} = -106 + 10 \cdot k \quad \cdot\cdot\cdot \quad (37)$$

$$6.1 \leq k \leq 8 \quad \cdot\cdot\cdot \quad (38)$$

[Math 2]

$$M_{cr} = \frac{1}{(1-\beta-\gamma)A + (\beta+\gamma)C + \gamma D}\left(B\frac{2\pi^2 EId_b}{l^2} + A\frac{GJ}{d_b}\right) \quad \cdot\cdot\cdot \quad (12)$$

$$A = l\int_0^l \theta_y'^2 dy \quad \cdot\cdot\cdot \quad (13)$$

$$B = \frac{l^3}{2\pi^2}\int_0^l \theta_y''^2 dy \quad \cdot\cdot\cdot \quad (14)$$

$$C = \int_0^l y\theta_y'^2 dy \quad \cdot\cdot\cdot \quad (15)$$

$$D = \frac{2}{l}\int_0^l \int_0^y (y-a)\theta_y'^2 da\,dy \quad \cdot\cdot\cdot \quad (16)$$

[Math 3]

$$V_{cr} = -(\beta + \gamma)\frac{M_{cr}}{l} \quad \cdot\cdot\cdot \quad (1)$$

$$\int_0^l W_{cr} y\,dy = \gamma M_{cr} \quad \cdot\cdot\cdot \quad (2)$$

(4) A rolled H-section steel according to a second aspect of the present invention is a rolled H-section steel including: an upper flange; a lower flange; and a web which connects the upper flange to the lower flange, in which an outer circumferential surface of each of the upper flange, the lower flange, and the web is subjected to a surface treatment, a height dimension H from the upper flange to the lower flange is 700 mm or more, a width dimension W of each of the upper flange and the lower flange is 1/5 or more and 1/2 or less of the height dimension H, a plate thickness tw of the web is 9 mm or more and 32 mm or less, a plate thickness tf of each of the upper flange and the lower flange is 12 mm or more and 40 mm or less, and when it is assumed that a value obtained by dividing a second moment of area Ix about a strong axis by an outer circumferential length Lp in a cross-sectional shape when viewed in a cross section perpendicular to a member axis direction is a surface treatment economy Ix/Lp and an area of the cross-sectional shape is S, the height dimension H, the width dimension W, the plate thickness tw, and the plate thickness tf satisfy Formulas (35) to (38).

(5) A method of manufacturing a rolled H-section steel according to a third aspect of the present invention includes: manufacturing the rolled H-section steel having the height dimension H, the width dimension W, the plate thickness tw, and the plate thickness tf set according to the method of designing a rolled H-section steel according to any one of (1) to (3).

[Effects of the Invention]

[0010] According to the aspects of the present invention, it is possible to reduce the costs for the surface treatments such as coating or painting while suppressing local fracture phenomena caused by local buckling and the like.

[Brief Description of the Drawings]

[0011]

FIG. 1 is a perspective view showing a rolled H-section steel according to an embodiment of the present invention.
FIG. 2A is a front view showing the rolled H-section steel.
FIG. 2B is a side view showing the rolled H-section steel.
FIG. 3 is an enlarged front view showing a surface treatment economy of the rolled H-section steel.
FIG. 4 is a graph showing a relationship between a surface treatment economy Ix/Lp and H/S in an H-section steel in the related art.
FIG. 5 is a graph showing that the relationship between the surface treatment economy Ix/Lp and H/S in the H-section steel in the related art becomes "$Ix/Lp < 730 \cdot \exp(-45 \cdot H/S)$".
FIG. 6 is a graph showing that a relationship between a surface treatment economy Ix/Lp and H/S in the rolled H-section steel according to the embodiment of the present invention becomes "$Ix/Lp \geq 730 \cdot \exp(-45 \cdot H/S)$".
FIG. 7 is a graph showing that a relationship between a cross-sectional area S and a height dimension H in the rolled H-section steel becomes "$0.015 \leq H/S \leq 0.065$".
FIG. 8A is a front view of a beam using the rolled H-section steel, and shows a state in which both end portions are fixed and lateral movement is restricted.

FIG. 8B is a side view of the state shown in FIG. 8A.

FIG. 9A is a side view showing an example of virtual displacement of the beam using the rolled H-section steel.

FIG. 9B is a bottom view showing the virtual displacement of the beam shown in FIG. 9A.

FIG. 9C is a cross-sectional view taken along line A-A' in FIG. 9A.

FIG. 10 is a graph for comparison in transition of shapes of beams, steel weights, and capacities between a designing method of the related art and a designing method of the present invention.

FIG. 11A is a schematic side view showing a uniform bending moment in a beam using the rolled H-section steel according to the embodiment of the present invention in a case where an intermediate load is uniform bending.

FIG. 11B is a schematic side view showing an example of an antisymmetric moment and the like in the beam using the rolled H-section steel in a case where an intermediate load is not uniform bending.

FIG. 11C is a schematic side view showing another example of the antisymmetric moment and the like in the beam using the rolled H-section steel in a case where an intermediate load is not uniform bending.

FIG. 11D is a schematic side view showing another example of the antisymmetric moment and the like in the beam using the rolled H-section steel in a case where an intermediate load is not uniform bending.

FIG. 12A is a graph showing a calculation result using θ_y approximated by a predetermined series in the beam using the rolled H-section steel.

FIG. 12B is a graph showing a calculation result using θ_y approximated by a Fourier series in the beam using the rolled H-section steel.

FIG. 13 is a schematic side view showing a moment gradient used in evaluation of examples of the rolled H-section steel.

FIG. 14 is a graph showing various rolled H-section steels (present invention examples) satisfying Formulas (35) to (38) and rolled H-section steels in the related art not satisfying the formulas.

[Embodiments of the Invention]

[0012] Hereinafter, a rolled H-section steel 1 (hereinafter, simply referred to as "H-section steel 1") according to an embodiment of the present invention will be described with reference to the drawings. In the present specification and the drawings, like elements having substantially the same functional configurations are denoted by like reference numerals, and overlapping descriptions thereof will be omitted.

[0013] As shown in FIG. 1, the H-section steel 1 mainly becomes a structural material such as a floor structure, an earthen floor structure, or a frame structure in buildings houses, schools, offices, hospital facilities, low-rise buildings, high-rise buildings, and skyscrapers.

[0014] The H-section steel 1 is a rolled H-section steel (rolled H-section steel) formed from a single steel plate by hot rolling or the like. That is, in the H-section steel 1, an upper flange 21, a lower flange 22, and a web 23 are integrally formed.

[0015] In addition, in a built-up H-section steel (the upper flange 21, the lower flange 22, and the web 23 are produced as separate steel plates and are welded together into a built-up H-section steel) produced by welding a plurality of steel plates, in a case where fatigue cracking occurs due to a force repeatedly acting on the welds, or in a case where the welding assembly accuracy of the H-section steel is poor, there is concern that the application accuracy of a designing method may be reduced. On the other hand, in the case of the rolled H-section steel, since the flanges and the web are integrated (since there is no joint portion), the occurrence of fatigue cracking is not postulated, and the dimensional accuracy is high, so that the application accuracy of a designing method is maintained at a high level. From these viewpoints, the present invention is targeted at a rolled H-section steel.

[0016] The H-section steel 1 is used as a beam 2 extending in a member axis direction Y (the longitudinal direction of the H-section steel 1), for example, like a steel framed beam in a building. As shown in FIGS. 2A and 2B, the H-section steel 1 has a substantially H-shaped cross-sectional shape (a cross-sectional shape orthogonal to the member axis direction Y) when viewed in a cross section perpendicular to the member axis direction Y, and includes the upper flange 21 and the lower flange 22 extending in a width direction X, and the web 23 extending in a height direction Z.

[0017] As shown in FIG. 2A, the H-section steel 1 is provided with the upper flange 21 and the lower flange 22 forming a pair in an up-down direction, and the web 23 connects the upper flange 21 to the lower flange 22. That is, in the H-section steel 1, the upper and lower end portions of the web 23 are connected to substantially the center in the width direction X of the upper flange 21 and the lower flange 22 facing each other.

[0018] As shown in FIG. 2B, the entire H-section steel 1 extends in the member axis direction Y and has a predetermined length 1. In the H-section steel 1, the distance in the height direction Z from the plate thickness center of the upper flange 21 to the plate thickness center of the lower flange 22 becomes a plate thickness center-to-center distance d_b between the upper flange 21 and the lower flange 22.

[0019] The plate thickness center-to-center distance d_b can be treated as being substantially the same as the distance in the height direction Z from the upper surface of the upper flange 21 to the upper surface of the lower flange 22, or the distance in the height direction Z from the lower surface of the upper flange 21 to the lower surface of the lower flange

22. In addition, the plate thickness center-to-center distance d_b can be treated as being substantially the same as the distance in the height direction Z from the lower surface of the upper flange 21 to the upper surface of the lower flange 22 or an overall height dimension H of the H-section steel 1.

[0020] As shown in FIG. 3, the H-section steel 1 is formed so that the upper flange 21 and the lower flange 22 extend in the width direction X, and the web 23 extends in the height direction Z. The H-section steel 1 has two main axes including a strong axis that passes through the center of the figure (the point (centroid) at which the first moment of area about any axis passing through the point is zero) and extends in the width direction X, and a weak axis that passes through the center of the figure and extends in the height direction Z. The second moment of area about the strong axis is defined as Ix, and the second moment of area about the weak axis is defined as ly.

[0021] In the H-section steel 1, for example, an outer circumferential surface 20 (the surface of the H-section steel 1) of the upper flange 21, the lower flange 22, and the web 23 are subjected to a surface treatment such as pasting, winding, or spraying of a refractory coating material, applying of a refractory painting or corrosion resistant painting, or plating. That is, in the H-section steel 1, a surface treatment material such as a coating material, painting, or plating is provided on the outer circumferential surface 20. In addition, in the H-section steel 1, the entire outer circumferential surface 20 of the upper flange 21, the lower flange 22, and the web 23 may be subjected to the surface treatment, or a part of the outer circumferential surface 20 may be subjected to the surface treatment.

[0022] In the H-section steel 1, the total extension length in the cross-sectional shape, which is the sum of both upper and lower surfaces 21 a and both left and right end surfaces 21b of the upper flange 21, both upper and lower surfaces 22a and both left and right end surfaces 22b of the lower flange 22, and both left and right side surfaces 23a of the web 23 is referred to as an outer circumferential length Lp in the cross-sectional shape of the upper flange 21, the lower flange 22, and the web 23. In addition, in the H-section steel 1, as the outer circumferential length Lp increases, the use amount of the refractory coating material, painting, plating, and the like (use amount of surface treatment materials) increases.

[0023] In the H-section steel 1 in which the web and the flanges are integrally formed, curved connection portions 23b called fillets are present at the joint points (four points) between the web 23, the upper flange 21, and the lower flange 22. In calculation of the outer circumferential length Lp, the fillets 23b (curved connection portions) may be taken into consideration. For example, in the H-section steel 1 represented by H1000 × W350 × tw12 × tf19, the outer circumferential length Lp in a case of being calculated on the assumption that one fillet is a quarter circle with a radius of curvature of 18 mm, is 3345 mm. On the other hand, in the same H-section steel, the outer circumferential length Lp in a case where there is no fillet, that is, in a case assuming that there is no curved connection portion and the web and the flanges are connected at right angles is calculated to be 3376 mm. As described above, it can be seen that the difference between the two kinds of outer circumferential lengths Lp calculated by the presence or absence of the fillet is about 1%, and the influence of the presence or absence of the fillet on the calculation result is sufficiently small. The radius of curvature of the fillet is generally in a range of about 12 mm to 20 mm in the targeted rolled H-section steel, but in the following description, the radius of curvature of the fillet is calculated to be 18 mm.

[0024] Here, the "H-section steel 1 represented by H1000 × W350 × tw12 × tf19" means an H-section steel 1 in which the height dimension H, a width dimension W, a web plate thickness tw, and a flange plate thickness tf, which will be described later, are respectively 1000 mm, 350 mm, 12 mm, and 19 mm. The same applies to the following description.

[0025] In the H-section steel 1, the height dimension H from the upper flange 21 to the lower flange 22 (the distance in the height direction Z from the upper surface of the upper flange 21 to the lower surface of the lower flange 22) is 700 mm or more.

[0026] In the H-section steel 1, the distance in the width direction X between both the left and right end surfaces 21b of the upper flange 21 and the distance in the width direction X between both the left and right end surfaces 22b of the lower flange 22 are respectively referred to as a width dimension W of the upper flange 21 and a width dimension W of the lower flange 22, and the width dimensions W are 1/5 or more and 1/2 or less of the height dimension H.

[0027] In the H-section steel 1, each of the upper flange 21 and the lower flange 22 has a predetermined plate thickness tf (the distance between both the upper and lower surfaces 21a in the height direction Z, or the distance between both the upper and lower surfaces 22a), and the web 23 has a predetermined plate thickness tw (the distance between both the left and right side surfaces 23a in the width direction X). The ratio of the plate thickness tf to the plate thickness tw is defined as a plate thickness ratio tw/tf.

[0028] In the H-section steel 1, the plate thickness tw of the web 23 is 9 mm or more and 32 mm or less, and the plate thickness tf of the upper flange 21 and the lower flange 22 is 12 mm or more and 40 mm or less.

[0029] Here, in a case where the H-section steel 1 is used as, for example, the beam 2 shown in FIG. 1, in order to suppress deflection in the height direction Z, an improvement in bending rigidity in the height direction Z is required. By increasing the height dimension H of the H-section steel 1 (by extending the H-section steel in the height direction), the second moment of area Ix about the strong axis is increased. Therefore, by improving bending rigidity per unit weight, the bending rigidity of the H-section steel 1 in the height direction Z can be improved.

[0030] In the H-section steel 1, when the outer circumferential length Lp in the cross-sectional shape of the upper flange 21, the lower flange 22, and the web 23 is increased, the surface area of the outer circumferential surface 20 subjected to the surface treatment such as coating is also increased. In this case, the use amount of the surface treatment material such as a refractory coating material, painting, or plating is also increased, and the amount of work such as coating is increased, resulting in an increase in the cost for the surface treatment.

[0031] Therefore, it is required to reduce the cost for the surface treatment by reducing the outer circumferential length Lp and reducing the surface area of the outer circumferential surface 20.

[0032] In general, for example, a fixed outer dimension H-section steel defined in JIS G 3192 (H-section steel represented by H900 × W400 × tw19 × tf28) has a steel weight of about 304 kg/m per meter and a surface area of about 3.36m^2 per meter. In addition, for example, in a case where the outer circumferential surface of the fixed outer dimension H-section steel is coated with an expensive refractory coating or cold-resistant coating, the unit cost of the material is, for example, 10,000 yen/m^2.

[0033] Assuming that the unit cost of the fixed outer dimension H-section steel is 120,000 yen/ton, in the beam 2 having a length of 10 m in the member axis direction Y, the cost for the steel is about 365,000 yen (120,000 yen/ton × 0.304 ton/m × 10 m), whereas the cost for the coating material is about 336,000 yen (10,000 yen/m^2 × 3.36 m^2/m × 10 m). That is, by comparing the cost for the steel and the cost for the coating material, it can be seen that it is necessary to reduce not only the steel weight of the H-section steel 1 but also the surface area of the outer circumferential surface 20 thereof in balance in order to reduce the total cost of the building or the like.

[0034] Therefore, in the H-section steel 1, a surface treatment economy Ix/Lp, which is a value obtained by dividing the second moment of area Ix about the strong axis by the outer circumferential length Lp in a shape of a cross section perpendicular to the member axis direction Y, is used as an index. When the surface treatment economy Ix/Lp is increased, the second moment of area Ix about the strong axis becomes relatively large with respect to the outer circumferential length Lp, so that the bending rigidity per unit weight can be improved while reducing the cost for the surface treatment.

[0035] In addition, in the H-section steel 1, the height dimension H, the width dimension W, the web plate thickness tw, and the flange plate thickness tf mentioned above are determined based on the surface treatment economy Ix/Lp.

[0036] By causing the H-section steel 1 to have the height dimension H, the width dimension W, the web plate thickness tw, and the flange plate thickness tf determined based on the surface treatment economy Ix/Lp as described above, the cost for the surface treatment can be reduced while increasing the second moment of area Ix about the strong axis.

[0037] Specifically, as described above, in the H-section steel 1, the height dimension H is 700 mm or more, the width dimension W is 1/5 or more and 1/2 or less of the height dimension H, the plate thickness tw of the web 23 is 9 mm or more and 32 mm or less, and the plate thickness tf of the flange is 12 mm or more and 40 mm or less.

[0038] Furthermore, assuming that the cross-sectional area in the cross-sectional shape of the H-section steel 1 is S (the sum of the cross-sectional areas of the upper flange 21, the lower flange 22, and the web 23 when the H-section steel 1 is viewed in a cross section perpendicular to the member axis direction Y), in the H-section steel 1, the surface treatment economy Ix/Lp described above satisfies the relationships defined by Formulas (35) to (38) in terms of the relationship between the cross-sectional area S and the height dimension H. In other words, in the H-section steel 1, the height dimension H, the width dimension W, the plate thickness tw, and the plate thickness tf satisfy Formulas (35) to (38). Accordingly, the cost for the surface treatment can be reduced, and at the same time, the bending rigidity per unit weight can be improved, so that it is possible to suppress excessive deflection of the H-section steel 1 in the height direction Z.

[0039] [Math 4]

$$Ix / Lp = C_{k1} \cdot \exp\left(C_{k2} \cdot H / S\right) \quad \cdots \quad (35)$$

$$C_{k1} = 120 + 100 \cdot k \quad \cdots \quad (36)$$

$$C_{k2} = -106 + 10 \cdot k \quad \cdots \quad (37)$$

$$6.1 \leq k \leq 8 \quad \cdots \quad (38)$$

[0040] There are four important performance indexes of the H-section steel 1 including the second moment of area Ix about the strong axis as a structural index dominating bending rigidity, the section modulus Zx about the strong axis as a structural index dominating bending strength, the steel weight ($\propto$ the cross-sectional area S) as an economic index, and the outer circumferential length Lp also as an economic index. At this time, if a large second moment of area Ix can be exhibited about the strong axis with the least possible outer circumferential length Lp, it can be said that the economy is high. Therefore, in FIGS. 4 to 7, the vertical axis represents the surface treatment economy Ix/Lp. In addition, since the section modulus Zx is expressed as a function of the second moment of area Ix about the strong axis and the height dimension H of the H-section steel 1, that is, Zx = Ix/(H/2), using the height dimension H as a structural index, the horizontal axis in FIGS. 4 to 7 represents H/S obtained by dividing the dimension H by the cross-sectional area S as an economic index.

[0041] Here, in an H-section steel in the related art, all existing standards are shown as marks Δ, ◊, □, and ○ in FIGS. 4 to 7.

[0042] The marks Δ represent H-section steels in the related art described in "ASTM A6/A6M-10a Annex A2 lists the dimensions of some shape profiles, ASTM International".

[0043] The marks ◊ represent H-section steels in the related art described in "BS 4-1 Structural steel sections, Part1, British Standard, (2005)".

[0044] The marks □ represent H-section steels in the related art described in "fixed inner dimension H-shapes, JIS handbook, Ferrous materials & metallurgy 2, Japanese Standards Association (2015)".

[0045] The marks ○ represent H-section steels in the related art described in "fixed outer dimension H-shapes, JIS handbook, Ferrous materials & metallurgy 2, Japanese Standards Association (2015)".

[0046] These H-section steels in the related art are comprehensively identified in a range of $k < 6.1$ in Formulas (35) to (37) as shown in FIG. 5. That is, it was found that these H-section steels in the related art did not satisfy $k \geq 6.1$ in Formulas (35) to (37) based on the surface treatment economy Ix/Lp. Contrary to this, the H-section steel 1 according to this embodiment can simultaneously take the structural indexes and the economic indexes into consideration by considering Formulas (35) to (37) based on the surface treatment economy Ix/Lp.

[0047] Specifically, the bending rigidity is required to be increased while suppressing the cost for the surface treatment even in the related art. However, in a designing method in the related art (a designing method in which Formula (12) is not used), as shown in FIG. 4, k cannot exceed 6.0. The reason is that in a case where the above requirements are satisfied, the design value of lateral buckling strength (earthquake resistance) is calculated to be lower than an actual value, and lateral buckling stiffeners for preventing the reduction in lateral buckling strength are necessary, resulting in a reduction in economy. For example, a buckling reinforcement length Lb in a case of being calculated for an H-section steel (H1100 × W300 × tw32 × tf40) satisfying $k \approx 6 (k < 6)$ using the designing method in the related art is smaller than 4.6 times H (1100 × 4.6 = 5060). That is, in the category of the designing method in the related art, lateral buckling stiffeners had to be installed every 5 m. In addition, in a range of $k \geq 6.1$, Lb further tends to relatively decrease, and the number of buckling stiffeners also tends to increase. For this reason, in the related art, $k < 6.1$.

[0048] On the other hand, in the H-section steel 1 according to this embodiment, since $k \geq 6.1$ is satisfied in Formulas (35) to (37), the structural indexes and the economic indexes can be simultaneously considered, whereby it is possible to reduce the cost for the surface treatment and simultaneously improve the bending rigidity per unit weight. In addition, from the viewpoint of reliably reducing the cost for the surface treatment and simultaneously reliably improving the bending rigidity, as shown in FIG. 6, the H-section steel 1 satisfies preferably $k \geq 6.2$ or $k \geq 6.25$, and more preferably $k \geq 6.3$ or $k \geq 6.4$ in Formulas (35) to (37).

[0049] In addition, in the H-section steel 1, from the viewpoint of avoiding a reduction in strength due to the occurrence of lateral buckling and avoiding a reduction in energy absorption performance during an earthquake, and from the viewpoint of preventing the web from being undulated or twisted during rolling, the width dimension W of the H-section steel 1 is set to 1/5 or more of the height dimension H, and $k \leq 8$ is satisfied in Formulas (35) to (37). For example, the surface treatment economy Ix/Lp of the H-section steel 1 represented by H1200 × W160 × tw7 × tf16 is relatively high, that is, the value of k in FIG. 5 is relatively high, and $k > 8$ is satisfied. However, in the H-section steel 1, there is concern that even if calculation is performed based on a designing method of the present invention, which will be described later, sufficiently high bending strength cannot be obtained (in a case where calculation is performed under the same conditions as those of examples described later, lateral buckling occurs in a range in which the buckling reinforcement interval Lb is shorter than about 15 times H, and the ratio of a design strength to a full plastic moment Mp obtained by the product of a full plastic section modulus Zxp about the strong axis and a steel F value decreases to about 75%), and sufficient earthquake resistance cannot be secured. Based on these examinations, the upper limit of $k \leq 8$ is provided.

[0050] For example, in the case of H-section steels of H1500 × W350 × tw19 × tf40, H1500 × W400 × tw22 × tf40, and H1500 × W500 × tw16 × tf36, when calculation is performed using $k \approx 8$ (and $k < 8$) and F = 345 in the same method as in the examples described later, it can be confirmed that lateral buckling does not occur until the buckling reinforcement interval Lb exceeds 15 times H (= 1500 mm).

[0051] In addition, in FIG. 6, the examples of the H-section steel 1 are shown by marks ●.

Here, Example 1 has a height dimension H = 1150 mm, a width dimension W = 300 mm, a web plate thickness tw = 32 mm, and a flange plate thickness tf = 40 mm, and satisfies Formulas (35) to (38) (H1150 × W300 × tw32 × tf40). Example 2 has a height dimension H = 1100 mm, a width dimension W = 280 mm, a web plate thickness tw = 16 mm, and a flange plate thickness tf = 30 mm, and satisfies Formulas (35) to (38) (H1100 × W280 × tw16 × tf30). Example 3 has a height dimension H = 1000 mm, a width dimension W = 250 mm, a web plate thickness tw = 12 mm, and a flange plate thickness tf = 16 mm, and satisfies Formulas (35) to (38) (H1000 × W250 × tw12 × tf16). Example 4 has a height dimension H = 950 mm, a width dimension W = 250 mm, a web plate thickness tw = 11 mm, and a flange plate thickness tf = 25 mm, and satisfies Formulas (35) to (38) (H950 × W250 × tw11 × tf25). Example 5 has a height dimension H = 850 mm, a width dimension W = 200 mm, a web plate thickness tw = 10 mm, and a flange plate thickness tf = 16 mm, and satisfies Formulas (35) to (37) (H850 × W200 × tw10 × tf16).

[0052] Furthermore, in the H-section steel 1, as shown in FIG. 7, in Formula (35), $H/S \geq 0.015$ and $Ix/Lp \geq 50$ are satisfied. In a case where the value of H/S is less than 0.015, for example, a special ultra thick H-section steel having a flange plate thickness of more than 60 mm is used, so that use in a floor structure of a building, which is an application object of the present invention, is difficult. In such a case, H decrease to 500 mm or less, and is applied to a column of the building, which is not the object of the present invention.

[0053] The lower limit of Ix/Lp may be, for example, 35. However, when Ix/Lp is less than 50, the surface treatment economy Ix/Lp becomes too small. Therefore, from the viewpoint of reducing the cost for the surface treatment and simultaneously improving the bending rigidity, the lower limit of Ix/Lp is preferably 50.

[0054] The upper limit of H/S is preferably 0.065 ($H/S \leq 0.065$), and more preferably 0.060 ($H/S \leq 0.060$).

[0055] Here, from the viewpoint of reducing the cost for the surface treatment and simultaneously improving the bending rigidity, as described above, the height dimension H may be increased (the H-section steel may be extended in the height direction). However, in the beam 2, as shown in FIGS. 8A, 8B, and 9A to 9C, as the web 23 undergoes out-of-plane deformation with respect to a structural plane in the member axis direction Y and the height direction Z, lateral buckling occurs. In addition, under the designing method (the designing method in the related art) of the beam 2 according to the architectural standards laws in the relate dart, there is a need to sufficiently consider lateral buckling occurring in the beam 2 at both end portions 2a and 2a of the beam 2 on which a horizontal load acts during an earthquake, or at a part in a middle portion 2b of the beam 2 where a negative bending moment occurs. Therefore, the height dimension H cannot be easily increased.

[0056] FIG. 10 is a graph of the calculation results shown in Table 1. A to I columns in Table 1 show the cross-sectional specifications of each H-section steel. A column shows the cross-sectional area S, and B column shows the ratio of the cross-sectional area of the other H-section steels to the cross-sectional area of H900 × W400 × tw22 × tf40, which is a basic H-section steel for performance comparison. C column shows the outer circumferential length Lp, and D column shows the ratio of the outer circumferential length of the other H-section steels to the outer circumferential length Lp of the above-mentioned basic H-section steel (H900 × W400 × tw22 × tf40). E column shows the second moment of area Ix about the strong axis, and F column shows the ratio of the second moment of area of the other H-section steels to the second moment of area Ix of the basic H-section steel. G column shows the full plastic section modulus Zxp about the strong axis, H column shows the steel F value, and I column shows the full plastic moment Mp obtained by the product of Zxp and F.

[0057] Here, since the cross-sectional dimensions are set so that the values of the full plastic moments Mp are substantially the same, the values of the G column and the I column are substantially the same. In addition, J column shows the design strength (calculation results based on the present invention) calculated based on the designing method of the present invention, which will be described later, K column shows the ratio of the design strength Mcn of each H-section steel to the full plastic moment Mp (in Table 1, the value is defined as Mpo) of H900 × W400 × tw22 × tf40, L column shows the design strength Mcc (calculation results based on the related art) calculated based on the designing method in the related art, and column M shows the ratio of the design strength Mcc of each H-section steel to the full plastic moment Mpo.

[0058] In the designing method in the related art, calculation is performed using a strength factor of 1.0 based on the calculation of an H-shaped cross section shown in Recommendation for limit state design of steel structures by Architectural Institute of Japan.

[0059] On the other hand, in the designing method of the related art, the derivation formula of the elastic lateral buckling moment shown in the same document is substituted with Formula (12), and calculation is performed using a strength factor of 1.0 as in the designing method in the related art. In addition, when Formula (12) is used in the designing method of the present invention, calculation is performed for a case where, on a beam (solid line) that receives antisymmetric bending due to a horizontal load shown in FIG. 13, a vertical load (broken line) also acts.

[0060] The buckling reinforcement length Lb is set to 20 m in any case, and the steel F value is set to 325 N/mm^2 in any case.

[0061] Here, the designing method in the related art described above is described in detail. In the designing method in the related art described above, first, using the bending rigidity about the weak axis, the bending torsional rigidity, the Saint-Venant's torsional rigidity, the lateral buckling length, and the like of an H-section steel calculated based on conditions such as the cross-sectional shape, the material length, and both end support conditions of the H-section steel which is targeted, and the presence or absence of lateral reinforcement, the elastic lateral buckling moment of Formula (1.a) is calculated. Next, a lateral buckling slenderness ratio is calculated from the full plastic moment of the H-section steel which is targeted, and the elastic lateral buckling moment. There are three cases classified according to the magnitude relationship between the value of the lateral buckling slenderness ratio and the elastic limit slenderness ratio and plastic limit slenderness ratio described in the same guideline, and in each case, the calculation formula of a lateral buckling limit strength of the H-section steel is determined. The lateral buckling limit strength is calculated by the nominal value of each of elements constituting the calculation formula. However, in a case where the ultimate limit state is postulated, it is necessary to consider variations in the strength of a member which is targeted. Therefore, by introducing the strength factor which is a reliability index based on engineering judgment and multiplying this by the lateral buckling limit strength, the lateral buckling limit strength in the ultimate limit state is determined. According to the above guideline, the strength factor is 1.0.

[0062] [Math 5]

$$Me = C_b \sqrt{\frac{\pi^4 EI_Y \cdot EI_w}{{}_k l_b^4} + \frac{\pi^2 EI_Y \cdot GJ}{l_b^2}} \quad \cdots \quad (1.\ a)$$

[0063] In Formula (1.a), EI_Y: bending rigidity about the weak axis, EI_W: bending torsional rigidity, GJ: Saint-Venant's torsional rigidity, ${}_k l_b$: lateral buckling length, l_b: material length or lateral buckling reinforcement-to-reinforcement length, C_b: moment coefficient.

[0064] Cases of the lateral buckling length ${}_k l_b$ are classified as follows.

(a) Beam in which both material ends are joined to a column in a rigid manner and the middle is not subjected to lateral reinforcement: ${}_k l_b = 0.75 \times l_b$
(b) Bending material such as a section of a beam in which one end is joined to a column in a rigid manner and the other end is subjected to lateral reinforcement by a lateral buckling stiffener, a section of a beam in which both ends are subjected to lateral reinforcement by lateral buckling stiffeners, purlins, and furring strips: ${}_k l_b = 0.75 \times l_b$
(c)

Simple beam: ${}_k l_b = l_b$

[0065] Cases of the moment coefficient C_b are classified as follows.

(a) Case in which the bending moment changes linearly in a lateral buckling reinforcing section: Formula (1.b)
(b) Case in which the intermediate bending moment is maximized in a lateral buckling reinforcing section: $C_b = 1.0$
(c) Simple beam without lateral buckling reinforcement support:

(i) Case in which a uniform distributed load acts: C_b=1.3
(ii) Case in which a center concentrated load acts: C_b = 1.36

[0066] [Math 6]

$$C_b = 1.75 + 1.05\left(\frac{M_2}{M_1}\right) + 0.30\left(\frac{M_2}{M_1}\right)^2 \leq 2.3 \quad \cdots \quad (1.\ b)$$

[0067] M_2/M_1 in Formula (1.b) represents the bending moment ratio between both material ends or the lateral buckling reinforcement ends.

[0068] Classification of cases of the magnitude relationship between the value of the lateral buckling slenderness ratio λ_b, and the elastic limit slenderness ratio ${}_e\lambda_b$ and the plastic limit slenderness ratio ${}_p\lambda_b$, and the lateral buckling limit strength M_c (nominal strength) in each case are as follows.

(a)

$$\lambda_b \leq {}_p\lambda_b\text{: } M_c = M_p$$

(b)

$${}_p\lambda_b < \lambda_b \leq {}_e\lambda_b\text{: Formula (1.c)}$$

(c)

$$\lambda_b > {}_e\lambda_b\text{: Formula (1.d)}$$

[0069] [Math 7]

$$M_c = \left(1.0 - 0.4\frac{\lambda_b - {}_p\lambda_b}{\lambda_b - {}_e\lambda_b}\right) M_p \quad \cdots \text{(1. c)}$$

$$M_c = \frac{1}{\lambda_b^2} M_p \quad \cdots \text{(1. d)}$$

[0070] Here, the lateral buckling slenderness ratio λ_b is calculated by Formula (1.e). In Formula (1.e), M_p: full plastic moment = $F_y \times Z_p$, F_y: yield strength, Z_p: plastic section modulus.

[0071] [Math 8]

$$\lambda_b = \sqrt{\frac{M_p}{Me}} \quad \cdots \text{(1. e)}$$

[0072] In addition, the elastic limit slenderness ratio ${}_e\lambda_b$ is 1/√0.6. Cases of the plastic limit slenderness ratio ${}_p\lambda_b$ are classified as follows.

(a) Case in which the bending moment changes linearly in a lateral buckling reinforcing section: Formula (1.f)
(b) Case in which the intermediate bending moment is maximized in a lateral buckling reinforcing section: ${}_p\lambda_b = 0.3$

[0073] In addition, the lateral buckling limit strength M_{cr} in the ultimate limit state is obtained by Formula (1.g).

[0074] [Math 9]

$${}_p\lambda_b = 0.6 + 0.3\left(\frac{M_2}{M_1}\right) \quad \cdots \text{(1. f)}$$

$$M_{cr} = \phi_b \cdot M_c \quad \cdots \text{(1. g)}$$

[0075] Contrary to the designing method in the related art described above, in the designing method of the present invention, the calculation formula of the elastic lateral buckling moment (Formula (1.a)) shown in the same document is substituted with Formula (12) to calculate the lateral buckling slenderness ratio and the lateral buckling limit strength. The strength factor for considering the ultimate limit state is set to 1.0 as in the designing method in the related art.

[0076] The horizontal axis of the graph shown in FIG. 10 shows four kinds of H-section steels, and by the vertical axis, the ratio of the cross-sectional area S (values shown in B column of Table 1), the ratio of the outer circumferential length (values shown in column D of Table 1), the ratio of the second moment of area about the strong axis (values shown in column F of Table 1), the ratio of the design strength based on the designing method of the present invention (values shown in column K of Table 1), and the ratio of the design strength based on the designing method in the related art (values shown in column M of Table 1) can be compared.

[0077] As shown in FIG. 10, under the designing method in the related art, by increasing the height dimension H relatively to the width dimension W, the bending rigidity ($\propto$ second moment of area Ix about the strong axis) can be increased and the steel weight ($\propto$ cross-sectional area S) can be reduced, while the bending strength ($\propto$ "allowable bending strength" given by the product of "section modulus Zxp about the strong axis" and "allowable bending stress fc") tends to decrease. This is because the section modulus Zx about the strong axis is expressed as Zx = Ix/(H/2) and thus Zx tends to decrease as H increases if Ix is the same (reason 1), and the allowable bending stress fc needs to be reduced in consideration of lateral buckling occurring in the beam 2 and lateral buckling tends to occur as the height dimension H becomes relatively large (reason 2).

[Table 1]

	A column	B column	C column	D column	E column	F column	G column	H column	I column	column	K column	L column	M column
	Cross-sectional specifications and the like									Calculation results based on the present invention		Calculation results based on the related art	
	S (cm^2)	Ratio of S	Lp (cm)	Ratio of Lp	Ix (cm^4)	Ratio of Ix	Zxp (cm^3)	F (N/mm^2)	Full plastic moment Mp (kN mm)	Design strength Men (kN mm)	Mcn/Mpo	Design strength Mcc (kN mm)	Mcc/Mpo
900×400×22×40	503	1	3325	1	697778	1	17571	325	5710611	5710611	1.00	4058375	0.71
1000×350×22×38	472	0.94	3325	1.00	766207	1.10	17618	325	5725766	5725766	1.00	3360114	0.59
1100×290×22×38	448	0.89	3285	0.99	825740	1.18	17612	325	5723799	5723799	1.00	2341996	0.41
1200×240×22×38	432	0.86	3285	0.99	884933	1.27	17701	325	5752888	5605844	0.98	1637642	0.29

[0078] Regarding the reason 1 described above, there may be cases where performance degradation can be alleviated when the height dimension H and the width dimension W of the beam 2 are set appropriately to each other. Contrary to this, regarding the reason 2, the problem cannot be solved only by appropriately setting the height dimension H and the width dimension W of the beam 2, so that a main technical object is to prevent a reduction in the allowable bending stress fc due to lateral buckling of the beam 2. As a method of preventing the reduction in the allowable bending stress fc, a method of providing a reinforcing member for lateral buckling in the beam 2 and reducing the buckling reinforcement interval may be considered. However, when the beam 2 is provided with the reinforcing member, the effect of reducing cost by reducing the cost for the surface treatment and the like becomes meaningless.

[0079] The H-section steel 1 is used as the beam 2 extending in the member axis direction Y, and as shown in FIGS. 8A and 8B, both end portions 2a and 2a of the beam 2 in the member axis direction Y are joined and fixed to the column 3 or the like in a rigid manner. At this time, for example, in a case where a square steel pipe or the like is used as the column 3, both end portions 2a and 2a of the beam 2 are welded to diaphragms 30 provided on the side surfaces of the square steel pipe and are thus fixed and joined to the column 3 in a rigid manner so as to be supported.

[0080] In a case where a reinforced concrete column or a plain concrete column is used as the column 3, both end portions 2a and 2a of the beam 2 may be welded and joined to steel framed beams which are substantially orthogonal to each other inside the column 3. Furthermore, in a case where a steel reinforced concrete column is used as the column 3, both end portions 2a and 2a of the beam 2 may be welded and joined to a steel column extending in the height direction Z inside the column 3.

[0081] In the H-section steel 1, both end portions 2a and 2a of the beam 2 in the member axis direction Y may be fixed to the column 3 or the like by a semi-rigid joint or a pin joint. The semi-rigid joint refers to a joint type in which the rotational movement of the beam 2 with respect to the column 3 is restricted to some extent, and the bending stress transmitted between the column 3 and the beam 2 is smaller than that in a completely rigid joint. In addition, the pin joint refers to a joint type in which the rotational movement of the beam 2 with respect to the column 3 is not restricted and there is no or minimal bending stress transmitted between the column 3 and the beam 2. The definition of the semi-rigid joint, pin joint, and rigid joint is based on European Design Standards (Eurocode 3 Part 1-8).

[0082] In the H-section steel 1, a floor slab 4 such as concrete is provided on the upper flange 21 in the middle portion 2b of the beam 2 in the member axis direction Y. As the floor slab 4, for example, a concrete slab having concrete as the main structure, or a deck composite slab having concrete and a deck plate made of steel or the like as the main structure is used.

[0083] Furthermore, in the H-section steel 1, in the middle portion 2b of the beam 2 in the member axis direction Y, one or a plurality of shear connectors 25 such as headed studs are provided on the upper surface of the upper flange 21 at predetermined intervals. The shear connectors 25 are provided to protrude upward from the upper surface of the upper flange 21 of the beam 2, and are embedded in concrete of the floor slab 4 or the like above the upper flange 21 of the beam 2. At this time, in the H-section steel 1, since one or the plurality of shear connectors 25 are embedded in the floor slab 4 or the like, as shown in FIG. 8A, lateral movement of the beam 2 in the width direction X in the middle portion 2b of the beam 2 in the member axis direction Y is restricted.

[0084] Further, as shown in FIG. 8B, the H-section steel 1 to which the present invention is applied is subjected to an intermediate load due to the self-weight of the floor slab 4, a live load, and the like. At this time, in the H-section steel 1, in a case where an intermediate load such as a uniform distributed load acts from above on the upper flange 21 in the middle portion 2b of the beam 2 in the member axis direction Y, or each column 3 is inclined due to an earthquake or the like, end loads act on both end portions 2a and 2a of the beam 2 in the member axis direction from the column 3. Furthermore, in the H-section steel 1, a bending moment and a shear force act on each of both end portions 2a and 2a of the beam 2 in the member axis direction Y.

[0085] Under the designing method of the present invention, as shown in FIGS. 9A to 9C, using the beam 2 extending in the member axis direction Y as a target, under the condition that both end portions 2a and 2a of the beam 2 in the member axis direction Y are fixed, lateral movement of the beam 2 in the width direction X in the middle portion 2b of the beam 2 in the member axis direction Y is restricted, an intermediate load acts on the upper flange 21 from above, and end loads act on both end portions 2a and 2a of the beam 2 in the member axis direction, the elastic lateral buckling moment M_{cr} of the beam 2 can be calculated with high accuracy.

[0086] In FIGS. 9A to 9C, using the local coordinate system X-Y-Z fixed at the left end portion 2a of the beam 2, the rotation of the beam 2 is positive in a direction in which a left-handed thread advances. In FIGS. 9A to 9C, the solid line represents the free body of the beam 2, and the broken line represents an example of virtual displacement that occurs in the free body of the beam 2 due to lateral buckling.

<Geometric Boundary Condition>

[0087] It is assumed that the displacement (lateral movement) of the upper flange 21 of the beam 2 in the X direction is restrained on the center line 0-0'. The geometric boundary condition of the end portion 2a of the beam 2 is defined by the terminal condition of a series approximating the lateral buckling deformation. In the beam 2, bending torsion about 0-0' as a predetermined rotation axis occurs due to lateral buckling, and deflection occurs as secondary small deformation. In this analysis, it is assumed that the upper flange 21, the lower flange 22, and the web 23 are treated as flat plates, and the strength of the beam 2 against lateral buckling is dominated by the in-plane bending rigidity of the upper flange 21 and the lower flange 22, and the torsional rigidity of the upper flange 21, the lower flange 22, and the web 23.

<Dynamic Boundary Condition>

[0088] It is assumed that a vertical uniform distributed load W_{cr} acts as the intermediate load on 0-0' on the middle portion 2b of the beam 2. In addition, it is assumed that bending moment M_{cr} and the shear force V_{cr} act on the right end portion 2a of the beam 2, and a bending moment M and a shear force V that balance those act on the left end portion 2a of the beam 2. At this time, the relationship between M_{cr}, V_{cr}, and W_{cr} can be expressed by Formulas (1) and (2), according to the force balance condition.

[0089] [Math 10]

$$V_{cr} = -(\beta + \gamma)\frac{M_{cr}}{l} \quad \cdot\cdot\cdot \quad (1)$$

$$\int_0^l W_{cr} y\, dy = \gamma M_{cr} \quad \cdot\cdot\cdot \quad (2)$$

$$0 \le \beta \le 3 \quad \cdot\cdot\cdot \quad (3a)$$

$$0 \le \gamma \le 6 - 2\beta \quad \cdot\cdot\cdot \quad (3b)$$

[0090] Here, 1 is the length of the beam 2 in the member axis direction Y, and y is the length from one end portion of the beam 2 in the member axis direction as a reference (in the case shown in FIG. 5, the left end portion 2a) to any point of the beam 2 in the member axis direction. β and γ are coefficients determined by the load condition of the intermediate load to be expressed as the elastic lateral buckling moment M_{cr} by eliminating V_{cr}, W_{cr}, M, and V from the analytical solution.

[0091] The relationship between the bending moment distribution of the beam 2 and β and γ is shown in FIGS. 11A to 11D. In a case where the intermediate load is uniform bending in the member axis direction Y of the beam 2 (symmetric buckling), β is set to zero as shown in FIG. 11A. In a case where the intermediate load does not become uniform bending in the member axis direction Y of the beam 2 (asymmetric buckling), as shown in FIGS. 11B to 11D, β is a real number greater than 0 and not more than 3 (FIGS 11B to 11D show cases of $\beta = 1$, $\beta = 2$, and $\beta = 3$, respectively). β and γ are determined by Formula (3a) and (3b).

<Generalized Displacement>

[0092] In order to treat lateral buckling as a linear buckling problem, deformation of each portion of the beam 2 due to the lateral buckling is expressed as a continuous function of the coordinate value y in the member axis direction (that is, the length from the left end portion 2a of the beam 2 to any point of the beam 2 in the member axis direction). At this time, the torsion angle θ_y of the cross section generated in the beam 2 due to the lateral buckling may gently continuous in the member axis direction Y as shown in FIGS. 9A to 9C.

[0093] In the present invention, an analytical solution of the elastic lateral buckling moment is derived by series approximation of the deformation of each portion of the beam 2 due to the lateral buckling. Since the lateral buckling is not accompanied by strain of the cross section of the beam 2, other deformations necessary for deriving the analytical solution, that is, the deflection δ_z of the beam 2 shown in FIG. 9C, the rotation angle θ_x of the beam 2 shown in FIG. 9A, and the rotation angle θ_z of the lower flange 22 shown in 9B can be respectively expressed by Formulas (3) to (5). As described above, the deformation (δ_z, θ_x, θ_z) of each portion of the beam 2 due to the lateral buckling can be uniquely represented by θ_y.

[0094] [Math 11]

$$\delta_z = \frac{d_b}{2}\int_0^y (y-a)\theta_y'^2 da \quad \cdot \cdot \cdot \quad (3)$$

$$\theta_x = \frac{d_b}{2}\int_0^y \theta_y'^2 da \quad \cdot \cdot \cdot \quad (4)$$

$$\theta_z = \theta_y' d_b \quad \cdot \cdot \cdot \quad (5)$$

[0095] Here, d_b is the plate thickness center-to-center distance between the upper flange 21 and the lower flange 22, and y is the length from one end portion of the beam in the member axis direction as a reference to any point of the beam in the member axis direction. θ'_y represents the first order derivative of θ_y. a is a parameter for integration.

<Potential Energy>

[0096] When lateral buckling occurs in the beam 2, the total potential energy Π of this system is given by Formula (6).

[0097] [Math 12]

$$\Pi = \Delta U - \Delta T \quad \cdot \cdot \cdot \quad (6)$$

[0098] Here, ΔU is the strain energy of the beam 2, and ΔT is the potential energy of an external force.

[0099] Next, ΔU is given by Formula (7) as the sum of strain energy due to bending and strain energy due to pure torsion.

[0100] [Math 13]

$$\Delta U = \frac{1}{2}EI\int_0^l \theta_z'^2 dy + \frac{1}{2}GJ\int_0^l \theta_y'^2 dy \quad \cdot \cdot \cdot \quad (7)$$

[0101] Here, E is the Young's modulus, I is the second moment of area about the weak axis (Z-axis) of the lower flange 22, G is the shear elastic modulus, and J is the Saint-Venant's torsion constant. θ'_z represents the first order derivative of θ_z.

[0102] Next, ΔT is given by Formula (8) as the sum of potential energies of M_{cr}, V_{cr}, and W_{cr}.

[0103] [Math 14]

$$\Delta T = M_{cr}\theta_{x(l)} + V_{cr}\delta_{z(l)} + \int_0^l W_{cr}\delta_z dy \quad \cdot \cdot \cdot \quad (8)$$

[0104] Here, $\theta_{x(1)}$ and $\delta_{z(1)}$ respectively represent θ_x and δ_z of the right end portion 2a of the beam 2.

<Approximation of Lateral Buckling Deformation>

[0105] Arbitrary θ_y allowed for the beam 2 in which both end portions 2a and 2a in the member axis direction Y are fixed and supported can be approximated by a finite series with any accuracy.

[0106] That is, since a Fourier series expansion given by Formula (9) can be applied to most continuous functions and the series calculation is simple, in any existing buckling studies according to the energy method, buckling deformation is approximated by a Fourier series.

[0107] [Math 15]

$$\theta_y = \frac{a_0}{2} + \sum_{n=1}^{N} a_n \cos\frac{n\pi y}{l} \quad \cdots \quad (9)$$

[0108] On the other hand, in the present invention, in a case where both end portions 2a and 2a of the beam 2 are fixed by a rigid joint, as the lateral buckling deformation of the beam 2 in which both end portions 2a and 2a in the member axis direction Y are fixed and supported, in particular, θ_y can be approximated by a series given by Formula (10).

[0109] [Math 16]

$$\theta_y = \frac{a_0}{2} + \sum_{n=1}^{N} a_n \cos\frac{\kappa\pi y^n}{l^n} \quad \cdots \quad (10)$$

[0110] Here, a_n is an undetermined coefficient of the n-th term. In a case of solving asymmetric buckling, k is set to 2.

[0111] In a case of solving symmetric buckling, k is set to 1, and Formula (10) is applied to 1/2 of the length 1 of the beam 2.

<Derivation of Elastic Lateral Buckling Moment>

[0112] By substituting Formulas (7) and (8) into Formula (11) according to the minimum total potential energy principle, and further substituting Formulas (1) to (5), Formula (12) can be obtained as a basic formula of the elastic lateral buckling moment.

[0113] [Math 17]

$$\Pi = \Delta U - \Delta T = 0 \quad \cdots \quad (11)$$

[0114] [Math 18]

$$M_{cr} = \frac{1}{(1-\beta-\gamma)A + (\beta+\gamma)C + \gamma D}\left(B\frac{2\pi^2 EId_b}{l^2} + A\frac{GJ}{d_b}\right) \quad \cdots \quad (12)$$

[0115] Here, A, B, C, and D are functionals of θ_y shown in Formulas (13) to (16), and since 1 in each formula disappears by integration, these become coefficients determined by only θ_y.

[0116] [Math 19]

$$A = l\int_0^l \theta_y'^2 dy \quad \cdots \quad (13)$$

$$B = \frac{l^3}{2\pi^2}\int_0^l \theta''^2_y dy \quad \cdot\cdot\cdot \quad (14)$$

$$C = \int_0^l y\theta'^2_y dy \quad \cdot\cdot\cdot \quad (15)$$

$$D = \frac{2}{l}\int_0^l \int_0^y (y-a)\theta'^2_y da\,dy \quad \cdot\cdot\cdot \quad (16)$$

[0117] Here, β and γ are coefficients determined from Formula (1) and (2) depending on the load conditions V_{cr} and W_{cr} as the premise. In addition, 1 is the length of the beam 2 in the member axis direction Y, E is the Young's modulus, I is the second moment of area about the weak axis of the lower flange 22, G is the shear elastic modulus, J is the Saint-Venant's torsion constant, d_b is the plate thickness center-to-center distance between the upper flange 21 and the lower flange 22, and y is the length from one end portion of the beam in the member axis direction as a reference to any point of the beam in the member axis direction. θ_y is the torsion angle generated in the beam 2 due to lateral buckling. θ'_y represents the first order derivative of θ_y, and θ''_y represents the second order derivative of θ_y. a is a parameter for integration.

[0118] However, Formula (12) is a linear sum of the strength against bending torsion and the strength against pure torsion, and generally $B \neq A$. In a designing method disclosed in Japanese Unexamined Patent Application, First Publication No. 2016-23446, in a case where an antisymmetric bending moment acts on the beam 2 in which lateral movement of the upper flange 21 is restricted, different correction factors are given to two strengths, so that a highly accurate approximate solution of an elastic lateral buckling moment is proposed.

<Minimum Condition>

[0119] In a case where θ_y is approximated by the series of Formula (9) or (10), an analytical solution of the elastic lateral buckling moment is obtained. The necessary condition for minimizing Formula (12) with respect to an undetermined coefficient sequence (a_n) is obtained from Formula (17), and Formula (18) can be obtained by differentiation thereof. Here, f_{nm} in Formula (18) is expressed by Formula (19).

[0120] [Math 20]

$$\frac{\partial}{\partial a_n} M_{cr} = 0 \qquad n = 1, 2, \cdots, N \quad \cdot\cdot\cdot \quad (17)$$

$$[f_{nm}](a_n) = 0 \qquad n = 1, 2, \cdots, N \qquad m = 1, 2, \cdots, N \quad \cdot\cdot\cdot \quad (18)$$

[0121] [Math 21]

$$f_{nm} = \{(1-\beta)L_{nm} + \beta N_{nm} + \gamma O_{nm}\}M_{cr} - M_{nm}M_b - L_{nm}M_t \quad \cdot\cdot\cdot \quad (19)$$

[0122] Here, L_{nm}, M_{nm}, N_{nm}, and O_{nm} in Formula (19) are expressed by Formulas (20) to (23).

[0123] [Math 22]

$$L_{nm} = l\int_0^l \theta'_n \theta'_m dy \quad \cdot \cdot \cdot \quad (20)$$

$$M_{nm} = \frac{l^3}{2\pi^2}\int_0^l \theta''_n \theta''_m dy \quad \cdot \cdot \cdot \quad (21)$$

$$N_{nm} = \int_0^l y\theta'_n \theta'_m dy \quad \cdot \cdot \cdot \quad (22)$$

$$O_{nm} = \frac{2}{l}\int_0^l \int_0^y (y-a)\theta'_m \theta'_n da\, dy \quad \cdot \cdot \cdot \quad (23)$$

[0124] Here, θ_n represents the n-th basis function of a series approximating θ_y. For example, Formula (24) is obtained for Formula (10). Here, θ'_n and θ''_n respectively represent the first and second order derivatives of θ_n.

[0125] [Math 23]

$$\theta_n = \cos\frac{\kappa\pi y^n}{l^n} \quad \cdot \cdot \cdot \quad (24)$$

<Analytical solution>

[0126] When Formula (17) gives a non-zero value to at least one of the undetermined coefficients a_1, a_2, ..., a_n, a possibility of buckling occurs. Therefore, the determinant of the coefficient matrix of Formula (17) has to be zero. That is, an analytical solution of the elastic lateral buckling moment can be obtained by solving the Nth-order equation of Formula (25).

[0127] [Math 24]

$$\left|f_{nm}\right| = 0 \quad \cdot \cdot \cdot \quad (25)$$

[0128] Furthermore, analytical solutions of the elastic lateral buckling moment in a case where θ_y is approximated by the third term partial sum of the series of Formula (9) or (10) are given by Formulas (26) to (33).

[0129] [Math 25]

$$M_e = \omega^k \sqrt[3]{-\frac{q}{2}+\sqrt{\left(\frac{q}{2}\right)^2+\left(\frac{p}{3}\right)^3}} + \omega^{3-k}\sqrt[3]{-\frac{q}{2}-\sqrt{\left(\frac{q}{2}\right)^2+\left(\frac{p}{3}\right)^3}} - \frac{A_2}{3} \quad (\mathrm{k}=0,1,2) \quad \cdot \cdot \cdot \quad (26)$$

$$\omega^0 = \omega^3 = 1 \quad \cdot \cdot \cdot \quad (27a)$$

$$\omega^1 = \frac{-1+\sqrt{3}i}{2} \quad \cdot \cdot \cdot \quad (27b)$$

$$\omega^2 = \frac{-1-\sqrt{3}i}{2} \quad \cdots \quad (27c)$$

$$p = A_1 - \frac{1}{3}A_2^2 、 q = A_0 - \frac{1}{3}A_1A_2 + \frac{2}{27}A_2^3 、 A_j = \frac{\alpha_j}{\alpha_3} \quad (j=1,2,3) \quad \cdots \quad (28)$$

$$\alpha_3 = \begin{vmatrix} g_{11} & g_{12} & g_{13} \\ g_{21} & g_{22} & g_{23} \\ g_{31} & g_{32} & g_{33} \end{vmatrix} 、 \alpha_0 = \begin{vmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{vmatrix} \quad \cdots \quad (29)$$

$$\alpha_2 = \begin{vmatrix} h_{11} & h_{12} & h_{13} \\ g_{21} & g_{22} & g_{23} \\ g_{31} & g_{32} & g_{33} \end{vmatrix} + \begin{vmatrix} g_{11} & g_{12} & g_{13} \\ h_{21} & h_{22} & h_{23} \\ g_{31} & g_{32} & g_{33} \end{vmatrix} + \begin{vmatrix} g_{11} & g_{12} & g_{13} \\ g_{21} & g_{22} & g_{23} \\ h_{31} & h_{32} & h_{33} \end{vmatrix} \quad \cdots \quad (30)$$

$$\alpha_1 = \begin{vmatrix} g_{11} & g_{12} & g_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{vmatrix} + \begin{vmatrix} h_{11} & h_{12} & h_{13} \\ g_{21} & g_{22} & g_{23} \\ h_{31} & h_{32} & h_{33} \end{vmatrix} + \begin{vmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ g_{31} & g_{32} & g_{33} \end{vmatrix} \quad \cdots \quad (31)$$

$$g_{nm} = (1-\beta)L_{nm} + \beta N_{nm} + \gamma O_{nm} \quad \cdots \quad (32)$$

$$h_{nm} = -M_{nm}\frac{2\pi^2 EI}{L^2}d_b - L_{nm}\frac{GJ}{d_b} \quad \cdots \quad (33)$$

[0130] At this time, the smallest positive value in the actual solution of Formula (26) is the first order elastic lateral buckling moment of the beam 2. Under the condition that the H-section steel 1 is used as the beam 2 extending in the member axis direction Y, both end portions 2a and 2a of in the member axis direction Y are fixed, lateral movement of the beam 2 in the width direction X in the middle portion 2b in the member axis direction Y is restricted, an intermediate load acts on the upper flange 21 from above, and end loads act on both end portions 2a and 2a of the beam 2 in the member axis direction, based on the elastic lateral buckling moment M_{cr} of the beam 2 calculated from Formulas (12) to (16), the upper limit of the surface treatment economy Ix/Lp is preferably determined that lateral buckling does not occur in the beam 2.

[0131] In other words, it is preferable that the upper limit of the surface treatment economy Ix/Lp is determined so that the design strength Mcn calculated by the designing method of the present invention using a strength factor of 1.0 as in the designing method in the related art described above is in a range not significantly smaller than the full plastic moment Mp, and more specifically, the square root of a value obtained by dividing the full plastic moment Mp by the elastic lateral buckling moment M_{cr} calculated from Formulas (12) to (16) becomes 0.6 or less ($\sqrt{(Mp/M_{cr})} \leq 0.6$), and each of the dimensions of the H-section steel 1 (height dimension H, width dimension W, web plate thickness tw, and flange plate thickness tf) is set so that the surface treatment economy becomes equal to or less than the upper limit. As an example of this case, regarding Mcn in a case where the buckling reinforcement interval Lb is about 15 times H, the upper limit of the surface treatment economy Ix/Lp is determined so that Mcn/Mp ≥ 0.95 is satisfied.

[0132] [Math 26]

$$M_{cr} = \frac{1}{(1-\beta-\gamma)A + (\beta+\gamma)C + \gamma D}\left(B\frac{2\pi^2 EId_b}{l^2} + A\frac{GJ}{d_b}\right) \quad \cdots \quad (12)$$

$$A = l\int_0^l \theta_y'^2 dy \quad \cdots \quad (13)$$

$$B = \frac{l^3}{2\pi^2}\int_0^l \theta_y''^2 dy \quad \cdots \quad (14)$$

$$C = \int_0^l y\theta_y'^2 dy \quad \cdots \quad (15)$$

$$D = \frac{2}{l}\int_0^l\int_0^y (y-a)\theta_y'^2 da\,dy \quad \cdots \quad (16)$$

[0133] Here, β and γ are coefficients determined from Formulas (1) and (2) depending on the load conditions V_{cr} and W_{cr} as the premise. V_{cr} is the shear force acting on the end portion 2a of the beam 2 in the member axis direction Y, and W_{cr} is the intermediate load acting on the middle portion 2b of the beam 2 in the member axis direction Y.

[0134] In addition, 1 is the length of the beam 2 in the member axis direction Y, E is the Young's modulus, I is the second moment of area about the weak axis of the lower flange 22, G is the shear elastic modulus, J is the Saint-Venant's torsion constant, d_b is the plate thickness center-to-center distance between the upper flange 21 and the lower flange 22, and y is the length from one end portion of the beam in the member axis direction as a reference to any point of the beam in the member axis direction. θ_y is the torsion angle generated in the beam 2 due to lateral buckling. θ'_y represents the first order derivative of θ_y, and θ''_y represents the second order derivative of θ_y. a is a parameter for integration.

[0135] [Math 27]

$$V_{cr} = -(\beta + \gamma)\frac{M_{cr}}{l} \quad \cdots \quad (1)$$

$$\int_0^l W_{cr} y\, dy = \gamma M_{cr} \quad \cdots \quad (2)$$

[0136] The designing method described above 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 above-described designing method in response to a command from an input device operated by an operator, and outputs each of the dimensions of the H-section steel 1 (height dimension H, width dimension W, web plate thickness tw, and flange plate thickness tf) as the design result. In addition, it is preferable that the output design result is output in a visible manner via an output device (not shown).

[0137] It is preferable that the H-section steel 1 is manufactured by an existing rolling technique according to the design result (each of the dimensions: height dimension H, width dimension W, web plate thickness tw, and flange plate thickness tf) set by executing the above-described designing method. Accordingly, the H-section steel 1 of each of the dimensions (height dimension H, width dimension W, web plate thickness tw, and flange plate thickness tf) specified by the designing method described above can be obtained.

[0138] As shown in FIG. 10, under the designing method in the related art, if the height dimension H of the beam 2 is simply increased, the bending rigidity can be improved, but the bending strength of the beam 2 is reduced and the lateral buckling strength is reduced. Therefore, it was not possible to improve both the bending rigidity and the lateral buckling strength of the beam 2.

[0139] Contrary to this, in the H-section steel 1 according to this embodiment, under the designing method of the present invention, the upper limit of the surface treatment economy Ix/Lp is determined based on the elastic lateral buckling moment M_{cr} of the beam 2 calculated from Formulas (12) to (16). Therefore, in the H-section steel 1, the cross-sectional area S of the beam 2 is reduced, the surface treatment economy Ix/Lp is improved, and at the same time, not only the bending rigidity of the beam 2 but also the bending strength can be maintained at a high level. Therefore, it becomes possible to improve both the bending rigidity and the lateral buckling strength of the beam 2.

[0140] Table 2 shows Examples 1 to 5 and shows a comparison to the designing method in the related art in the design strength of a bending material which is to be the beam 2. In the designing method in the related art, the calculation of the design strength of the bending material performed here is performed using a strength factor of 1.0 based on the calculation of an H-shaped cross section shown in Recommendation for limit state design of steel structures by Architectural Institute of Japan mentioned above. In addition, calculation of examples based on the designing method of the present invention was performed by substituting the derivation formula of the elastic lateral buckling moment shown in the same document with Formula (12) using a strength factor of 1.0 as in the designing method in the related art.

[0141] In the example shown here, although the strength factor is set to 1.0 for comparison between the designing method in the related art and the designing method of the present invention, the strength factor can be appropriately set according to the actual situation. In the designing method of the present invention, the derivation formula of the elastic lateral buckling moment is given by Formula (12). However, in an actual member design, there is a need to consider influences of the yield and initial imperfections of steel and convert the elastic lateral buckling moment into the design strength. Here, as described above, an example based on Recommendation for limit state design of steel structures by Architectural Institute of Japan is described. However, the calculation for conversion from the elastic lateral buckling moment to the design strength shown in this document may be based on other design guidelines or design standards. In addition, the bending moment acting on the H-section steel beam is calculated for a case where a vertical load (broken line) is applied to a beam subjected to antisymmetric bending (solid line) due to a horizontal load shown in FIG. 13. However, the same effect can be obtained in other load cases shown in FIGS. 11A to 11D.

[0142] The effects of the present invention will be described with reference to Table 2 for each of Example 1 (H1150 × W300 × tw32 × tf40), Example 2 (H1100 × W280 × tw16 × tf30), Example 3 (H1000 × W250 × tw12 × tf16), Example 4 (H950 × W250 × tw11 × tf25), and Example 5 (H850 × W200 × tw10 × tf16) to which the present invention is applied.

[0143] Table 2 shows the second moment of area (Ix) about the strong axis, the plastic section modulus (Zxp) about the strong axis, the design reference strength (F) of steel, the full plastic moment (Mp) represented by the product of Zxp and F in A to D columns, respectively. Here, F in Table 2 is a design reference strength (value called steel F value) determined based on the yield point of the steel. Alternatively, the yield strength of the steel may also be used as F. In the examples, F is set to 325 N/mm^2 to 385 N/mm^2, but in the present invention, an elastic buckling moment is provided, and the value of the F value can be widely utilized.

[0144] E to G columns in Table 2 show the results calculated based on the designing method of the present invention (calculation results based on the present invention), H to J columns show the results calculated based on the designing method in the related art (calculation results based on the related art), and K and L columns show the comparison between the designing method of the present invention and the designing method in the related art. E column shows the buckling length (Lon) that enables no lateral buckling reinforcement calculated based on the designing method of the present invention, H column shows the buckling length (Loc) that enables no lateral buckling reinforcement calculated based on the designing method in the related art, and K column shows the comparison therebetween.

[0145] From the numerical values shown in K column, it can be seen that the length that enables no buckling reinforcement can be quadrupled or more based on the designing method of the present invention. In addition, from the numerical values shown in K column, it is shown that in a case where a rolled H-section steel having a surface treatment economy as high as in the examples is manufactured using the designing method in the related art, the structural economy cannot be maintained, that is, many lateral buckling stiffeners need to be installed, and thus the rolled H-section steel having such a surface treatment economy has not been used in the related art.

[0146] The value (Lon) shown in E column is the limit buckling length (Lon) that can exhibit the full plastic moment (Mp) without installing lateral buckling reinforcement in the designing method of the present invention. Therefore, the ratio of Mcn to the full plastic moment Mp is all 1.0 as shown in G column. In a case where the same value is 1.0, the steel F value is not reduced, and the steel F value can be used as it is as a short-term allowable stress for lateral buckling. On the other hand, regarding the design strength Mcc shown in I column, the design strength in a case where no lateral stiffener is provided is calculated based on the designing method in the related art by setting the same limit buckling length (Lon) as in the designing method of the present invention. The ratio of the design strength Mcc to the full plastic moment Mp is as shown in J column, 0.52 at the maximum and decreases to 0.28 at the minimum. It can also be understood from the low numerical values that in the designing method in the related art, a rolled H-section steel having a high surface treatment economy as shown in the examples is not manufactured.

[0147] The values shown in L column show the comparison of design strength in Lon, and it can be seen that the design strength based on the designing method of the present invention is 1.9 to 3.8 times that in the designing method in the related art.

[0148] Here, the buckling length Lon is a buckling length calculated so that the design strength Men based on the present invention has the same value as the full plastic moment Mp. In addition, the buckling length Loc is a buckling length calculated so that the design strength Mcc based on the designing method in the related art has the same value as the full plastic moment Mp.

[Table 2]

		A column	B column	C column	D column	E column	F column	G column	H column	I column	J column	K column	L column
		Cross-sectional specifications and the like				Calculation results based on the present invention			Calculation results based on the related art			Comparison between the present invention and the related art	
		Ix (cm^4)	Zxp (Cm^3)	F (N/mm^2)	Full plastic moment Mp (kN mm)	Lon (m)	Design strength Men at Lon (kN mm)	Mcn/Mp	Loc (m)	Design strength Mcc at Lon (kN mm)	Mcc/Mp	Lon/Loc	Mcn/Mcc
Example 1	1150×300×32×40	1,074,103	22,627	325	7,353,735	23.6	7,353,735	1	5.2	3,832,467	0.52	4.6	1.9
Example 2	1100×280×16×30	638,374	13,458	385	5,181,293	22.0	5,181,293	1	5.0	2,356,393	0.45	4.4	2.2
Example 3	1000×250×12×16	290,783	6,881	325	2,236,184	17.0	2,236,184	1	4.0	616,986	0.28	4.3	3.6
Example 4	950×250×11×25	339,808	8,133	345	2,805,811	19.0	2,805,811	1	4.4	1,137,236	0.41	4.3	2.5
Example 5	850×200×10×16	161,479	4,454	345	1,536,714	13.6	1,536,714	1	3.2	399,931	0.26	4.3	3.8

[Table 3]

		A column	B column	C column I	D column	E column	F column	G column	H column	I column	J column	K column I	L column	M column	N column
		Cross-sectional specifications and the like						Design strength at L/H=15		Ratio of example to comparative example					
		Ix (cm^4)	Zxp (cm^3)	F (N/mm^2)	Fullplastic moment Mp (kN mm)	Cross-sectional area S (mm^2)	Outer circumference Lp (mm)	Reduction ratio from F	Design strength M15 (kN mm)	Ix	Zxp	S	Lp	Design strength M15	(Ix·M15)/(S·Lp)
Example 1	1150×300×32×40	1,074,103	22,627	325	7,353,735	58,518.1	3,405	1	7,353,735	1.00	0.94	0.92	0.94	1.05	1.21
Example 2	1100×380×16×30	638,374	13,458	385	5,181,293	33,718.1	3.257	1	5.181,293	1.00	0.93	0.90	0.95	1.73	2.02
Example 3	1000×250×12×16	290,783	6,881	325	2,236,184	19,894.1	2,945	1	2,236,184	1.00	0.94	0.91	0.93	1.46	1.73
Example 4	950×250×11×25	339,808	8,133	345	2,805,811	22,678.1	2,847	1	2,805,811	1.00	0.96	0.94	0.98	1.64	1.78
Example 5	850×200×10×16	161,479	4,454	345	1,536,714	14,858.1	2,449	1	1,536,714	1.00	0.96	0.94	0.97	2.29	2.50
Comparative Example 1	1050×404×32×40	1,074,488	23,983	385	9,233,290	63,638.1	3,621	0.76	7,022,590	1	1	1	1	1	1.00
Comparative Example 2	1000×369×16×30	637,741	14,402	325	4,680,617	37,458.1	3,413	0.64	2,989,085	1	1	1	1	1	1.00
Comparative Example 3	900×352×12×16	290,624	7,359	325	2,391,528	21,958.1	3,153	0.64	1,526,630	1	1	1	1	1	1.00
Comparative Example 4	900×291×11×25	339,799	8,470	385	3,260,790	24,178.1	2,911	0.53	1,715,507	1	1	1	1	1	1.00

(continued)

		A column	B column	C column I	D column	E column	F column	G column	H column	I column	J column	K column I	L column	M column	N column
		Cross-sectional specifications and the like						Design strength at L/H=15		Ratio of example to comparative example					
		Ix (cm^4)	Zxp (cm^3)	F (N/mm^2)	Fullplastic moment Mp (kN mm)	Cross-sectional area S (mm^2)	Outer circumference Lp (mm)	Reduction ratio from F	Design strength M15 (kN mm)	Ix	Zxp	S	Lp	Design strength M15	(Ix·M15)/(S·Lp)
Comparative Example 5	800×243×10×16	161,273	4,628	325	1,504,241	15,734.1	2,521	0.45	671,982	1	1	1	1	1	1.00

[0149] In Table 2, the designing methods of the present invention and the related art were compared to each other by setting the examples to be constant. In Table 3, rolled H-section steels in the ranges determined as the related art in FIG. 6 were determined for the corresponding examples, and through specific comparison therebetween, the significance of the present invention is described.

[0150] For each of the examples described above, the height dimension H and the width dimension W of the H-section steels were set while setting the web plate thickness tw and the flange plate thickness tf to be constant so that the setting conforms to the related art, that is, k becomes less than 6.1. That is, H1050 × W404 × tw32 × tf40 was set as Comparative Example 1 for Example 1, H1000 × W369 × tw16 × tf30 was set as Comparative Example 2 for Example 2, H900 × W352 × tw12 × tf16 was set as Comparative Example 3 for Example 3, H900 × W291 × tw11 × tf25 was set as Comparative Example 4 for Example 4, and H800 × W243 × tw10 × tf16 was set as Comparative Example 5 for Example 5.

[0151] A to C columns of Table 3 sequentially show the second moment of area (Ix) about the strong axis, the plastic section modulus (Zxp), and the steel F value (F). The full plastic moment (Mp) calculated as the product of Zxp and F is shown in D column, the cross-sectional area (S) is shown in E column, and the outer circumferential length (Lp) is shown in F column.

[0152] For comparison between the examples and the comparative examples, the design strength for lateral buckling is necessary. Here, the comparison is based the design strength (M15) at which the buckling length Lb becomes 15 times the height dimension H. The design strengthes (M15) of the rolled H-section steels are the same as the conditions shown in Table 2, and the calculation results are as shown in H column. G column shows the ratio of the design strength (M15) to the full plastic strength (Mp). As shown in G column, it can be seen that while there is no reduction in F in the examples, F is reduced at a ratio of 0.45 to 0.76 in the comparative examples.

[0153] The superiority of the examples to the comparative examples can be confirmed by the values of I to N columns. In each column, the relative value of each value of the examples in a case of setting each value of the comparative examples to 1 is shown. Ix in all the examples is 1.00 because the dimensions are determined such that Ix in the comparative examples matches the examples. From the values in J column, it can be seen that the relative value of the examples regarding Zxp in the examples decreases in a range of 0.93 to 0.96. This is because the height dimensions (H) of the examples are larger than those of the comparative examples.

[0154] From the values of K and L columns, it can be seen that the cross-sectional area (S) decreases in a range of 0.90 to 0.94, and the outer circumferential length (Lp) decreases in a range of 0.93 to 0.98.

[0155] In addition, it can be seen from the values of M column that the design strength (M15) increases in a range of 1.05 to 2.29. Performance needs to be comprehensively evaluated. For example, among the values shown in I to M columns, a reference value derived by using Ix and Zxp, which are desirably large values, as the numerator, and S and Lp, which are desirably small values, as the denominator is shown in N column.

[0156] Based on this index, it can be said that the performance is improved in a range of 1.21 to 2.50 times that of the related art.

[0157] As described above, in the H-section steel 1 according to this embodiment, the cross-sectional area S of the beam 2 is reduced, the surface treatment economy Ix/Lp s improved, and at the same time, not only the bending rigidity but also the bending strength of the beam 2 can be maintained at high levels. That is, in the H-section steel 1 according to this embodiment, it is possible to improve both the bending rigidity and the lateral buckling strength of the beam 2, and reduce the cost for the surface treatment such as coating or painting while suppressing local fracture phenomena and the like due to local buckling of the beam 2.

[0158] In the H-section steel 1 according to this embodiment, even though the lateral buckling deformation of the beam 2 of which lateral movement is restricted is complex, it is possible to evaluate the elastic lateral buckling moment of such a steel framed beam with high accuracy by calculating the elastic lateral buckling moment M_{er} of the beam 2 from Formulas (12) to (16) under the condition that the lateral movement of the beam 2 is restricted and an intermediate load acts on the upper flange 21 from above.

[0159] In the H-section steel 1 according to this embodiment, by setting β to zero in a case where the intermediate load is uniform bending in the member axis direction Y of the beam 2 (symmetric buckling), and setting β to a real number in a range of greater than 0 and not more than 3 in a case where the intermediate load does not become uniform bending in the member axis direction Y of the beam 2 (asymmetric buckling), any of a case of a uniform bending moment at which the intermediate load becomes uniform bending and a case of an antisymmetric moment at which the intermediate load does not become uniform bending can be coped with using Formulas (12) to (16), so that it is possible to evaluate of the elastic lateral buckling moment of the steel framed beam while considering various load conditions postulated for real steel framed beams.

[0160] In the H-section steel 1 according to this embodiment, in particular, in a case where θ_y is approximated, it is preferable that θ_y is approximated by the series of Formula (10). In the H-section steel 1 according to this embodiment, in a case where θ_y is approximated by the third term partial sum, by plotting a non-dimensionalized lateral buckling strength (=M_{cr}/Mp) obtained by dividing the elastic lateral buckling moment by the full plastic bending moment as the vertical axis and the slenderness ratio λb obtained by dividing the length 1 of the beam 2 by the beam depth as the horizontal axis, an example of an analytical solution of the elastic lateral buckling moment is as shown in FIGS. 12A and 12B.

[0161] At this time, in the H-section steel 1 according to this embodiment, as shown in FIG. 12A, when the series of Formula (10) is used, the analytical solutions of the elastic lateral buckling moment are substantially coincident and the elastic lateral buckling moment of the steel framed beam can be evaluated with high accuracy. Contrary to this, as shown in FIG. 12B, when the Fourier series of Formula (9) is used, the analytical solutions of the elastic lateral buckling moment greatly vary. At this time, in order to evaluate the elastic lateral buckling moment with high accuracy using the Fourier series of Formula (9), for example, it is necessary to approximate θ_y by the tenth term partial sum, resulting in complex elastic lateral buckling moment analysis calculation.

[0162] As described above, in the H-section steel 1 to which the present invention is applied, by approximating θ_y by the series of Formula (10), it is possible to evaluate the elastic lateral buckling moment of the steel framed beam with high accuracy while avoiding more complexity of the elastic lateral buckling moment analysis calculation than necessary.

[0163] Tables 4 to 16 show various rolled H-section steels. In Tables 4 to 16, "Example" refers to a rolled H-section steel (present invention example) satisfying Formulas (35) to (38), and "related art" refers to a rolled H-section steel in the relate dart not satisfying the formulas. Then, a graph in which the horizontal axis is plotted as H/S and the vertical axis is plotted as Ix/Lp regarding each of the examples and the related art in Tables 4 to 16 is shown in FIG. 14. In FIG. 14, "○" represents the plot of the example, and "×" represents the plot of the related art.

[Table 4]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1500	300	32	40
Example	1500	300	32	36
Example	1500	300	28	40
Example	1500	300	28	36
Example	1500	300	28	32
Example	1500	300	25	40
Example	1500	300	25	36
Example	1500	300	25	32
Example	1500	300	25	28
Example	1500	300	22	40
Example	1500	300	22	36
Example	1500	300	22	32
Example	1500	300	22	28
Example	1500	300	22	25
Example	1500	300	22	22
Example	1500	300	19	40
Example	1500	300	19	36
Example	1500	300	19	32
Example	1500	300	19	28
Example	1500	300	19	25
Example	1500	300	19	22
Example	1500	300	16	36
Example	1500	300	16	32
Example	1500	300	16	28

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1500	300	16	25
Example	1500	300	16	22
Example	1500	300	16	19
Example	1500	350	32	40
Example	1500	350	32	36
Example	1500	350	28	40
Example	1500	350	28	36
Example	1500	350	28	32
Example	1500	350	25	40
Example	1500	350	25	36
Example	1500	350	25	32
Example	1500	350	25	28
Example	1500	350	22	40
Example	1500	350	22	36
Example	1500	350	22	32
Example	1500	350	22	28
Example	1500	350	22	25
Example	1500	350	22	22
Example	1500	350	19	40
Example	1500	350	19	36
Example	1500	350	19	32
Example	1500	350	19	28
Example	1500	350	19	25
Example	1500	350	19	22
Example	1500	350	16	36
Example	1500	350	16	32
Example	1500	350	16	28
Example	1500	350	16	25
Example	1500	350	16	22
Example	1500	350	16	19
Example	1500	400	32	40
Example	1500	400	32	36
Example	1500	400	28	40
Example	1500	400	28	36
Example	1500	400	28	32
Example	1500	400	25	40
Example	1500	400	25	36

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1500	400	25	32
Example	1500	400	25	28
Example	1500	400	22	40
Example	1500	400	22	36
Example	1500	400	22	32
Example	1500	400	22	28
Example	1500	400	22	25
Example	1500	400	22	22
Example	1500	400	19	36
Example	1500	400	19	32
Example	1500	400	19	28
Example	1500	400	19	25
Example	1500	400	19	22
Example	1500	400	16	36
Example	1500	400	16	32
Example	1500	400	16	28
Example	1500	400	16	25
Example	1500	400	16	22
Example	1500	400	16	19

[Table 5]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1500	450	32	40
Example	1500	450	32	36
Example	1500	450	28	36
Example	1500	450	28	32
Example	1500	450	25	36
Example	1500	450	25	32
Example	1500	450	25	28
Example	1500	450	22	36
Example	1500	450	22	32
Example	1500	450	22	28
Example	1500	450	22	25
Example	1600	450	22	22
Example	1500	450	19	36

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1500	450	19	32
Example	1500	450	19	28
Example	1500	450	19	25
Example	1500	450	19	22
Example	1500	450	16	36
Example	1500	450	16	32
Example	1500	450	16	28
Example	1500	450	16	25
Example	1500	450	16	22
Example	1500	450	16	19
Example	1500	500	32	36
Example	1500	500	28	36
Example	1500	500	28	32
Example	1500	500	25	36
Example	1500	500	25	32
Example	1500	500	25	28
Example	1500	500	22	36
Example	1500	500	22	32
Example	1500	500	22	28
Example	1500	500	22	25
Example	1500	500	22	22
Example	1500	500	19	36
Example	1500	500	19	32
Example	1500	500	19	28
Example	1500	500	19	25
Example	1500	500	19	22
Example	1500	500	16	36
Example	1500	500	16	32
Example	1500	500	16	28
Example	1500	500	16	25
Example	1500	500	16	22
Example	1500	500	16	19
Example	1400	300	32	40
Example	1400	300	32	36
Example	1400	300	28	40
Example	1400	300	28	36
Example	1400	300	28	32

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1400	300	25	40
Example	1400	300	25	36
Example	1400	300	25	32
Example	1400	300	25	28
Example	1400	300	22	40
Example	1400	300	22	36
Example	1400	300	22	32
Example	1400	300	22	28
Example	1400	300	22	25
Example	1400	300	22	22
Example	1400	300	19	40
Example	1400	300	19	36
Example	1400	300	19	32
Example	1400	300	19	28
Example	1400	300	19	25
Example	1400	300	19	22
Example	1400	300	16	36
Example	1400	300	16	32
Example	1400	300	16	28
Example	1400	300	16	25
Example	1400	300	16	22
Example	1400	300	16	19

[Table 6]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1400	350	32	40
Example	1400	350	32	36
Example	1400	350	28	40
Example	1400	350	28	36
Example	1400	350	28	32
Example	1400	350	25	40
Example	1400	350	25	36
Example	1400	350	25	32
Example	1400	350	25	28
Example	1400	350	22	40

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1400	350	22	36
Example	1400	350	22	32
Example	1400	350	22	28
Example	1400	350	22	25
Example	1400	350	22	22
Example	1400	350	19	40
Example	1400	350	19	36
Example	1400	350	19	32
Example	1400	350	19	28
Example	1400	350	19	25
Example	1400	350	19	22
Example	1400	350	16	36
Example	1400	350	16	32
Example	1400	350	16	28
Example	1400	350	16	25
Example	1400	350	16	22
Example	1400	350	16	19
Example	1400	400	32	40
Example	1400	400	32	36
Example	1400	400	28	40
Example	1400	400	28	36
Example	1400	400	28	32
Example	1400	400	25	40
Example	1400	400	25	36
Example	1400	400	25	32
Example	1400	400	25	28
Example	1400	400	22	25
Example	1400	400	22	36
Example	1400	400	22	32
Example	1400	400	22	28
Example	1400	400	22	25
Example	1400	400	22	22
Example	1400	400	19	40
Example	1400	400	19	36
Example	1400	400	19	32
Example	1400	400	19	28
Example	1400	400	19	25

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1400	400	19	22
Example	1400	400	16	36
Example	1400	400	16	32
Example	1400	400	16	28
Example	1400	400	16	25
Example	1400	400	16	22
Example	1400	400	16	19
Example	1400	450	32	40
Example	1400	450	32	36
Example	1400	450	28	40
Example	1400	450	28	36
Example	1400	450	28	32
Example	1400	450	25	40
Example	1400	450	25	36
Example	1400	450	25	32
Example	1400	450	25	28
Example	1400	450	22	40
Example	1400	450	22	36
Example	1400	450	22	32
Example	1400	450	22	28
Example	1400	450	22	25
Example	1400	450	22	22
Example	1400	450	19	40
Example	1400	450	19	36
Example	1400	450	19	32
Example	1400	450	19	28
Example	1400	450	19	25
Example	1400	450	19	22
Example	1400	450	16	36
Example	1400	450	16	32
Example	1400	450	16	28
Example	1400	450	16	25
Example	1400	450	16	22
Example	1400	450	16	19

[Table 7]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1400	500	32	40
Example	1400	500	32	36
Example	1400	500	28	40
Example	1400	500	28	36
Example	1400	500	28	32
Example	1400	500	25	40
Example	1400	500	25	36
Example	1400	500	25	32
Example	1400	500	25	28
Example	1400	500	22	40
Example	1400	500	22	36
Example	1400	500	22	32
Example	1400	500	22	28
Example	1400	500	22	25
Example	1400	500	22	22
Example	1400	500	19	40
Example	1400	500	19	36
Example	1400	500	19	32
Example	1400	500	19	28
Example	1400	500	19	25
Example	1400	500	19	22
Example	1400	500	16	36
Example	1400	500	16	32
Example	1400	500	16	28
Example	1400	500	16	25
Example	1400	500	16	22
Example	1400	500	16	19
Example	1300	300	32	40
Example	1300	300	32	36
Example	1300	300	28	40
Example	1300	300	28	36
Example	1300	300	28	32
Example	1300	300	25	40
Example	1300	300	25	36
Example	1300	300	25	32
Example	1300	300	25	28
Example	1300	300	22	40

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1300	300	22	36
Example	1300	300	22	32
Example	1300	300	22	28
Example	1300	300	22	25
Example	1300	300	22	22
Example	1300	300	19	40
Example	1300	300	19	36
Example	1300	300	19	32
Example	1300	300	19	28
Example	1300	300	19	25
Example	1300	300	19	22
Example	1300	300	16	36
Example	1300	300	16	32
Example	1300	300	16	28
Example	1300	300	16	25
Example	1300	300	16	22
Example	1300	300	16	19
Example	1300	350	32	40
Example	1300	350	32	36
Example	1300	350	28	40
Example	1300	350	28	36
Example	1300	350	28	32
Example	1300	350	25	40
Example	1300	350	25	36
Example	1300	350	25	32
Example	1300	350	25	28
Example	1300	350	22	40
Example	1300	350	22	36
Example	1300	350	22	32
Example	1300	350	22	28
Example	1300	350	22	25
Example	1300	350	22	22
Example	1300	350	19	40
Example	1300	350	19	36
Example	1300	350	19	32
Example	1300	350	19	28
Example	1300	350	19	25

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1300	350	19	22
Example	1300	350	16	36
Example	1300	350	16	32
Example	1300	350	16	28
Example	1300	350	16	25
Example	1300	350	16	22
Example	1300	350	16	19

[Table 8]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1300	400	32	40
Example	1300	400	32	36
Example	1300	400	28	40
Example	1300	400	28	36
Example	1300	400	28	32
Example	1300	400	25	40
Example	1300	400	25	36
Example	1300	400	25	32
Example	1300	400	25	28
Example	1300	400	22	40
Example	1300	400	22	36
Example	1300	400	22	32
Example	1300	400	22	28
Example	1300	400	22	25
Example	1300	400	22	22
Example	1300	400	19	40
Example	1300	400	19	36
Example	1300	400	19	32
Example	1300	400	19	28
Example	1300	400	19	25
Example	1300	400	19	22
Example	1300	400	16	36
Example	1300	400	16	32
Example	1300	400	16	28
Example	1300	400	16	25

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1300	400	16	22
Example	1300	400	16	19
Example	1300	450	32	40
Example	1300	450	32	36
Example	1300	450	28	40
Example	1300	450	28	36
Example	1300	450	28	32
Example	1300	450	25	40
Example	1300	450	25	36
Example	1300	450	25	32
Example	1300	450	25	28
Example	1300	450	22	40
Example	1300	450	22	36
Example	1300	450	22	32
Example	1300	450	22	28
Example	1300	450	22	25
Example	1300	450	22	22
Example	1300	450	19	40
Example	1300	450	19	36
Example	1300	450	19	32
Example	1300	450	19	28
Example	1300	450	19	25
Example	1300	450	19	22
Example	1300	450	16	36
Example	1300	450	16	32
Example	1300	450	16	28
Example	1300	450	16	25
Example	1300	450	16	22
Example	1300	450	16	19
Example	1300	500	32	40
Example	1300	500	32	36
Example	1300	500	28	40
Example	1300	500	28	36
Example	1300	500	28	32
Example	1300	500	25	40
Example	1300	500	25	36
Example	1300	500	25	32

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1300	500	25	28
Example	1300	500	22	40
Example	1300	500	22	36
Example	1300	500	22	32
Example	1300	500	22	28
Example	1300	500	22	25
Example	1300	500	22	22
Example	1300	500	19	40
Example	1300	500	19	36
Example	1300	500	19	32
Example	1300	500	19	28
Example	1300	500	19	25
Example	1300	500	19	22
Example	1300	500	16	36
Example	1300	500	16	32
Example	1300	500	16	28
Example	1300	500	16	25
Example	1300	500	16	22
Example	1300	500	16	19

[Table 9]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1200	300	32	40
Example	1200	300	32	36
Example	1200	300	28	40
Example	1200	300	28	36
Example	1200	300	28	32
Example	1200	300	25	40
Example	1200	300	25	36
Example	1200	300	25	32
Example	1200	300	25	28
Example	1200	300	22	40
Example	1200	300	22	36
Example	1200	300	22	32
Example	1200	300	22	28

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1200	300	22	25
Example	1200	300	22	22
Example	1200	300	19	40
Example	1200	300	19	36
Example	1200	300	19	32
Example	1200	300	19	28
Example	1200	300	19	25
Example	1200	300	19	22
Example	1200	300	16	36
Example	1200	300	16	32
Example	1200	300	16	28
Example	1200	300	16	25
Example	1200	300	16	22
Example	1200	300	16	19
Example	1200	350	32	40
Example	1200	350	32	36
Example	1200	350	28	40
Example	1200	350	28	36
Example	1200	350	28	32
Example	1200	350	25	40
Example	1200	350	25	36
Example	1200	350	25	32
Example	1200	350	25	28
Example	1200	350	22	40
Example	1200	350	22	36
Example	1200	350	22	32
Example	1200	350	22	28
Example	1200	360	22	25
Example	1200	350	22	22
Example	1200	350	19	40
Example	1200	350	19	36
Example	1200	350	19	32
Example	1200	350	19	28
Example	1200	350	19	25
Example	1200	350	19	22
Example	1200	350	16	36
Example	1200	350	16	32

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1200	350	16	28
Example	1200	350	16	25
Example	1200	350	16	22
Example	1200	350	16	19
Example	1200	400	32	40
Example	1200	400	32	36
Example	1200	400	28	40
Example	1200	400	28	36
Example	1200	400	28	32
Example	1200	400	25	40
Example	1200	400	25	36
Example	1200	400	25	32
Example	1200	400	25	28
Example	1200	400	22	40
Example	1200	400	22	36
Example	1200	400	22	32
Example	1200	400	22	28
Example	1200	400	22	25
Example	1200	400	22	22
Example	1200	400	19	40
Example	1200	400	19	36
Example	1200	400	19	32
Example	1200	400	19	28
Example	1200	400	19	25
Example	1200	400	19	22
Example	1200	400	16	36
Example	1200	400	16	32
Example	1200	400	16	28
Example	1200	400	16	25
Example	1200	400	16	22
Example	1200	400	16	19

[Table 10]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1200	450	32	40

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1200	450	32	36
Example	1200	450	28	40
Example	1200	450	28	36
Example	1200	450	28	32
Example	1200	450	25	40
Example	1200	450	25	36
Example	1200	450	25	32
Example	1200	450	25	28
Example	1200	450	22	40
Example	1200	450	22	36
Example	1200	450	22	32
Example	1200	450	22	28
Example	1200	450	22	25
Example	1200	450	22	22
Example	1200	450	19	40
Example	1200	450	19	36
Example	1200	450	19	32
Example	1200	450	19	28
Example	1200	450	19	25
Example	1200	450	19	22
Example	1200	450	16	36
Example	1200	450	16	32
Example	1200	450	16	28
Example	1200	450	16	25
Example	1200	450	16	22
Example	1200	450	16	19
Example	1200	500	32	40
Example	1200	500	32	36
Example	1200	500	28	40
Example	1200	500	28	36
Example	1200	500	28	32
Example	1200	500	25	40
Example	1200	500	25	36
Example	1200	500	25	32
Example	1200	500	25	28
Example	1200	500	22	40
Example	1200	500	22	36

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1200	500	22	32
Example	1200	500	22	28
Example	1200	500	22	25
Example	1200	500	22	22
Example	1200	500	19	40
Example	1200	500	19	36
Example	1200	500	19	32
Example	1200	500	19	28
Example	1200	500	19	25
Example	1200	500	19	22
Example	1200	500	16	36
Example	1200	500	16	32
Example	1200	500	16	28
Example	1200	500	16	25
Example	1200	500	16	22
Example	1200	500	16	19
Example	1150	300	32	40
Example	1150	300	32	36
Example	1150	300	28	40
Example	1150	300	28	36
Example	1150	300	28	32
Example	1150	300	25	40
Example	1150	300	25	36
Example	1150	300	25	32
Example	1150	300	25	28
Example	1150	300	22	40
Example	1150	300	22	36
Example	1150	300	22	32
Example	1150	300	22	28
Example	1150	300	22	25
Example	1150	300	22	22
Example	1150	300	19	40
Example	1150	300	19	36
Example	1150	300	19	32
Example	1150	300	19	28
Example	1150	300	19	25
Example	1150	300	19	22

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Example	1150	300	16	36
Example	1150	300	16	32
Example	1150	300	16	28
Example	1150	300	16	25
Example	1150	300	16	22
Example	1150	300	16	19

[Table 11]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (m)
Example	1150	350	32	40
Example	1150	350	32	36
Example	1150	350	28	40
Example	1150	350	28	36
Example	1150	350	28	32
Example	1150	350	25	40
Example	1150	350	25	36
Example	1150	350	25	32
Example	1150	350	25	28
Example	1150	350	22	40
Example	1150	360	22	36
Example	1150	350	22	32
Example	1150	350	22	28
Example	1150	350	22	25
Example	1150	350	22	22
Example	1150	350	19	40
Example	1150	350	19	36
Example	1150	350	19	32
Example	1150	350	19	28
Example	1150	350	19	25
Example	1150	350	19	22
Example	1150	350	16	36
Example	1150	350	16	32
Example	1150	360	16	28
Example	1150	350	16	25
Example	1150	350	16	22

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (m)
Example	1150	350	16	19
Example	1150	400	32	40
Example	1150	400	32	36
Example	1150	400	28	40
Example	1150	400	28	36
Related art	1150	400	28	32
Example	1150	400	25	40
Example	1150	400	25	36
Example	1150	400	25	32
Related art	1150	400	25	28
Example	1150	400	22	40
Example	1150	400	22	36
Example	1150	400	22	32
Example	1150	400	22	28
Example	1150	400	22	25
Related art	1150	400	22	22
Example	1150	400	19	40
Example	1150	400	19	36
Example	1150	400	19	32
Example	1150	400	19	28
Example	1150	400	19	25
Example	1150	400	19	22
Example	1150	400	16	36
Example	1150	400	16	32
Example	1150	400	16	28
Example	1150	400	16	25
Example	1150	400	16	22
Example	1150	400	16	19
Example	1150	450	32	40
Related art	1150	450	32	36
Example	1150	450	28	40
Example	1150	450	28	36
Related art	1150	450	28	32
Example	1150	450	25	40
Example	1150	450	25	36
Example	1150	450	25	32
Related art	1150	450	25	28

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (m)
Example	1150	450	22	40
Example	1150	450	22	36
Example	1150	450	22	32
Example	1150	450	22	28
Related art	1150	450	22	25
Related art	1150	450	22	22
Example	1150	450	19	40
Example	1150	450	19	36
Example	1150	450	19	32
Example	1150	460	19	28
Example	1160	450	19	25
Example	1150	450	19	22
Example	1150	450	16	36
Example	1150	450	16	32
Example	1150	450	16	28
Example	1150	450	16	25
Example	1150	450	16	22
Example	1150	450	16	19

[Table 12]

A column	B column	C column	D column	E column
	H (mm)	w (mm)	tw (mm)	tf (mm)
Example	1150	500	32	40
Related art	1150	500	32	36
Example	1150	500	28	40
Example	1150	500	28	36
Related art	1150	500	28	32
Example	1150	500	25	40
Example	1150	500	25	36
Related art	1150	500	25	32
Related art	1150	500	25	28
Example	1150	500	22	40
Example	1150	500	22	36
Example	1150	500	22	32
Related art	1150	500	22	28
Related art	1150	500	22	25

(continued)

A column	B column	C column	D column	E column
	H (mm)	w (mm)	tw (mm)	tf (mm)
Related art	1150	500	22	22
Example	1150	500	19	40
Example	1150	500	19	36
Example	1150	500	19	32
Example	1150	500	19	28
Example	1150	500	19	25
Related art	1150	500	19	22
Example	1150	500	16	36
Example	1150	500	16	32
Example	1150	500	16	28
Example	1150	500	16	25
Example	1150	500	16	22
Example	1150	500	16	19
Related art	1100	300	32	40
Related art	1100	300	32	36
Related art	1100	300	28	40
Related art	1100	300	28	36
Related art	1100	300	28	32
Example	1100	300	25	40
Related art	1100	300	25	36
Related art	1100	300	25	32
Related art	1100	300	25	28
Example	1100	300	22	40
Example	1100	300	22	36
Example	1100	300	22	32
Related art	1100	300	22	28
Related art	1100	300	22	25
Related art	1100	300	22	22
Example	1100	300	19	40
Example	1100	300	19	36
Example	1100	300	19	32
Example	1100	300	19	28
Example	1100	300	19	25
Example	1100	300	19	22
Example	1100	300	16	36
Example	1100	300	16	32
Example	1100	300	16	28

(continued)

A column	B column	C column	D column	E column
	H (mm)	w (mm)	tw (mm)	tf (mm)
Example	1100	300	16	25
Example	1100	300	16	22
Example	1100	300	16	19
Related art	1100	350	32	40
Related art	1100	350	32	36
Related art	1100	350	28	40
Related art	1100	350	28	36
Related art	1100	350	28	32
Related art	1100	350	25	40
Related art	1100	350	25	36
Related art	1100	350	25	32
Related art	1100	350	25	28
Example	1100	350	22	40
Example	1100	350	22	36
Related art	1100	350	22	32
Related art	1100	350	22	28
Related art	1100	350	22	25
Related art	1100	350	22	22
Example	1100	350	19	40
Example	1100	350	19	36
Example	1100	350	19	32
Example	1100	350	19	28
Example	1100	350	19	25
Related art	1100	350	19	22
Example	1100	350	16	36
Example	1100	350	16	32
Example	1100	350	16	28
Example	1100	350	16	25
Example	1100	350	16	22
Example	1100	350	16	19

[Table 13]

A column	B column	C column	D column	E column
	H (mm)	w (mm)	tw (mm)	tf (mm)
Related art	1100	400	32	40
Related art	1100	400	32	36

(continued)

A column	B column	C column	D column	E column
	H (mm)	w (mm)	tw (mm)	tf (mm)
Related art	1100	400	28	40
Related art	1100	400	28	36
Related art	1100	400	28	32
Related art	1100	400	25	40
Related art	1100	400	25	36
Related art	1100	400	25	32
Related art	1100	400	25	28
Example	1100	400	22	40
Related art	1100	400	22	36
Related art	1100	400	22	32
Related art	1100	400	22	28
Related art	1100	400	22	25
Related art	1100	400	22	22
Example	1100	400	19	40
Example	1100	400	19	36
Related art	1100	400	19	32
Related art	1100	400	19	28
Related art	1100	400	19	25
Related art	1100	400	19	22
Example	1100	400	16	36
Example	1100	400	16	32
Example	1100	400	16	28
Example	1100	400	16	25
Example	1100	400	16	22
Example	1100	400	16	19
Related art	1100	450	32	40
Related art	1100	450	32	36
Related art	1100	450	28	40
Related art	1100	450	28	36
Related art	1100	450	28	32
Related art	1100	450	25	40
Related art	1100	450	25	36
Related art	1100	450	25	32
Related art	1100	450	25	28
Related art	1100	450	22	40
Related art	1100	450	22	36
Related art	1100	450	22	32

(continued)

A column	B column	C column	D column	E column
	H (mm)	w (mm)	tw (mm)	tf (mm)
Related art	1100	450	22	28
Related art	1100	450	22	25
Related art	1100	450	22	22
Example	1100	450	19	40
Related art	1100	450	19	36
Related art	1100	450	19	32
Related art	1100	450	19	28
Related art	1100	450	19	25
Related art	1100	450	19	22
Example	1100	450	16	36
Example	1100	450	16	32
Related art	1100	450	16	28
Related art	1100	450	16	25
Related art	1100	450	16	22
Related art	1100	450	16	19
Related art	1100	500	32	40
Related art	1100	500	32	36
Related art	1100	500	28	40
Related art	1100	500	28	36
Related art	1100	500	28	32
Related art	1100	500	25	40
Related art	1100	500	25	36
Related art	1100	500	25	32
Related art	1100	500	25	28
Related art	1100	500	22	40
Related art	1100	500	22	36
Related art	1100	500	22	32
Related art	1100	500	22	28
Related art	1100	500	22	25
Related art	1100	500	22	22
Related art	1100	500	19	40
Related art	1100	500	19	36
Related art	1100	500	19	32
Related art	1100	500	19	28
Related art	1100	500	19	25
Related art	1100	500	19	22
Related art	1100	500	16	36

(continued)

A column	B column	C column	D column	E column
	H (mm)	w (mm)	tw (mm)	tf (mm)
Related art	1100	500	16	32
Related art	1100	500	16	28
Related art	1100	500	16	25
Related art	1100	500	16	22
Related art	1100	500	16	19

[Table 14]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Related art	1050	300	32	40
Related art	1050	300	32	36
Related art	1050	300	28	40
Related art	1050	300	28	36
Related art	1050	300	28	32
Related art	1050	300	25	40
Related art	1050	300	25	36
Related art	1050	300	25	32
Related art	1050	300	25	28
Related art	1050	300	22	40
Related art	1050	300	22	36
Related art	1050	300	22	32
Related art	1050	300	22	28
Related art	1050	300	22	25
Related art	1050	300	22	22
Related art	1050	300	19	40
Related art	1050	300	19	36
Related art	1050	300	19	32
Related art	1050	300	19	28
Related art	1050	300	19	25
Related art	1050	300	19	22
Example	1050	300	16	36
Example	1050	300	16	32
Example	1050	300	16	28
Example	1050	300	16	25
Example	1050	300	16	22
Example	1050	300	16	19

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Related art	1050	350	32	40
Related art	1050	350	32	36
Related art	1050	350	28	40
Related art	1050	350	28	36
Related art	1050	350	28	32
Related art	1050	350	25	40
Related art	1050	350	25	36
Related art	1050	350	25	32
Related art	1050	350	25	28
Related art	1050	350	22	40
Related art	1050	350	22	36
Related art	1050	350	22	32
Related art	1050	350	22	28
Related art	1050	350	22	25
Related art	1050	350	22	22
Related art	1050	350	19	40
Related art	1050	350	19	36
Related art	1050	350	19	32
Related art	1050	350	19	28
Related art	1050	350	19	25
Related art	1050	350	19	22
Related art	1050	350	16	36
Related art	1050	350	16	32
Related art	1050	350	16	28
Related art	1050	350	16	25
Related art	1050	350	16	22
Related art	1050	350	16	19
Related art	1050	400	32	40
Related art	1050	400	32	36
Related art	1050	400	28	40
Related art	1050	400	28	36
Related art	1050	400	28	32
Related art	1050	400	25	40
Related art	1050	400	25	36
Related art	1050	400	25	32
Related art	1050	400	25	28
Related art	1050	400	22	40

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Related art	1050	400	22	36
Related art	1050	400	22	32
Related art	1050	400	22	28
Related art	1050	400	22	25
Related art	1050	400	22	22
Related art	1050	400	19	40
Related art	1050	400	19	36
Related art	1050	400	19	32
Related art	1050	400	19	28
Related art	1050	400	19	25
Related art	1050	400	19	22
Related art	1050	400	16	36
Related art	1050	400	16	32
Related art	1050	400	16	28
Related art	1050	400	16	25
Related art	1050	400	16	22
Related art	1050	400	16	19

[Table 15]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Related art	1050	450	32	40
Related art	1050	450	32	36
Related art	1050	450	28	40
Related art	1050	450	28	36
Related art	1050	450	28	32
Related art	1050	450	25	40
Related art	1050	450	25	36
Related art	1050	450	25	32
Related art	1050	450	25	28
Related art	1050	450	22	40
Related art	1050	450	22	36
Related art	1050	450	22	32
Related art	1050	450	22	28
Related art	1050	450	22	25
Related art	1050	450	22	22

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Related art	1050	450	19	40
Related art	1050	450	19	36
Related art	1050	450	19	32
Related art	1050	450	19	28
Related art	1050	450	19	25
Related art	1050	450	19	22
Related art	1050	450	16	36
Related art	1050	450	16	32
Related art	1050	450	16	28
Related art	1050	450	16	25
Related art	1050	450	16	22
Related art	1050	450	16	19
Related art	1050	500	32	40
Related art	1050	500	32	36
Related art	1050	500	28	40
Related art	1050	500	28	36
Related art	1050	500	28	32
Related art	1050	500	25	40
Related art	1050	500	25	36
Related art	1050	500	25	32
Related art	1050	500	25	28
Related art	1050	500	22	40
Related art	1050	500	22	36
Related art	1050	500	22	32
Related art	1050	500	22	28
Related art	1050	500	22	25
Related art	1050	500	22	22
Related art	1050	500	19	40
Related art	1050	500	19	36
Related art	1050	500	19	32
Related art	1050	500	19	28
Related art	1050	500	19	25
Related art	1050	500	19	22
Related art	1050	500	16	36
Related art	1050	500	16	32
Related art	1050	500	16	28
Related art	1050	500	16	25

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Related art	1050	500	16	22
Related art	1050	500	16	19
Example	1000	250	12	28
Example	1000	250	12	25
Example	1000	250	12	22
Example	1000	250	12	19
Example	1000	250	12	16
Example	1000	300	12	28
Example	1000	300	12	25
Example	1000	300	12	22
Example	1000	300	12	29
Example	1000	300	12	16
Related art	1000	350	12	25
Related art	1000	350	12	22
Example	1000	350	12	19
Example	1000	350	12	16
Example	950	250	11	28
Example	950	250	11	25
Example	950	250	11	22
Example	950	250	11	19
Example	950	250	11	16
Related art	950	300	11	28
Related art	950	300	11	25
Related art	950	300	11	22
Related art	950	300	11	29
Example	950	300	11	16
Related art	950	350	11	25
Related art	950	350	11	22
Related art	950	350	11	19
Related art	950	350	11	16

[Table 16]

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Related art	900	250	11	28
Related art	900	250	11	25

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Related art	900	250	11	22
Example	900	250	11	19
Example	900	250	11	16
Related art	900	300	11	28
Related art	900	300	11	25
Related art	900	300	11	22
Related art	900	300	11	29
Related art	900	300	11	16
Related art	900	350	11	25
Related art	900	350	11	22
Related art	900	350	11	19
Related art	900	350	11	16
Related art	850	200	10	25
Example	850	200	10	22
Example	850	200	10	19
Example	850	200	10	16
Example	850	200	10	12
Related art	850	250	10	25
Related art	850	250	10	22
Related art	850	250	10	19
Example	850	250	10	16
Example	850	250	10	12
Related art	850	300	10	28
Related art	850	300	10	25
Related art	850	300	10	22
Related art	850	300	10	19
Related art	850	300	10	16
Related art	850	350	10	25
Related art	850	350	10	22
Related art	850	350	10	19
Related art	850	350	10	16
Related art	800	200	10	25
Related art	800	200	10	22
Related art	800	200	10	19
Example	800	200	10	16
Example	800	200	10	12
Related art	800	250	10	25

(continued)

A column	B column	C column	D column	E column
	H (mm)	W (mm)	tw (mm)	tf (mm)
Related art	800	250	10	22
Related art	800	250	10	19
Related art	800	250	10	16
Related art	800	250	10	12
Related art	800	300	10	28
Related art	800	300	10	25
Related art	800	300	10	22
Related art	800	300	10	19
Related art	800	300	10	16
Related art	800	350	10	25
Related art	800	350	10	22
Related art	800	350	10	19
Related art	800	350	10	16
Related art	750	200	9	25
Related art	750	200	9	22
Related art	750	200	9	19
Related art	750	200	9	16
Example	750	200	9	12
Related art	700	200	9	25
Related art	700	200	9	22
Related art	700	200	9	19
Related art	700	200	9	16
Related art	700	200	9	12

[0164] While the embodiments of the present invention have been described above, the embodiments are presented by way of example only, and the scope of the present invention is not limited only to the embodiments. The embodiments can be embodied in a variety of other forms, and various omissions, substitutions, and changes can be made without departing from the gist of the invention. The embodiments and the modifications thereof are included in the scope and gist of the invention as well as in the inventions described in the claims and their equivalents.

[Brief Description of the Reference Symbols]

[0165]

1: rolled H-section steel
2: beam
2a: end portion
2b: middle portion
20: outer circumferential surface
21: upper flange
21a: both upper and lower surfaces
21b: both left and right end surfaces
22: lower flange

22a: both upper and lower surfaces
22b: both left and right end surfaces
23: web
23a: both left and right side surfaces
23b: curved connection portions (fillets)
25: shear connector
3: column
30: diaphragm
4: floor slab
X: width direction
Y: member axis direction
Z: height direction

Claims

1. A method of designing a rolled H-section steel, the rolled H-section steel including

an upper flange,
a lower flange, and
a web connecting the upper flange to the lower flange,

an outer circumferential surface of each of the upper flange, the lower flange, and the web being subjected to a surface treatment,
the method comprising:
setting a height dimension H from the upper flange to the lower flange, a width dimension W of each of the upper flange and the lower flange, a plate thickness tw of the web, and a plate thickness tf of each of the upper flange and the lower flange so that, when it is assumed that a value obtained by dividing a second moment of area Ix about a strong axis by an outer circumferential length Lp in a cross-sectional shape when viewed in a cross section perpendicular to a member axis direction is a surface treatment economy Ix/Lp and an area of the cross-sectional shape is S, Formulas (35) to (38) are satisfied, the height dimension H is 700 mm or more, the width dimension W is 1/5 or more and 1/2 or less of the height dimension H, the plate thickness tw is 9 mm or more and 32 mm or less, and the plate thickness tf is 12 mm or more and 40 mm or less.
[Math 28]

$$Ix / Lp = C_{k1} \cdot \exp\left(C_{k2} \cdot H / S\right) \quad \cdots \quad (35)$$

$$C_{k1} = 120 + 100 \cdot k \quad \cdots \quad (36)$$

$$C_{k2} = -106 + 10 \cdot k \quad \cdots \quad (37)$$

$$6.1 \leq k \leq 8 \quad \cdots \quad (38)$$

2. The method of designing a rolled H-section steel according to claim 1,
wherein, under a condition that the rolled H-section steel is used as a beam extending in the member axis direction and both end portions of the rolled H-section steel in the member axis direction are fixed, a condition that lateral movement of the rolled H-section steel in a width direction in a middle portion in the member axis direction is restricted, and a condition in which an intermediate load acts on the upper flange from above and end loads act on both end portions in the member axis direction, using an elastic lateral buckling moment M_{cr} of the beam calculated

from Formulas (12) to (16), the height dimension H, the width dimension W, the plate thickness tw, and the plate thickness tf are set so that lateral buckling does not occur in the beam, wherein, V_{cr}: a shear force acting on the end portions of the beam in the member axis direction, W_{cr}: the intermediate load acting on the middle portion of the beam in the member axis direction, β and γ: coefficients determined from Formulas (1) and (2) depending on loads V_{cr} and W_{cr}, 1: a length of the beam in the member axis direction, E: a Young's modulus, 1: a second moment of area about a weak axis of the lower flange, G: a shear elastic modulus, J: a Saint-Venant's torsion constant, d_b: a plate thickness center-to-center distance between the upper flange and the lower flange, y: a length from one end portion of the beam in the member axis direction as a reference to any point of the beam in the member axis direction, θ_y: a torsion angle generated in the beam due to lateral buckling, θ'_y: a first order derivative of θ_y, θ''_y: a second order derivative of θ_y, and a: a parameter for integration.
[Math 29]

$$M_{cr} = \frac{1}{(1-\beta-\gamma)A+(\beta+\gamma)C+\gamma D}\left(B\frac{2\pi^2 EId_b}{l^2}+A\frac{GJ}{d_b}\right) \quad \cdots \quad (12)$$

$$A = l\int_0^l \theta_y'^2 dy \quad \cdots \quad (13)$$

$$B = \frac{l^3}{2\pi^2}\int_0^l \theta_y''^2 dy \quad \cdots \quad (14)$$

$$C = \int_0^l y\theta_y'^2 dy \quad \cdots \quad (15)$$

$$D = \frac{2}{l}\int_0^l\int_0^y (y-a)\theta_y'^2 da\,dy \quad \cdots \quad (16)$$

[Math 30]

$$V_{cr} = -(\beta+\gamma)\frac{M_{cr}}{l} \quad \cdots \quad (1)$$

$$\int_0^l W_{cr} y\,dy = \gamma M_{cr} \quad \cdots \quad (2)$$

3. The method of designing a rolled H-section steel according to claim 2, wherein the height dimension H, the width dimension W, the plate thickness tw, and the plate thickness tf are set so that a square root of a value obtained by dividing a full plastic moment Mp of the rolled H-section steel by the elastic lateral buckling moment M_{cr} becomes 0.6 or less.

4. A rolled H-section steel comprising:

an upper flange;
a lower flange; and
a web which connects the upper flange to the lower flange,
wherein an outer circumferential surface of each of the upper flange, the lower flange, and the web is subjected

to a surface treatment,
a height dimension H from the upper flange to the lower flange is 700 mm or more,
a width dimension W of each of the upper flange and the lower flange is 1/5 or more and 1/2 or less of the height dimension H,
a plate thickness tw of the web is 9 mm or more and 32 mm or less,
a plate thickness tf of each of the upper flange and the lower flange is 12 mm or more and 40 mm or less, and when it is assumed that a value obtained by dividing a second moment of area Ix about a strong axis by an outer circumferential length Lp in a cross-sectional shape when viewed in a cross section perpendicular to a member axis direction is a surface treatment economy Ix/Lp and an area of the cross-sectional shape is S, the height dimension H, the width dimension W, the plate thickness tw, and the plate thickness tf satisfy Formulas (35) to (38).
[Math 31]

$$Ix / Lp = C_{k1} \cdot \exp\left(C_{k2} \cdot H / S\right) \quad \cdots \quad (35)$$

$$C_{k1} = 120 + 100 \cdot k \quad \cdots \quad (36)$$

$$C_{k2} = -106 + 10 \cdot k \quad \cdots \quad (37)$$

$$6.1 \leq k \leq 8 \quad \cdots \quad (38)$$

5. A method of manufacturing a rolled H-section steel comprising:
manufacturing the rolled H-section steel having the height dimension H, the width dimension W, the plate thickness tw, and the plate thickness tf set according to the method of designing a rolled H-section steel according to any one of claims 1 to 3.

FIG. 1

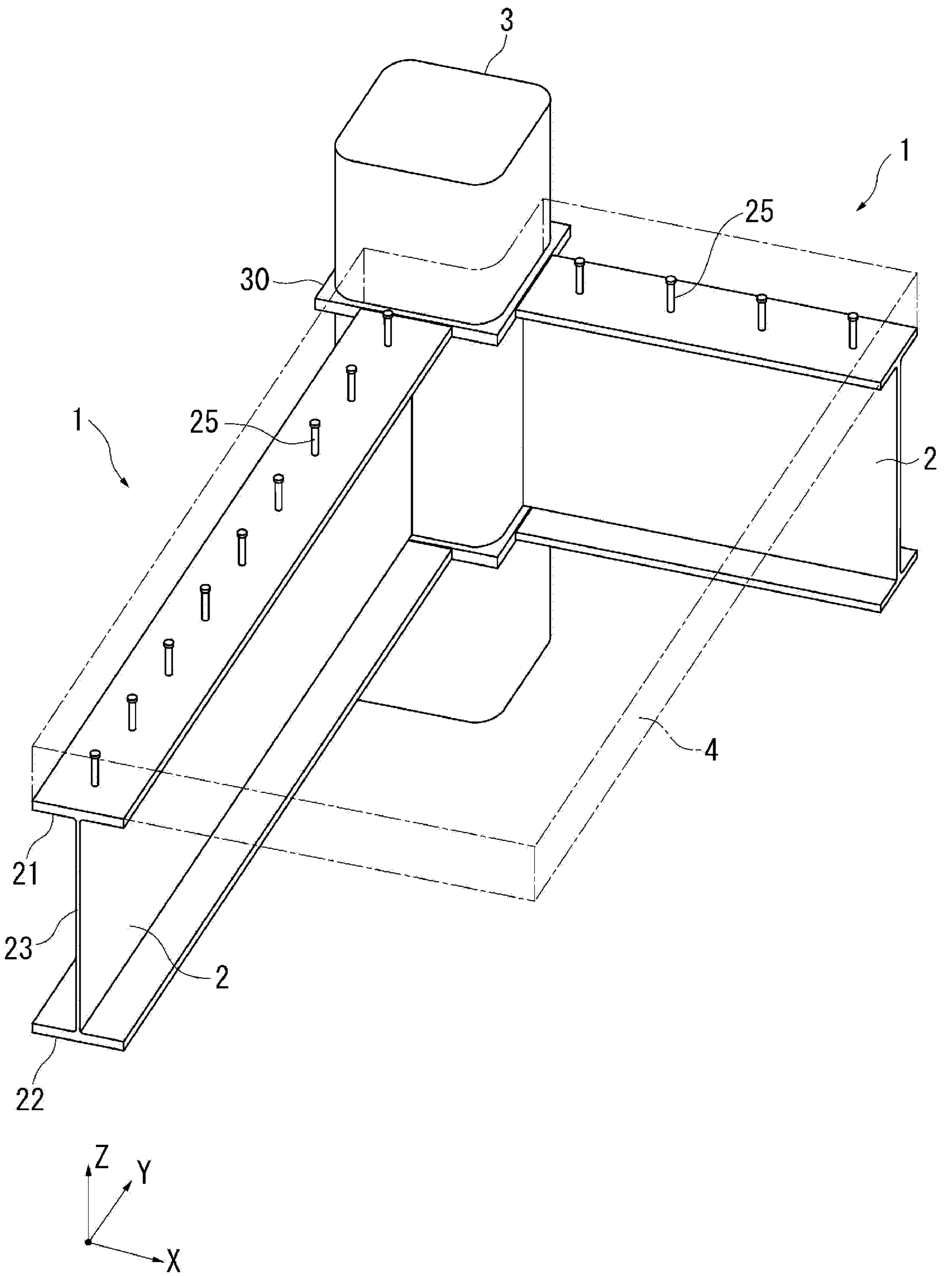


FIG. 2A

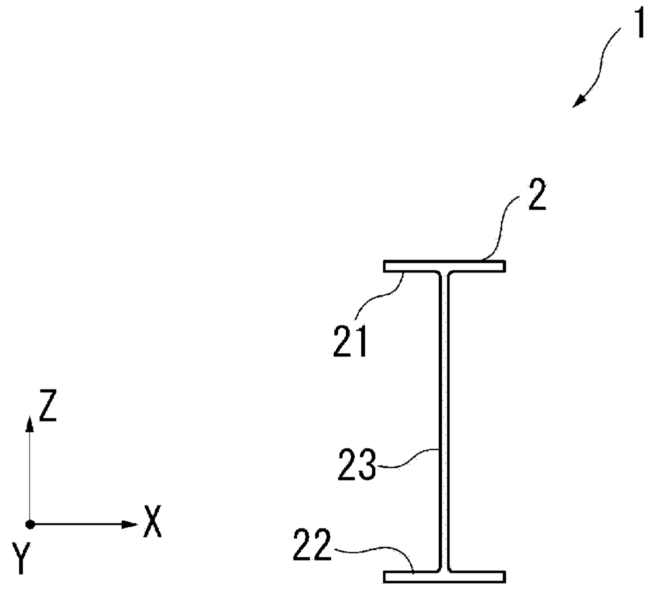


FIG. 2B

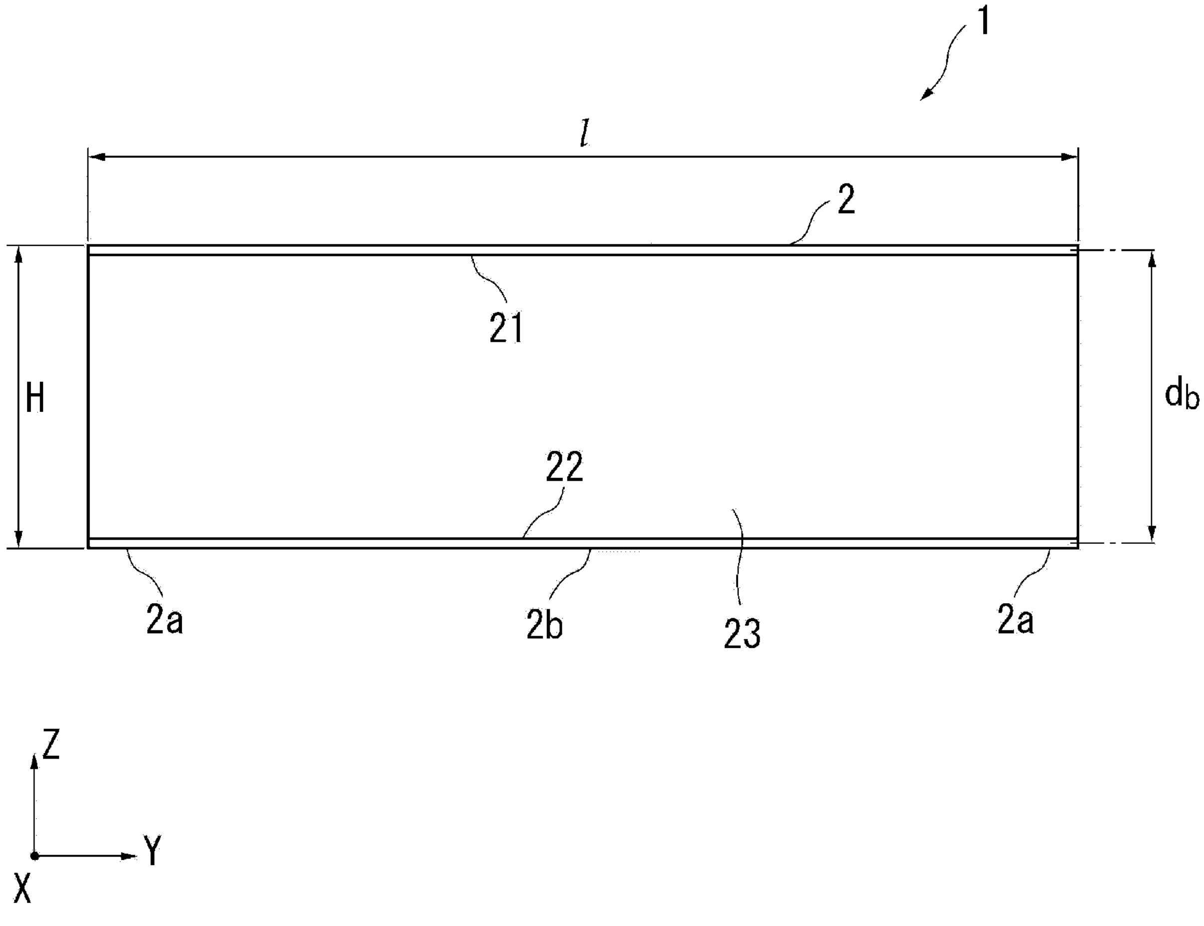


FIG. 3

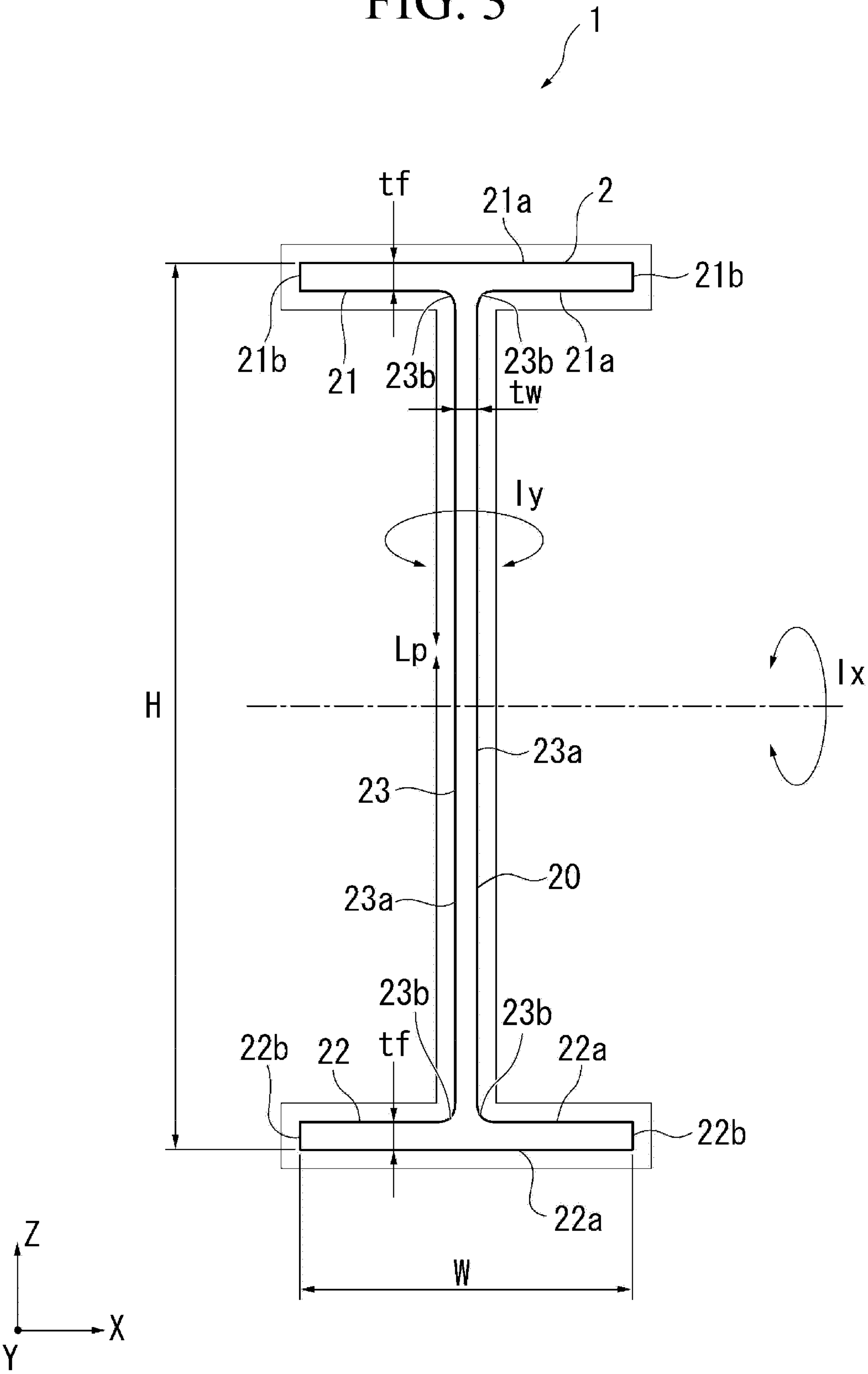

1
tf
21a
2
21b
21b
21
23b
23b
21a
tw
Iy
Lp
Ix
H
23a
23
20
23a
23b
23b
22b
22
tf
22a
22b
22a
W
Z
X
Y

FIG. 4

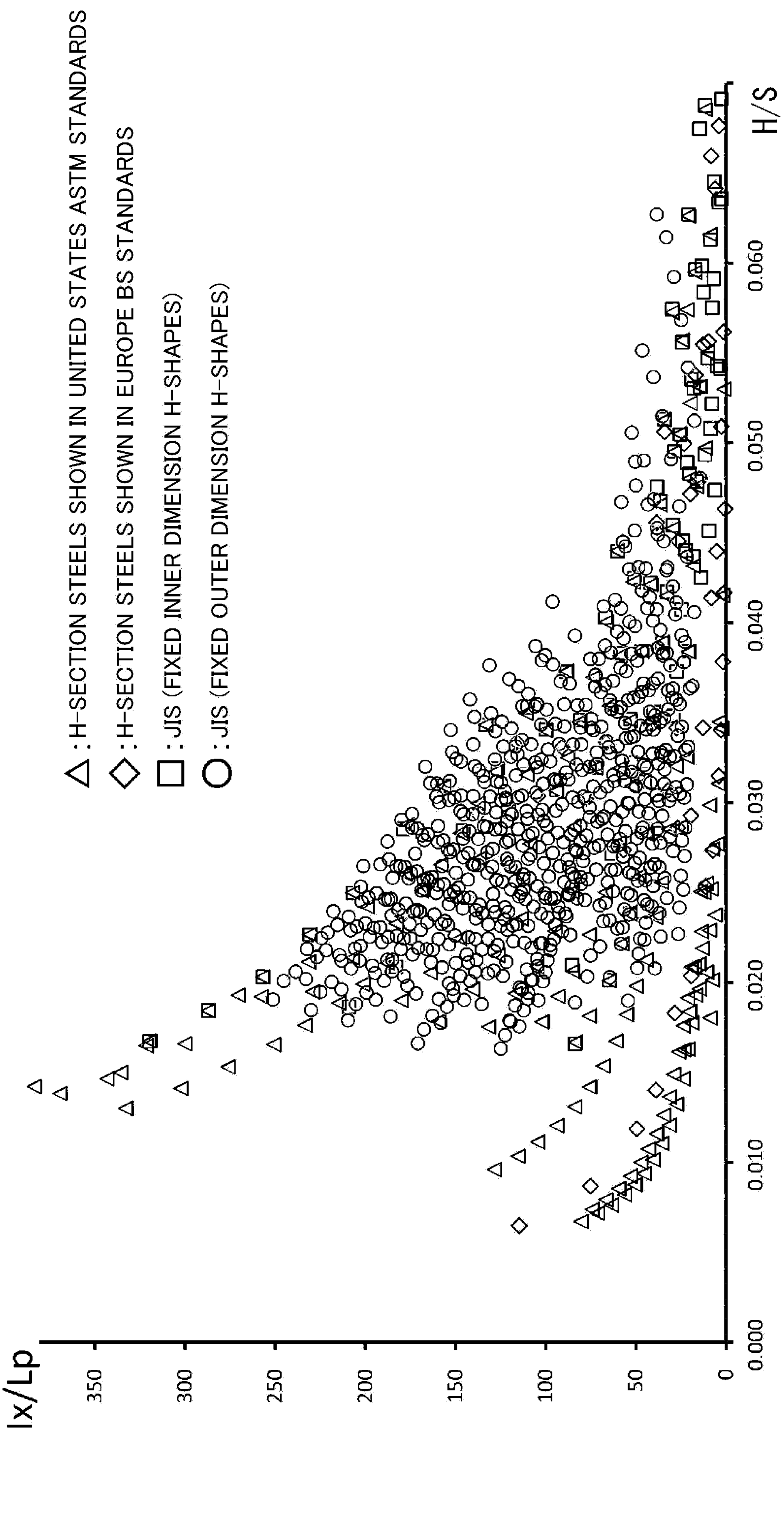

△ : H-SECTION STEELS SHOWN IN UNITED STATES ASTM STANDARDS
◇ : H-SECTION STEELS SHOWN IN EUROPE BS STANDARDS
□ : JIS (FIXED INNER DIMENSION H-SHAPES)
○ : JIS (FIXED OUTER DIMENSION H-SHAPES)
Ix/Lp
350
300
250
200
150
100
50
0
0.000
0.010
0.020
0.030
0.040
0.050
0.060
H/S

FIG. 5

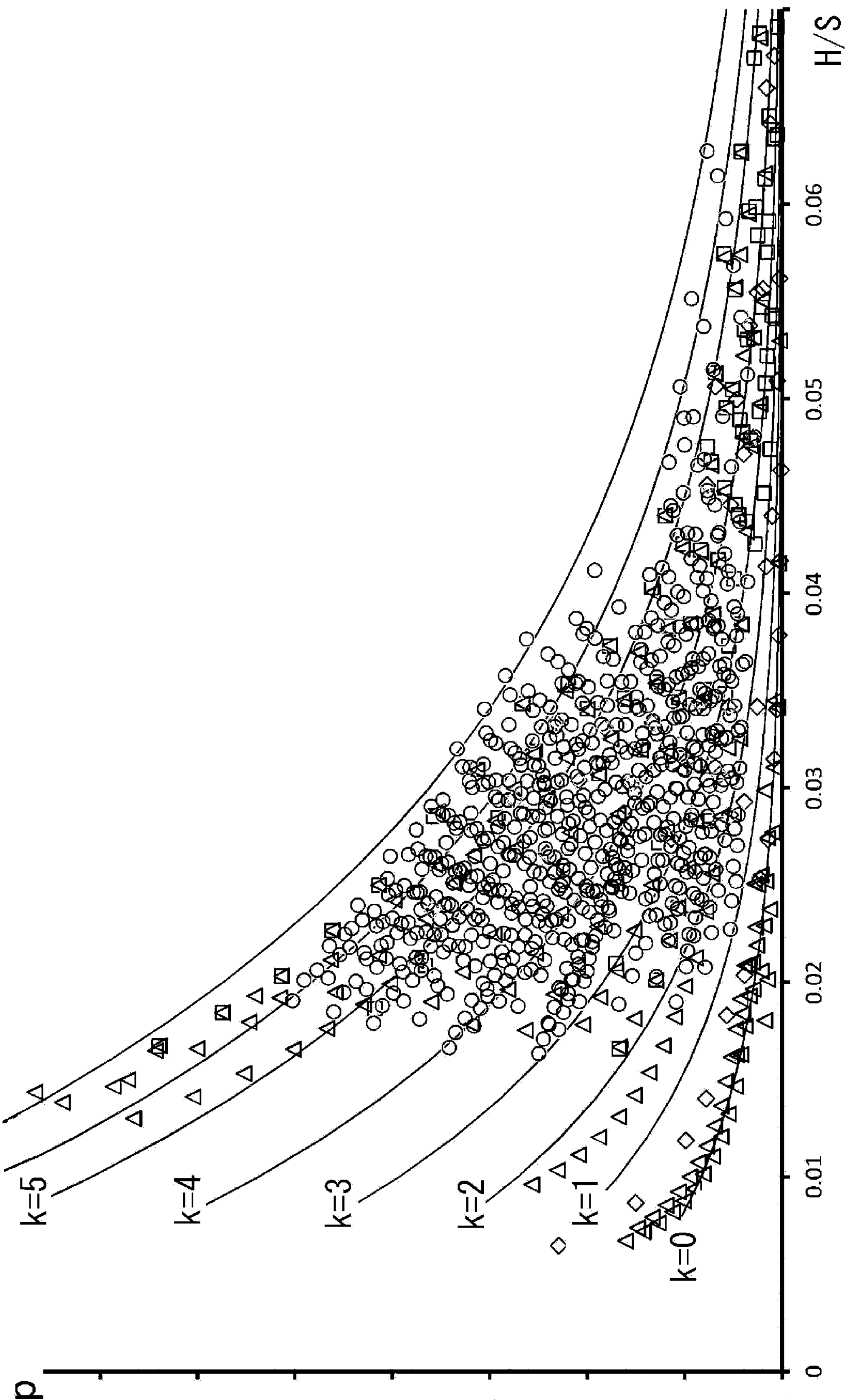

Ix/Lp
H/S
k=6
k=5.5
k=5
k=4
k=3
k=2
k=1
k=0
0
50
100
150
200
250
300
350
0.01
0.02
0.03
0.04
0.05
0.06

FIG. 6

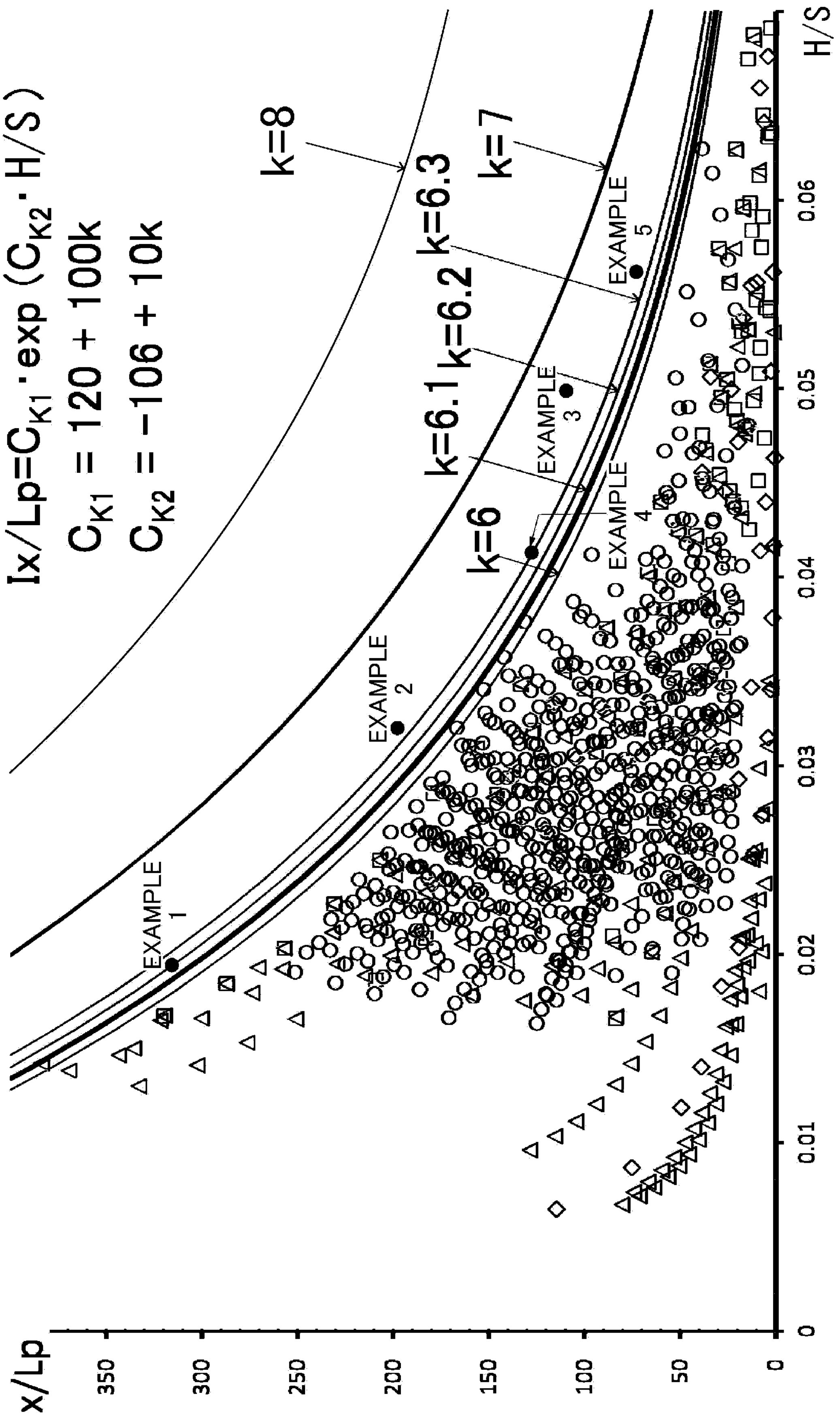

Ix/Lp=CK1·exp (CK2·H/S)
CK1 = 120 + 100k
CK2 = −106 + 10k
k=8
k=7
k=6.3
k=6.2
k=6.1
k=6
EXAMPLE 1
EXAMPLE 2
EXAMPLE 3
EXAMPLE 4
EXAMPLE 5
Ix/Lp
350
300
250
200
150
100
50
0
0
0.01
0.02
0.03
0.04
0.05
0.06
H/S

FIG. 7

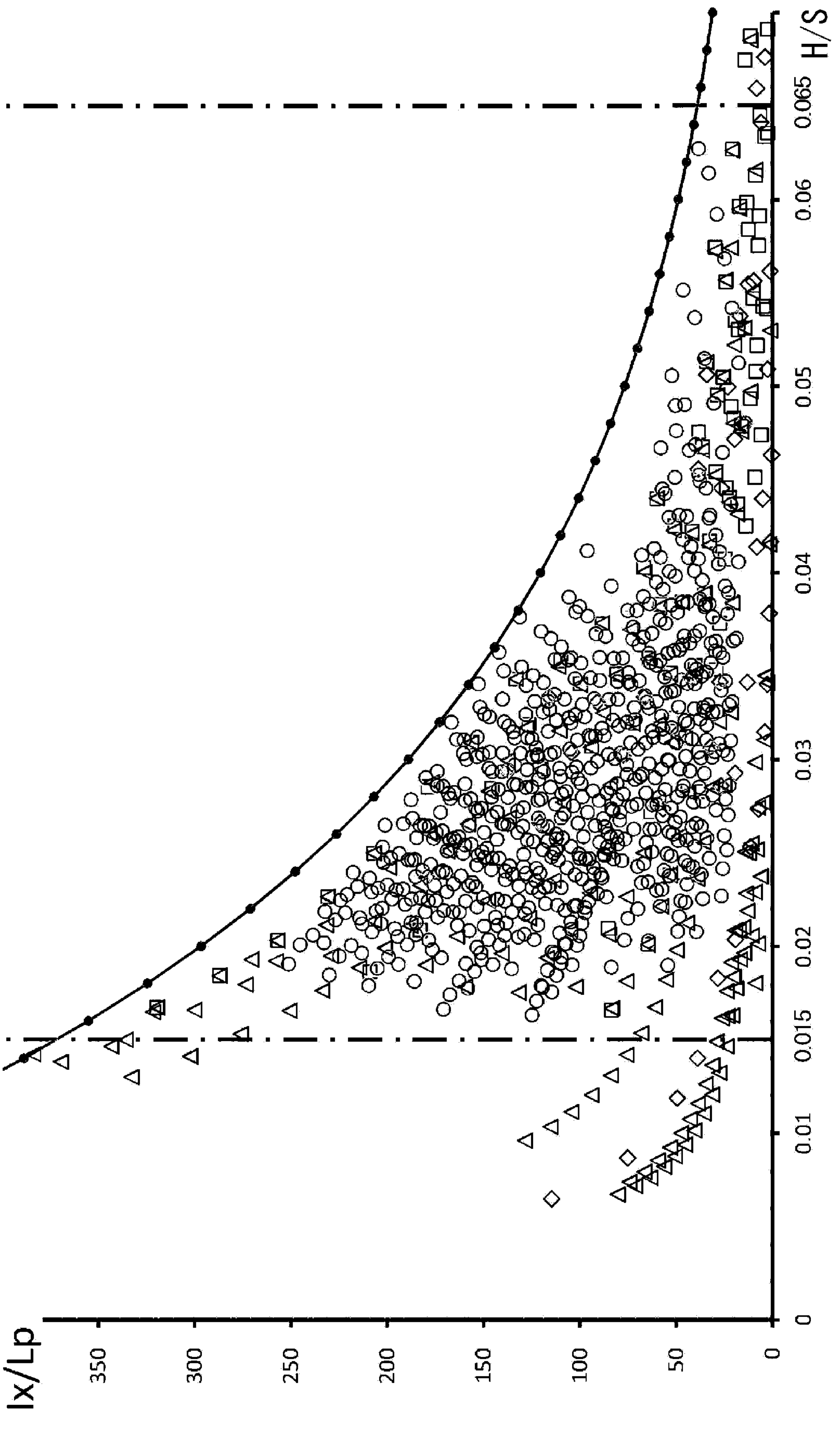

Ix/Lp
350
300
250
200
150
100
50
0
H/S
0
0.01
0.015
0.02
0.03
0.04
0.05
0.06
0.065

FIG. 8A

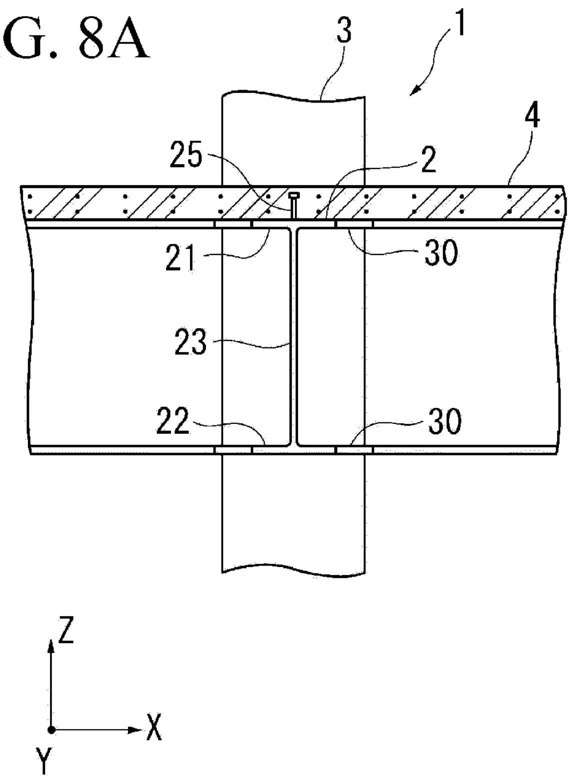

3
1
4
25
2
21
30
23
22
30
Z
X
Y

FIG. 8B

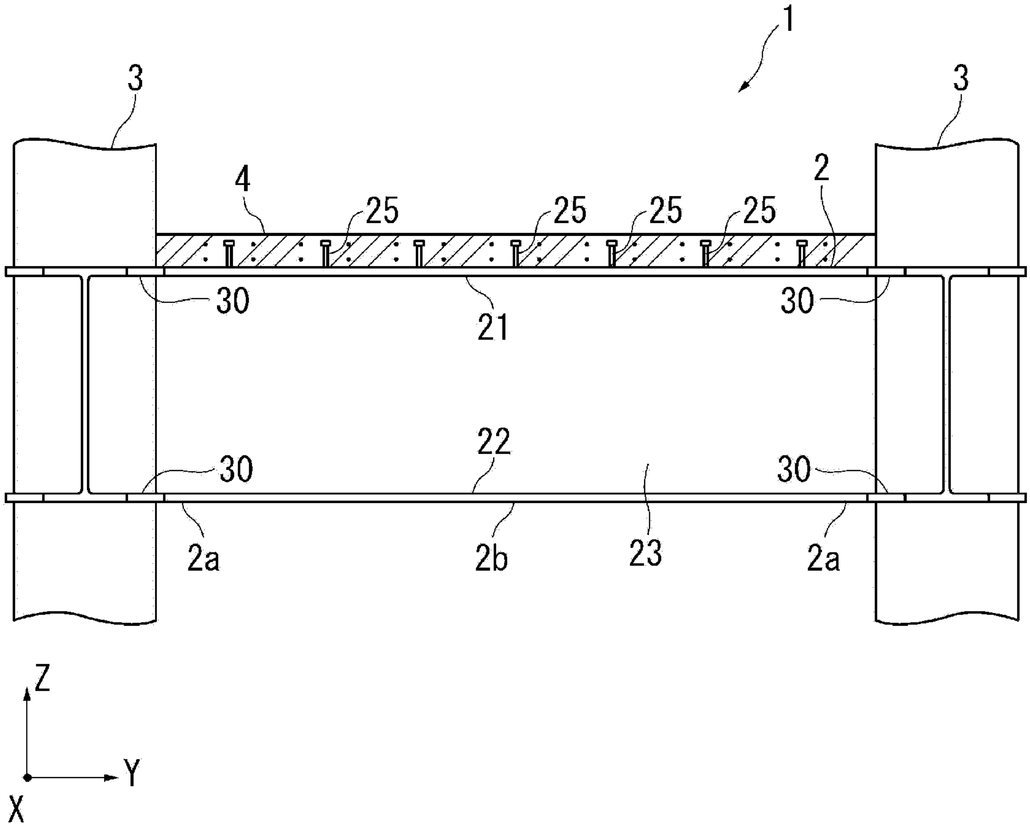

1
3
3
4
25
25
25
25
2
30
21
30
22
30
30
2a
2b
23
2a
Z
Y
X

FIG. 9A

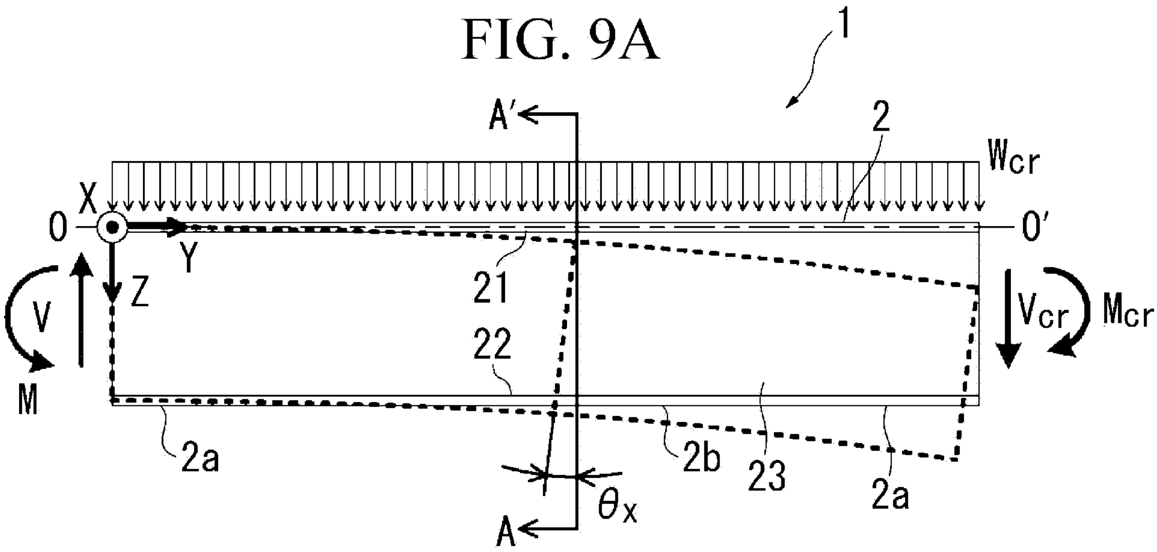


FIG. 9B

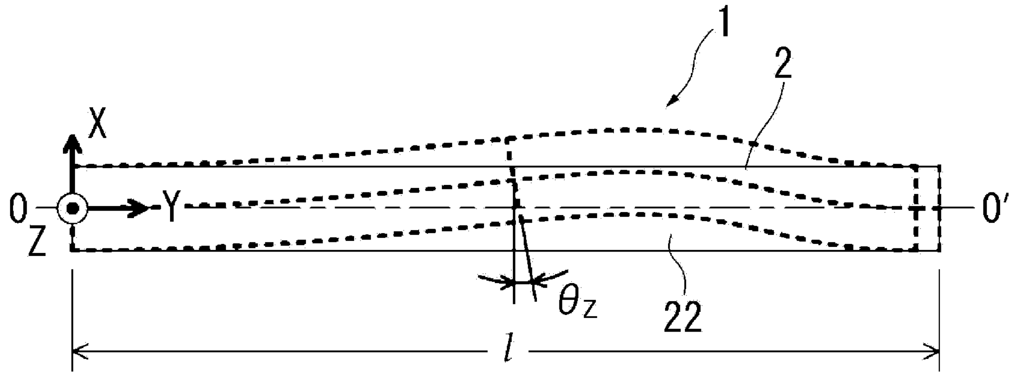


FIG. 9C

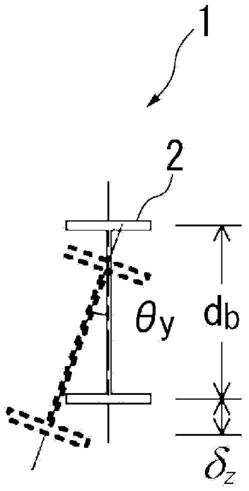


FIG. 10

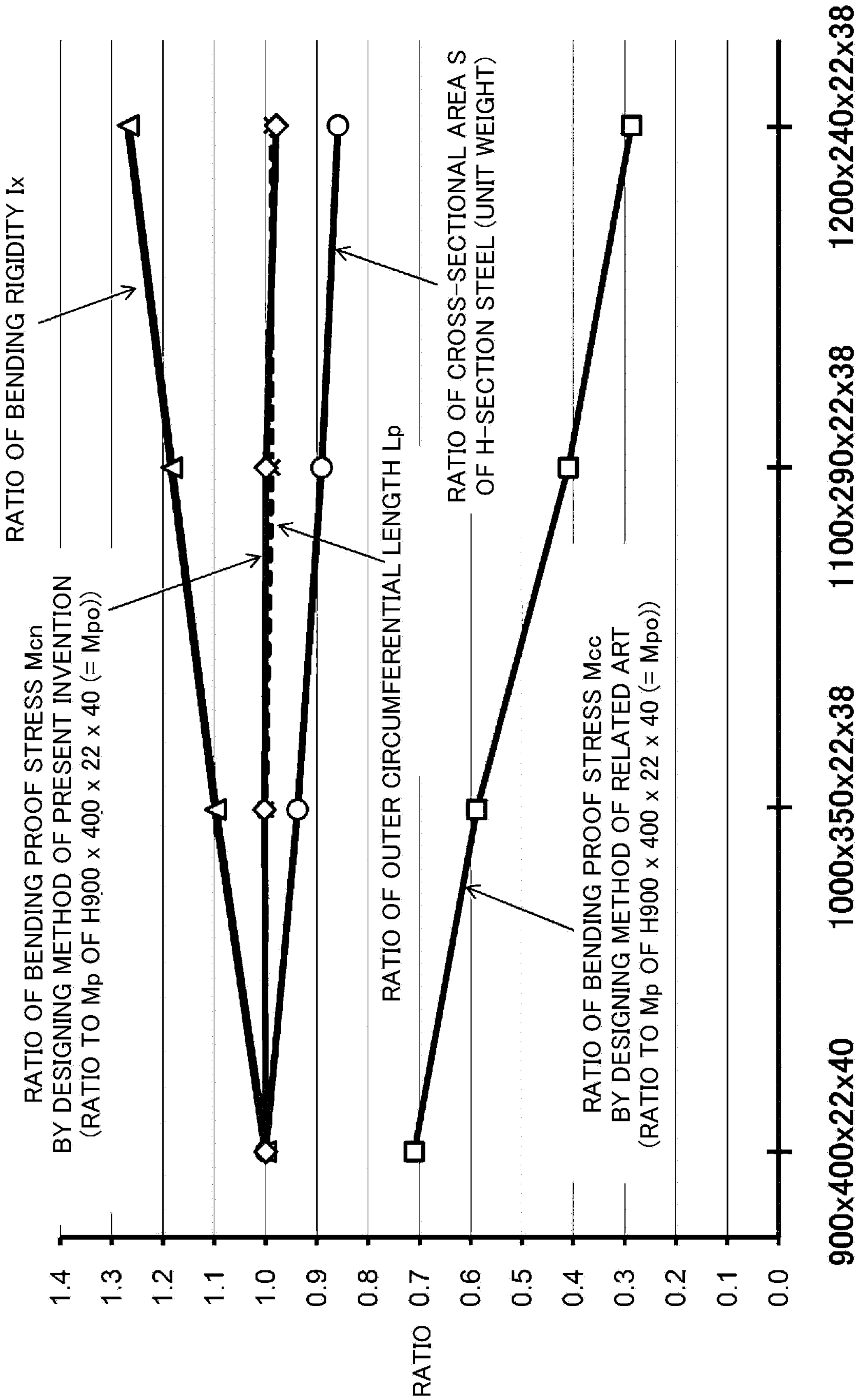

RATIO
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
900x400x22x40
1000x350x22x38
1100x290x22x38
1200x240x22x38
RATIO OF BENDING RIGIDITY Ix
RATIO OF BENDING PROOF STRESS Mcn BY DESIGNING METHOD OF PRESENT INVENTION (RATIO TO Mp OF H900 x 400 x 22 x 40 (= Mpo))
RATIO OF OUTER CIRCUMFERENTIAL LENGTH Lp
RATIO OF CROSS-SECTIONAL AREA S OF H-SECTION STEEL (UNIT WEIGHT)
RATIO OF BENDING PROOF STRESS Mcc BY DESIGNING METHOD OF RELATED ART (RATIO TO Mp OF H900 x 400 x 22 x 40 (= Mpo))

FIG. 11A

β =0,　0≤ γ ≤6

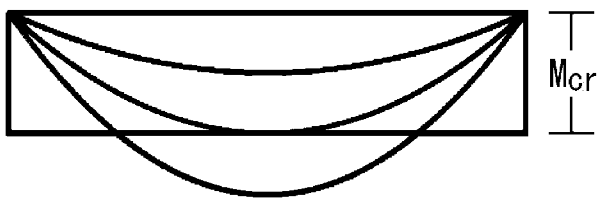


FIG. 11B

β =1,　0≤ γ ≤4

FIG. 11C

$\beta=2, \quad 0 \leq \gamma \leq 2$

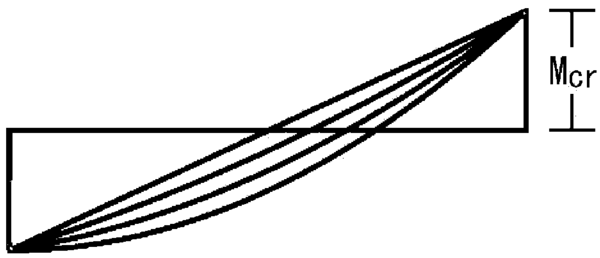


FIG. 11D

$\beta=3, \quad \gamma=0$

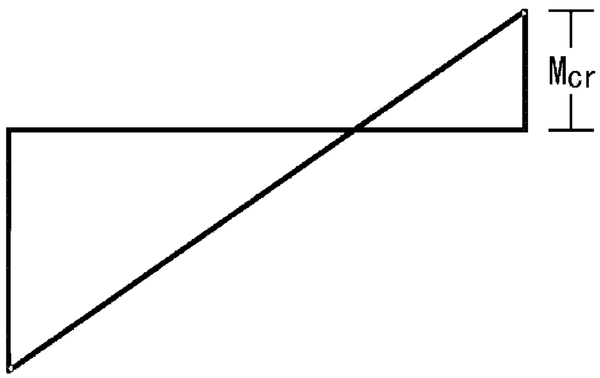


FIG. 12A

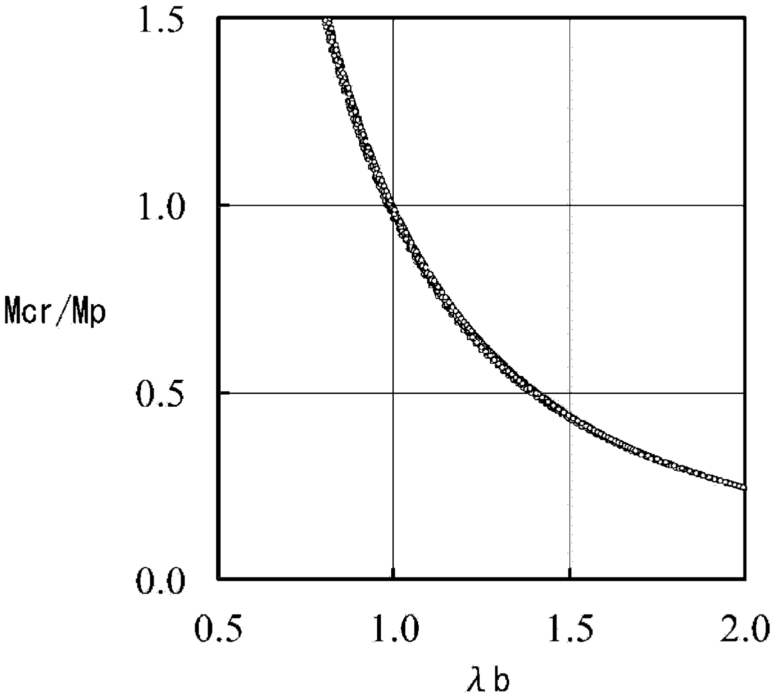


FIG. 12B

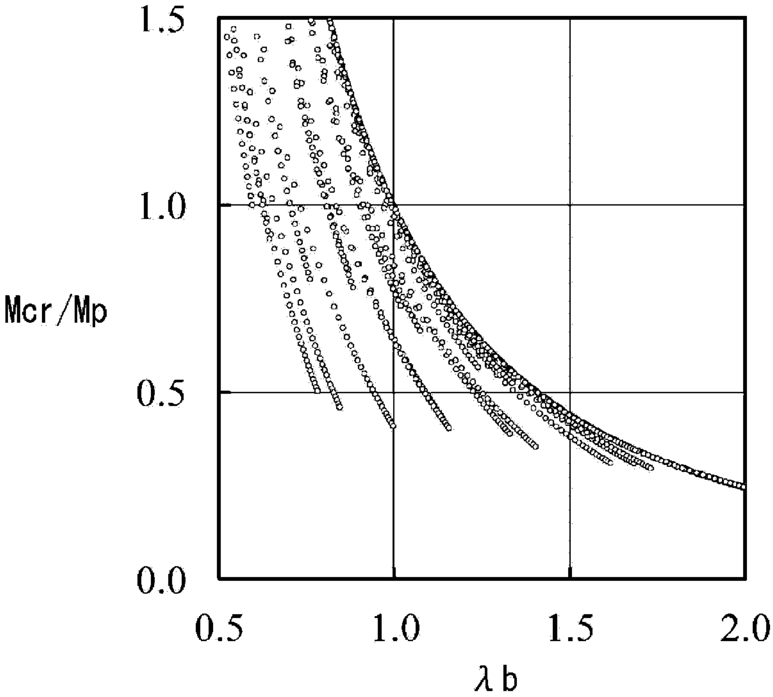
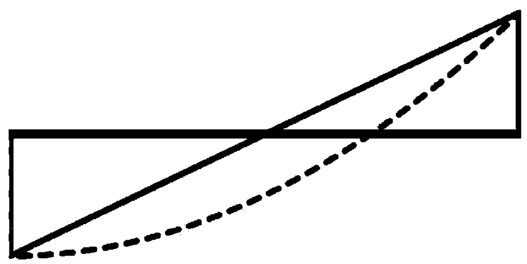
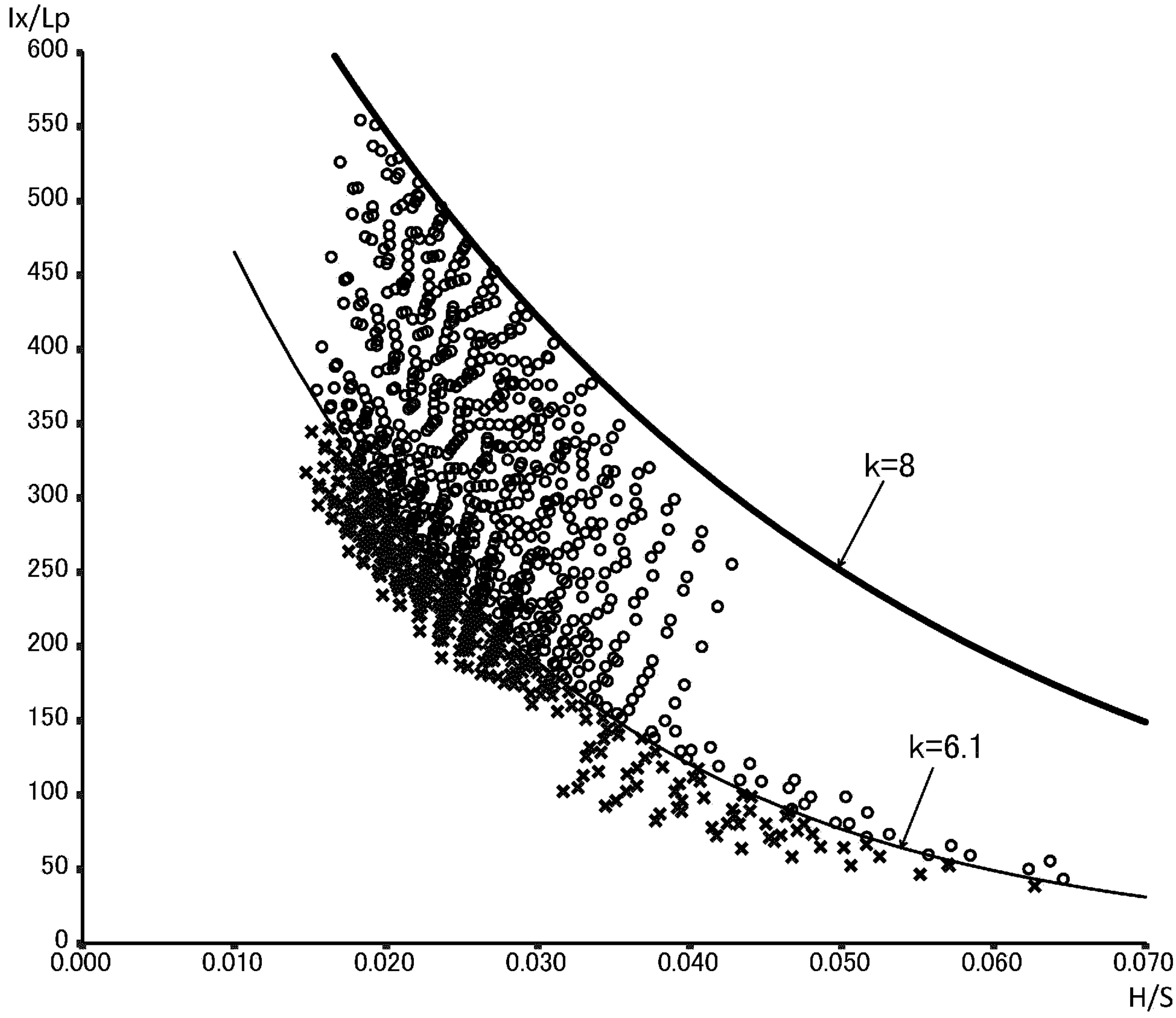


FIG. 13



MOMENT GRADIENT USED IN EVALUATION OF EXAMPLES

FIG. 14



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/005763

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. E04C3/06(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. E04C3/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2018
Registered utility model specifications of Japan	1996-2018
Published registered utility model applications of Japan	1994-2018

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP 2014-109149 A (NIPPON STEEL & SUMITOMO METAL CORPORATION) 12 June 2014, paragraphs [0029]-[0055] (Family: none)	4, 5 1-3
A	CN 103437425 A (SHAANXI JIANKE XINGYE STEEL STRUCTURE CO., LTD.) 11 December 2013, paragraphs [0004]-[0026] (Family: none)	1-5

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
13.03.2018	27.03.2018

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2017028465 A **[0002]**
- JP 2008175056 A **[0005]**
- JP 2016023446 A **[0118]**

Non-patent literature cited in the description

- ASTM A6/A6M-10a Annex A2 lists the dimensions of some shape profiles. *ASTM International* **[0042]**
- *BS 4-1 Structural steel sections,* 2005 **[0043]**
- fixed inner dimension H-shapes, JIS handbook, Ferrous materials & metallurgy 2. Japanese Standards Association, 2015 **[0044]**
- fixed outer dimension H-shapes, JIS handbook, Ferrous materials & metallurgy 2. Japanese Standards Association, 2015 **[0045]**