LOW CYCLE FATIGUE BEHAVIOR OF CONCRETE FILLED STEEL PIERS

Nagoya University Student Member ○Jin Eun PARK Nagoya University Member Takeshi HANJI
Nagoya University Fellow Member Kazuo TATEISHI

1. INTRODUCTION

During the Hyogo-ken Nanbu Earthquake in 1995, two types of failure modes were observed in steel bridge piers; one is a local buckling and the other is a brittle fracture triggered by a low cycle fatigue. A large number of researches on the local buckling have been conducted after the earthquake and proposed several aseismic retrofit methods, such as filling concrete in the steel pier. The concrete steel pier has high deformation capacity, but when improving the deformation capacity of the pier, the low cycle fatigue may be a key issue. In this paper, the low cycle fatigue behavior of the concrete filled steel pier was investigated by experiments and elasto-plastic finite element analysis.

2. LOW CYCLE FATIGUE TESTS

Fig. 1 shows the dimensions of the specimen which has triangle ribs at its base joint, because they are often used in existing steel piers. Test matrix is shown in Table 1. The specimens were named NCF20, CF20 and CF10, respectively according to the applied axial load level and the filling concrete state. Incremental cyclic loading was applied under displacement control. The material properties were carried out by tensile test on steel and compression test on concrete. The results are shown in the chapter 4.

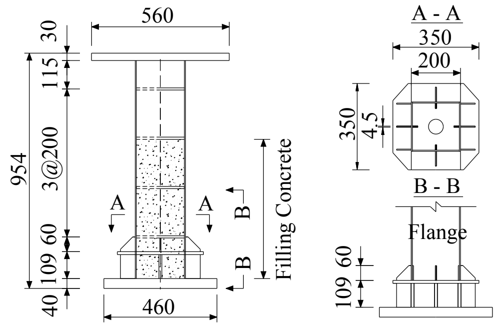


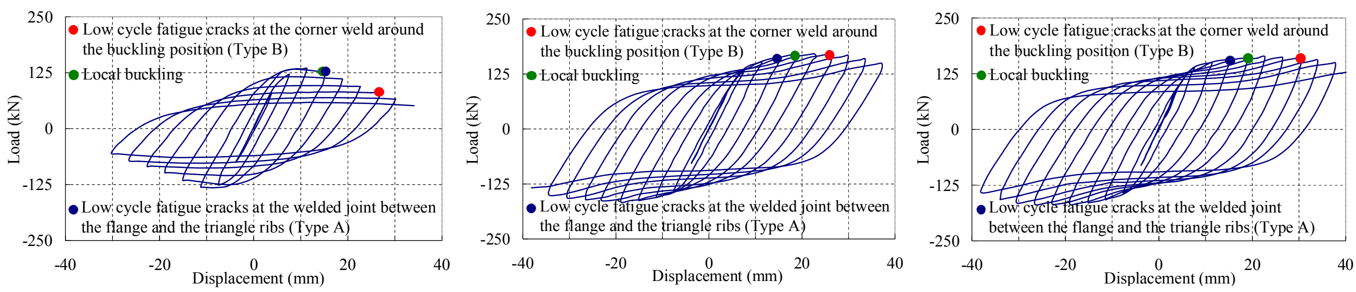
Fig. 1 Dimension of test specimen

3. EXPERIMENTAL RESULTS

The load-displacement hysteresis loops and their failure scenario are shown in Fig. 2 and Fig. 3. In case of NCF20 specimen, the maximum loading capacity rapidly decreased after the local buckling. As the local buckling grows, another crack was initiated from the corner welds around the buckling position. The crack propagated perpendicular to the corner weld.

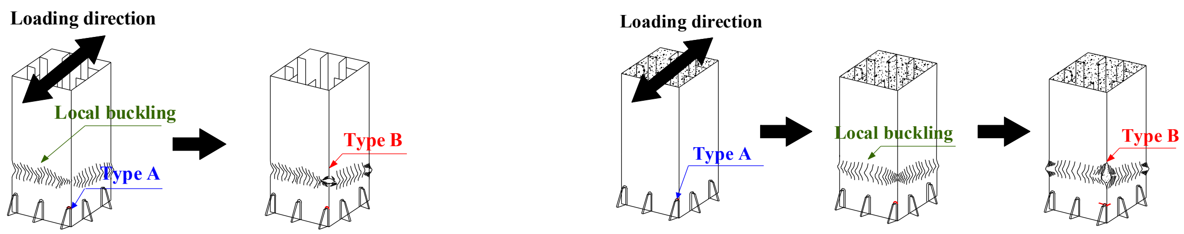
Table 1 Test matrix

Specimen	State of filling concrete	Axial loading	Lateral loading
NCF20	none	$0.2\sigma_y$	Incremental cyclic loading
CF20	○	$0.2\sigma_y$	
CF10	○	$0.1\sigma_y$	



(a) NCF20 (b) CF20 (c) CF10

Fig. 2 Load-displacement hysteresis loops



(a) NCF20 (b) CF20 & CF10

Fig. 3 Failure scenario of the specimen

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Department of Civil Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603 Tel. 052-789-4620

On the other hands, although the buckling was observed on the both flange and web plate in the CF series specimen, the load carrying capacity did not decrease after the buckling. Then, the corner weld around the buckling position was split vertically due to the cyclic plastic deformation under the buckling. As this crack (Type B) propagates, the maximum loading capacity gradually decreased. Therefore, it is proved that one of the main failure modes of concrete filled steel pier is the crack from the corner weld by the low cycle fatigue.

4. FINITE ELEMENT MODELING

It is useful to investigate the distribution of the local strain at the location of fatigue failure for low cycle fatigue. Elasto-plastic finite element was conducted by using ABAQUS program under the same condition of the experiment.

The steel pier and the filling concrete are represented by shell and solid elements, respectively. Contact elements between the steel and the concrete were applied. The friction coefficient are determined as 0.2 for the steel-to-concrete and 1.0 for the crack surface of concrete-to-concrete from the previous study[1].

Results of material tests were applied to the constitutive model. In case of the steel, the yield strength, Young's modulus and Poisson's ratio are 338MPa, 2.0×10^5MPa and 0.3, respectively. The combined isotropic /kinematic hardening model was used with the von Mises yield surface. Also, in the filling concrete, compressive strength, Young's modulus and Poisson's ratio are 27.7MPa, 2.5×10^4MPa and 0.2, respectively. Concrete damaged plasticity model and discrete crack model is applied to the analysis model.

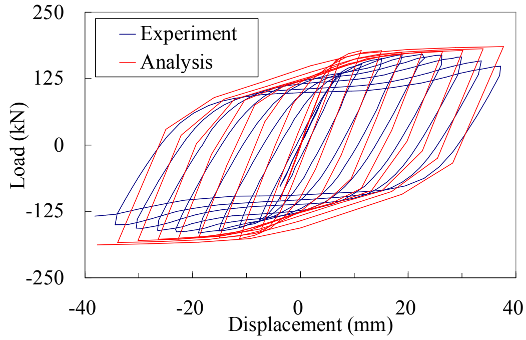

Fig. 4 Hysteresis loop of analysis (CF20)

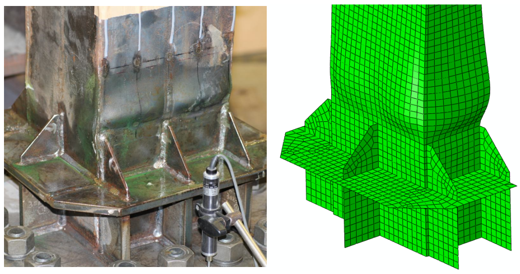

Fig. 5 Comparison of deformation shapes between experiment and analysis (CF20)

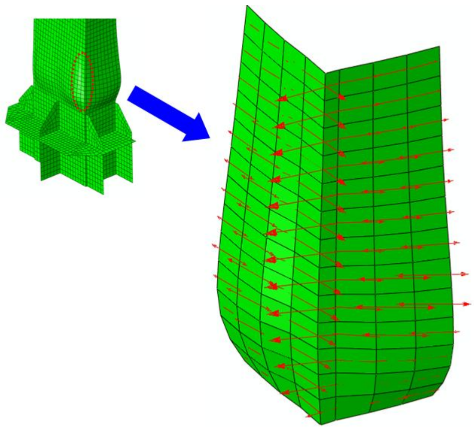

Fig. 6 Example of vector components at the corner weld around buckling position (CF20)

5. ANALYSIS RESULTS

The comparison of the hysteresis loops and the deformation shapes between the experiment and the analysis are shown Fig. 4 and Fig. 5, respectively. Validity of the analysis model was proved by comparing the load-displacement hysteresis loop and the location and shape of the local buckling between the experiment and the analysis. Fig. 6 shows an example of vector components of maximum principal stress at the corner weld around buckling position. These vectors show that the occurrence of fatigue crack and their direction of progress tend to match the results of analysis.

6. CONCLUSIONS

As a fundamental study, the low cycle fatigue behavior of the concrete filled steel pier was experimentally and analytically investigated. It was indicated that the crack from the corner weld of the pier due to the low cycle fatigue is one of the main failure modes of the concrete filled steel pier.

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