HYSTERETIC CHARACTERISTICS OF BEAM-TO-COLUMN CONNECTIONS IN STEEL REINFORCED CONCRETE STRUCTURES

by

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SUMMARY

Parametric experimental study is carried out on the shear behavior of interior, exterior and coner beam-to-column connections in steel reinforced concrete frames subjected to monotonic and alternately repeated loading. 30 specimens which are designed so as to prevent flexural and shear failure of beam and column elements are tested. The effects of the ratio of beam width to column width on the behavior of connections are investigated. It is indicated that the ultimate shear strength of concrete in panel zone of exterior and corner connections is considerably smaller than that of an exterior connection and that hysteresis loops can be well predicted theoretically.

INTRODUCTION

The elastic-plastic behavior of structural frames is strongly affected by that of beam-to-column connections under strong earthquake, in particular, when the connection is not strong enough. Therefore, it is important to clarify the ultimate load carrying capacity and deformability of a beam-to-column connection and efficiency of various type of practical compositions of a connection panel under earthquake load. A semi-empirical formula to estimate the shear capacity of composite interior beam-to-column connection was proposed first by Yokoo, Wakabayashi and Suenaga [1] in 1967. The current recomendation in the commentary on AIJ specification [2] with respect to the shear strength of composite connection is based on this formula. On the other hand, very little information is available on the behavior of composite exterior and corner beam-to-column connections. Furthermore very few researches on the deformation characteristics of composite connection have been conducted in any cases of interior, exterior and corner connections.

TESTING PARAMETERS

Dimensions of the test specimens and the method of loading are shown in Fig. 1. The cross section of a column and that of a beam are shown in Fig. 2. Column cross section is identical for all of 30 specimens. The ratio of beam width B_b to column B_c chosen was 0, 0.6, 0.8 and 1.0, where $B_b/B_c = 0$ indicates that the adjoining beam was made of bare steel.

FAILURE MECHANISM AND ULTIMATE SHEAR CAPACITY OF CONCRETE PANEL

Examples of crack pattern around the connection panel at the final state of the test are shown in Fig. 3. The patterns of the crack initiation and growing clearly show the difference of the failure mechanism of each specimen.

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Fig. 4 shows the relationships between the ratio of nominal ultimate shear stress of concrete panel to compressive strength of concrete τ_u/F_c and the ratio of beam width to column width B_b/B_c, under monotonic and repeated loading. Nominal ultimate shear stress ratios are in the range of (0.20 - 0.45), (0.13 - 0.26) and (0.12 - 0.24) for interior, exterior and corner connections, respectively. Ultimate shear capacities of concrete panel increase as the ratio of beam width to column width increases and ultimate shear capacities of exterior and corner connections are considerably smaller than that of interior connection. The reason why concrete in the panel zone of the exterior and corner connection has rather smaller load carryng capacity lies in the fact that complete formation of diagonal compression field by concrete struts can not be expected after diagonal cracks have taken place, as shown in Fig. 3, because sufficient ability of adjacent members to support the reactions from concrete struts in diagonal compression field could not be expected. Further quantitative examination on the ultimate shear capacity of concrete in exterior or corner connection is required, since the formation of diagonal compression field is affected by the arrangement of main reinforcements in panel zone.

HYSTERETIC CHARACTERISTICS OF COMPOSITE CONNECTION

Examples of hysteresis loops for the interior, exterior and corner connections under repeated loading are shown in Fig. 5. It is observed in the figure that hysteresis loops show spindle-shapes distorted to reversed-S shapes and that the deterioration in load carrying capacity is relatively small. Fig. 6 shows a mathematical model to estimate the hysteretic inelastic response of a composite corner connection failing in shear. It is composed of four fundamental elements, they are (a) web panel of encased steel, (b) rigid frame composed of four flange elements surrounding the web, (c) concrete panel zone surrounded by steel flanges and (d) reinforced concrete panel element with width equal to the sum of the distance from a tip edge of steel flange to a side surface of adjacent beam, in both sides. Hysteresis loops of the panel zone can be obtained by summing values of load in hysteresis loops of the individual elements which compose the panel zone. Fundamental element (c) is replaced to an equivalent concrete strut under compression whose effective width is determined from the failure mechanism of surrounding frame fully plastified by the reactions of the concrete strut in which the compressive strength of concrete is maintained.

Comparison of the theoretical results with experimental ones are shown in Fig. 7. In the figures, solid lines and dashed lines denote the theoretical hysteresis loops and experimental ones in the first cycle of loading in each deformation amplitude, respectively. The theoretical curves well predict the experimental ones. Particularly, the maximum load carrying capacity and recovering in stiffness due to closing of cracks are well predicted by the theory, except sudden change in stiffness in the loop. Since strain hardening and Bauschinger effect of steel and deterioration in load carrying capacity and in stiffness of equivalent concrete strut have not been taken into account in this analysis, further refinement is expected.

CONCLUDING REMARKS

From the results presented above, the following conclusions can be drawn.

(1) Nominal ultimate shear stress of concrete in panel zone of exterior and corner connections is considerably smaller than that of an interior connection.

(2) Nominal ultimate shear stress of concrete in panel zone increases, as the ratio of beam width to column width increases, in all cases of interior, exterior and corner connections.

(3) Hysteresis loops of connections under cyclic loading can be well estimated theoretically using the proposed simple model. Strain hardening and Bauschinger effect of steel and deterioration of load carrying capacity of concrete should be taken into consideration to improve the method of analysis.

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References

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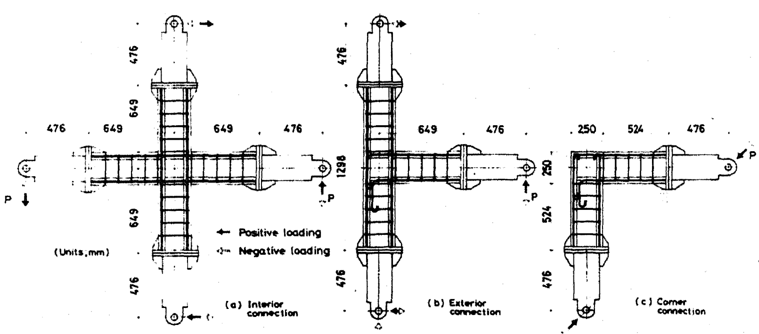
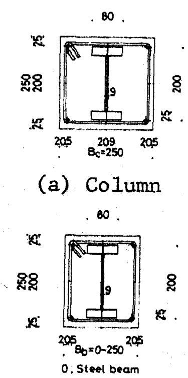


(a) Interior Connection (b) Exterior Connection (c) Corner Connection

Fig. 1 Dimensions of Test Specimens. (Units; mm)



(a) Column

(b) Beam

Fig. 2 Cross Sections. (Units; mm)

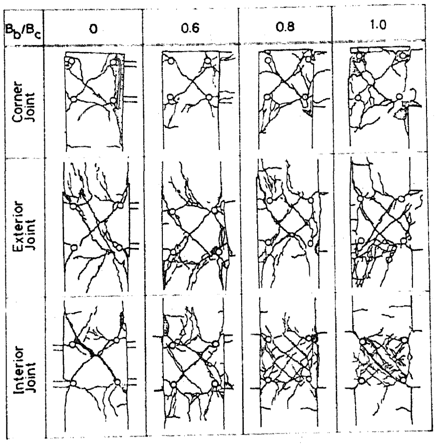
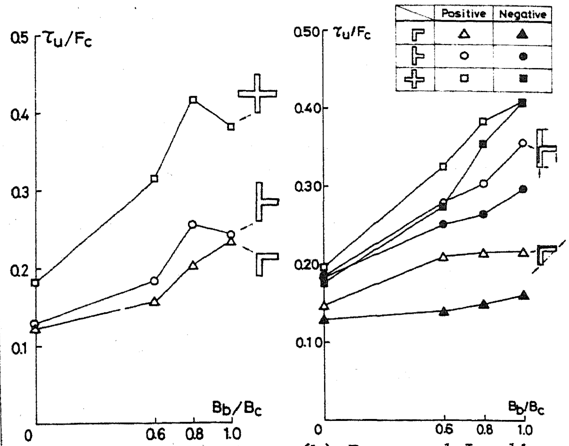


Fig. 3 Crack Patterns.

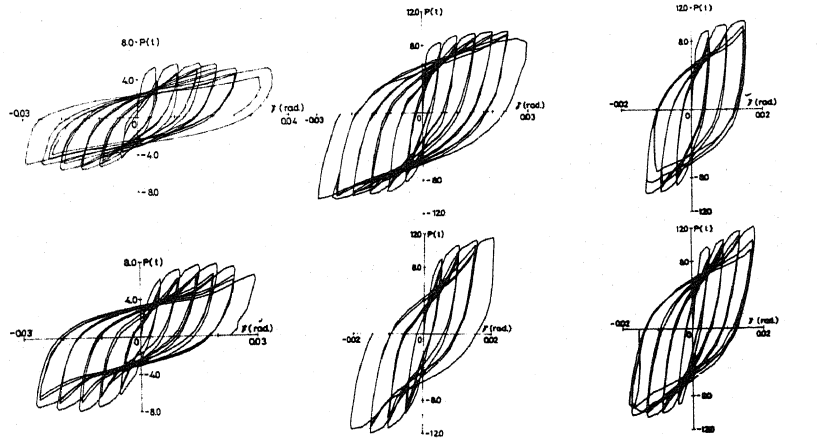


(a) Monotonic Loading (b) Repeated Loading

Fig. 4 Shear Capacity of Concrete Panel.

B_b/B_c = 0

B_b/B_c = 1.0



Interior Connection Exterior Connection Corner Connection

Fig. 5 Hysteresis Loops for Composite Connection.

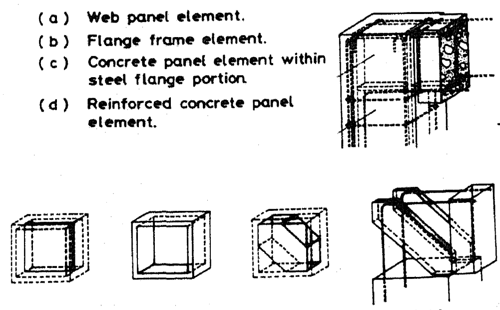
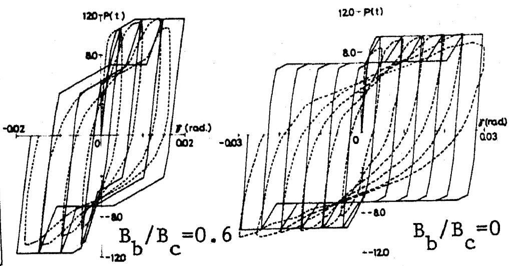


Fig. 6 Mathematical Model of Composite Corner Connections.



(a) Corner Connection

(b) Eeterior Connection

Fig. 7 Comparison of Hysteresis Loops of Composite Connections.