EXPERIMENTAL STUDY ON ELASTO–PLASTIC BEHAVIOR OF STRUCTURAL STEEL UNDER BIAXIAL CYCLIC LOADING

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1. Introduction

This study is concerned with the observations of experimental behavior of structural steel subjected to biaxial torsional moment–compression force under nonproportional cyclic loading histories.

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 structural steel of type SS400. Since the residual stress sets in the steel due to welding, the initial isotropy of the material is ensured by annealing the specimen in a vacuum at $650°C$ temperature for 2.5 hrs.

3. Example of loading paths and experimental results

Nine annealed square tubular specimens are tested by using the torsion-compression testing system reported in [1]. A typical loading path employed is shown schematically in Fig.2, in torsional moment T-axial force P space. The experiment is carried out in five 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 response is given in Fig.3.

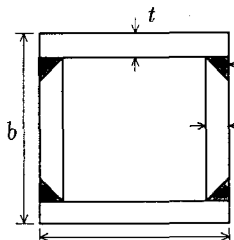

Fig. 1 Specimen cross-section

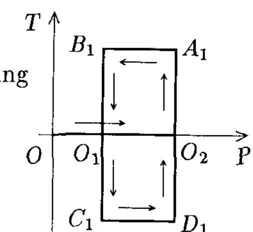

Fig. 2 Rectangular non-proportional loading path

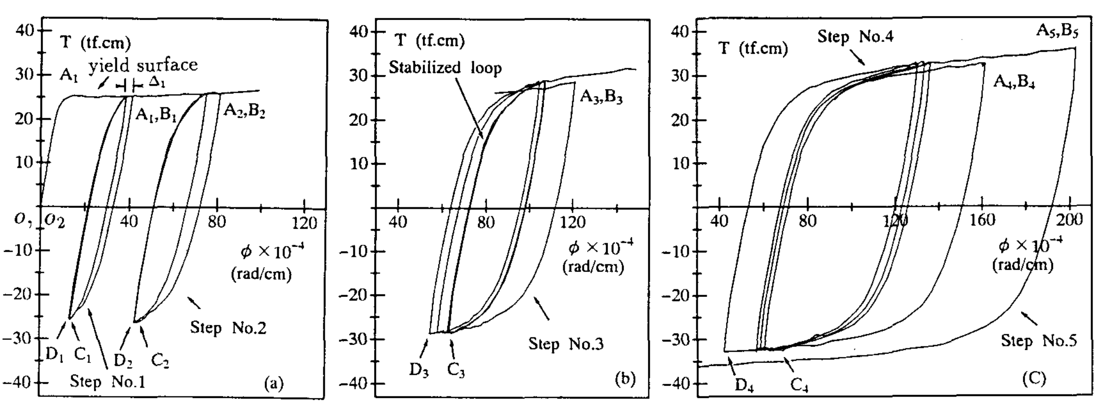

Fig. 3 Torsional moment T-twisting angle rate ϕ response

4. Evaluation of experimental results with two-surface model

4.1 Path OO_2A_1: In the first step, the axial force is increased to a value of $P_{max} = 0.55P_y$ along the path OO_2, then torsional moment is applied along the path O_2A_1 until the material yields at the loading point A_1, where the plastic flow, $d\epsilon^p_{ij}$, is initiated under the assumption of associated flow rule, Fig.4(a). The material exhibits yield plateau from loading point A_1, Fig.3(a). In order to study the cyclic elasto-plastic behavior within the yield plateau, the twisting angle rate is limited to ϕ_1, and the corresponding value of torsional moment, $T(\phi_1)$, is recorded. Due to the Bauschinger effect the size of the yield surface decreases. The size of bounding surface increases as the plastic deformation takes place, Fig.4(a).

4.2 Path $A_1B_1C_1$: Unloading is started along path A_1B_1 by reducing axial force to $P = 0.2P_y$ at point B_1. Later, the value of torsional moment is decreased up to a value of $-T(\phi_1)$ at point C_1, (path B_1C_1). The response is elastic until the loading point hits the yield surface at l. Along path lC_1 the response is elasto-plastic and, both the twisting angle rate and axial strain decrease due to the normality condition of plastic flow, Fig.4(b).

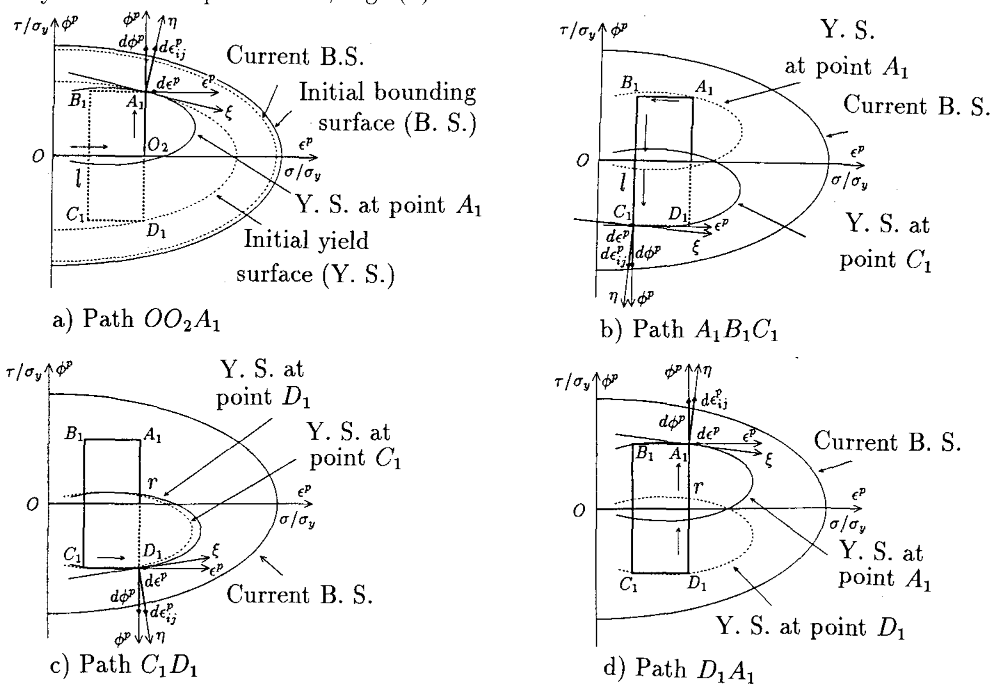

Fig. 4 Schematic illustration of the material response

4.3 Path $C_1D_1A_1$: Re-loading of axial force is started along path C_1D_1 on which the response of the material is elasto-plastic and, while the axial strain increases the twisting angle rate decreases under the constant torsional moment according to the normality condition of plastic flow, Fig.4(c). Then, path D_1A_1, is imposed on the specimen. At this stage, one cycle of rectangular loading path is completed,(path $A_1B_1C_1D_1A_1$), Fig.4(d). The axial strain does not change while the twisting angle rate increases elastically until point r. Along rA_1 the response is elasto-plastic and, both the twisting angle rate and axial strain are increased. The cycling is continued until the stabilized state of material is achieved for two successive cycles, Fig.3(a).

4.4 Strain hardening: The decrease in the width of the hysteresis loop along ϕ axis, Δ_1, indicates the strain hardening of the material. Plastic strain hardening occurs mainly in the first cycle. The reason is that the size of the bounding surface increases and the size of the yield surface decreases as the accumulated effective plastic strain (A.E.P.S.) increases while the material yields along the yield plateau. But the size of both surfaces remain unchanged during cycling, since the A.E.P.S. does not change significantly. As a result, in the first cycle along the paths lC_1 and rA_1, the distance between the loading point on the yield surface and its conjugate point on the bounding surface, which affects the plastic modules E^p [1], becomes larger for the first cycle and it remains almost unchanged for the second cycle. The experimental procedure and cyclic response follows almost the same features for the subsequent steps as that of the first step. The reduction in hysteresis loop width along ϕ axis becomes larger as the number of step increases, (see Figs.3(a) to 3(c)).

5. Conclusions

From the experiments conducted the following common results can be obtained. a) The more the twisting angle rate (strain), the more the reduction of the hysteresis loop width, (cyclic strain hardening). b) The cyclic reduction of the hysteresis loop width is quite gradual after the first cycle. c) The axial strain increases due to cyclic effect under the constant axial load.

Reference [1] 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.