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EFFECT OF JOINT DETAILS FOR BEHAVIOR OF MOMENT RESISTING STEEL FRAMES WITH COMPOSITE GIRDERS-TO-SHS COLUMN

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SUMMARY

This paper provides the experimental and analytical results on the new detail of joint of composite girders-to-SHS (Square Hollow Section) column. To evaluate the elasto-plastic behavior of composite girders subjected to both positive and negative bending moments, the "├" shape full-scale subassembly specimens were tested. There were two important parameters in this study. First was whether the gap of concrete slab around SHS column should be constructed or not. Second was the distance between the stud shear connectors and the SHS column. The nonlinear behaviors are compared with those obtained numerically from a FEM package. In conclusion, the gap between column and concrete slab brings the neutral axis of composite girder down about the center of steel girder, near the column under positive bending moment. And then, the gap creates the deformation capacity of composite girder similar to that of steel girder.

INTRODUCTION

When framed structures of steel buildings were subjected to extraordinary strong horizontal load, such as earthquake loading e.g. HYOGOKEN-NAMBU earthquake of JAPAN in 1995□, a number of failures have occurred in the bottom-flanges of steel girders which were attached to SHS (Square Hollow Section) Column [AIJ, 1996]. One of the reasons for such failure is composite effect between steel girder and concrete slab. Because of this effect, the neutral axis of composite girders under the positive bending regions moves toward the concrete slab and therefore, a larger strain occurs in the bottom-flange of steel girder.

The authors propose a new joint detail for having almost the neutral axis of steel girder as well as the merits of composite girder with the exception of the superior strength under the positive bending regions. In previous experimental study for the "+" shape full-scale subassembly specimens, the authors already shown test results for composite girders with new joint details [Tagawa, Yang and Takesita, 1998]. In this paper, we analyzed moment resisting steel frames for the purpose of investigating the behaviors of frame with new joint details.

TEST SETUP AND EXPERIMENTAL OBSERVATIONS

The main tests were performed to clarify a structural behavior of composite girders with new detail of joint when the horizontal force is applied to a multi-story frame. All specimens were modeled to the full scale. The specimen's girder (Figure 1, 2) consists of steel girder (H-500x200x10x16), R.C. slab (2000mm width and 150mm thickness), and stud (19mm diameter and 110mm height) shear connectors. The number of stud shear connectors in all specimens are equal and designed to have adequate shear capacity according to conventional theory so that failure would be governed by flexure [AIJ, 1985]. And then, the column and the panel zone are designed to avoid yielding. Although the detail of U-CG (Usual Composite Girder) specimen is common in multistory construction, we suggest the detail of N-CG (New Composite Girder) specimen with the gap of concrete slab around SHS column. In addition, the stud shear connectors of N-CG specimen were

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approximately set up to the height of steel girder apart from the surface of SHS columns. Thus, N-CG specimen is able to maintain the deformation capacity similar to that of the steel girder when horizontal forces are applied.

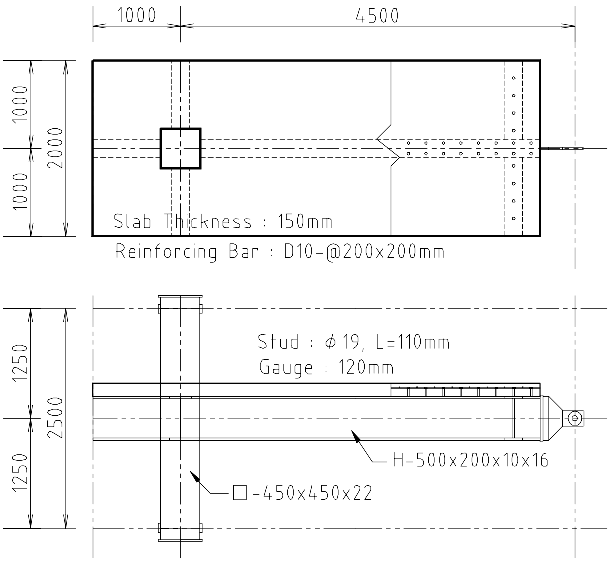


Figure 1: Configuration of Specimen

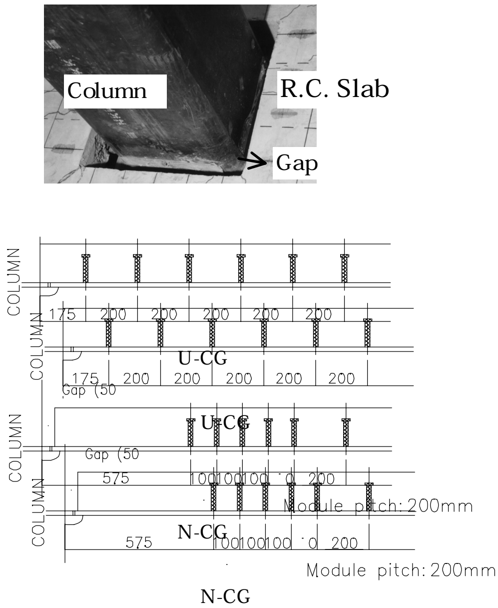


Figure 2 :Specimen Details

The test setting and load-application are shown in Figure 3. Thrust forces of 5ton were constantly applied as the axial force of column using 100ton oil jack. Cyclic load was applied using 50ton capacities double action jack attached to the end of steel girders. The peak displacements in the cyclic loading are proportional to the vertical deflection corresponding to ±1/300rad, ±1/200rad, ±1/150rad, ±1/100rad, ±1/75rad and □1/30rad of the composite girders. Displacement Transducers (DT) were installed to measure the deflection of frame and the slip between the concrete slab and the steel girder. Wire strain gauges were attached to measure the neutral axis of composite girder and the strain distribution in the bottom-flange of composite girder and the R.C. slab.

Figure 3: Overall View of Testing Set Up

DESCRIPTION OF THE FINITE ELEMENT MODEL

The program described in this paper is based on a Finite Element Method program, MARC, which is capable of analyzing nonlinear behaviors. The partial interaction composite girder consists of steel girder, a concrete slab, and shear connectors. Although the testing indicates that the composite girder showed in non-symmetrical mode, the numerical analysis was done on half of the girder to reduce degree of freedom. The result of the material testing steels and the result of the material testing of concrete used on these analyses are shown in Table 1 and 2, respectively. The materials were assumed isotropic and homogeneous. The stress-strain of concrete and steel were modeled by Figure 4 and 5, respectively. And, stud shear connector between concrete slab and steel girder was modeled by nonlinear shear spring. As shown in Figure 6, stud element was modeled by the bilinear using Load /Deflection relation which are obtained by push-out tests [JSSC, 1996]. After first yield, the second stiffness was assumed to 0.02Kst by the testing results. In the analysis under the positive moment, reinforcing bars were neglected. Figure 7 shows a typical FEM mesh of the composite girder. 3D solid elements (814 elements) were used to model both steel girder and concrete slab. Each node has three degree of freedom in the form of displacements in x, y and z directions. The end of H-girder was modeled by fixing all displacements components, while the mid-width section of the slab was modeled by fixing all displacements in the horizontal plane. In addition, the friction between concrete slab and the steel girder was neglected for simplifying the numerical model.

Table 1: Material Testing of Concrete

Compression Strength (kgf/cm^2)	Tensile Strength (kgf/cm^2)	Elastic Modulus (kgf/cm^2)
371	27.82	$2.37x10^5$

Table 2: Material Testing of Steels

	Yield Stress (tf/cm^2)	Yield Strain (%)	Ultimate Stress (tf/cm^2)	Elong. (%)
Flange	2.93	0.13	4.51	31.77
Web	3.27	0.16	4.72	29.35
Rein.Bar	3.55	0.17	5.24	-

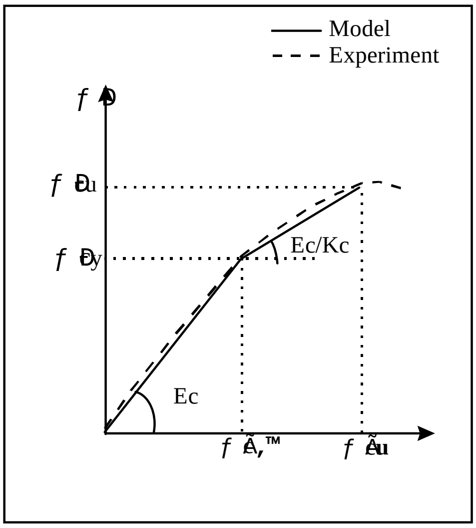


Figure 4: Stress-Strain of Concrete

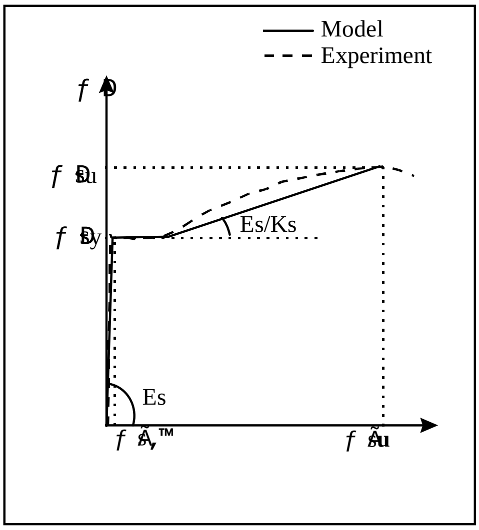


Figure 5: Stress-Strain of Steel

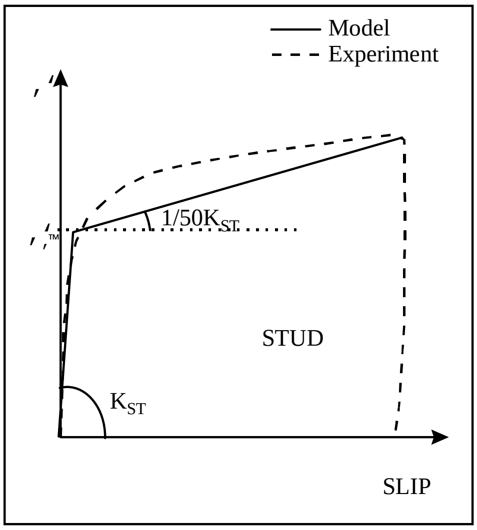


Figure 6: Load-Slip Relation of Stud

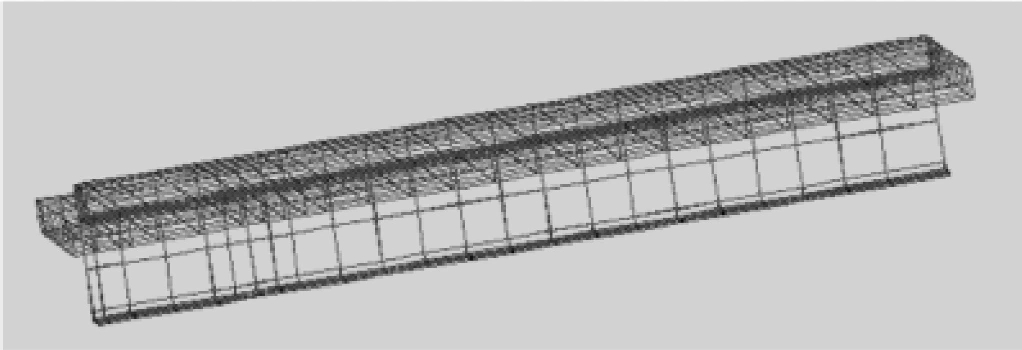


Figure 7: Typical FEM Mesh Arrangement

RESULTS AND DISCUSSIONS

Moment and Rotation Relation

The relationships between moment at the column face and the relative rotational angle at the end of girder are shown in Figure 8. The results of experiments are summarized in Table 3. The yield moments (M_y) are values when strain gauges (305mm position apart from column center) attached at the bottom-flange of composite girders were yielded. As shown in Figure 8 regarding the moment-rotational angle relationships of specimens under cyclic loading, the usual composite girder has excellent high strength and rigidity and shows sufficient deformation capacity and stable hysteresis loop in the positive bending moment. However, the usual composite girder shows greatly difference in rigidity under the positive and negative bending moment. The new composite girder with the gap in concrete slabs around columns has the sufficient deformation capacity, the stable hysteresis loop and the merits of usual composite girder (buckling restraint, increased floor stiffness etc.). However, the strength of the new composite girder in the positive bending moment is similar to that of the steel girder.

The result of FEM analysis in the positive bending moment regions are shown in Figure 8 as bolded lines. The dotted lines are analytical values of the steel girder. The analytical maximum strength of U-CG specimen was higher than experimental one. However, the analytical maximum strength of N-CG specimen was slightly lower than experimental one. The discrepancies might come from shear spring model of the stud shear connector and the neglecting of the transverse beam to simply analysis. Because the shear spring was directly connected between a node of concrete element and a node of steel element, the stress concentration was occurred in the node. And, the N-CG specimen with the gap was resisted only by the shear spring because the transverse beam did not consider. And, the second rigidities of the analyses are higher than that of the experiments in both specimens. There are several reasons that can be attributed to the discrepancies between experimental and FEM analysis results. In the FEM analysis, the assumed material property of concrete and steel may not represent its real stress strain behavior. In addition, the FEM analysis by the monotonic loading did not considered the Bauschinger's effect by the cyclic loading in the experiment.

Table 3: Test Results

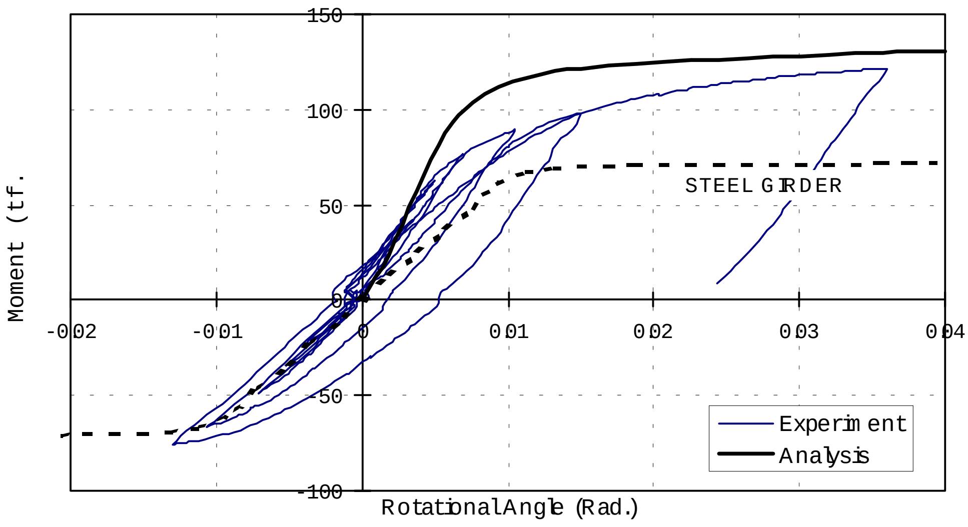
SPECIMEN	M_{max} (t.m)	θ_{max} (Rad.)	${}_nM_{max}$ (t.m)	${}_n\theta_{max}$ (Rad.)	M_y (t.m)	θ_y (Rad.)	K_0 (tf/mm)	${}_nK_0$ (tf/mm)
U-CG	121.62	0.036	-76.22	-0.013	54.29	0.004	6.65	3.80
N-CG	97.04	0.030	-66.82	-0.016	42.88	0.005	5.37	3.24

$M_{max}({}_nM_{max})$: Maximum Moment in Positive Moment Region (Negative)

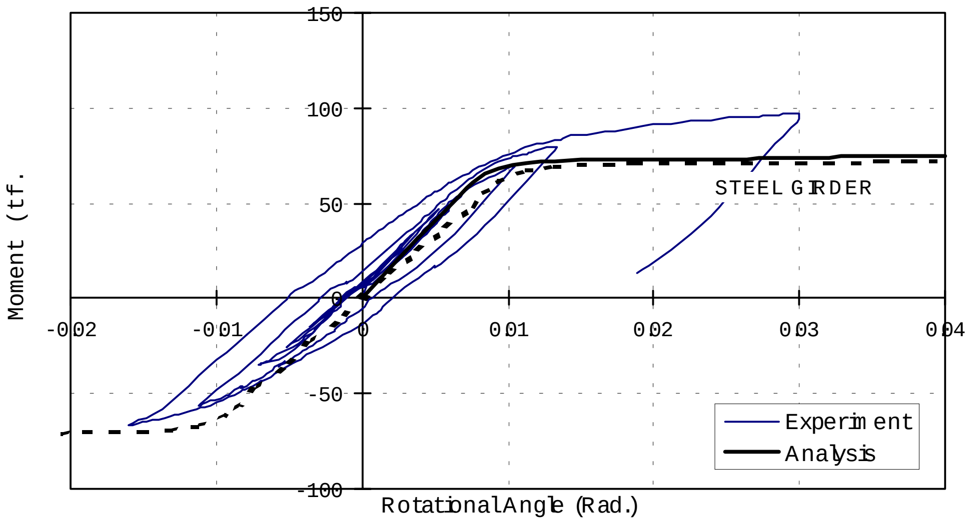
$\theta_{max}({}_n\theta_{max})$: Maximum Rotational Angle in Positive Moment Region (Negative)

M_y: Yielding Moment in Positive Moment Region θ_y: Yielding Rotational Angle in Positive Moment Region

K_0 : Initial Stiffness of Positive Moment, nK_0 : Initial Stiffness of Negative Moment



(a) U-CG Specimen



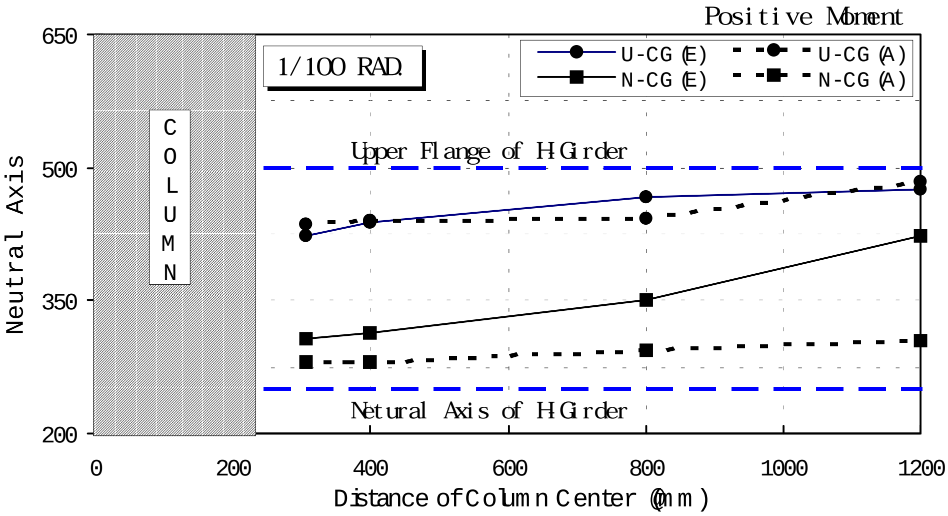
(b) N-CG Specimen

Figure 8: Moment-Rotation Angle Relations

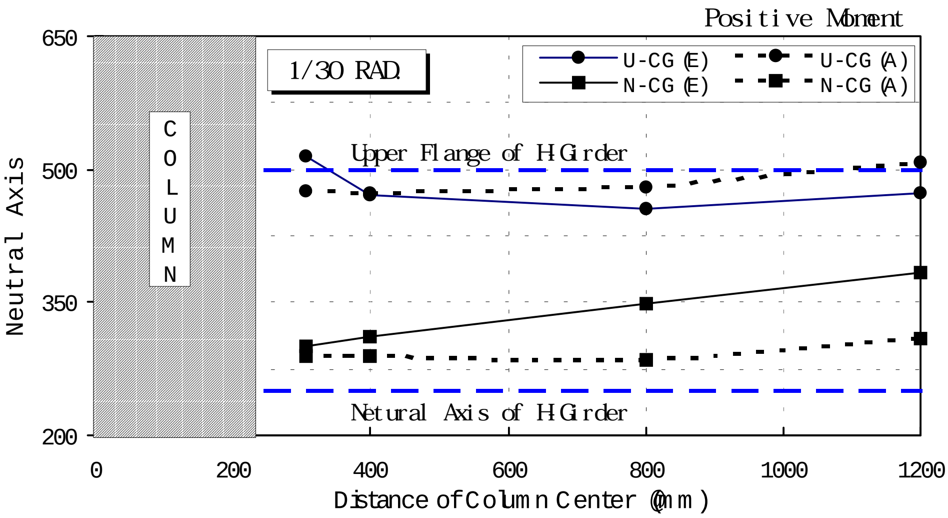
Neutral Axes and Strain Distribution in the Bottom-Flange of Steel Girder

The positions of neutral axes are summarized in Figure 9. The neutral axes of U-CG specimen were remarkably altered by the composite effect as the loading direction changed. However, those of N-CG specimen were not significantly altered. The neutral axes of U-CG specimen under the positive bending moment region risen toward the upper-flange as a result of composite effect between concrete slab and steel girder. The gap between concrete slab and SHS column and the change of stud shear connectors position brought the neutral axes of composite girder down about the center of steel girder, near the column under the positive bending moment. Thus, N-CG specimen is permitted deformation capacities similar to those of steel girder. The results of FEM analysis are shown in Figure 10 as dotted lines. The neutral axes of U-CG specimen agree with the experimental results. On the other hand, those of N-CG specimen are shown the slightly values because of disregarding the transverse girder.

The strain distributions of steel girder in the 1/30 radian are shown Figure 10. The results of FEM analysis are shown in Figure 10 as dotted lines. It seems that the strain values of U-CG specimen are larger than 2 times of N-CG specimen in the 305mm position apart from column center because of the composite effect. Thus, the concentration of stress at the bottom-flange of steel girder under positive bending moments occurred in the U-CG specimen.



(a) 1/100 Rotational Angle



(b) 1/30 Rotational Angle

Figure 9: Position of Neutral Axes

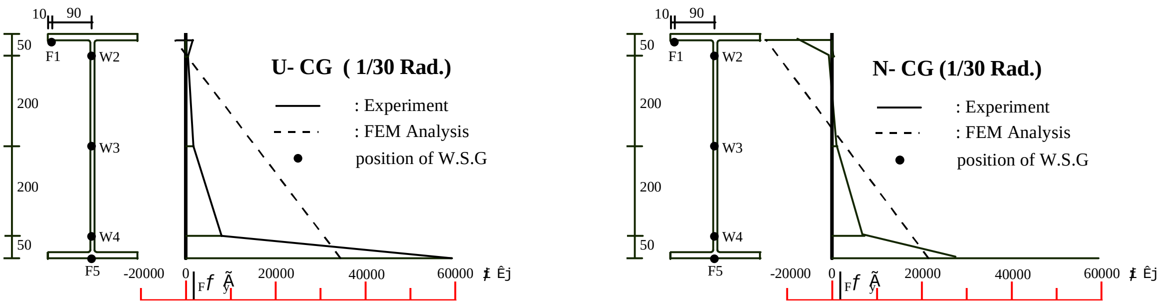


Figure 10: Strain Distribution in the Bottom-Flange of Steel Girder

CONCLUSION

The effect of joint details for the composite girder-to-SHS column in a moment resisting frame under repeated and reversed horizontal loading was investigated experimentally and analytically. The major findings are summarized as follows.

1. The usual composite girder has excellent strength and rigidity in the positive bending moment. However, the bottom-flange of steel girder in adjacent to column surface show large strain value as a result of □composite effect. Thus, the concentration of stress occurred in the bottom-flange of steel girder.

2. The new composite girder with the gap in concrete slabs around columns has stable hysteresis loops and deformation capacities as bring the neutral axis of composite girder down about the center of steel girder. In addition, that has the merits of usual composite girder (buckling restraint, increased floor stiffness etc.) except for the strength under the positive bending moment regions.

3. The strain values in the bottom-flange of the new composite girder are half values of the usual composite girder in the large deflection range. Thus, the gap of new composite girder is one of effective measures to avoid the failure of the bottom-flange in the small deflection range.

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