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Seismic Design of Gusset Plate Connection considering Frame Action

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Abstract—**The current design method of the gusset plate connection is based on brace action in concentrically braced frames (CBFs). However, the failure of the gusset-beam or gusset-column interface designed with current method has been reported in earthquakes and large-scale braced frames tests. A more secure design method to ensure the gusset plate connection not fail before the brace is required. Two large-scale braced frames specimens have been tested, showing that gusset plate is affected by both brace action and frame action. The current methods were used to evaluate two actions, respectively. A recommended design method considering both brace action and frame action is proposed.**

I. Introduction

CBFs are widely used as lateral-load resisting systems in buildings and these systems have the characteristics to meet performance-based seismic design criteria. The intact gusset plate connecting is prerequisite for offering stiffness and consumption of brace.

AISC[1] and AIJ[2] have the design methods for Gusset plate connection respectively. But those methods assume that gusset plate is affected by brace action only. However, the failure of the gusset-beam or gusset-column interface designed with current method has been reported in earthquake and large-scale braced frames tests in Fig.1[3]. The force at the interface between the gusset plate and frame is not clear. For BRB frame, Lin et al.[4] proposed a design method based on the stress of the gusset plate connection interface. For CBFs, the design method of gusset plate considering frame action has not been reported.

(a) The hanshin earthquake (b) Experiment

Fig.1 Failure of gusset plate connection

Based on the test results of SCBFs, this paper established effective finite element model to evaluate the brace action and frame action, and hence theoretic design methods are proposed. According to the results, a more practical design method for the gusset plate connection combining both brace action and frame action is proposed. Test results of 12 specimens are used for verifying proposed method.

II. FEM Program

A. Experimental and Finite Element Models

Quasi-static cyclic test is performed on two specimens. The strong- or weak-axis of the column are connected to the beam, named HS and HW, respectively. They are representing the frame action in two cases. The geometry of specimens is shown in Fig.2.

As shown in Fig.3, establishing numerical models to study the force of the gusset plate during the whole process, which used S4R elements. Boundary condition are consistent with the test, shown in Fig.4. A nonlinear isotropic hardening material model was used in the inelastic analysis.

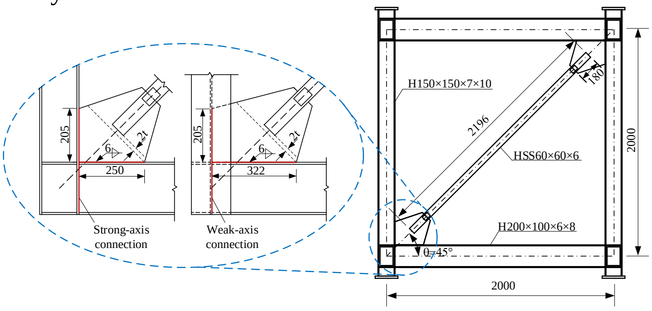

Fig.2 Specimen geometry (unit: mm)

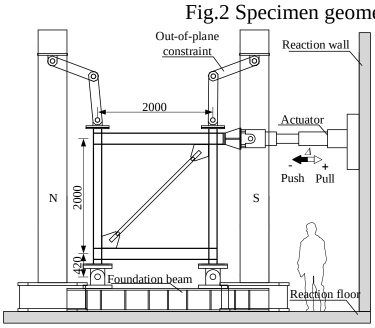

Fig.3 Test setup

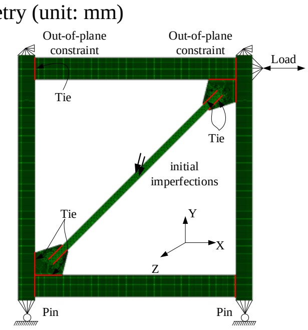

Fig.4 Finite element model

B. Verification

The hysteresis curve of test and FEM are shown in Fig.5. The shape of the curve and the capacity of the system are satisfied.

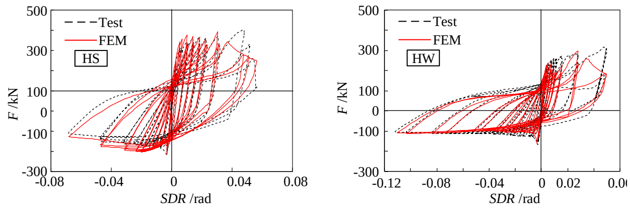

Fig.5 Comparison of curve of FEM results and test results

III. Theoretical Calculation Method

A. Force Analysis

It is necessary to consider the two actions separately. The GUFM[5] and RAIJ[6] methods used to calculating brace action temporarily. The direction of interface concentrated forces are different about two methods. Meanwhile, the

ESM[4] method used to evaluate the frame action. Three computing models are shown in Fig.6.

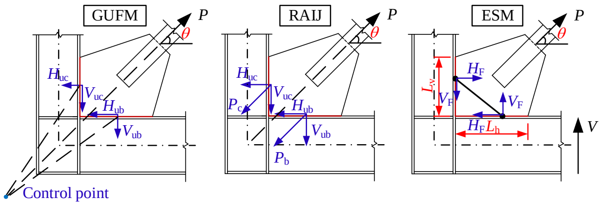

Fig.6 Theoretical design methods for separate action

The true force of interface is obtained by combining the brace action and frame action, as shown in Fig.7. The force on the gusset plate interface can be calculated by Equation 1:

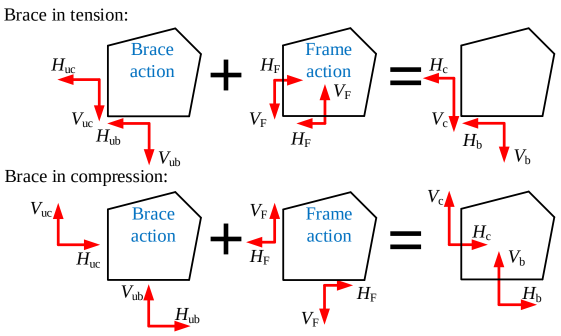

Fig.7 Force in gusset plate

$$H_b = H_{ub} + H_F \tag{1.a}$$

$$V_b = V_{ub} - V_F \tag{1.b}$$

$$H_c = H_{uc} - H_F \tag{1.c}$$

$$V_c = V_{uc} + V_F \tag{1.d}$$

B. Combine Action

The GUFM, RAIJ and ESM methods are combined according to Equation (1), respectively. Tables 1-2 show the connection interface force under the combined action. *VM* is the maximum Von Mises stress value of the gusset plate connection interface. It can be seen that the Von Mises stress values calculated by the combined action are greater than the finite element model, which proves that the thought of combined action is effective. However, the VM calculated by GUFM + ESM is significantly larger than RAIJ + ESM. Draw the results of Tables 1-2, as shown in Fig.8. The interface force calculated by GUFM + ESM of HW is quite different from the finite element result. Therefore, combining RAIJ with ESM is better.

TABLE 1 Interface forces under the combined action-HS

	H_c （kN）	V_c （kN）	H_b （kN）	V_b （kN）	*VM* (GPa)
FEM(HS)	-77	248	345	21	0.399
GUFM+ESM	47	327	406	125	0.476
RAIJ+ESM	76	300	376	152	0.446

TABLE 2 Interface forces under the combined action -HW

	H_c （kN）	V_c （kN）	H_b （kN）	V_b （kN）	*VM* (GPa)
FEM(HW)	-25	200	363	109	0.332
GUFM+ESM	-148	266	601	187	0.548
RAIJ+ESM	51	293	401	159	0.415

The force of the fillet weld at the connection interface is shown in Fig.9. The value and direction of *F* can be calculated by force components. Equation (2) [4] is used to calculate the size of the fillet weld (T_c, T_b) in gusset plate interface considering the direction of *F*. Where ψ =0.75, F_{exx} is the tensile strength of the welding material.

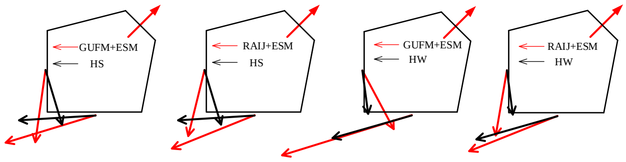

Fig.8 Comparison of interface forces under the combined action

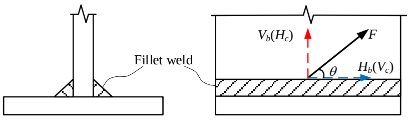

Fig.9 Fillet weld calculation

$$\psi \times 2 \times 0.707 \times T_c L_v (0.6F_{exx}) \left[1 + 0.5\sin^{1.5}(\tan^{-1}\left|\frac{H_c}{V_c}\right|) \right] \geq 1.25\sqrt{V_c^2 + H_c^2} \tag{2.a}$$

$$\psi \times 2 \times 0.707 \times T_b L_h (0.6F_{exx}) \left[1 + 0.5\sin^{1.5}(\tan^{-1}\left|\frac{V_b}{H_b}\right|) \right] \geq 1.25\sqrt{V_b^2 + H_b^2} \tag{2.b}$$

In order to ensure the practicality of the proposed design method, fillet weld size is calculated with proposed method in 12 specimens [3,7]. In particular, all specimens were designed considering brace action only. Comparison with the test results, as shown in Table 3. d_1 and d_2 respectively represent the actual size of the weld used in the test and the calculated results by the recommended method. λ is the weld tearing degree. The λ value of HSS-1, HSS-5 are 100%, indicating that the weld is damaged seriously. Fortunately, the proposed method indicates well because d_1 were less than d_2 obviously. HSS-6 and HSS-10 showed different degrees damage, and d_1 was also less than d_2.

TABLE 3 Comparison of the calculated results of interface weld

Specimens	Test			RAIJ+ESM
	True size/mm	d_1/mm	λ	d_2/mm
HSS-1	864×762	4.76	100%	8.4
HSS-2	635×533	12.70	0%	11
HSS-3	635×533	11.11	0%	10.1
HSS-4	648×543	11.11	0%	11
HSS-5	635×533	7.94	100%	10.3
HSS-6	635×533	7.94	30%	9
HSS-7	724×622	19.05	0%	10.4
HSS-10	476×416	12.7	40%	13.1
B	250×205	6	0%	5.8
HP	250×205	6	0%	5.8
HS	250×205	6	0%	5.8
HW	322×205	6	0%	5.8

IV. CONCLUSION

The gusset plate connection interface is affected by both brace action and frame action. A force-based gusset plate connection design method was proposed, in which RAIJ and ESM method calculate the brace action and frame action respectively.

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