I-48 FAILURE OF STEEL ANGLES UNDER VERY LOW-CYCLE LOADING

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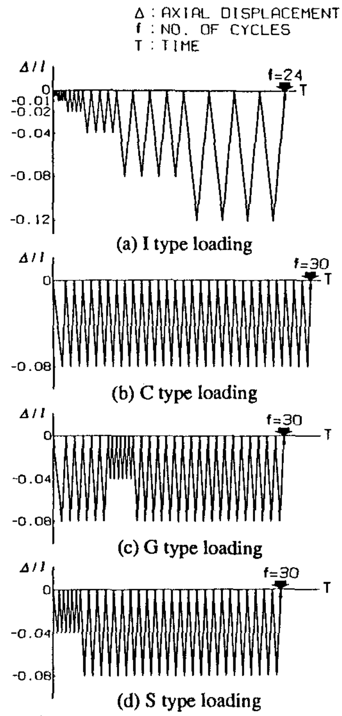
1. Introduction Structural damage and failure of steel members are often associated with plastic and/or unstable behavior due to large repeated deformations. Therefore, it is important to clarify decisive factors causing cracks and rupture under very low-cycle loading, which is herein meant to involve load repetitions of the order of a few to twenty cycles. The previous research[1)] showed that the maximum value of residual local strains in a cracked portion caused by very low-cycle loading is of the order of 25-40%. This experimental investigation is focused to observe effects of slenderness ratio of angles and loading sequence on failure behavior.

2. Test Program The specimens were angles L-40x40x3 and L-40x40x5 of SS41 grade. The yield stress and the ultimate tensile strength of the materials were ranged within 339-371 N/mm^2 and 449-469 N/mm^2, respectively. A total of 20 specimens was tested. Each specimen was pin-supported at both ends. The effective length l of the tested part was 318mm (or 300mm) or 618mm as shown in Table 1. Test parameters are: 1) slenderness ratio λ, 2) width-to-thickness ratio b/t, 3) loading pattern, and 4) deflection mode (positive and negative modes). Loading was controlled by the relative axial displacement Δ in the contraction side, programmed as in Fig. 1.

3. Effects of Slenderness Ratio and Width-to-thickness Ratio The global buckling deformation was accompanied by local buckling of the plates of the leg at the mid-part of the specimen. In the case of the positive deflection mode, no torsional deformation was observed in the L5 series of specimens, but occurred in both L3 and H3 series. This phenomenon was clearly observed in the H3 series which was more slender than the L3 series. Namely, torsion becomes more significant as b/t and λ become larger. In the negative deflection mode, a slight torsional deformation was observed in the H3 series only. During testing, visible cracks occurred and nine specimens, for which f_{rup} is listed in Table 1, ruptured completely within the programmed loading cycles (See Table 1 for nomenclature). The test results show that f_{rup} decreases as b/t becomes smaller and λ becomes larger. This may be because the local deformation of the angle was pronounced in these cases. On the other hand, regardless of the values of b/t and λ, the maximum absolute value of residual "net" strains in a cracked portion, excluding contributions from the crack opening, of all the specimens were in the range of 27.5-35% on the elongation side and 29-41% on the contraction side (See ε_{tens} and ε_{comp} in Table 1).

Table 1. Specimen sizes, test parameters and results.

Specimen Name	Length l (mm)	Slenderness ratio λ	Width-to-thickness ratio b/t	Loading pattern	Deflection mode	Number of load cycles: Crack f_{cav}	Crack f_{vex}	Crack f_{pen}	Rupture f_{rup}	Dimension-less energy E/E_o	Strain at cracked portion: Tens. ε_{tens} (%)	Comp. ε_{comp} (%)
L3IP	318	40.5	14.1	I	P	17	18	18	--	131	--	--
L3IN	301	37.4	15.8	I	N	20	21	21	--	235	--	--
L3CP$_a$	300	37.3	15.8	C	P	9	10	10	--	133	27.5	-29
L3CP$_b$	318	40.5	14.0	C	P	5	8	8	23	115	30	-32.5
L3CN	301	37.4	16.4	C	N	7	8	8	--	220	--	-41
L3GP	318	40.5	14.1	G	P	5	9	10	25	112	27.5	-35
L3SP	318	40.5	14.0	S	P	8	12	12	27	122	30	-32.5
L3GN	318	40.5	14.2	G	N	6	--	7	--	170	--	-30
L3SN	318	40.5	14.2	S	N	10	--	11	--	221	--	-35
L5IP	318	41.4	8.6	I	P	21	23	23	--	236	35	-35
L5IN	300	39.0	8.6	I	N	22	--	22	--	410	--	-30
L5CP$_a$	317	41.2	8.6	C	P	9	12	12	19	211	32.5	-35
L5CP$_b$	317	41.2	8.6	C	P	9	12	12	19	214	30	-32.5
L5CN	318	41.4	8.6	C	N	9	13	13	21	378	35	-35
H3IP	618	76.8	16.2	I	P	18	21	21	--	78	35	-35
H3IN	618	76.8	16.1	I	N	18	--	22	--	117	--	-35
H3CP	618	76.8	16.1	C	P	5	8	9	17	66	32.5	-35
H3CN	618	76.8	16.2	C	N	5	--	8	--	104	--	-35
H3GP	618	76.8	16.0	G	P	6	9	11	22	75	30	-35
H3SP	618	76.8	16.2	S	P	9	12	12	22	83	35	-35



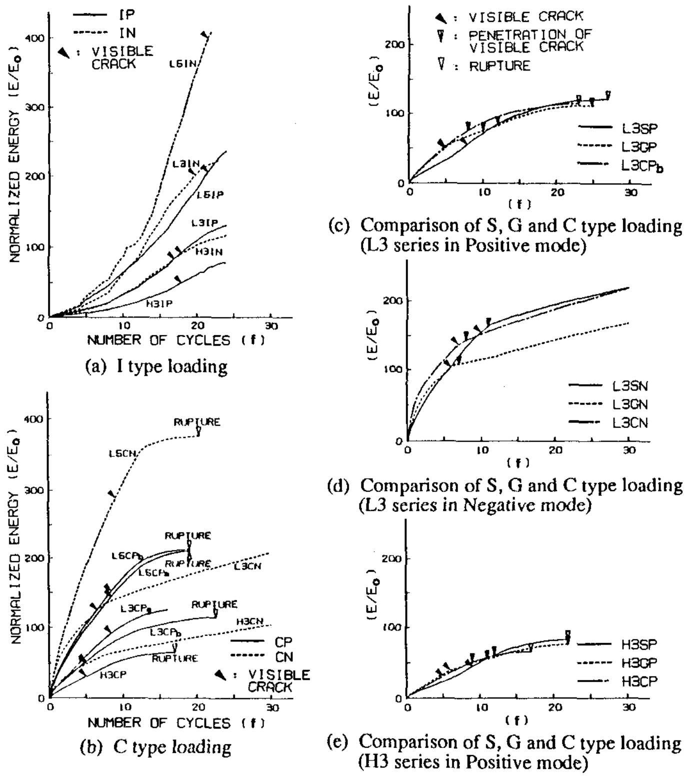
(a) I type loading

(b) C type loading

(c) G type loading

(d) S type loading

Fig. 1. Loading patterns.



(a) I type loading

(b) C type loading

(c) Comparison of S, G and C type loading (L3 series in Positive mode)

(d) Comparison of S, G and C type loading (L3 series in Negative mode)

(e) Comparison of S, G and C type loading (H3 series in Positive mode)

Fig. 2. Comparison of energy dissipation in the course of increasing number of cycles.

4. Energy Dissipation Behavior and Effect of Loading Sequence The relationships between the dissipated energy E and the number of cycles f are shown in Fig. 2 for all the specimens, where E_o is the maximum elastic strain energy which can be stored in the tested part of the specimen. In the cases of the same loading pattern and the same deflection mode, very similar processes of energy dissipation were observed (See curves for $L5CP_a$ and $L5CP_b$, and $L3CP_a$ and $L3CP_b$ in Fig. 2(b)). If deflection modes are different, however, cumulative energy dissipation behavior is quite different even among specimens under the same loading pattern (See (a), (b) and compare (c) with (d) in Fig. 2). From comparison of three types of loading patterns, C, G and S, effects of loading sequence are investigated (Fig. 1). In the case of the positive deflection mode (See Figs. 2(c) and (e)), f_{rup} becomes small in the order of the C, G and S types of loading. In other words, the specimen subjected to large displacement loading earlier (G type) resulted in slightly severer damage than the S type. However, the energy dissipation capacity does not differ much among these types.

5. Conclusions The main conclusions from this experimental study are summarized as follows:

1) The number of load cycles at rupture decreases as width-to-thickness ratio becomes smaller and slenderness ratio becomes larger, because of severe concentration of local deformation in angles.

2) Residual strains at the outbreak of a visible crack under very low-cycle loading were of the order of 25-40%, regardless of loading patterns, deflection modes, slenderness ratios and width-to-thickness ratios.

3) Energy dissipation capacity depends heavily on the entire history of loading, failure modes, slenderness ratios and width-to-thickness ratios. In view of the loading sequence for the C, G and S type loading of this experiment, the specimen subjected to early greater displacement loading ruptured in a smaller number of cycles and suffered slightly severer damage.

Reference 1) Y.-S. Park, S. Iwai, H. Kameda and T. Nonaka : Experimental Investigation on Structural Failure of Steel Angle Members due to Very Low Cycle Fatigue, Proc. of the 46th Annual Conference of Japan Society of Civil Engineers, Vol. 1, 1991, pp. 202-203.