Resilient Structures and Sustainable Construction
Edited by Pellicer, E., Adam, J. M., Yepes, V., Singh, A., and Yazdani, S.
Copyright © 2017 ISEC Press
ISBN: 978-0-9960437-4-8

EXPERIMENTAL STUDY ON H-SHAPED STEEL BEAM WITH CONTINUOUS BRACING SUBJECTED TO END MOMENT

MASAE KIDO[1], MAO LIU[2], KAZUAKI HOKI[1], YOICHI ONOMIYA[3], and KEIGO TSUDA[1]

[1]*Dept of Architecture, The University of Kitakyushu, Kitakyushu, Japan*
[2]*Dept of Civil Engineering and Architecture, National Institute of Technology, Tokuyama College, Shunan, Japan*
[3]*Kyushu Branch Office, Kajima Corp., Fukuoka, Japan*

As for H-shaped beams, concrete floor slab and purlins can be considered as bracing if they have enough stiffness and strength. There are many studies about bracing against lateral torsional buckling. However, the effect of lateral bracing cannot be properly considered in the practical design currently. The purpose of this study is to show the effect of the lateral bracing and vertical stiffener experimentally. The test on the lateral buckling of H-shaped steel beam with a steel plate which is a continuous bracing is carried out. Parameters are the position of bracing and presence or absence of vertical stiffener. The steel plate is welded on the compressive flange or the tensile flange. The vertical stiffener may be considered as the bracing for lateral buckling however the effects of them are not clear. The vertical stiffener is set at the position where the lateral deformation is assumed largest. The lateral buckling and local buckling occurs in the test specimens without bracing and with continuous bracing on the tensile flange. The maximum strength of the test specimen with a vertical stiffener is 5% smaller than that of the test specimen without a vertical stiffener. However, the strength degradation of the test specimen with a vertical stiffener is smaller and the load is 90 % more than the maximum load when the rotation angle is 0.07 rad.

Keywords: Lateral buckling, Bracing, Stiffener, Flexural member, Maximum strength, lateral deformation.

1 INTRODUCTION

There are cases that H-shaped steel beam in buildings needs bracing. As for H-shaped beams, concrete floor slab and purlins can be considered as bracing if they have enough stiffness and strength. There are many studies about bracing for lateral torsional buckling (AIJ 2013, Usami *et al.* 2011). Vertical stiffeners attached at a beam web have influence on the lateral buckling (Matsui *et al.* 2013). However, the effect of lateral bracing cannot be properly considered in the actual design currently. The purpose of this study is to show the effect of the lateral bracing and vertical stiffeners experimentally. The monotonic loading test of the H-shaped steel beam subjected to the end moment is carried out. A steel plate is attached as continuous bracing and vertical stiffeners are attached at the beam web. The effects of the steel plate attached at the compressive beam flange or at the tensile flange and the vertical stiffeners attached at the beam web on the buckling behavior are shown.

2 OUTLINE OF EXPERIMENT

2.1 Test Plan

The lateral buckling test of H-shaped steel beam subjected to the end moment at the one end was planned in order to clear the effect of the continuous bracing on the lateral buckling strength. The loading condition is monotonic loading. The loading condition and the bending moment diagram is shown by Figure 1. The one end of the specimen is fixed and the other end is pinned. Test parameters are the presence or absence of the bracing (steel plate) and the presence or absence of the vertical stiffeners. Table 1 shows the list of test specimens.

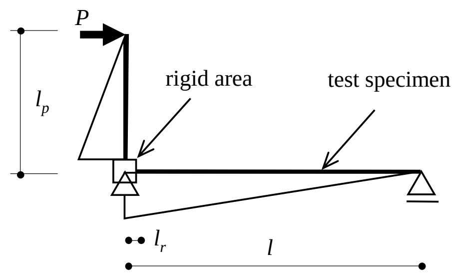

Figure 1. Loading condition and bending moment diagram.

Table 1. Test specimens.

Specimen No.	Steel plate as bracing	Vertical stiffener
No.1	not attached	not attached
No.2	attached at compressive flange	
No.3	attached at tensile flange	
No.4		
No.5		attached

2.2 Test Specimens

Specimens are H-shaped steel members whose size is H-200 x 100 x 5.5 x8. Figure 2 shows the test specimen that has the steel plate as continuous bracing and vertical stiffeners (No. 5 specimen in Table 1). The thickness of the steel plate is 6 mm. Vertical stiffeners are attached in order to examine the effect of them on the bracing for lateral buckling. The steel plate is attached by fillet welding and the welding length is 100 mm and the pitch is 400 mm. Material of the test specimen is SS400 and same lot materials are used in No. 1, 2, and 3 specimens and No. 4 and 5 specimens.

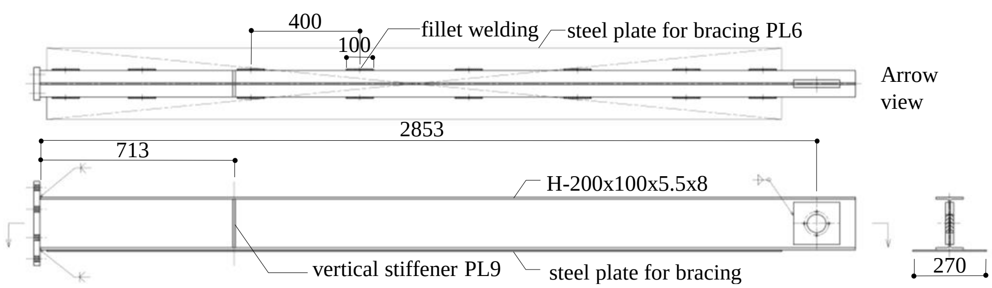

Figure 2. Test specimen No.5.

Table 2 shows the measured thickness and cross sectional amounts. The definitions of notations are listed under the table.

Table 2. Measured thickness and cross sectional different amounts.

	t_w (mm)	t_f (mm)	t (mm)	A (mm^2)	I_x ×10^7 (mm^4)	I_y ×10^6 (mm^4)	i_x (mm)	i_y (mm)	Z_x ×10^5 (mm^3)	Z_{px} ×10^5 (mm^3)	J ×10^4 (mm^4)	I_w ×10^{10} (mm^6)
No.1	5.19	7.55	-	2524	1.72	1.26	82.5	22.4	1.72	1.95	3.76	1.17
No.2	5.19	7.53	5.67	2524 (4043)	1.71	1.26 (10.6)	82.5	22.3 (51.1)	1.71	1.94	3.74	1.17
No.3	5.19	7.53	5.61	2524 (4027)	1.71	1.26 (10.5)	82.5	22.3 (51.0)	1.71	1.94	3.74	1.17
No.4	5.32	7.74	5.57	2585 (4087)	1.75	1.29 (10.4)	82.4	22.4 (50.5)	1.75	1.99	4.06	1.20
No.5	5.32	7.72	5.62	2581 (4098)	1.75	1.29 (10.5)	82.4	22.4 (50.6)	1.75	1.99	4.03	1.19

t_w: thickness of beam web, t_f :thickness of beam flange, t: thickness of plate for bracing, b : width of plate for bracing, A : Cross sectional area of beam and the value between brackets are the summation of H-shaped beam and plate for bracing, I_x : second moment of area around strong axis, I_y : second moment of area around week axis and the value between brackets is for a single cross section composed H-shaped beam and plate for bracing, i_x, i_y : radius of gyration around strong axis and week axis respectively, Z_x : section modulus around strong axis, Z_{px} : plastic section modulus around strong axis, J: St. Venant torsion constant, I_w: warping constant

2.3 Loading Apparatus and Measurement System

Figure 3 shows the loading apparatus. Bending moment occurs at the fixed end of the specimen by pushing the loading column by the 200 kN oil jack. We aimed to make the boundary condition that the deformation, the torsional angle and deflection angle are zero, and the deformation and the torsional angle are zero. However, the torsional angle at the pinned end was not restrained enough to be considered zero in reality.

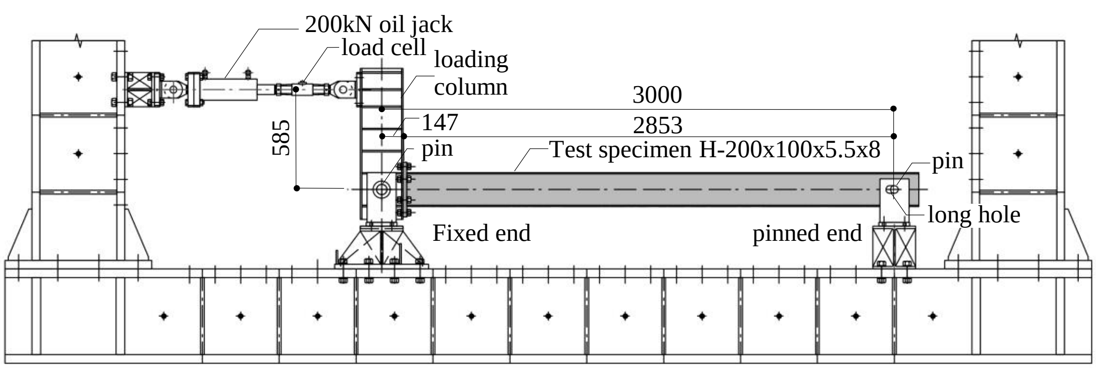

Figure 3. Loading apparatus.

The rotation angle at the fixed end and the lateral displacement of the beam are measured by displacement transducers. Figure 4 shows the measurement method for the lateral displacement. Displacement transducers are connected by wire with the test specimen. Numbers enclosed in boxes indicates the displacement transducer number and there are two displacement transducers for top flange and bottom flange per each number.

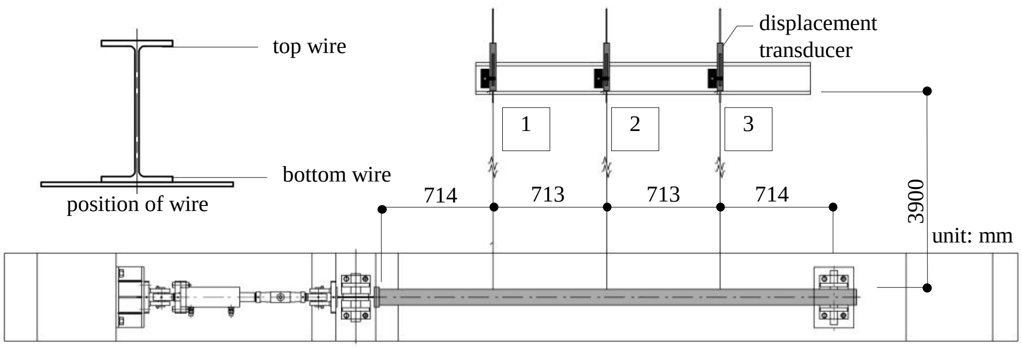

Figure 4. Measurement method of lateral displacement.

3 TEST RESULTS AND DISCUSSION

3.1 Rotation Angle and Load Relationship

Figure 5 shows test results. The left vertical axis is the load *P* shown in Figure 1 and the horizontal axis is the rotation angle at the fixed beam end. The maximum load of No. 1 specimen reached the full plastic moment of the beam 113kN. The maximum load did not reach the full plastic moment of the steel beam with the plate when the steel plate is attached at the tensile flange. Local buckling at the compressive flange and the lateral deformation were observed and the loads decreased because of the local buckling and lateral buckling. Figure 5(f) shows the effect of the vertical stiffener. The load degradation is milder when the vertical stiffeners are attached and the load is 90 % more than the maximum load when the rotation angle is 0.07 rad.

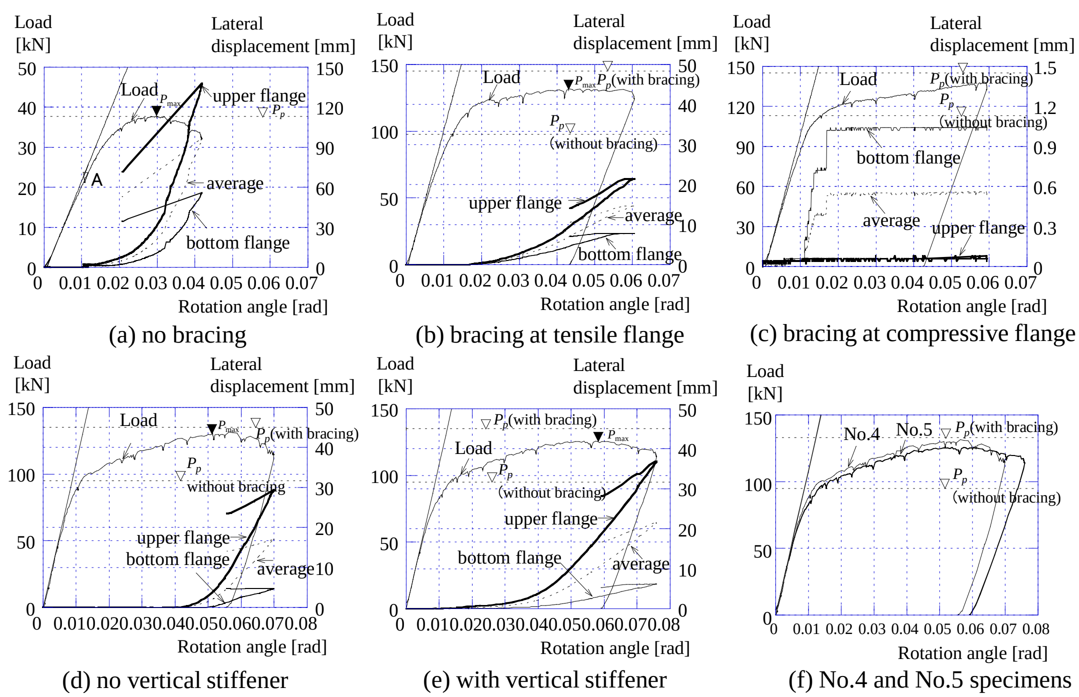

Figure 5. Load and lateral displacement.

3.2 Lateral Displacement and Load Relationship

The right vertical axis in Figure 5 is the lateral displacement. The displacement was measured at the position of No. 1 in Figure 4. According to the figure, the lateral displacement occurred in all specimens except for the specimen with bracing at compressive flange. According to Figure 5(a), when the plate was not attached, the lateral displacement begins to become larger when the rotation angle at the beam end reaches about 0.01 rad. When the rotation angle is 0.01 rad, the beam is considered to be elastic. The torsional deformation of the beam became conspicuous as the lateral displacement increased. Hence, the load decreased because of the lateral buckling although the beam reached the full plastic moment.

When the plate is attached at the tensile flange, the lateral deformation increased after the rotation angle reached 0.02 rad. This value of the rotation angle is smaller than the specimen without bracing, however, the lateral buckling occurred and the continuous bracing at the tensile flange cannot restrain the lateral buckling completely. When the plate is attached at the compressive flange, the lateral deformation rarely occurred (the maximum value is 1.1mm) and deformation of the tensile flange is larger than those of the compressive flange.

Figure 5(d) shows the case of the test specimen that the plate is attached at the tensile flange like Figure 5(b) and it was supposed that the same result should be observed. However, the lateral displacement became increasing when the rotational angle is 0.04 rad. This is the largest rotation angle among all specimens. This is because the rotation angle when the lateral displacement began to occur was larger. Figure 5(e) shows the case of the vertical stiffener is attached. The lateral displacement became increasing when the rotational angle is 0.02 rad same as Figure 5(b).

3.3 Buckling Deformation

Figure 6 shows the lateral displacement of the beam. Lateral displacement of the specimen with bracing at compressive flange was very little and it is not described in Figure 6. The left side of the horizontal axis is the fixed end. According to these figures, the lateral deformation is largest at the position of 713.3 mm from the fixed end. The buckling mode is similar without reference to the bracing.

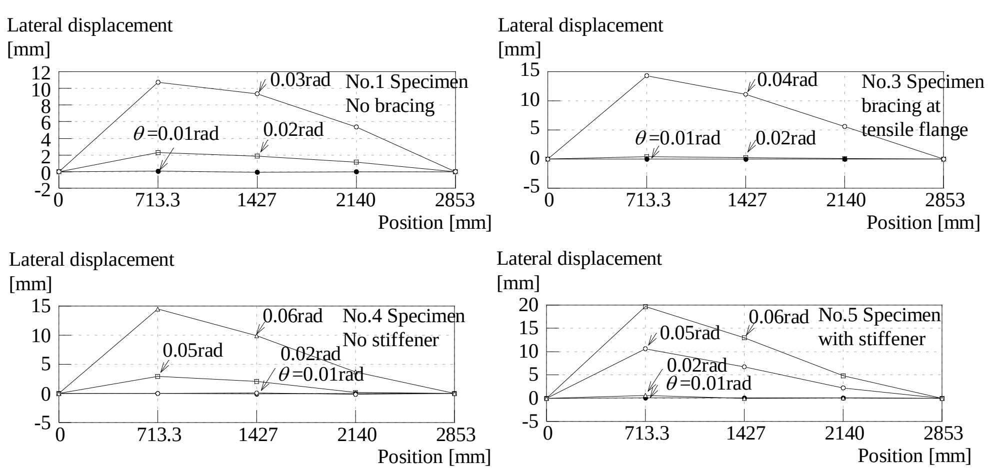

Figure 6. Buckling deformation.

3.4 Strain Behavior Close to the Vertical Stiffeners

In order to examine the factor that the load degradation is milder when the vertical stiffeners are attached, strain behavior is shown in this section. Figure 7 shows the position of strain gauges and the behavior of strain in case of the No.4 and No.5 specimens. According to Figure 7(c), the maximum strain is about 0.048% and this part is elastic although there is residual strain. On the other hand, according to Figure 7(d), the maximum strain is about 0.15% and this part is yielding (the yield strain of beam web is about 0.14% according to the tensile test.). Strain is larger when there are vertical stiffeners and it is supposed that this phenomenon influences on the load degradation after reaching the peak load. However, the strain shows the local strain behavior and further investigation is necessary.

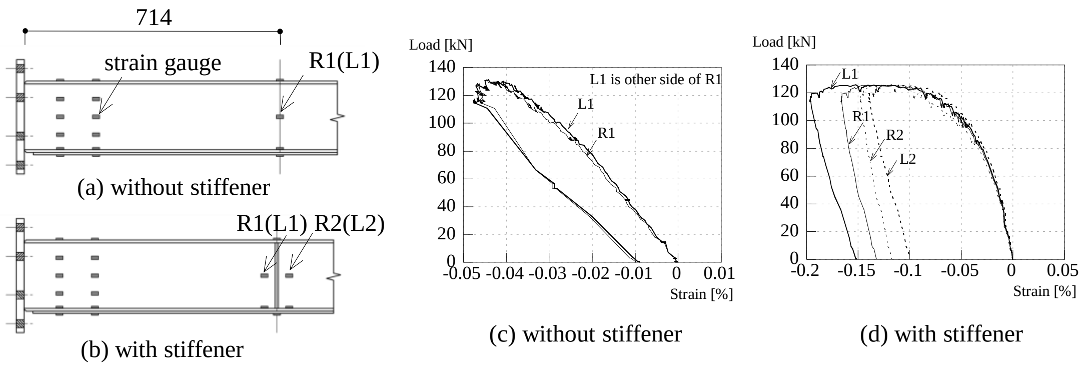

Figure 7. Position of gauges and strain behavior close the vertical stiffener.

4 CONCLUSIONS

In order to obtain the fundamental knowledge about the relationship between the lateral buckling strength of H-shaped steel beam and bracing, the experimental study was carried out. It has become clear that:

1) Lateral deformation occurred when the steel plate was attached at the tensile flange and the continuous bracing at the tensile flange cannot restrain the lateral buckling completely.

2) As for the effect of the vertical stiffeners, the maximum load of the specimen without vertical stiffeners was larger than that of the specimen with vertical stiffeners. However, the load degradation of the specimen with stiffener is milder compared with the specimen without stiffener, and the load is 90 % more than the maximum load when the rotation angle is 0.07 rad.

References

Architectural Institute of Japan (AIJ), *Stability Problems of Steel Structures 2013*, AIJ, 2013.

Matsui, R., Yamaura, Y. and, Takeuchi, T., Lateral Bracing Requirements for H-section Beams with Supports Attached to Top Flange Subjected to Cyclic Antisymmetric Moment, *Journal of Structure and Construction Engineering*, AIJ, 78(690), 1485-1492, August, 2013.

Usami, T., Kaneko H., and Yamazaki K., Studs Effect on Behavior of Lateral Buckling of Composite Steel Beam, *Journal of Structure and Construction Engineering*, AIJ, 77(671), 1773-1779, November, 2011.