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Influence Parameter Research on the Low Cycle Fatigue Life for Welded I-Section Bracings

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Abstract

A survey of past test and numerical simulation studies on the low cycle fatigue behaviour of the welded I-section bracing members subjected to constant amplitude cyclic axial displacement was carried out. Based on the numerical simulation results, some empirical formulas for estimating the low cycle fatigue life are presented and compared with the empirical formulas obtained by tests. It's found that the web plate height-thickness ratio h_0/t_w has no significant effect on the low cycle fatigue life, and the flange width-thickness ratio b/t and the slenderness λ are the most important parameters for estimating the low cycle fatigue life. In view of the low cycle fatigue life increasing with the decrease in the flange width-thickness ratio and the increase in the brace slenderness ratio, small flange width-thickness ratio and large slenderness ratio should be adopted in the brace design on the premise of "no buckling under frequent earthquake".

Keywords: bracing member; low cycle fatigue life;flange width-thickness ratio;slenderness ratio;web plate height-thickness ratio

1. Introduction

The early fracture of braces due to low cycle fatigue failure is identified as one of the main disadvantages of their use in concentrically braced steel frame structures. Early fracture of the brace can significantly affect the energy dissipation capacity, the lateral strength and the stiffness of the braced steel frame [1]. At present, some experimental research has been performed on the I-section steel bracing members [2-3]. The results showed that, the key parameters influencing the low cycle fatigue life are not the same, caused mainly by the observation error. However, the low cycle fatigue life simulated by the

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numerical method is not affected by the observation error. Based on the numerical simulation results, this paper presents some empirical formulas for estimating the low cycle fatigue life. Through a comparison of the formulas proposed by this paper and the test results, the parameters influencing the low cycle fatigue life are analyzed further.

2. Test research

Two tests were selected in this paper. The two tests [2-3] were performed using a 2500KN MTS hydraulic testing machine at the Structural and Earthquake Engineering Testing Laboratory in Harbin Institute of Technology. The end pins were made as shown in Fig.1. In the test, all specimens were subjected to similar loading sequences. After the initial elastic cycles, the specimens were loaded into elasto-plastic region. The applied axial displacement history for each specimen is a symmetrical displacement pattern with constant amplitude. The details of test specimens are shown in Table 1. λ is the slenderness ratio, $\Delta\delta$ is a summation of the maximum applied axial displacement in tension and in compression, δ_y is a yield axial displacement. The propagation of macroscopic surface cracks was monitored by a magnifying glass. A more detailed description about the tests is given in the literature [4].

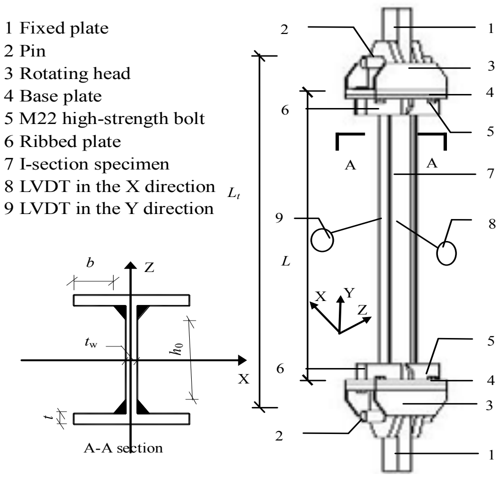

Fig.1 Details of pinned ends of specimens

For all specimens, overall buckling around the weak Z-axis occured in the first cycle when they were loaded in compression. During the second and subsequent cycles, the multiple-wave local buckling with about two or three half-waves occurred at mid-span for most of the specimens and a plastic hinge formed at mid-span for each specimen. At last, the macroscopic surface cracks occurred initially at the flange tip surfaces of the plastic hinge regions. For safety considerations, the low cycle fatigue life was defined as the numbers of cycles when the macroscopic surface cracks occurred. Based on this assumption, some empirical formulas were developed to predict the low cycle fatigue life.

Q235: $$N_f=13.3(\Delta\delta/\delta_y)^{-1.74}\,\lambda^{2.07}\,(b/t)^{-2.08} \tag{1}$$

ST12: $$N_f=3.16(\Delta\delta/\delta_y)^{-1.07}\lambda^{1.67}\,(b/t)^{-1.8}\,(h_0/t_w)^{0.53} \tag{2}$$

Where N_f is the estimate values of low cycle fatigue life and the other symbols are defined in Fig. 1 and Table 1. From the formulas (1) - (2), the low-cycle fatigue life N_f increases with the decrease in the flange width-thickness ratio, the increase in the brace slenderness ratio, and the decrease in the loading amplitude of the bracing members.

Table 1 Characteristics of the specimens

Test NO.	λ	h_0/t_w	b/t	$\Delta\delta/\delta_y$	t_w(mm)	t(mm)	f_y
P1-1/2	145.53	30.37	5.25	12	2.88	2.88	Q235
P2-1/2	127.42	48.87	7.40	8	2.88	2.88	Q235
P3-1/2	113.97	25.82	8.84	6	2.88	2.88	Q235
P4-1/2/3	102.52	43.32	10.96	4	2.88	2.88	Q235
P5-1/2	98.97	23.04	4.21	12	2.88	2.88	Q235
P6-1/2	83.60	38.46	6.22	8	2.88	2.88	Q235
P7-1/2/3	73.30	18.66	8.29	6	2.88	2.88	Q235
P8-1/2/3	62.03	33.25	9.87	4	2.88	2.88	Q235
PS1-1/2/3	127.4	34.61	7.05	12	2.92	2.50	ST12
PS2-1/2/3	112.2	17.11	8.80	12	2.50	2.50	ST12
PS3-1/2	101.7	42.61	11.35	12	2.92	2.50	ST12
PS4-1/2	91.7	21.01	13.30	12	2.50	2.50	ST12
PS5-1/2/3	84.5	46.71	5.75	12	2.92	2.50	ST12
PS6-1/2/3	74.2	25.31	7.80	12	2.50	2.50	ST12
PS7-1/2/3	64.4	55.31	10.55	12	2.92	2.50	ST12
PS8-1/2	61.1	29.61	12.30	12	2.50	2.50	ST12
A1-C6-1/2/3	80.1	21.61	11.30	6	2.50	2.50	ST12
A1-C8-1/2	80.1	21.61	11.30	8	2.50	2.50	ST12
A1-C10-1/2	80.1	21.61	11.30	10	2.50	2.50	ST12

3. Numerical simulation research

In literature [5], the numerical simulation on the low cycle fatigue behaviour of the Q235 steel bracing members [2] was conducted using the finite element program ABAQUS and FESAFE5.0 as shown in Fig.2. In the model, The middle part of brace with a length of 200mm, the rotating heads, the ribbed plates and the cover plates were modelled using the S3 shell element, and the other parts of the specimens were modelled using the S4 shell elements. The crack initiation lives were predicted based on the two critical plane damage models, including the maximum principal strain [6] and maximum shear strain [6] models. In general, the crack initiation lives predicted by the two damage models safely fell within a scatter band of 3.5. A more detailed description about the research is given in the literature [5]. Based on this research result, the simulation on the ST12 steel bracing members [2] was also conducted using the same method in the literature [5]. The comparison between the predicted and experimental crack initiation lives are shown in Fig. 3.

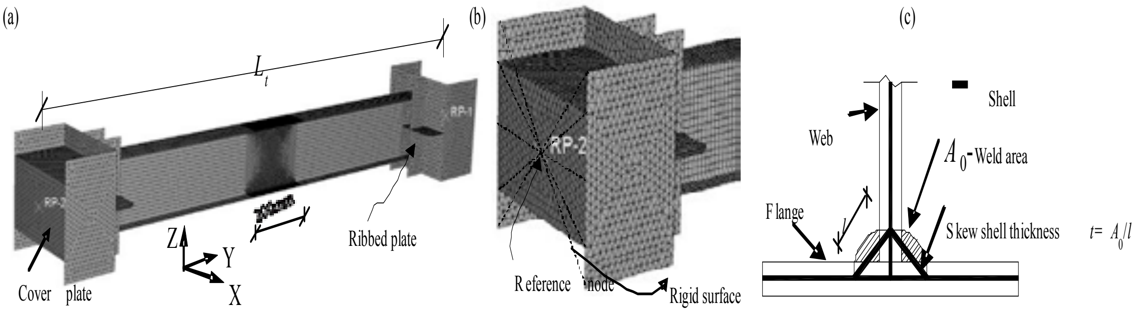

Fig.2: (a) Numerical model; (b) Simplified model of the rotating head; (c) Modeling of the welds

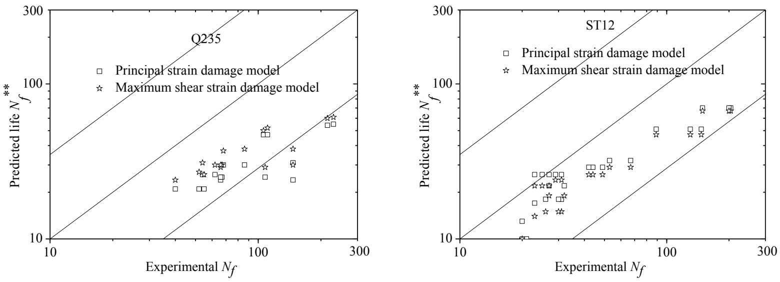

Fig.3 The comparison of the low cycle fatigue lives obtained by test and numerical simulation

In order to estimate the influence of different of parameters on the low cycle fatigue life of welded I-section steel bracing members, some empirical formulas were also developed based on the simulation lives as shown in formulas (3) - (6).

The maximum principal strain damage model:

Q235: $$N_{f1} = 233(\Delta\delta/\delta_y)^{-2.03}\lambda^{1.73}(b/t)^{-2.48}(h_0/t_w)^{-0.25} \quad (3)$$

ST12: $$N_{f1} = 5.42(\Delta\delta/\delta_y)^{-1.17}\lambda^{1.89}(b/t)^{-1.89} \quad (4)$$

The maximum shear strain damage model:

Q235: $$N_{f2} = 284(\Delta\delta/\delta_y)^{-1.84}\lambda^{1.50}(b/t)^{-2.32}(h_0/t_w)^{-0.20} \quad (5)$$

ST12: $$N_{f2} = 7.84(\Delta\delta/\delta_y)^{-1.04}\lambda^{1.68}(b/t)^{-1.73} \quad (6)$$

N_{f1} and N_{f2} are the estimate values of the low cycle fatigue lives based on the maximum principal strain and the maximum shear strain damage models.

4. Analysis of the influence parameters

From formulas (1) - (6), besides the material properties, note that the low cycle fatigue lives are greatly affected by $\Delta\delta/\delta_y$, b/t, λ and h_0/t_w.

Obviously, the larger $\Delta\delta/\delta_y$ is applied, the smaller N_f is got. However, the actual displacement histories can not be predicted before an earthquake, this parameter can not be considered in the brace design.

According to the analysis, if h_0/t_w is larger, the restriction effect of the web to the flange is smaller, the local buckling is easier to occur and N_f is smaller. However, the effect of h_0/t_w on N_f is just contrary in formula (2) and not considered in formulas (1), (4) and (6). Compared with b/t and λ in formulas (3) and (5), the effect of h_0/t_w on N_f is little, which is the reason why different formulas present different effect law of h_0/t_w on N_f.

From formulas (1) – (6), note that if λ is larger and b/t is smaller, N_f is larger due to more difficult occurrence of local buckling. It is also found that the absolute values of the exponent of b/t and λ are larger than that of other parameters (in general, the absolute values of the exponent of b/t are larger than that of λ.), indicating b/t and λ are the most important parameters for N_f.

According to the aforementioned results and the brace design requirement of “no buckling under frequent earthquake”, the small flange width-thickness ratio and large slenderness ratio should be adopted to improve the low cycle fatigue behaviour under rare earthquakes.

5. Conclusion

Based on the simulation results of the low cycle fatigue behaviour tests of the welded I-section Q235 and ST12 steel bracing members, four empirical formulas were developed, and the influence parameters of the low cycle fatigue life are analysed combined with the two empirical formulas obtained by tests. The results show that, besides the material properties, the low cycle fatigue lives are most affected by the flange width-thickness ratio b/t and the slenderness λ. The web plate height-thickness ratio h_0/t_w has no significant effect on the low cycle fatigue life. Finally, According to the effect law of different parameters on the low cycle fatigue life, it is suggested that the small flange width-thickness ratio and large slenderness ratio should be adopted in the brace design.

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References

[1] Brad Shaback, Tom Brown. Behavior of square hollow structural steel braces with end connections under reversed cyclic axial loading [J]. Canadian Journal of Civil Engineering. 2003, 30: 745-753.

[2] Lian weian. Low-cycle fatigue behavior and application of welded I-section bracing members. PH.D, thesis, Harbin institute of technology, 2006.

[3] Yu haifeng. Aseismic performance of welded I-section steel bracings and concentrically braced steel frames. PH.D, thesis, Harbin institute of technology, 2009.

[4] Zhang Yaochun, Yu Haifeng, Zhang Wenyuan, et al. Experimental study on low-cycle fatigue behavior of welded I- section steel bracing members under constant amplitude reveresd cyclic axial loading [J]. Journal of southeast university. 2009, 39(3): 525-530.

[5] Yu Haifeng, Zhang Yaochun, Du Shoujun. Numerical simulation on the low-cycle fatigue behaviour for welded I-section Q235 steel bracing members [J]. Construction Technology. 2010, 39 (supply): 568-570.

[6] Lin Xiaobin, P.J. Heyes, A. Buczynski, et al. An Engineering Approach for the Predict ion of Multiaxial Fatigue Life [J]. China Mechanical Engineering. 1998, 9 (11): 20-23.