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EXPERIMENTAL STUDY ON STRENGTH AND DEFORMATION CAPACITY OF REINFORCED CONCRETE COLUMNS AND STEEL BEAMS STRUCTURE JOINT

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SUMMARY

The purpose of this paper is to propose a formula to represent the shear strength of the joint, by clearly identifying, through experiments, the factors which may contribute to the shear strength of the joint. In this project, the joint is designed to be used for the mixed construction of a reinforced concrete column and a steel structure beam (RCS construction) and is composed of webs with opening, cover plate, face-bearing plates (FBP) and triangle stiffeners. The primary experimental factors are plate thickness of joint components and opening size in web. As a result of the experiment, it is known that the force borne by the in-joint concrete increases according to the size of the in-web opening. Paying attention to this, we hereby established a formula cumulating the shear force of the concrete and that of the web, including the size of the web opening as a coefficient. The results obtained from this formula agreed well with the experimental values.

INTRODUCTION

In recent years, rationalization of construction methods has been sought most earnestly in the building industry. With such circumstances, the mixed construction is one of prospective methods. With the mixed construction, it is possible to create a rational structural configuration and a free space through combination of the merits of simple constructions. Among various types of mixed constructions, there are already many studies on the one which consists of the reinforced concrete column (RC structure) and with the steel structure beam (S structure).

Authors considered as a most noteworthy solution the configuration of a through-column type joint as shown in Fig. 1; this joint is composed of an inside web with opening, cover plates, FBPs and triangle stiffeners. In this project, the web is provided with an opening, as a merit enabling the concrete to fill fully and to ensure excellent integrity.

This paper intends to propose a new model to determine the shear strength of the joint as described above; in this project, the gradual static loading test was implemented for a column-beam joint of crucifix type, taking the main components (web and cover plate) of the joint as primary experimental factors, in order to understand the effect which the web geometry and the cover plate may exert on the shear force and deformation capability of the column-beam joint.

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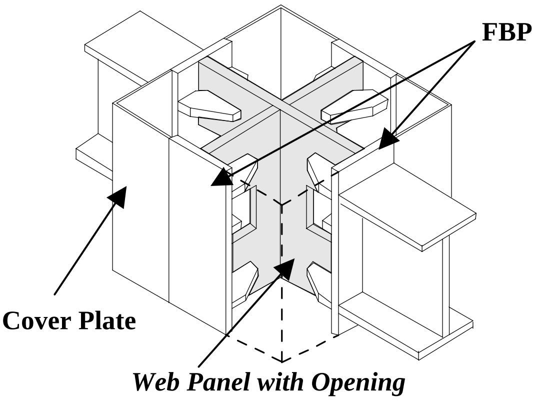


Fig .1 Details of Beam – Column Joint

Table 1 shows the specifications of the test specimen, Fig. 2 the geometry of the test specimen and Fig. 3 the details of steel structures of Test Specimen Nos. 1, 3 and 7.

The test specimen scaled at 1/2.5 totals 8, which respectively use the column and the beam of the same cross-section, the same span and the same story height. The joint consists of cover plates, FBPs, triangle stiffeners and webs with opening. The geometry of the joint can be divided into two kinds; the first is of type with the web with opening and the second of type in which the upper portion is separated from the lower portion. Here, as shown in Fig. 4, the opening in the web is defined in percentage. The experiment used three kinds of webs with 50%, 80% and 100% openings. The experiment was implemented twice.

The experimental factors used are failure type, opening ratio of the web, web geometry, thickness of cover plate, presence and non-presence of transverse stiffener. The experimental factors of each test specimen are shown in Table 1. Test Specimen No. 1 was to be used as standard for comparison with other test specimens. Test specimens after Test Specimen No. 1 used the model of joint-shear failure type.

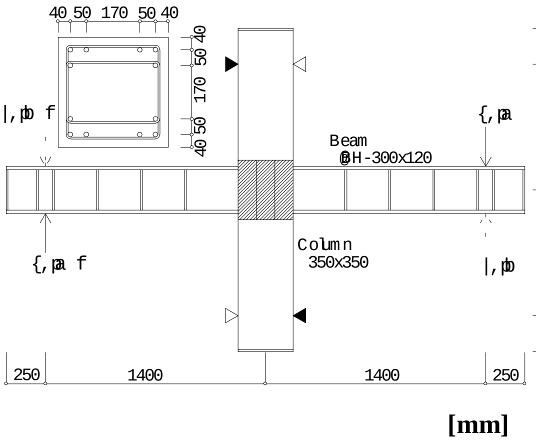


Fig . 2 Dimensions and Details of Test Specimens

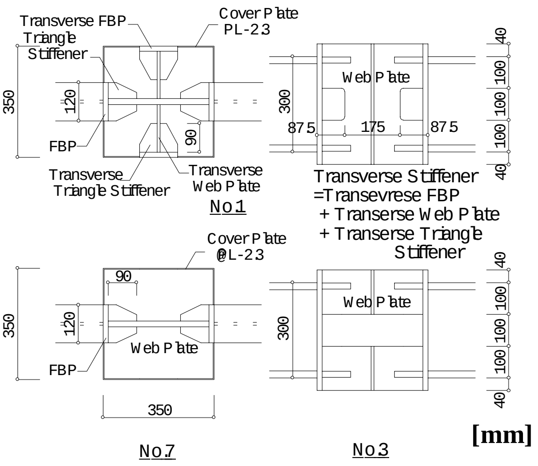


Fig . 3 Geometry of Beam-Column Joint

The axial force of the column is set at a constant value (0.2 Bc Dc $\sigma_{\square}$). The following loading histeresis are used; interlayer deformation angles R= ±0.5%, ±1.0%, ±0.5%, ±2.0%, ± 3.0%, ±4.0%. The first histeresis (R= ±0.5%) is given once, and the next ones are repeated twice. In each of the cases, the interlayer deformation angle of 15% was applied at the end of the loading.

EXPERIMENTAL RESULTS

Relationship between shear force and deformation

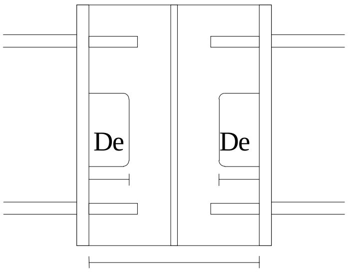
In Fig. 4 (a) to (f), the shear force is converted to the average shear stress, which is made dimensionless by dividing it by the concrete strength to show the relationship between this dimensionless stress ratio and the interlayer deformation angle as envelope (hereinafter relationship of $e\tau u/\sigma_0$□R). This intends to remove the effect of the concrete strength. Here, the effective cross-section in determining the average shear force of the joint is taken at the product of the average of column and beam widths and the total height of the column. The following section discusses comparison of histeresis according to the experimental factors used.

Influence of the opening and geometry of the web

From now on, we examine the influence of the opening ratio of the web on the shearing strength. As shown in Fig. 4(a), in Test Specimen Nos. 1, 2 and 3 with transverse stiffener, there is no significant difference in hysteresis characteristics, and they behaved in almost the same manner even with changed opening ratio. On the other hand, as shown in Fig. 7(b), in the case of Test Specimen No. 7 and Test Specimen No. 8 with no transverse stiffener, the latter generally exhibited a smaller strength due to the influence by the opening ratio. However, when they are compared in terms of the maximum strength, Test Specimen No. 8 exhibits approximately 85% of Test Specimen No. 8, and this amount cannot be said to be proportional to the area of the web (the area of Test Specimen No. 8 is 40% of the area of Test Specimen No. 7).

Table 1 Specifications of Test Specimen

Specimen Name	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8
Experimental Factors	Basic Type	Opening Web Ratio			Cover Plate		Transverse Stiffener	
Opening Ratio of Web (%)	50	80	100	100	50	50	50	80
Joint								
Web Panel (mm)	19			28×95	19			
Yield Strenguth (kgf/cm^2)	3345			3575	3345			3735
Transverse Stiffener (mm)	9						None	
Yield Strenguth (kgf/cm^2)	3705						———	
Cover Plate (mm)	2.3				None	6	2.3	
Yield Strenguth (kgf/cm^2)	4840				——	4550	4840	3585
FBP (mm)	16							
Yield Strenguth (kgf/cm^2)	3540							4280
Beam (BH-300×120×22×9)								
Flange (mm)	22							
Yield Strenguth (kgf/cm^2)	3580							3720
Web (mm)	9							
Yield Strenguth (kgf/cm^2)	3705							3900
Column (350mm×350mm)								
Reinforcement Bar	12-D19							
Yield Strenguth (kgf/cm^2)	7315							7070
Shear Reinforcement Bar	4-D10@50							
Yield Strenguth (kgf/cm^2)	8120							7415
Concrete Strength (kgf/cm^2)	343	345	294	294	350	350	359	346



Opening Ratio of Web (%)=2De/Dw

Fig .3 Definition of Opening Web Ratio

On the other hand, Fig. 4(c) demonstrates that there is some influence when the geometry of the web is changed, because when comparison is made at 100% opening ratio between Test Specimen No. 6 whose the geometry of the web is changed and Test Specimen No. 7, the latter demonstrates a slightly lower strength, exhibiting the influence from the changed web geometry.

Influence of the cover plate

We review the influence of cover plates in Fig .4(e). In the case of Test Specimen No. 5, there is no cover plate; this test specimen, as a general trend, exhibits a more dominant slipping characteristic in hysteresis than Test Specimen No. 1 , and the strength becomes smaller, but there has been no significant strength decline to the end of the loading. In the case of Test Specimen No. 6 which is provided with PL-6 cover plate demonstrates an about 11% larger strength than Test Specimen No. 1. This means the hysteresis of Test Specimen No. 6 has a large capacity of absorbing energy. Among the test specimens of this experiment, the strength of Test Specimen No. 6 is the largest. From theses results, we can conclude that the cover plate has a notable effect on the hysteresis, and the use of cover plates with large thickness enables to improve the shear force and the hysteresis.

Influence of Transverse Stiffener

Figs. 4(e) and (f) are provided to examine the influence of transverse stiffener through comparison between Test Specimen Nos. 1 and 7 with 50% web opening and Test Specimen Nos. 2 and 8 whose opening of the web is

80%. As a general trend, the strength does not depend on the opening of the web, but does on the presence of transverse stiffener. Among others, Test Specimen No. 8 with 80% opening is suffering no noticeable decrease in strength, after having reached the maximum strength. Furthermore, in the case of the test specimen with no transverse stiffener, swelling of the cover plate was observed at R = 3.0% in the course of its failing process. These facts demonstrate that transverse stiffener work well in preventing the concrete and cover plate from swelling, and serves effectively to maintain the strength after passing its peak.

Distribution of shear stress in the joint steel material

In Figs. 5 and 6, is shown the distribution of shear stress in the joint steel. Steel stress is calculated by the use of a three axial strain gauge which is applied to the steel plate, under Von Mises's yielding conditions. The shear-yielding strength is taken at the value given by dividing by $\sqrt{3}$ the yield strength obtained from uni-axial tensile test of steel material. Here, when determing shear stress, τw stands for the web and τo stands for the cover plate and FBP. The legends used in Fig. 5 are common with those in Fig. 6.

Fig. 5 shows distribution of shear stress in the web of Test Specimen Nos. 1, 5. At each specimen, measurement positions B and C which are located at the center yields respectively at R = 1.5%. At measurement positions A and D, the share stress does not exceed τw = 1500kgf /cm2. Trend of shear stress at the positions A and D is the same in each of test specimens. The shear stress distribution representing the whole web is of a parabola type.

FORMULA OF THE ULTIMATE SHEAR STRENGTH FOR THE JOINT

Study on the formula of the ultimate shear strength for the joint

From the experimental results, the influences of the factors that work on the joint are summarized as below;

1) At the comparison between the test specimen with 100 % web with opening and that with 50% web with opening, there is almost no difference in the shear strength of the joint.

2) The presence of transverse stiffener tends to enhance shear strength of the joint. Especially when the web opening is large, the presence of transverse stiffener exhibits a significant influence.

3) The larger is the cover plate's thickness, the higher is the shear strength of the joint.

4) For the cover plate and FBP, no yielding occurs.

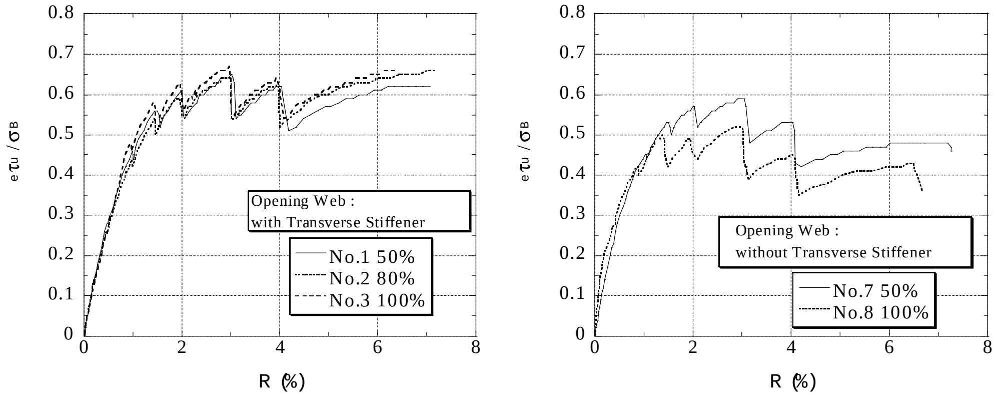
From the results thereof, transverse stiffener and cover plate are a primary factor which may exert effect on the shear strength of the joint. Considering the fact that the web yielded due to shear, the web itself may work on the shear strength of the joint. If the sectional area of the web becomes smaller, we generally think that the shear strength of the joint decreases according to the reduction in the sectional area of the web. As shown at item 1) as an experimental result, the web has no direct effect, the shear strength of the joint behaves independently from the presence of the web. This phenomenon seems to result from the fact that the change in the opening ratio of the web leads to changes in the load borne by the other elements than the web, therefore the opening ratio of the web should be considered to be one of the influential factors.

In this paper, the formula of the shear strength of the joint is evaluated referring to the sum of the force borne by the steel component and that of the concrete component. This is a cumulative formula assuming that each shear force-bearing portion will yield. From this, evaluation should be implemented excluding the web which did not yield at the maximum strength. We hereby propose a formula to represent this relationship

$$calQp = Kc \cdot Ac \cdot 0.3\sigma B + Kw \cdot As \cdot w\sigma y / \sqrt{3} \qquad (1)$$

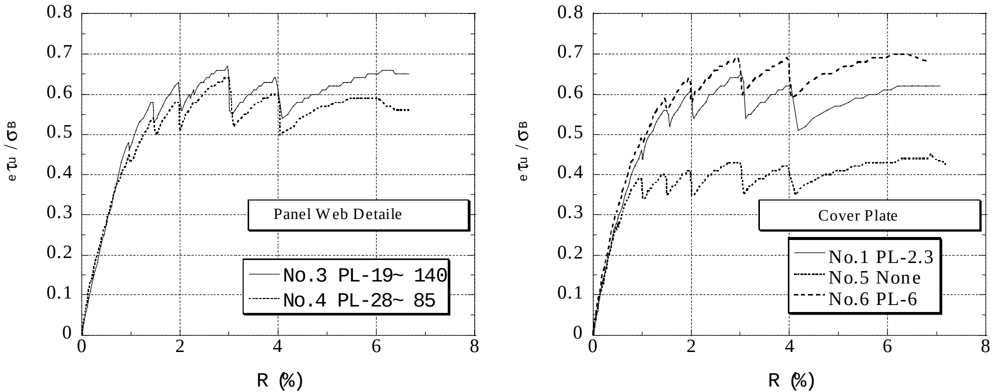
where

calQp = Calculated value of the ultimate shear strength for the joint
Kc = Constraining coefficient of the cover plate
Ac = Effective sectional area of the concrete
[column width + beam width]/ 2 x column width
0.3σB = Shear force of the concrete
Kw = Effective section factor of the web
As = Sectional area of the web (see Fig.4)
wσy = uni-axial tensile yielding stress of the web



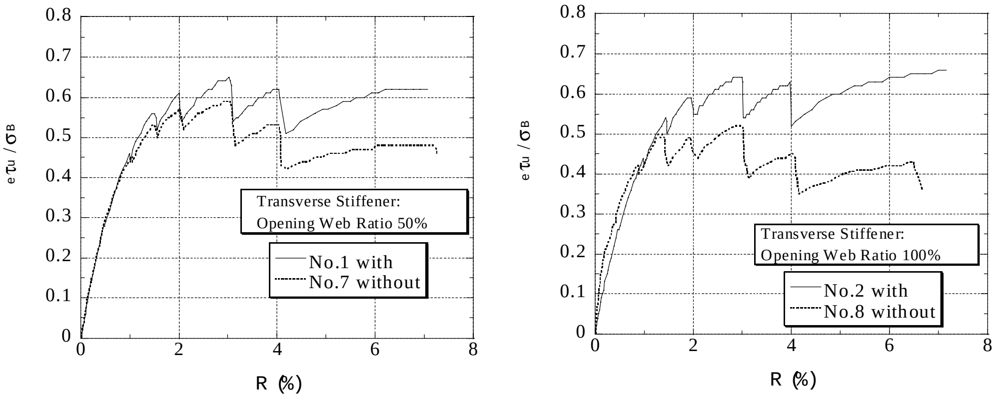
(a) Effect of Web with opening

(b) Effect of Web with opening



(c) Effect of Web Panel Detail

(d) Effect of Cover Plate



(e) Effect of Transverse Stiffener

(f) Effect of Transverse Stiffener

Fig . 4 Envelope Curve of Hysteresis

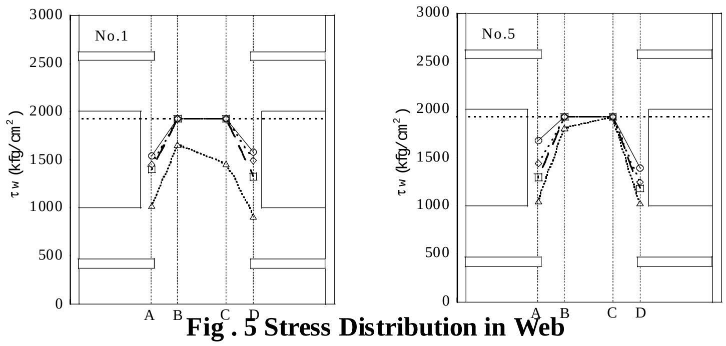


Fig . 5 Stress Distribution in Web Panel

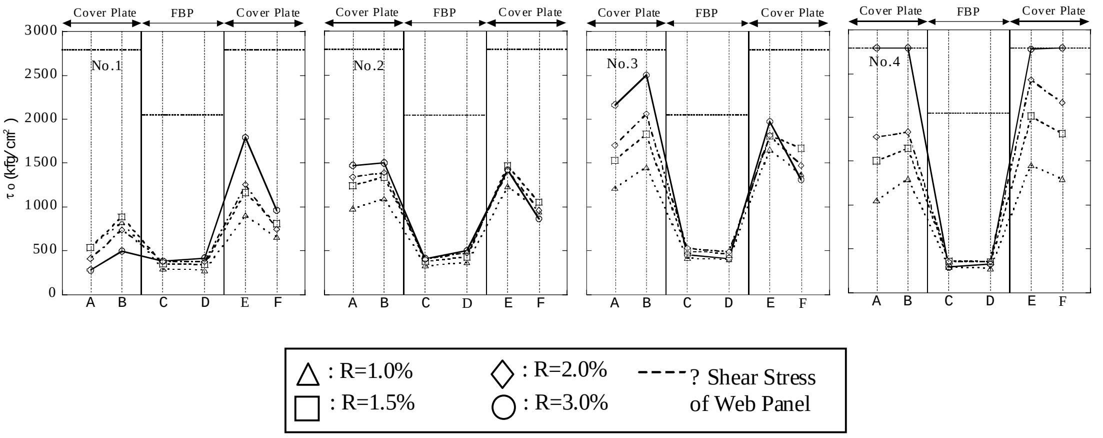


Fig . 6 Stress Distribution in Cover Plate

The formula proposed here is designed to evaluate the constraining effect of the cover plate for the term of concrete, and for the term of web, to evaluate the effective factor relating to the shear yielding field, because the experimental result demonstrates a parabolic distribution of shear stress.

Effective section factor of the web Kw

The effective section factor of the web Kw is expressed by the following formula, using the experimental shear force,

$$Kw=Qw / (As\ w\sigma y \sqrt{3}) \qquad (2)$$

where

Qw = experimental value of the web (Qw is determined by integrating the parabola-formed shear stress distribution).

Fig. 7 shows the effective section factor calculated for each of test specimens Nos. 3 and 4 whose the opening ratio of the web is 100%. Since Kw is about 0.785 on average, the effective section factor of the web is set at Kw=0.8.

Constraint coefficient of the concrete cover plate Kc

In order to examine this constraint coefficient Kc of the cover plate constraining the concrete, the following formula is used

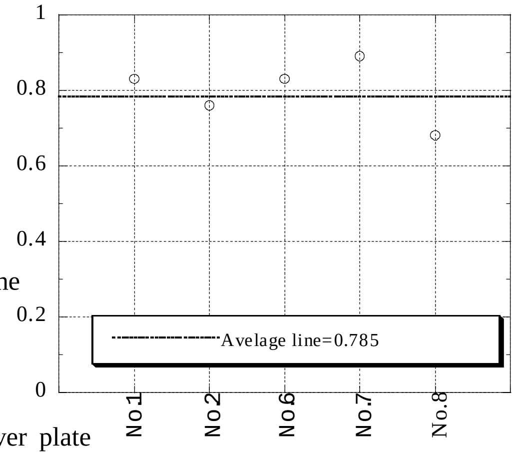


Fig .7 Effective Web Section Factor Kw

$$Kc = (expQp-Qw/(Ac\ 0.3\sigma_B) \qquad (3)$$

where

expQp = experimental value of the maximum shear strength at the joint.

Fig. 8 shows the relationship between the calculation value of Kc and the opening ratio of the web. The mark ○ represents a test specimen with transverse stiffener and cover plate and the mark □ represents the test specimen with without transverse stiffener. The dotted line in the figure is the approximation line for the samples with transverse stiffener and the double dot-dash line is the approximation line for the samples without transverse stiffener.

From this figure, we can know that the larger is the opening ratio of the web, the stronger is the constraint force, independently from the presence of transverse stiffener. With regard to transverse stiffener, their influence becomes larger according to the opening ratio of the web.

Fig. 9 shows the relationship between the presence of the cover plate and Kc. In comparing the joint with PL-2.3 cover plate with the joint without cover plate, Kc of the former decreases by around 40%. In the case of the joint using the PL-6 cover plate. Kc is approximately 10% larger than the joint with PL-2.3. The effect of the cover plate exhibits a qualitative trend, but needs no quantitative evaluation, therefore the evaluation of the cover plate in terms of the thickness is not conducted.

The constraint coefficient of the cover plate which is determined by each approximation line is shown below;

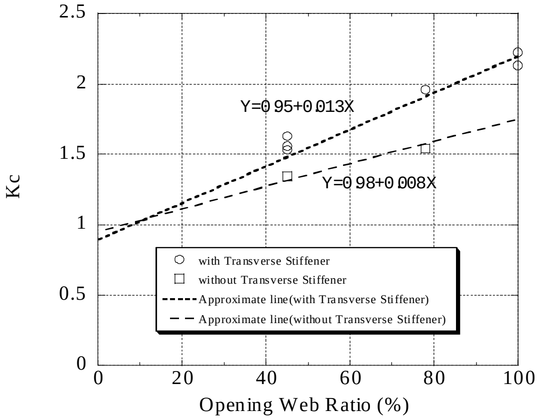


Fig .8 Kc and Web with opening Panel Ratio

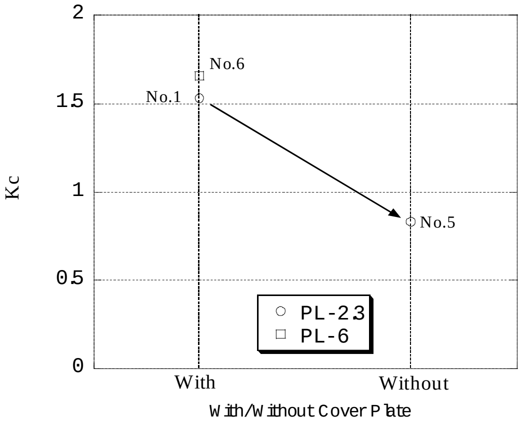


Fig .9 Relationship between Kc and Cover Plate

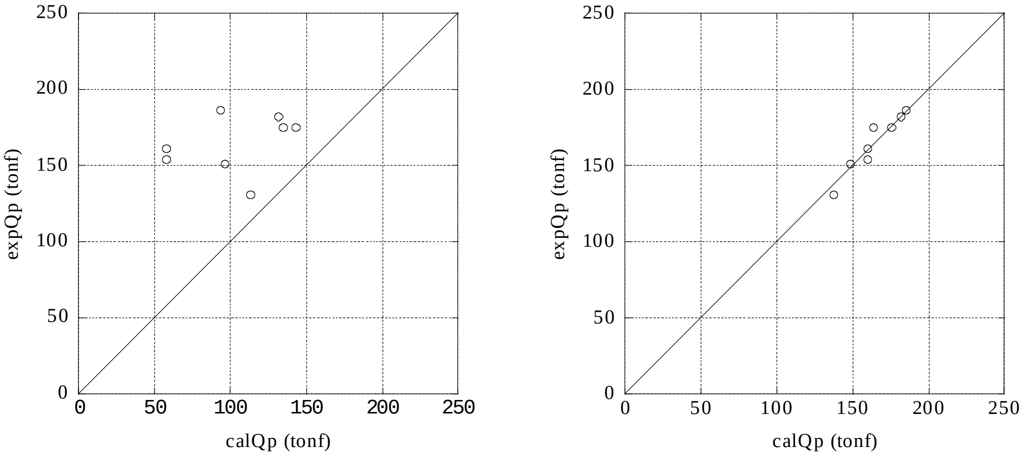


Fig .10 Calculation Value and Experimental Value of Shear Strength of Joints

$$Kc=1.0+1.3\alpha\beta \qquad (4)$$

where

α = opening ratio of the web/100 (see Fig.4)

β = 1 with transverse stiffener, 0.6 without transverse stiffener.

Shear strength of the joint, calculation value vs. experimental value

Fig.10 demonstrates comparison between calculation value and experimental value of the shear strength of the joint, according to the formula proposed by JCI [1] and that proposed by this paper.

In JCI’s formula, the calculation value is considerably smaller than the experimental value in most of the test specimens. This is due to underestimation of concrete-bearing force. The formula presented here exhibits good agreement in the case of the presence of transverse stiffener and even if the opening ration of the web is changed.

CONCLUSION

Concerning the joints studied in this paper, it is known that the opening ratio of the web exerts a significant effect on the shear strength of the joint, and the effect FBP gives to the joint is proportional to the opening ratio of the web. Considering these findings, we proposed a formula to represent the shear force of the joint considering the opening ratio of the web, and it is confirmed that the formula is able to exhibit good agreement with the experiment.

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