I-82 EXPERIMENTAL INVESTIGATION ON STRUCTURAL FAILURE OF STEEL ANGLE MEMBERS DUE TO VERY LOW CYCLE FATIGUE

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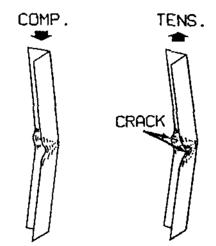
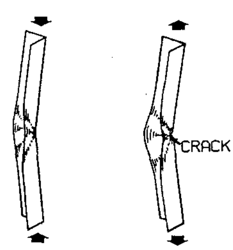
Introduction Structural damage and failure caused by repeated loading such as destructive earthquake motions are attributed to plastic and unstable behavior of steel structures and their members due to large cyclic deformations including those induced by local buckling. For the sake of improved seismic safety assessment, therefore, it is necessary to investigate the correlations for all of the important physical factors associated with very low cycle fatigue[1)] in about 5-30 cycles of load repetitions, which means structural fatigue. In this paper, quantitative investigations for these factors related to cumulative failure are performed on steel angle members through very low cycle fatigue tests.

Testing Program The specimens were SS41 grade angles of L-40x40x3 and L-40x40x5. The yield stress and the ultimate tensile strength of the materials were ranged within 339-344 N/mm^2 and 456-470 N/mm^2, respectively. The specimen was pin-supported at both ends and the testing length L between pin-supports was 30-31.8cm. A repeated uni-axial load was applied to the specimen. The load was controlled by the relative axial displacement Δ with the both ends approaching to each other, as indicated in Table 1. This causes buckling of the specimen in compression loading, inducing very high strain level. In order to measure local edge strains after testing, surface dots were marked with 2mm pitches parallel to the longitudinal axis for a mid-part length of 80mm, using a Vickers hardness tester.

Deformation and Cracking Behavior During testing, positive and negative deflection modes in the form of Fig. 1 were observed. Regardless of the deflection modes, visible cracks were initiated on the concave side of deformation while it was stretching. Typical load-axial displacement behavior of the specimens is shown in Fig. 2. Here load P and relative displacement Δ are normalized by the yield load N_y and the specimen length L, respectively. Inelastic local buckling caused a sudden decrease in the compressive load-carrying capacity, but a slight decrease in the tensile load-carrying capacity. In most specimens subjected to increased amplitude loading, no cracks were observed under the repetition of global strain Δ/L of 8%, but visible cracks were initiated in the 1st cycle at the amplitude level of 12% global strain. In the cases of constant amplitude cycling under the level of 8% global strain, visible cracks occurred during the 7-9th cycle. Just after the cracking, both compressive and tensile load-resisting capacities were considerably deteriorated. It is thus found that the ultimate failure is closely related to the initiation of a visible crack.



(a) Positive mode(L5IP)



(b) Negative mode(L5IN)

Fig. 1 Deflection modes and cracking patterns

Energy Absorption The relationships between the dissipated energy E and the number of cycles f for all the specimens are shown in Fig. 3, where E_o is the maximum elastic strain energy that can be stored in the specimen. In the case of the same loading pattern and the same deflection mode, a very similar process of energy absorption was observed (see L5CPa and L5CPb in ıg. 3(b)). However, if the deflection modes are different, the cumulative energy absorption processes were clearly different even among the specimens under the same loading pattern. No simple quantitative relations were observed between the initiation of a visible crack and the energy absorption capacity. Energy absorption processes and capacities depend upon the history of loading and the failure mode.

Local Strain Fig. 4 shows typical distributions of local strains accumulated at the edges after testing. Visible cracks resulted from a severe concentration of cumulative strains at the critical section. The maximum cumulative net strains, not including the crack opening, were in the range of 25-35% on the elongation side and 30-40% on the contraction side (see Table 1), and they do not depend upon loading patterns, failure modes, and width-to-thickness ratios.

Table 1 Loading program and test results

Specimen Name	No.	t(mm)	(Δ/L)x100	Mode of Deflection	Max. Strain(%) tens.	comp.
L3IN	4	2.55	-0.5 - 0 (4) -1.0 - 0 (4) -2.0 - 0 (4) -4.0 - 0 (4) -8.0 - 0 (4) -12.0 - 0 (4)	N	-	-
L3CN	5	2.47	-8.0 - 0(30)	N	25	-41
L3CP	6	2.55	-8.0 - 0(16)	P	27.5	-29
L5IN	7	4.58	same as No. 4	N	25	-30
L5CPa	8	4.55	-8.0 - 0(19)	P	32.5	-35
L5IP	9	4.56	same as No. 4	P	35	-35
L5CPb	10	4.55	same as No. 8	P	30	-32.5

[Note] C:Constant amplitude, I:Increasing amplitude
P:Positive deflection, N:Negative deflection
t:Thickness of angle leg
Δ:Relative axial displacement, ( ):No. of cycles
L:Specimen length between both pin-supports

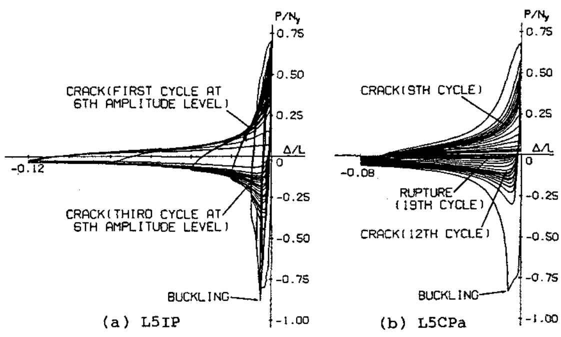


Fig. 2 Load-axial displacement relations

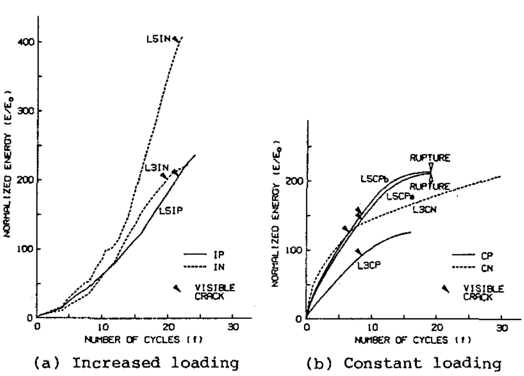


Fig. 3 Comparison of cumulative energy dissipation in the course of increasing No. of cycles

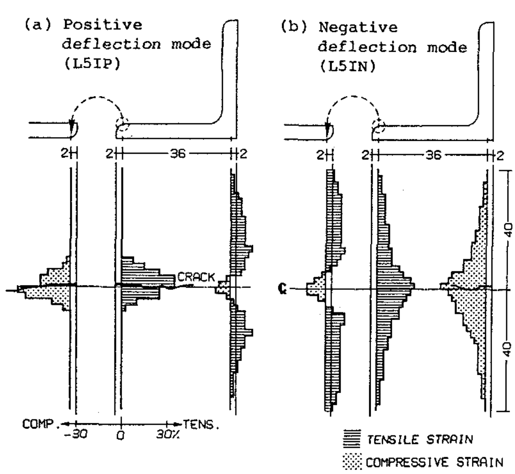


Fig. 4 Distributions of local strains

Conclusions The main results of this study are summarized as follows:

1) Energy absorption processes of structural steel members experienced large cyclic deformations depend upon the loading condition and the failure mode.

2) The cumulative strains at the initiation of a visible crack due to very low cycle fatigue were of the order of 25-40%, regardless of loading patterns, deflection modes, and of width-to-thickness ratios.

Reference 1) S. Iwai, T. Nonaka, U. Bourgund and H. Kameda: Structural Failure due to Very Low Cycle Fatigue of Steel Members and Elements under Earthquake Loading, Proc. of 8th Japan Earthquake Engrg. Symp., Vol. 2, 1990, pp. 1377-1382.