

WELDED STEEL H-SECTION AND METHOD OF MANUFACTURING SAME

TECHNICAL FIELD

5 **[0001]** This disclosure relates to a welded steel H-section (H-beam), and in particular to a welded steel H-section which can be suitably used for compression members such as columns.

BACKGROUND

10 **[0002]** H-sections are widely used as frame members in steel-framed structures because they have superior strength and rigidity per weight.

[0003] FIG. 1 is a schematic diagram illustrating a typical shape of an H-section. An H-section 100 is a steel material having an H-shaped cross section, consisting of two parallel plates (flange 1) and one plate (web 2) perpendicular to the flanges 1. In the cross-section, the height is referred to as web height H (also referred to as "cross-sectional height") and the width is referred to as flange width B. The thickness of the flange 1 is referred to as flange thickness t_f and the thickness of the web 2 is referred to as web thickness t_w . The "cross section" refers to a cross section perpendicular to the longitudinal direction of the H-section. FIG. 1 is a mere schematic diagram, and the ratios of width, height, depth, and thickness in FIG. 1 differ from actual values.

[0004] The H-section can be broadly classified into rolled steel H-section (RH-section (RH-beam)), which is manufactured by rolling, and welded steel H-section (also referred to as build-up steel H-section (BH-section (BH-beam))), which is manufactured by welding together flanges and a web. In particular, the rolled steel H-section is widely used, and rolled steel H-sections having various cross-sectional shapes for applications such as columns and beams are provided.

30 **[0005]** Examples of the rolled steel H-section for column include H-sections of the wide flange series as specified in the Japanese Industrial Standard JIS G 3192. The British Standard (BS) 4-1 also standardizes the H-section for column as universal columns (UC).

35 **[0006]** As a rolled steel H-section for beam, used is an H-section having an elongated cross-sectional shape, where the web height H is larger than the flange width B (e.g., JP 2014-109149 A (PTL 1)). In contrast, as a rolled steel

H-section for column, used is an H-section having a wide cross-sectional shape close to a square (e.g., JP 2000-234383 A (PTL 2)). This is to improve the flexural rigidity around weak axis and secure the necessary axial resistance in a column which is a member subjected to axial force.

5 **[0007]** Although the wide cross-sectional shape is thus desirable for structural performance, in practice it is difficult to manufacture a rolled steel H-section with a wide cross-sectional shape. This is because the flange is formed by rolling in manufacturing a rolled steel H-section, and thus it is difficult to stably form the flange when the flange has a larger width. From a structural-
10 mechanical point of view, as the flange width increases, the risk of buckling around weak axis and the risk of flexural-torsional buckling increase. Therefore, with some exceptions such as an H-section with a small cross section, an ordinary rolled steel H-section for column has a flange width B which is not greater than a web height H.

15 **[0008]** On the other hand, unlike the rolled steel H-section, the welded steel H-section (BH-section) has no manufacturing restrictions. Therefore, a welded steel H-section with any flange width B and web height H can be manufactured. However, for the aforementioned structural mechanical reasons, the welded steel H-section has a cross-sectional shape similar to that
20 of the rolled steel H-section.

[0009] In the design practice, it is customary to design a framework on the assumption that a rolled steel H-section is used, and to apply, in place of a rolled steel H-section which has insufficient cross-sectional proof stress or rigidity, a welded steel H-section similar in shape to the rolled steel H-section.
25 The sheet thickness and dimensions such as web height of the welded steel H-section are then fine-tuned according to design requirements. This design practice is one reason why the cross-sectional shape of a common welded steel H-section is similar to that of a rolled steel H-section.

30 CITATION LIST

Patent Literature

[0010] PTL 1: JP 2014-109149 A
PTL 2: JP 2000-234383 A

35 SUMMARY

(Technical Problem)

[0011] As described above, even though, unlike the rolled steel H-section, the welded steel H-section has a high degree of freedom in cross-sectional design, it has a cross-sectional shape similar to that of the rolled steel H-section where the flange width B is not greater than the web height H .

5 **[0012]** For reference, for H-sections for column with a relatively wide cross-sectional shape among H-sections for column of various standards, the relationship between the ratio of a flange width B to a web height H (B/H) and the ratio of a web thickness t_w to a flange thickness t_f (t_w/t_f) is illustrated in FIG. 2. The standards plotted in FIG. 2 are as follows.

- 10 - ASTM A6 (ASTM Standards)
- JIS G3192 (Japanese Industrial Standards)
- JIS G3353 (Japanese Industrial Standards)
- BS 4-1 (British Standards)
- AS/NZS 3679.1 (Australian Standards)
15 - AS/NZS 3679.2 (Australian Standards)

[0013] On the other hand, in the field of H-sections for column, there is a demand for developing H-sections that have higher buckling proof stress and can exhibit higher vertical supporting force with a smaller amount of steel materials.

20 **[0014]** It could thus be helpful to provide a welded steel H-section having a high buckling proof stress and high vertical supporting force even with a smaller amount of steel materials, taking advantage of the high degree of freedom in cross-sectional design of the welded steel H-section.

(Solution to Problem)

25 **[0015]** As a result of investigation, we discovered the following.

[0016] (1) The buckling resistance around web axis (weak axis) can be improved by increasing the flange width of an H-section. Therefore, the buckling resistance around weak axis can be improved by forming a welded steel H-section so as to have a cross-sectional shape in which the flange width
30 B is not less than the web height H (wide cross section), taking advantage of the high degree of freedom in cross-sectional design of the welded steel H-section.

[0017] (2) The conventional steel H-section has a cross-sectional shape which provides higher flexural-torsional buckling strength than the weak-axis
35 buckling strength. Therefore, in general design, it is sufficient to consider the weak-axis buckling and it is not necessary to consider the flexural-torsional

buckling. However, in the H-section with a wide cross section, the weak-axis buckling strength is higher than the flexural-torsional buckling strength depending on conditions. Therefore, simply increasing the flange width B induces the flexural-torsional buckling mode. The conditions under which
5 flexural-torsional buckling occurs are not common in design practice and are not desirable because they require very complex calculations in the design.

[0018] (3) By designing the longitudinal length and cross-sectional shape to satisfy specific conditions, the flexural-torsional buckling strength can be made higher than the weak-axis buckling strength. As a result, the buckling
10 resistance around weak axis can be improved by increasing the flange width while preventing the occurrence of flexural-torsional buckling.

[0019] The following is an example of the study that led to the above findings.

[0020] FIG. 3 plots the elastic buckling strength around weak axis, N_{cr_wf} , at the buckling length of an H-section of 8000 mm against the cross-sectional area of the H-section. The curve a in FIG. 3 indicates the elastic buckling
15 strength of an H-section (ASTM A6 W14"x16") having a conventional cross-sectional shape. The curve b indicates the elastic buckling strength of an H-section having a wide cross-sectional shape where the web height H is the same as that of the conventional H-section and the flange width B is 1.1 times the
20 web height H. In the wide cross-sectional shape, the flange thickness t_f is the same as that of the conventional H-section, and the web thickness t_w is 1/2 of the flange thickness t_f .

[0021] The elastic buckling strength around weak axis N_{cr_wf} illustrated in FIG. 3 is calculated using the following formula (A):

25
$$N_{cr_wf} = \pi^2 \times E \times I_y / L_{cr}^2 \quad (A),$$

where

E: Young's modulus of steel material,

I_y : cross-sectional secondary moment around weak axis given by:

$$I_y = 2 \times b^3 \times t_f / 12 + (h - 2t_f) \times t_w^3 / 12, \text{ and}$$

30 L_{cr} : buckling length.

[0022] As can be seen from the example illustrated in FIG. 3, the buckling resistance around weak axis can be improved by forming a welded steel H-section so as to have a cross-sectional shape in which the flange width B is not less than the web height H (wide cross section).

35 **[0023]** On the other hand, FIG. 4 illustrates a graph of the relationship between the buckling length α and the elastic buckling proof stress in an H-section.

The "buckling length α " is defined as $L/(H-t_f)$ using a longitudinal length: L , a web height: H , and a flange thickness: t_f .

[0024] In FIG. 4, the curve a1 (solid line) indicates the elastic buckling proof stress around weak axis in a conventional H-section and the curve a2 (dashed line) indicates the elastic flexural-torsional proof stress in the same conventional H-section. Thus, in the conventional H-section, the cross-sectional shape is designed so that the flexural-torsional buckling proof stress is higher than the weak-axis buckling proof stress. Therefore, in the conventional H-section, it is sufficient to consider weak-axis buckling and it is not necessary to consider flexural-torsional buckling.

[0025] As the conventional H-section, a conventional H-section for column having a cross-sectional shape of $H-500 \times 400 \times 40 \times 70$ mm is used. The notation of the cross-sectional shape is commonly used in the art, and the four numbers represent the web height H , flange width B , web thickness t_w , and flange thickness t_f , respectively.

[0026] On the other hand, the curves b1 (solid line) and b2 (dashed line) in FIG. 4 indicate the elastic buckling proof stress of an H-section having a wide cross-sectional shape in which the flange width B is increased to 750 mm from that of the conventional H-section. The curve b1 (solid line) indicates the elastic buckling proof stress around weak axis, and the curve b2 (dashed line) indicates the elastic flexural-torsion proof stress. The other dimensions of the H-section having the wide cross-sectional shape are the same as those of the conventional H-section.

[0027] As can be seen from the example in FIG. 4, in the H-section with the wide cross section, the weak-axis buckling proof stress is higher than the flexural-torsional buckling proof stress depending on conditions. Therefore, simply increasing the flange width B induces the flexural-torsional buckling mode.

[0028] The elastic buckling proof stress illustrated in FIG. 4 is calculated using the formula below. The elastic buckling strength around weak axis is calculated by the same method as in 2 above.

Flexural-torsional elastic buckling proof stress = $A \times F_e$

$$F_e = (\pi^2 E \times C_w / L^2 + G \times J) \times I / (I_x + I_y)$$

where

A: cross-sectional area given by:

$$A = 2 \times B \times t_f + (H - 2 \times t_f) \times t_w,$$

I_y: cross-sectional secondary moment around weak axis given by:

$$I_y = 2 \times b^3 \times tf/12 + (h - 2tf) \times tw^3/12,$$

I_x: cross-sectional secondary moment around strong axis given by:

$$I_x = B \times (H^3 - (H - 2 \times tf)^3) / 12 + (H - 2 \times tf)^3 \times tw / 12,$$

5 E: Young's modulus of steel material,

G: shear rigidity of steel material given by:

$$G = E / (2 \times (1 + \nu)),$$

ν: Poisson's ratio of steel material,

C_w: warping constant given by:

10
$$C_w = I_y \times (H - tf)^2 / 4,$$

J: torsional constant given by:

$$J = (2 \times B \times tf^3 + (H - tf) \times tf^3) / 3, \text{ and}$$

L_{cr}: buckling length.

[0029] This disclosure is based on the above discoveries and has the following
15 primary features.

[0030] 1. A welded steel H-section comprising a steel material having a yield
point strength of 325 N/mm² or more, wherein the welded steel H-section has
a longitudinal length L, a web height H, a flange width B, a flange thickness
tf, a web thickness tw, α defined as L/(H-tf), β defined as B/(H-tf), γ defined
20 as tf/B, and δ defined as tw/tf which satisfy the following formulas (1) to (8):

$$H \geq 400 \text{ mm} \quad (1)$$

$$B \geq 400 \text{ mm} \quad (2)$$

$$H \leq B \quad (3)$$

$$\alpha \geq 10 \quad (4)$$

25
$$B/16 \leq tf \leq H/4 \quad (5)$$

$$\max[tf/3, H/37] \leq tw \leq \min[tf, tf \times \delta_{req}(\gamma = 1/16)] \quad (6)$$

$$1.0 \leq \beta \leq 1.6 \quad (7)$$

$$\delta \geq \delta_{req} \quad (8)$$

where δ_{req} is defined by the following formula (9) and δ_{req} (γ=1/16) refers to
30 a value of δ_{req} when 1/16 is substituted for γ:

$$\delta_{req} = (2.58\beta - 1.12) + (17.2\beta^2 - 52.8\beta + 18.0) \times \gamma \quad (9).$$

[0031] 2. The welded steel H-section according to 1., comprising a web cross-
sectional area ratio of 20 % or less as defined as a ratio of a web cross-sectional
area to a total cross-sectional area.

35 [0032] 3. The welded steel H-section according to 1. or 2., comprising a steel
material having a yield point strength of 385 N/mm² or more and an equivalent

carbon content C_{eq} of 0.43 or less.

[0033] 4. A method of manufacturing the welded steel H-section according to any one of 1. to 3., comprising:

5 joining a flange material and a web material which are made of a steel material having a yield point strength of 325 N/mm^2 or more into an H-shape; and

welding the flange material and the web material to form a welded steel H-section.

(Advantageous Effect)

10 **[0034]** According to this disclosure, in a welded steel H-section, the weak-axis buckling strength can be improved by increasing the flange width while preventing local buckling of the flange and web that is undesirable in terms of structural performance or design and the emergence of the flexural-torsional buckling mode. Therefore, the welded steel H-section of this disclosure can
15 exhibit a high vertical supporting force with a smaller amount of steel materials. In addition, this disclosure makes it possible to increase the flange width without interfering with the manufacturability in welding. Furthermore, according to this disclosure, strength can be ensured even when the thickness of the web and flanges which are parts of the H-section is
20 reduced. Therefore, according to this disclosure, it is also possible to reduce the sheet thickness, thereby reducing the amount of welding in the manufacture of the welded steel H-section itself and the amount of welding in a weld joint portion that connects the welded steel H-sections with each other at the time of construction.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0035] In the accompanying drawings:

FIG. 1 is a schematic diagram illustrating a typical shape of an H-section;

30 FIG. 2 is a graph illustrating, for an H-section for column with a relatively wide cross-sectional shape among H-sections for column of various standards, the relationship between the ratio of a flange width B to a web height H (B/H) and the ratio of a web thickness t_w to a flange thickness t_f (t_w/t_f);

FIG. 3 is a graph illustrating the relationship between the cross-sectional area and the elastic buckling strength of an H-section;

35 FIG. 4 is a graph illustrating the relationship between the buckling

length and the elastic buckling proof stress of an H-section;

FIG. 5 is a graph illustrating the relationship between the elastic buckling proof stress and the welding volume;

FIG. 6 is a graph illustrating the relationship between the buckling length and the elastic buckling proof stress of a welded steel H-section according to one embodiment of this disclosure;

FIG. 7 is a schematic diagram illustrating the cross-sectional shape of a welded steel H-section according to one embodiment of this disclosure;

FIG. 8 is a schematic diagram illustrating the cross-sectional shape of a welded steel H-section according to another embodiment of this disclosure;

FIG. 9 is a schematic diagram illustrating the relationship between the cross-sectional shape of a welded steel H-section according to one embodiment of this disclosure and the angle of a welding torch; and

FIG. 10 is a schematic diagram illustrating the relationship between the cross-sectional shape of a welded steel H-section according to another embodiment of this disclosure and the angle of a welding torch.

DETAILED DESCRIPTION

[0036] The following provides details of a method of carrying out this disclosure. The following merely provides preferred embodiments of this disclosure, and this disclosure is by no means limited to the embodiments described herein.

[0037] [Welded steel H-section]

The welded steel H-section of this disclosure is a welded steel H-section in which the longitudinal length L and the cross-sectional shape satisfy the aforementioned formulas (1) to (8). The reasons for the limitation are explained below.

[0038] As mentioned above, the elastic flexural-torsional proof stress tends to converge to a constant value, $A \times G \times J / (I_x + I_y)$, as the buckling length is increased. In contrast, the weak-axis buckling proof stress decreases in inverse proportion to the square of the buckling length as the buckling length is increased. Therefore, as illustrated in FIG. 4, flexural-torsional buckling is more likely to occur than weak-axis buckling in a region where the buckling length is shorter than a certain threshold (stub column region) in an H-section with a wide cross-sectional shape. On the contrary, weak-axis buckling is more likely to occur than flexural-torsional buckling in a region where the

buckling length is longer than the aforementioned threshold (slender column region).

[0039] Therefore, based on the above findings, we derived the conditions under which the weak-axis buckling strength can be improved by increasing the flange width and flexural torsional buckling which is undesirable in design does not occur. The specific derivation method is described below.

[0040] First, the buckling strength around weak axis N_{cr_wf} and the flexural-torsional buckling strength N_{cr_ft} are expressed by the following formulas, respectively.

$$N_{cr_wf} = \frac{\pi^2 \cdot E \cdot I_y}{L_{cr}^2}$$

$$N_{cr_ft} = \left(\frac{\pi^2 \cdot E \cdot C_w}{L_{cr}^2} + G \cdot J \right) \cdot \left(\frac{A}{I_x + I_y} \right)$$

[0041] Therefore, the ratio R of N_{cr_ft} to N_{cr_wf} can be expressed as follows. In order to avoid flexural-torsional buckling, R needs to be more than 1.0.

$$R = \frac{N_{cr_ft}}{N_{cr_wf}} = \left(C_w + \frac{G \cdot J \cdot L_{cr}^2}{\pi^2 \cdot E} \right) \cdot \left(\frac{A}{I_y \cdot (I_x + I_y)} \right)$$

[0042] As mentioned earlier, J represents the torsional constant, C_w represents the warping constant, and G represents the shear rigidity of a steel material, which are expressed by the following formulas, respectively.

$$J = \frac{2 \cdot B \cdot tf^3 + H' \cdot tw^3}{3}$$

$$C_w = \frac{H'^2 \cdot I_y}{4}$$

$$G = \frac{E}{2 \cdot (1 + \nu)} = E / 2.6$$

$$H' = H - tf$$

[0043] Therefore, the ratio of N_{cr_ft} to N_{cr_wf} can be organized as follows.

$$\frac{N_{cr_ft}}{N_{cr_wf}} = \left(\frac{H'^2}{4} + \frac{J \cdot L_{cr}^2}{2.6 \cdot \pi^2 \cdot I_y} \right) \cdot \frac{A}{I_x + I_y}$$

[0044] Here, the ranges of the cross-sectional dimensions of the targeted H-section are as follows:

$$H \geq 400 \text{ mm}$$

$$B \geq 400 \text{ mm}$$

$$H \leq B$$

$$1.0 \leq \beta \leq 1.6$$

5 $B/16 \leq t_f \leq H/4$

$$\text{Max}[t_f/3, H/37] \leq t_w \leq \text{min}[t_f, t_f \times \delta_{\text{req}}(\gamma=1/16)]$$

where δ_{req} is defined by the following formula and $\delta_{\text{req}} (\gamma = 1/16)$ refers to a value of δ_{req} when 1/16 is substituted for γ :

$$\delta_{\text{req}} = (2.58\beta - 1.12) + (17.2\beta^2 - 52.8\beta + 18.0) \times \gamma.$$

10 **[0045]** The H-section is made of a steel material having a yield point strength of 325 N/mm² or more.

[0046] As used herein, the "max" is a mathematical symbol that refers to the maximum value of the values listed in the bracket that follows. Thus, in other words, t_w satisfies both of the following two formulas.

15 $t_f/3 \leq t_w$

$$H/37 \leq t_w$$

[0047] In addition, as used herein, "min" is a mathematical symbol that refers to the minimum value of the values listed in the bracket that follows. Thus, in other words, t_w satisfies both of the following two formulas.

20 $t_w \leq t_f$

$$t_w \leq t_f \times \delta_{\text{req}}(\gamma=1/16)$$

[0048] A is the cross-sectional area of the welded steel H-section and is expressed by the following formula.

$$A = 2 \cdot B \cdot t_f + (H - 2 \cdot t_f) \cdot t_w$$

25 **[0049]** I_y is the cross-sectional secondary moment around weak axis and is expressed by the following formula.

$$I_y = 2 \cdot B^3 \cdot t_f / 12 + (H - 2 \cdot t_f) \cdot t_w^3 / 12$$

[0050] Then, I_y can be approximated by the following formula. The error in the following approximation is in the range of -0.4 % to 0.0 % within the range
30 of the cross-sectional dimensions described above.

$$I_y \approx 2 \cdot B^3 \cdot t_f / 12$$

[0051] I_x is the cross-sectional secondary moment around strong axis and is expressed by the following formula.

$$I_x = \frac{B \cdot (H^3 - (H - 2tf)^3)}{12} + \frac{tw \cdot (H - 2tf)^3}{12}$$

[0052] Then, I_x can be approximated by the following formula. The error in the following approximation is in the range of -2.0 % to +2.0 % within the range of the cross-sectional dimensions described above.

$$I_x \approx \frac{2 \cdot B \cdot tf \cdot H^2}{4} + \frac{tw \cdot H^3}{12}$$

[0053] Therefore, when the ratio R of Ncr_ft to Ncr_wf is nondimensionalized with the variables α , β , δ and γ defined as follows, the ratio R can be expressed by the following formula. When the value of R is more than 1.0, flexural-torsion buckling can be avoided.

$$R = \frac{\left[0.25 + \frac{4 \cdot (\gamma)^2 + 2(\delta \cdot \gamma)^2 (\delta / \beta)}{\pi^2 \cdot 2.6} \cdot (\alpha)^2 \right] \cdot 12 \cdot [2 + (\delta / \beta) - (\delta \cdot \gamma)]}{(\delta / \beta) + 6 + 2 \cdot (\beta)^2}$$

$$\alpha = L / (H - tf)$$

$$\beta = b / (H - tf)$$

$$\gamma = tf / B$$

$$\delta = tw / tf$$

[0054] Next, a regression analysis with δ , β , and γ as variables was performed to derive the conditions under which R was more than 1.0. R , which is expressed as a function of α , takes the lower limit when α is minimum. In the aforementioned regression analysis, the lower limit of α was set to 10. The lower limit of α was determined based on a minimum length of a column member in a non-residential building structure. That is, when α is 10, the longitudinal length L of the H-section is 4 m, assuming that the web height H is the minimum value of 400 mm and the flange thickness tf is negligible. This value of L corresponds to the floor height of a non-residential building structure, i.e., the minimum length as a column member.

[0055] The web height L and flange width B were both set to 400 mm or more, based on the publicly-known standards for H-sections for column.

[0056] In the regression analysis, since approximate formulas were used to evaluate the cross-sectional secondary moments I_x and I_y , the necessary condition was set to $R \geq 1.02$ in consideration of the evaluation error. As mentioned above, the evaluation error of the aforementioned approximation formulas is largest for I_x and is distributed among ± 2.0 %. The necessary

condition was determined taking into account the maximum range of the error.
[0057] The conditions derived by the aforementioned regression analysis are as the following formula. In order to avoid flexural-torsional buckling, the following formula, i.e., formula (8), needs to be satisfied.

5 $\delta \geq \delta_{req}$

[0058] Next, other conditions that define the cross-sectional shape of the welded steel H-section of this disclosure are described.

[0059] First, as to the flange width, as already mentioned above, it is desirable to use a wide cross-sectional shape to improve the flexural rigidity around
10 weak axis and to ensure the necessary axial resistance in a column which is a member subjected to axial force. Therefore, the flange width B is set to equal to or greater than the web height H.

[0060] On the other hand, when the flange width B is excessively large, the risk of flexural-torsional buckling increases and local buckling of the flange is
15 also likely to occur. Therefore, in order to ensure proper resistance to compressive axial forces and suppress flexural-torsional buckling, the following conditions are set for the flange width B, web height H, flange thickness t_f , and web thickness t_w .

[0061] First, the conditions for ensuring proper resistance to compressive axial
20 force are described. The Building Standard Law stipulates that, for a steel material with a yield point strength of 325 N/mm² or more, the ratio of a flange building dimension (B/2) to a flange thickness (t_f) should be 8 or less as an indicator indicating that sufficient plastic deformation against local buckling is possible. Therefore, in the formula (5) which specifies the conditions for
25 flange thickness, t_f is set to B/16 or more.

[0062] Similarly, the Building Standards Law stipulates that, for a steel material with a yield point strength of 325 N/mm² or more, the ratio of a web height (H) to a web thickness (t_w) should be 37 or less as an indicator indicating that sufficient plastic deformation against local buckling is possible.
30 Therefore, in the formula (6), which specifies the conditions for web thickness, t_w is set to H/37 or more.

[0063] On the other hand, the condition for suppressing flexural-torsional buckling is derived as follows by using the sheet thickness ratio δ ($= t_w/t_f$) required to avoid flexural-torsional buckling, which is defined in the formula
35 (9).

[0064] First, as mentioned above, in order to avoid flexural-torsion buckling,

δ needs to be δ_{req} or greater. On the other hand, since the flange thickness t_f is $B/16$ or more as specified in the formula (5), γ defined as t_f/B is $1/16$ or more. Therefore, the upper limit of δ is δ_{req} ($\gamma = 1/16$), which is a value obtained by substituting the lower limit of γ , $1/16$ for δ_{req} .

5 **[0065]** Therefore, when δ is δ_{req} or greater and δ_{req} ($\gamma = 1/16$) or less, flexural-torsion buckling can be avoided. Since δ is t_w/t_f , t_w needs to be not greater than $t_f \times \delta_{req}$ ($\gamma = 1/16$), as specified in the formula (6). By using a cross-sectional shape that satisfies the above conditions, the buckling resistance around weak axis can be improved while preventing the occurrence
10 of flexural-torsional buckling.

[0066] In the preceding paragraphs, we focused on the structural performance of the specially-shaped welded steel H-section specified in this disclosure, derived the shape conditions required to satisfy the required performance in terms of member function, and described the significance of the shape
15 conditions. In the following paragraphs, we study shape conditions required in the manufacture of a welded steel H-section and describe the significance thereof.

[0067] First of all, in the manufacture of a welded steel H-section, a web material is abutted on a center of the width of a flange material and welded to
20 form a welded steel H-section. The welding is performed from the left and right sides at the intersection of the web and flange, as indicated by the arrows in FIG. 9. The welding amount required to join the flange to the web usually increases as the thickness of the web is increased. However, the increase of welding heat input due to the increase of welding amount causes the
25 deterioration of mechanical properties and the shape distortion of a steel material. Therefore, the web thickness t_w is set to equal to or less than the flange thickness t_f .

[0068] Thus, the upper limit of the web thickness t_w is $t_f \times \delta$ ($\gamma = 1/16$) from the viewpoint of ensuring the structural performance, and t_f from the viewpoint
30 of manufacturability. In other words, t_w needs to satisfy the condition of the following formula.

$$t_w \leq \min[t_f, t_f \times \delta (\gamma = 1/16)]$$

[0069] On the other hand, as mentioned earlier, the lower limit of the web thickness t_w is $H/37$ from the viewpoint of enabling sufficient plastic
35 deformation against local buckling. In addition, when the web is excessively thin, distortional deformation of a cross section may occur in manufacturing

and using the welded steel H-section. Therefore, t_w is set to $t_f/3$ or more. Thus, t_w needs to satisfy the conditions of the following formula.

$$\max[t_f/3, H/37] \leq t_w$$

[0070] The upper limit of the flange width is then discussed. As mentioned
5 above, welding in the manufacture of a welded steel H-section is performed from the sides of the web, against the left and right sides of the web. At that time, in order to ensure an equal bead leg length on the web and flange, the angle of a welding torch is desirably around 45 degrees to a web surface. Further, in order to enable simultaneous welding of both left and right sides,
10 the angle of the welding torch is desirably around 45° to the web surface.

[0071] However, when the flange width is excessively large, the flange interferes with the torch, making it difficult to achieve the ideal torch angle of 45°.

[0072] The amount of bulging per side of the flange is 1/2 of the flange width
15 B, or B/2. Therefore, assuming that the thickness of the flange and web can be neglected, it is possible to perform welding at a torch angle of 45° when B/2 is H or less. On the other hand, the minimum value of the flange thickness t_f is B/16 as specified in the formula (5). Therefore, assuming that the flange thickness t_f is B/16, B/2 needs to be not greater than H-2 (B/16) in order to
20 perform welding with a torch angle of 45°. Thus, organizing the relationship between B and H, it can be seen that B needs to be 1.6H or less. However, assuming that the effect of the flange thickness t_f can be ignored, β defined as $B/(H - t_f)$ is set to 1.6 or less.

[0073] Next, referring to FIG. 10, the case in which the flange width B is equal
25 to the web height H is considered. Although in the case indicated by FIG. 9, it is necessary to consider the interference of a torch with the flange width, in the case indicated by FIG. 10, the constraining factor for torch insertion is the flange thickness t_f . The amount of bulging per side of the flange is B/2, that is, H/2 because B is equal to H. Therefore, in order to enable welding at a
30 torch angle of 45°, the height X of the space into which the torch can be inserted needs to be greater than or equal to the amount of bulging per side of the flange, H/2. In order to satisfy the above conditions, the flange thickness needs to be H/4 or less.

[0074] In both cases of FIGS. 9 and 10, t_w is not considered because an
35 increase in the web thickness t_w acts in the direction of relaxing the conditions.

[0075] The above conditions can be summarized as the following formulas (1)

to (9):

$$H \geq 400 \text{ mm} \quad (1)$$

$$B \geq 400 \text{ mm} \quad (2)$$

$$H \leq B \quad (3)$$

$$5 \quad \alpha \geq 10 \quad (4)$$

$$B/16 \leq t_f \leq H/4 \quad (5)$$

$$\max[t_f/3, H/37] \leq t_w \leq \min[t_f, t_f \times \delta_{req}(\gamma = 1/16)] \quad (6)$$

$$1.0 \leq \beta \leq 1.6 \quad (7)$$

$$\delta \geq \delta_{req} \quad (8)$$

10 where δ_{req} is defined by the following formula (9) and $\delta_{req}(\gamma=1/16)$ refers to a value of δ_{req} when 1/16 is substituted for γ :

$$\delta_{req} = (2.58\beta - 1.12) + (17.2\beta^2 - 52.8\beta + 18.0) \times \gamma \quad (9).$$

However, the welded steel H-section is made of a steel material with a yield point strength of 325 N/mm² or more.

15 **[0076]** By satisfying the above conditions, in the welded steel H-section, the weak-axis buckling strength can be improved by increasing the flange width while preventing the occurrence of the flexural-torsional buckling mode which is undesirable in design. Therefore, the welded steel H-section of this disclosure can exhibit a high vertical supporting force with a smaller amount
20 of steel materials. Also, according to this disclosure, strength can be ensured even when the sheet thickness of the web and flange which are parts of the H-section is reduced. Therefore, according to this disclosure, it is also possible to reduce the sheet thickness, thereby reducing the amount of welding in the manufacture of the welded steel H-section itself and the amount of welding in
25 a weld joint portion that connects welded steel H-sections with each other at the time of construction.

[0077] The dashed lines in FIG. 2 indicate the following conditions, respectively:

- Dashed line a: the formula (3);
- 30 - Dashed line b: Lower limit $t_f/3$ in the formula (6);
- Dashed line c: Upper limit value t_f in the formula (6);
- Dashed line d: the formula (9); and
- Dashed line e: Upper limit $t_f \times \delta_{req}(\gamma = 1/16)$ in the formula (6).

Therefore, in FIG. 2, the region surrounded by the dashed lines a to e is a
35 region that satisfies the conditions of this disclosure. As can be seen from FIG. 2, the standards of the conventional steel H-section fail to meet the

conditions of this disclosure.

[0078] Further, in this disclosure, the web cross-sectional area ratio, defined as the ratio of a web cross-sectional area to a total cross-sectional area, is preferably set to 20 % or less. By reducing the web thickness, the cross-sectional area can be effectively reduced. This is because the web is located at the neutral axis in weak-axial flexural, and the contribution of the web as a resistance element against buckling is very low.

[0079] Further, by reducing the web thickness, the size of the welded portion joining the flange to the web can be reduced in approximate proportion to the square of the reduction ratio. And as a result, the amount of welding in the manufacture of a welded steel H-section can be further significantly reduced. In addition, reducing the amount of welding also reduces welding heat input, which further reduces strain and deformation caused by welding.

[0080] FIG. 5 is a graph illustrating the relationship between the weak-axis elastic buckling proof stress and the welding volume. In FIG. 5, the curve a indicates the welding volume of a welded steel H-section in accordance with the dimensional size of a conventional steel H-section (ASTM A6 W14"x16"), and the curve b indicates the welding volume in a welded steel H-section (our example) that satisfies the conditions of this disclosure. The "welding volume" is defined as welded cross-sectional area/total cross-sectional area.

[0081] Specifically, the cross-sectional shape in our example has a web height H and a flange thickness t_f equal to those of the H-section with the size of ASTM A6 W14"x16", and a flange width B of 1.1 times the web height H. The web thickness t_w is selected so that the conditions of the formulas (1) to (7) are satisfied and the web cross-sectional area ratio ($t_w \times H/A$) is 20 % or less. The buckling length is set to 8000 mm. The following conditional formulas for the web cross-sectional area ratio can be replaced as follows by the shape indexes of the cross-sectional area, (B/H) , $\gamma(t_f/B)$ and $\delta(t_w/t_f)$.

$$(t_w \times H/A) \leq 0.2$$

$$\delta \leq 1/\{2/(B/H) + \gamma\}$$

[0082] As can be seen from the results in FIG. 5, the welding volume can be reduced to about 1/2 or 1/2 or less by satisfying the above conditions.

[0083] Further, the welded steel H-section is preferably a welded steel H-section made of a steel material having a yield point strength of 385 N/mm² or more. No upper limit is placed on the yield point strength. For example, the yield point strength may be 800 N/mm² or less. The welded steel H-

section is preferably a welded steel H-section made of a steel material having an equivalent carbon content C_{eq} of 0.43 or less. No lower limit is placed on the C_{eq} . For example, the C_{eq} may be 0.3 or more. Moreover, the welded steel H-section is further preferably a welded steel H-section made of a steel material having a yield point strength of 385 N/mm² or more and an equivalent carbon content C_{eq} of 0.43 or less.

[0084] The equivalent carbon content C_{eq} is defined by the following formula. Each element symbol in the formula refers to the content (mass%) of the corresponding element in the steel material.

10
$$C_{eq}(\%) = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15$$

[0085] By constructing a welded steel H-section using a steel material having a yield point strength of 385 N/mm² or more, it is possible to further reduce the sheet thickness while ensuring high strength. For the welded steel H-section made of a steel material having a yield point strength of 385 N/mm² or more, it is preferable to satisfy the following formulas (5') and (6') instead of formulas (5) and (6) above.

$$B/14.8 \leq t_f \leq H/4 \quad (5')$$

$$\max[t_f/3, H/33.6] \leq t_w \leq \min[t_f, t_f \times \delta_{req}(\gamma = 1/14.8)] \quad (6')$$

[0086] Further, by constructing a welded steel H-section with a steel material having an equivalent carbon content C_{eq} of 0.43 or less, it is possible to construct a sound welded portion without weld cracking even without preheating. As a result, the amount of used steel materials can be further reduced.

[0087] Further, by reducing the sheet thickness, the amount of welding in the manufacture of the welded steel H-section can be further significantly reduced. In addition, reducing the amount of welding also reduces the welding heat input, which can further reduce the strain and deformation caused by welding.

[0088] In another embodiment of this disclosure, a flange material and a web material made of a steel material having a yield point strength of 325 N/mm² or more can be joined in an H-shape and welded to manufacture a welded steel H-section satisfying the above conditions. In the manufacturing method, the dimensions of the flange material and the web material to be used may be selected so that the resulting welded steel H-section satisfies the aforementioned conditions.

[0089] In the welding, the angle of a welding torch to a web surface is

preferably set to 40° to 50° .

EXAMPLES

5 [0090] Next, the effects of this disclosure will be described in more detail through some specific examples.

[0091] (Example 1)

FIG. 6 is a graph illustrating the relationship between the buckling length α and the elastic buckling proof stress of a welded steel H-section according to one embodiment of this disclosure. In FIG. 6, the curve b1 (solid line) indicates the elastic buckling proof stress around weak axis, and the curve b2 (dashed line) indicates the elastic flexural-torsion proof stress. The dimensions of the welded steel H-section were H-500 $\times$ 580 $\times$ 30 $\times$ 36.2 mm.

10 [0092] As can be seen from FIG. 6, the flexural-torsional buckling proof stress exceeds the weak-axis buckling proof stress in the welded steel H-section that satisfies the conditions of this disclosure.

[0093] Table 1 lists the total cross-sectional areas, unit weights (weight per meter), and cross-sectional secondary moments of an H-section having a conventional cross-sectional shape (conventional example) and an H-section satisfying the conditions of this disclosure (our example). The H-sections having the cross-sectional shapes listed in Table 1 were adopted as the conventional example and our example. The cross-sectional shape of the H-section of our example was determined to have a buckling proof stress equal to or greater than that of the H-section of the conventional example. The buckling length was set to 8 m.

[0094]

Table 1

	Conventional Example	Example
Web height H (mm)	500	500
Flange width B (mm)	400	580
Web thickness t_w (mm)	40	30
Flange thickness t_f (mm)	70	36.2
Total cross-sectional area (cm^2)	704	548.2
Unit weight (kg/m)	552.6	430.3
Cross-sectional secondary moment around weak axis (cm^4)	74859	117814
Weak-axis elastic flexural buckling proof stress (kN)	24243	38154

[0095] As listed in Table 1, the unit weight of the H-section of our example is about 0.78 times the unit weight of the H-section of the conventional example. In other words, although the cross-sectional shape of the H-section of our example exhibits a buckling proof stress equal to or greater than that of the H-section of the conventional example, our example is about 22 % lighter than the conventional example.

[0096] (Example 2)

FIG. 7 is a schematic diagram illustrating the cross-sectional shape of a welded steel H-section 100 according to one embodiment of this disclosure. The specific cross-sectional shape is H-500 × 580 × 30 × 36.2 mm. As already described, the flexural-torsional buckling proof stress exceeds the weak-axis buckling proof stress in the welded steel H-section that satisfies the conditions of this disclosure (FIG. 6).

[0097] FIG. 8 is a schematic diagram illustrating the cross-sectional shape of a welded steel H-section 100 according to another embodiment of this disclosure. The specific cross-sectional shape is H-500 × 550 × 22 × 36 mm.

[0098] Table 2 lists the total cross-sectional areas, unit weights (weight per meter), cross-sectional secondary moments, and welded cross-sectional areas

of an H-section having a conventional cross-sectional shape (conventional example) and an H-section satisfying the conditions of this disclosure (our example). The H-sections having the cross-sectional shapes listed in Table 1 were adopted as the conventional example and our example. The cross-sectional shape of the H-section of our example was determined to have a buckling proof stress equal to or greater than that of the H-section of the conventional example and a web cross-sectional area ratio of 20 % or less. The groove angle of the welded portion was set to 60°.

[0099]

Table 2

	Conventional Example	Example
Web height H (mm)	500	500
Flange width B (mm)	400	550
Web thickness t_w (mm)	40	22
Flange thickness t_f (mm)	70	36
Total cross-sectional area (cm^2)	704	546
Web cross-sectional area ratio (cm^2)	20.5%	6.5%
Unit weight (kg/m)	552.6	384.8
Cross-sectional secondary moment around weak axis (cm^4)	74859	99863
Weak-axis elastic flexural buckling proof stress (kN)	24243	32340
Welded cross-sectional area (cm^2)	5.61	2.93
Welding ratio	0.010	0.006

[0100] The "welded cross-sectional area" in Table 2 is the total cross-sectional area of welded portions of the welded steel H-section. When the cross-sectional area of one welded portion is A_w , the welded cross-sectional area is $4A_w$ because the welded steel H-section has four welded portions. A_w is calculated based on the introduction described in the "Welding Standard" of the Japan Federation of Construction Contractors. The "welding ratio" in Table 2 is defined as the ratio of a welded cross-sectional area $4A_w$ to a cross-sectional area A of a welded steel H-section, $4A_w/A$.

REFERENCE SIGNS LIST

[0101]	100	H-section (welded steel H-section)
	1	flange
	2	web

CLAIMS

1. A welded steel H-section comprising a steel material having a yield point strength of 325 N/mm² or more and an equivalent carbon content
5 Ceq of 0.43 or less, wherein the welded steel H-section has a longitudinal length L, a web height H, a flange width B, a flange thickness tf, a web thickness tw, α defined as L/(H-tf), β defined as B/(H-tf), γ defined as tf/B, and δ defined as tw/tf which satisfy the following formulas (1) to (8):

$$H \geq 400 \text{ mm} \quad (1)$$

10 $B \geq 400 \text{ mm} \quad (2)$

$$H \leq B \quad (3)$$

$$\alpha \geq 10 \quad (4)$$

$$B/16 \leq tf \leq H/4 \quad (5)$$

$$\max[tf/3, H/37] \leq tw \leq \min[tf, tf \times \delta_{req}(\gamma = 1/16)] \quad (6)$$

15 $1.0 \leq \beta \leq 1.6 \quad (7)$

$$\delta \geq \delta_{req} \quad (8)$$

where δ_{req} is defined by the following formula (9) and $\delta_{req}(\gamma=1/16)$ refers to a value of δ_{req} when 1/16 is substituted for γ :

$$\delta_{req} = (2.58\beta - 1.12) + (17.2\beta^2 - 52.8\beta + 18.0) \times \gamma \quad (9).$$

20

2. The welded steel H-section according to claim 1, comprising a web cross-sectional area ratio of 20 % or less as defined as a ratio of a web cross-sectional area to a total cross-sectional area.

25 3. The welded steel H-section according to claim 1 or 2, comprising a steel material having a yield point strength of 385 N/mm² or more.

4. A method of manufacturing the welded steel H-section according to any one of claims 1 to 3, comprising:

30 joining a flange material and a web material which are made of a steel material having said yield point strength and said equivalent carbon content Ceq into an H-shape; and

welding the flange material and the web material to form the welded steel H-section.