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TENSILE BEHAVIORS OF A SIMPLIFIED BEAM NEAR A BEAM-COLUMN CONNECTION WHICH DRIVING-PIN IS INSTALLED IN

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SUMMARY

Mechanical methods have appeared to be an alternative to metallurgical methods in the connection of a structural steel member and a thin steel plate. In this article, we will consider a mechanical connection method instantaneously driven in a structural steel member using the explosive power of gunpowder. The tensile test with mechanical method used in the beam flange near the beam-column connection was conducted to investigate the effect of this mechanical method on the structural steel member. This research supplies the fundamental data to the design criterion of this mechanical method by clarifying the influence of the mechanical method on the tensile property of the structural steel member. When using the driving-pin in the end portion of a beam flange close to a beam-column connection, there was less influence of the driving-pin on the tensile behavior than what was expected. However, when the driving-pin is installed near a beam scallop where stress is concentrated and fracture is expected, it should be considered that there is a possibility to change the fracture line by means of installing the driving-pin.

INTRODUCTION

Metallurgical connection methods, such as stud weld and puddle weld, have been used for a long time to attach a steel beam and a steel deck. Recently, the mechanical connection method has been used as an alternative to the metallurgical connection method. This method uses the explosive power of gunpowder to instantaneously drive a pin to combine a steel deck and a steel beam. The pin and the gun used in this study are shown in Figure 1.

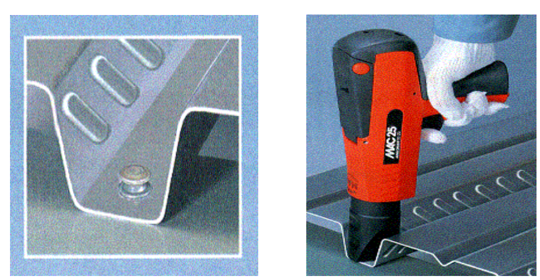

Figure 1. Mechanical Connection Method

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This mechanical connection method has many advantages over metallurgical connection methods. First of all a power supply is unnecessary and there are no concerns about an electrical accident. Also, the mechanical connection method is cordless and so can be used simultaneously in several places. Since this method has an excellent workability, it can be an improvement over the conventional metallurgical connection method. However, the handling of the mechanical connection method takes severe caution. Since the sound at the time of installation is loud, discretion is needed in a quiet place. Above all, when a pin is installed in a steel beam, the cross-section of the steel beam is reduced. Therefore, the effect of the pin on the tensile properties of the steel beam is the focus of this research.

In this article, we will call this mechanical connection method the driving-pin method. The shape and the dimensions of the driving-pin are shown in Figure 2. Presently, regulations related to connection of a steel beam and a steel deck in Japan require that the driving-pin must not be used at the center of a beam flange (right above the beam web), within 15mm from the edge of a beam flange, or within 15mm from a weld. Except for these restrictions, the driving-pin can be fired anywhere; moreover, in the regulations it is not required to take the effect of the driving-pin on the steel beam into consideration.

Through experiments performed at the Yokohama National University in Japan, this research supplies the fundamental data to the design criterion of this mechanical connection method by clarifying the influence of the driving-pin. This paper describes tensile test program on structural steel member with driving-pin installed in them. The steel members used in this research are the SN and SM material of the Japan Industrial Standard (JIS), both of which are excellent in earthquake resistance and weldability. This research focused on using the driving-pin for the junction of a steel beam and a steel deck, however the results could be applied using the driving-pin for the junction of any steel member and any thin metal plate.

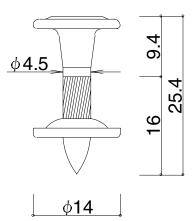

Figure 2. Driving-pin

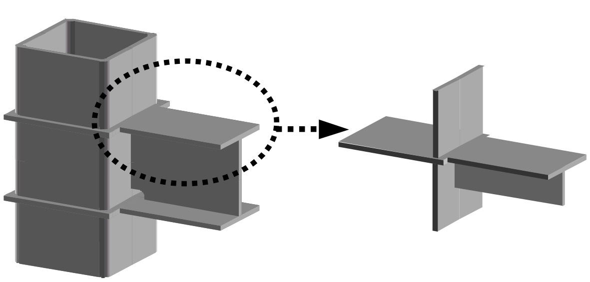

Figure 3. Portion of Simplified Specimen

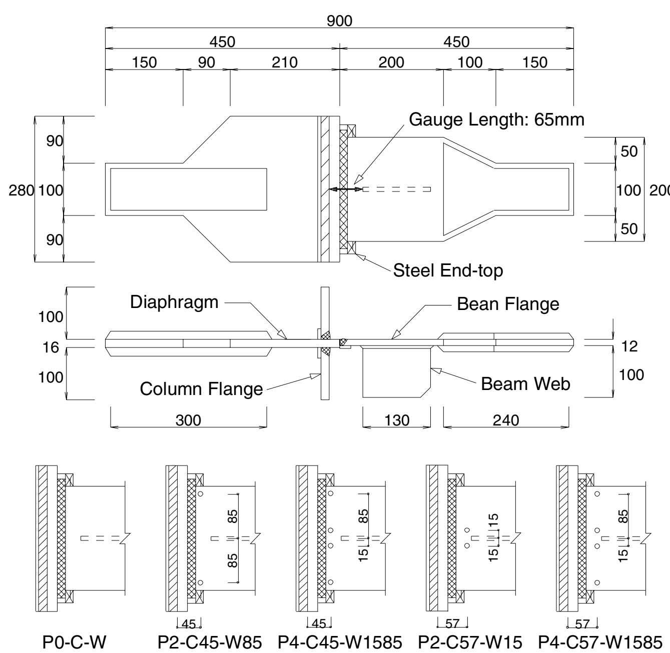

Figure 4. Shapes of Specimen & Placement of Driving-pins

TENSILE TEST PLAN

Development of Beam-Column Joint for Test Specimens

A simplified beam near a beam-column connection is prepared in this tensile test. Call this specimen an end beam simplified specimen. The driving-pins were installed in the end portion of a beam flange close to a beam-column connection; they were installed at that potion because that is where a plastic hinge is initially produced within the beam when it is loaded. The location of the end beam simplified specimen in an actual beam-column connection is shown in the circle of Figure 3. The axial tensile load to the beam flange of the simplified specimen was conducted to reproduce the bending load condition of an actual beam. The scope of this experiment is to investigate the influence of the driving-pin on the tensile behavior of the beam flange.

Test Specimens

The lists of the simplified specimens are shown in Table 1. The dimensions of each simplified specimen and the placement of the driving-pins are shown in Figure 4. The dimensions of the beam and column member used in the simplified specimen assume a building scale of a ten-story structure. The column member is larger than the beam member on the assumption of beam mechanisms. A square tube steel column and a built-up steel wide-flange beam were used in the simplified specimens. The beam-column connection is based on a diaphragm-to-beam welding.

The detail of the diaphragm-to-beam welding connection is shown in Figure 5. A complete joint penetration groove weld (butt weld) was used in the connection of the diaphragm and beam flange. JIS YGW11 of MAG welding solid wire was used in the butt weld and the properties of YGW11 are shown in Table 2. Four weld passes were used in all butt welds. A fillet weld was used in the connection of the beam web and the beam flange. The throat thickness of the fillet weld was 6mm. The scallop portion of beam is terminated with fillet weld.

Table 1. List of Specimens

Name of Specimen	Location of Driving-pin		Number of Driving-pin	Thickness	
	Distance from Column Flange	Distance from Web Center		Beam Flange	Column Flange
P0-C-W	-	-	0	12mm	16mm
P2-C45-W85	45mm	85mm	2		
P4-C45-W1585	45mm	15, 85mm	4		
P2-C57-W15	57mm	15mm	2		
P4-C57-W1585	57mm	15, 85mm	4		

(P0 / P2 / P4) - (C / C45 / C57) - (W / W15 / W85 / W1585)

(1) (2) (3)

(1) : Number of Driving-pin
(2) : Distance from Column Flange
(3) : Distance from Web Center

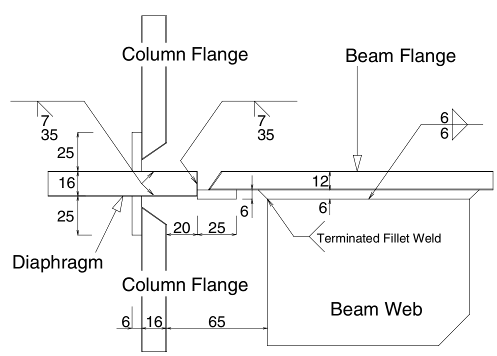

Figure 5. Detail of Diaphragm-to-beam Welding Connection

Table 2. Condition of Butt Weld used in Beam-to-column Connection

Class	Kind of Shielding Gas	Chemical Composition of Wires (%)									Mechanical Properties of Deposited Metal				
											Tension Test			Impact Test	
		C	Si	Mn	P	S	Cu	Mo	Al	Ti+Zr	Tensile Strength (N/mm^2)	Yield Point (N/mm^2)	Elingation (%)	Temperature (°C)	Charpy Absorbed Energy (J)
YGW11	CO_2	≦0.150	0.55 ~1.10	1.40 ~1.90	≦0.03	≦0.03	≦0.50	-	≦0.10	≦0.30	≧490	≧390	≧22	0	≧47

Detail Description of Specimens

Five types of simplified specimens were prepared in order to investigate the effects of the location and number of driving-pins. The driving-pins on the simplified specimens were arranged in two different cross-sections on the beam flange. The first cross-section is the heat-affected zone (HAZ) of the butt weld between a diaphragm and a beam flange. The driving-pin installed on the HAZ section of butt weld is located 45mm away from the surface of column flange. The second cross-section is close to the reentrant corners (scallop) of the beam web; here the driving-pin is installed 57mm away from the column flange. The P0-C-W specimen has no driving-pin in it. The P2-C45-W85 specimen has two driving-pins installed 45mm from the column flange and 85mm from the center of the beam web. The P4-C45-W1585 specimen has four driving-pins installed 45mm from the column flange and at both 15mm and 85mm from the center of the beam web. Both P2-C45-W85 and P2-C45-W1585 specimens have all driving-pins at the HAZ section. The P2-C57-W85 specimen has two driving-pins installed 57mm from the column flange and 85mm from the center of the beam web. The P4-C57-W1585 specimen has four driving-pins installed 57mm from the column flange and at both 15mm and 85mm from the center of the beam web. Both P2-C57-W85 and P2-C57-W1585 specimens have all driving-pins very near the beam scallop.

Measurement

The simplified specimens were subjected to an axial tensile load applied by a 2MN capacity universal testing machine. Two LVDTs with 65mm gauge length were symmetrically placed to measure the displacement of the simplified specimen; here, 65mm was chosen since that was the spacing between the column flange and the beam web. The tensile tests were performed until the specimen completely fractured under the axial tensile load.

Material Properties

The material properties of a steel plate used to specimens are presented in Table 3. One kind of steel material, JIS SN490B, was used in all members (column flange, beam flange, beam web and diaphragm). The steel plate used for the column flange and the diaphragm of the beam-column connection was 16mm thick. The steel plates used for the beam flange and the beam web were 12mm and 9mm thick, respectively.

Table 3. Material Properties of Steel Plates

		σ_y(N/mm^2)	σ_u(N/mm^2)	σ_y/σ_u	Elo(%)
Steel Plate (SN490B)	9mm	399	555	0.72	24
	12mm	369	536	0.69	24
	16mm	434	560	0.78	27

σ_y : The Yeild Strength, σ_u: The Ultimate Tensile Strength, Elo: Elongation Ratio

TEST RESULTS

The values of the tensile properties obtained by the tensile test are shown in Table 4 and the relationships of stress-strain are shown in Figure 6. There are enlargements of both the yielding points and ultimate points below this figure. Here, the stress value is calculated by dividing the strength by the cross-sectional area (again, the area of a driving-pin is ignored). The strain value is calculated by dividing the displacement of the specimen by the gauge length, 65mm, of the LVDTs. The yield stress value is assessed by the 0.2% offsetting method. The ultimate strain indicates the strain value at the ultimate stress. The parenthesized value in each column is a ratio to the value of P0-C-W Specimen. The tests show that all specimens showed deformation value under 10%, and the simplified specimens reached the ultimate load. There are hardly any differences between the tensile properties of the simplified specimens whether the specimen had a driving-pin installed in it or not. The effect of the driving-pin on the simplified specimens was less than expected, even though the driving-pins were installed at a critical portion on the beam near the beam-column connection.

Strength

Although there were a couple of driving-pins in the end portion of the beam flange, the values of the yield stress of four specimens with driving-pins were not smaller at all compared to the specimen with no driving-pins installed (P0-C-W). The values of the ultimate stresses of the specimens having driving-pins were also not smaller in comparison to the P0-C-W specimen--except for the P2-C57-W15 specimen. The value of ultimate stress of the P2-C57-W15 specimen is only 3% smaller compared to the P0-C-W specimen. So, the driving-pin had hardly any effect on the ultimate stress value of the simplified specimens.

Deformation Capacity

However, depending on the location of the driving-pins, the driving-pins did have an effect on the deformation capacity at the ultimate load (ultimate strain) in the simplified specimens. The ultimate strain values of the P2-C57-W15 and P4-C57-W1585 specimens were 20% less than the value for the P0-C-W specimen, whereas the ultimate strain values of the P2-C45-W85 and P4-C45-W1585 specimens were almost the same as the value for the P0-C-W specimen. Therefore, the driving-pin located near the scallop of the beam member has more influence on the ultimate strain value than the driving-pin located at the HAZ of the butt weld. Although the P4-C57-W1585 specimen has two more driving-pins on the same cross-section than the P2-C57-W15 specimen, the ultimate strain value of the P4-C57-W1585 specimen is almost equal to that of the P2-C57-W15 specimen. So, the extra two driving-pins did not impose any influence on the ultimate strain.

Table 4. Tests Results

Name of Specimen	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Ultimate Strain (%)
P0-C-W	356	519	9.0
P2-C45-W85	357 (1.00)	526(1.01)	9.2 (1.03)
P4-C45-W1585	362 (1.02)	530(10.2)	8.7 (0.96)
P2-C57-W15	368 (1.03)	**506 (0.97)**	**7.1 (0.79)**
P4-C57-W1585	363 (1.02)	519 (1.00)	**7.2 (0.80)**

Note: the parenthesized values in each column is a ratio to the value of P0-C-W Specimen

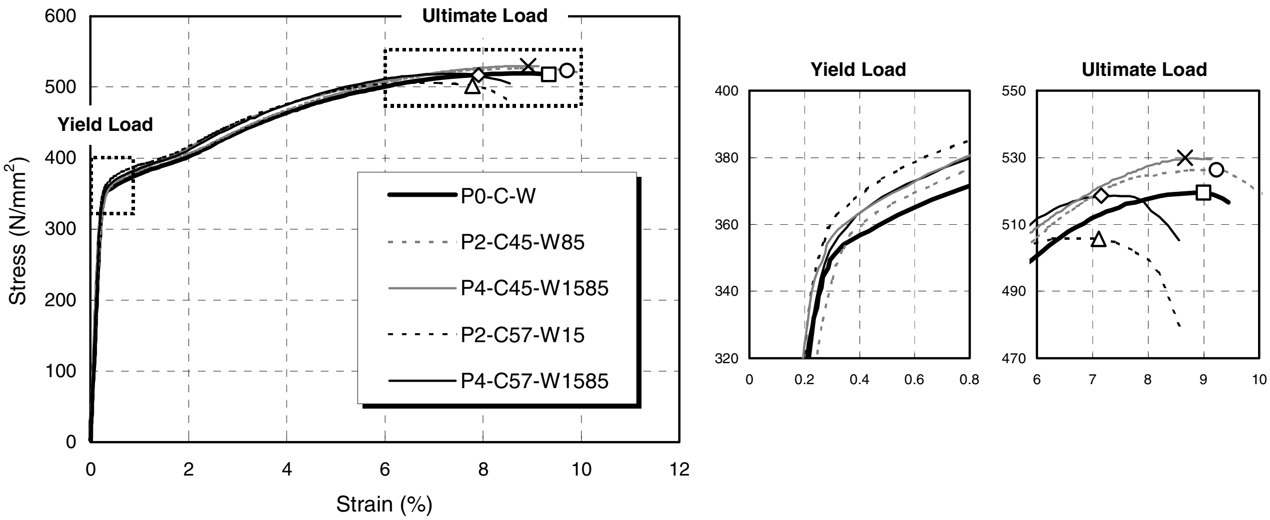

Figure 6. Relationships of Stress-strain

Fracture

The fracture lines based on the pictures of the simplified specimens after fracturing are shown in Figure 7. All specimens, including the P0-C-W specimen, initially fractured on the portion of the beam flange close to the beam scallop, and then the fracture moved to the edges of the beam flange. There were two kinds of fracture lines in the five simplified specimens. First, fracture lines originating from the beam flange close to the beam scallop propagated horizontally and then terminated at the same cross-section containing the driving-pins. Three types of specimens, the P0-C-W, P2-C57-W15, and P4-C57-W1585

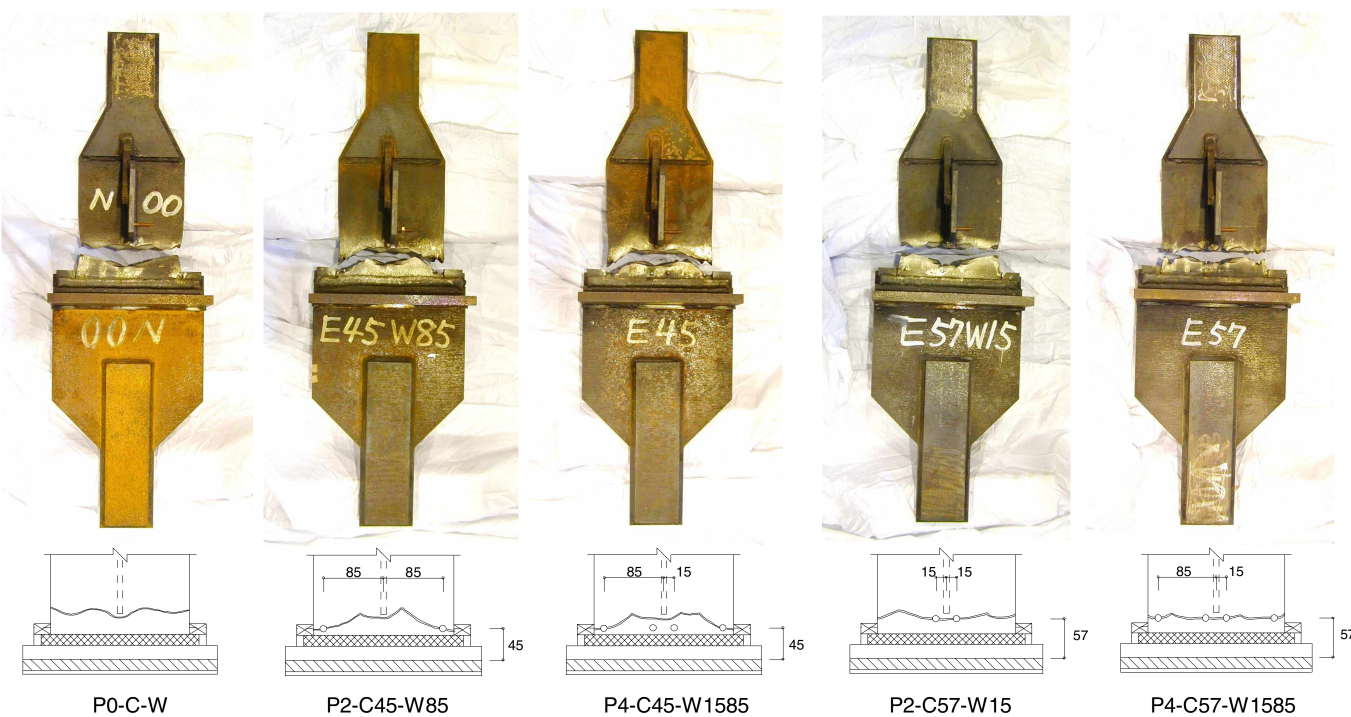

Figure 7. Simplified Specimens after Fracturing with Fracture Lines

specimens, displayed this first type of fracture line. Second, fracture lines originating from the beam flange close to the beam scallop propagated to the driving-pin near the end-top of the butt-weld and then terminated at the end-top. Two types of specimens, the P2-C45-W85 and P4-C45-W1585 specimens, displayed the second type of fracture line. All fracture lines in the five simplified specimens passed through the driving-pins except for the P4-C45-W1585 specimen. This result shows that in this specimen the strain concentration of the beam scallop was larger than the strain concentration of the driving-pin for the simplified specimen. In general, however, the test results show that the location of the driving-pins on the beam flange can possibly change the fracture line. To conclude, if the driving-pin is used in a region of high strain (such as a beam flange close to beam-column connection) and if it is contributes to the strain flow, then the driving-pin has an effect on the fracture line of the beam flange.

CONCLUSIONS

The geometrical condition of a structural steel member should be considered when installing the driving-pin in it. When using the driving-pin in the end portion of a beam flange close to a beam-column connection, there was less influence of the driving-pin on the tensile behavior than what was expected. The tests also showed that the specimens with the driving-pins had similar yield stresses and only slightly smaller ultimate stresses and deformation capacities compared to a specimen without the driving-pins. However, when the driving-pin is installed near a beam scallop where stress is concentrated and fracture is expected, it should be considered that there is a possibility to change the fracture line by means of installing the driving-pin.

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