I - 88 CYCLIC BEHAVIOR OF STRUCTURAL STEEL UNDER BIAXIAL NONPROPORTIONAL LOADING

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1. Introduction

This paper is a sequel to reference [1] and is focused on the experimental observation on cyclic characteristics of structural steel subjected to biaxial torsional moment−compression force under nonproportional loading histories within the yield plateau.

2. Specimen

Specimens are square tubes of size $b = 50mm$, thickness $t = 4.5mm$, and effective length $257mm$ as shown in Fig.1. The material of specimen is SS400 structural steel. Since the residual stress sets in the steel during welding, the initial isotropy of the material is ensured by annealing the specimen in vacuum at $650°C$ temperature for 2.5 hrs.

3. Loading paths and experimental results

A total of nine specimens were tested by using the torsion-compression testing system reported in [2]. Two typical loading paths employed are shown schematically in Fig. 2, in torsional moment T-axial force P space. The experiments are carried out in multiple steps for limited values of the twisting angle rates $\phi_i = (40, 80, 120, 160, 200) \times 10^{-4} rad/cm$, where i stands for the step number. The torsional moment T-twisting angle rate ϕ responses are given in Figs.3 and 4 for these paths.

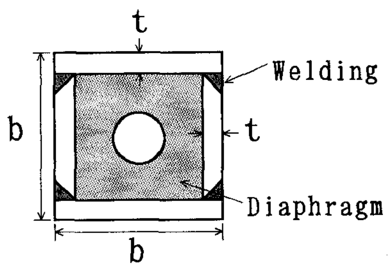
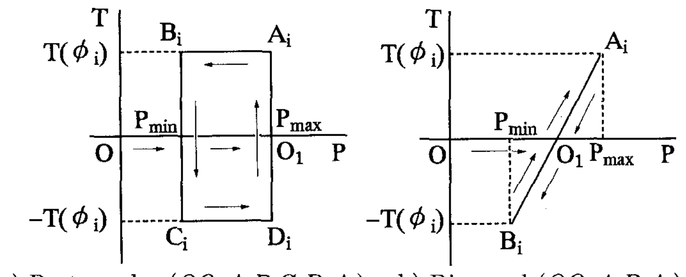


Fig.1 Cross-section of specimen



a) Rectangular $(OO_1A_iB_iC_iD_iA_i)$ b) Diagonal $(OO_1A_iB_iA_i)$

Fig. 2 Two typical nonproportional loading paths

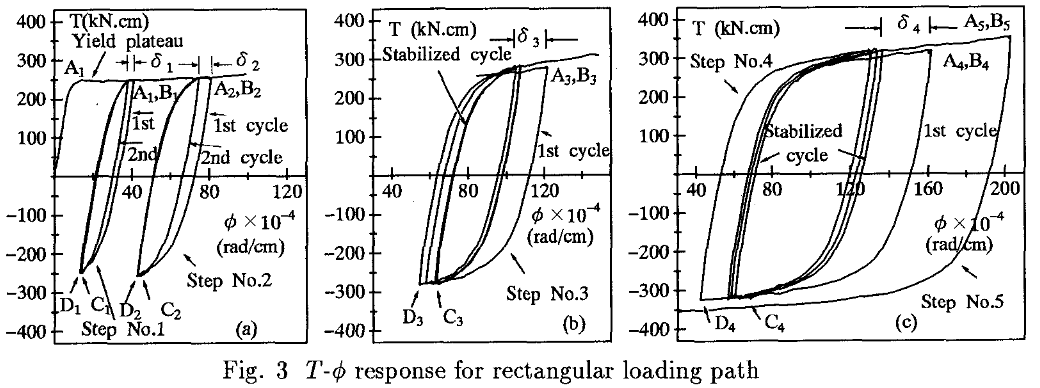


Fig. 3 T-ϕ response for rectangular loading path

4. Evaluation of experimental results and conclusions

4.1 Bauschinger effect:

Bauschinger effect can be defined as the reduction of the elastic range due to cycling. This effect is apparent in the test results. The elastic range of the hysteresis curve for the first and second steps (small strain range) decreases rapidly and later it doesn't change noticeably (Figs. 3 and 4).

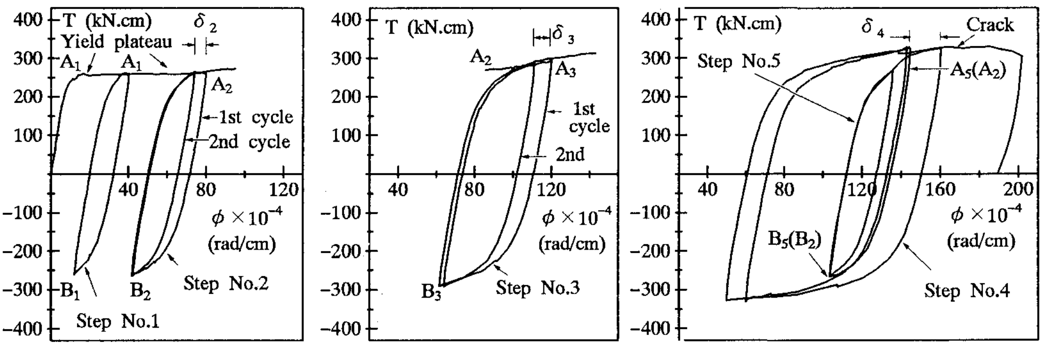


Fig. 4 T-ϕ response for diagonal loading path

4.2 Strain hardening:

$\delta_i (i = 1,4)$ is the difference between the first and stabilized loop width for step i along the ϕ axis, as shown in Figs. 3 and 4. The decrease in the width of the hysteresis loop along ϕ axis, δ_i, indicates the strain hardening of the material. The change in δ_i is quite gradual after the first cycle for each step. The stabilized hysteresis curves are achieved after a few cycles without further noticeable hardening. This is a typical behavior of the structural steel. From the $T - \phi$ curves of the tests results it can be seen that $\delta_1 < \delta_2 < \delta_3 < \delta_4$. This feature means that an increase in strain range increases the strain hardening.

4.3 Nonproportionality effect of loading paths:

The degree of nonproportionality in the rectangular loading path is more severe than that of diagonal one, since there is an abrupt change in the direction of loading in the former case. In case of the rectangular path δ_i is more than that of diagonal one within the yield plateau for corresponding steps . That is, the material experiences more strain hardening as the degree of nonproportionality of loading history is more.

4.4 Fading and nonfading memory of the material:

In the fifth step of the second experiment, after the stabilized state is achieved for the fourth step with a big effective stress, the experiment is continued by repeating the loading path for the second step with a smaller effective stress. From Fig. 5 it can be seen that the $T - \phi$ hysteresis loops for the fifth and second steps are nearly identical with the exception that it is translated in the positive direction of ϕ axis. This observation has an important significance, because if a loading path with a small effective stress is repeated after a path with a big effective stress, it washes out the influence of the preceding one with a big effective stress (fading memory of the material for the fifth step) and has a unique hysteresis loop which characterizes that loading path (nonfading memory of the material for the second step).

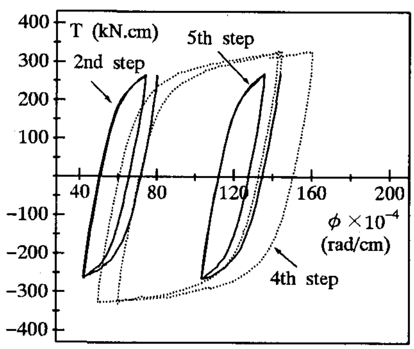


Fig. 5 Fading and nonfading memory of the material

References:

[1] I. H. P. Mamaghani, E. Mizuno, T. Usami: " Experimental study on elasto-plastic behavior of structural steel under biaxial cyclic loading ", Proceeding of JSCE, Chubu branch, March, 1994.

[2] E. Mizuno, C. Shen, T. Usami:" A cyclic torsion test of structural steel member and two-surface model simulation ", Proc. of JSCE, Str. Eng. / Earq. Eng., vol. 39A, March, 1993.