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Experimental Study on Steel Beam-Columns under Repeated Bending

Etudes expérimentales de colonnes en acier soumises à flexion répétée

Experimentelle Studie an Stahlträger-Stützen unter wiederholter Biegung

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1. Introduction. There have been a large number of experimental and theoretical studies that deal with steel structures subjected to alternating loads. The most significant aspect of these tests on steel frames or subassemblages whose columns are under constant high axial compression are that the maximum horizontal loads which could be carried by the frames or subassemblages are increased gradually with repetition of loading cycles. To predict rationally behaviors of such frames or structural subassemblages, which exhibit characteristics of multi-story frames, realistic relation of alternating moment-curvature of the cross section of members under constant axial compressive load is needed basically. Herein, experimental studies on steel beam-columns which are subjected to constant axial compressive load and alternately repeated bending are carried out. To determine the alternating moment-curvature relation of the members under constant axial compression, these experimental results are compared with theoretical ones by a simple method of analysis on the basis of bi-linear and curved stress-strain relations.

2. Description of Tests. Five specimens with 240mm length and with rectangular cross section (40mm × 19mm) were taken from 19mm thickness plate. Material is a structural steel, SS41, with lower yield stress, $\sigma_y = 3.17\ t/cm^2$ and ultimate tensile stress, $\sigma_u = 4.56\ t/cm^2$, which are the average of three measurements obtained from monotonic tension tests on three tensile coupons. Values of

constant axial compression to which specimens are loaded are summarized in Table 1.

Fig. 1 shows the loading arrangement. The upper and lower ends of a specimen are clamped rigidly into the arm plates by high strength bolts. Constant axial compression, P, was loaded vertically to the specimen by hydraulic testing machine with 50 ton capacity through the knife-edged pin supports. Alternately repeated bending was applied statically to the specimen by a high strength bolt, which was attached through the pin supports in perpendicular direction to the arm plates. Bending was applied to the specimen about the weak axis of the cross section. Axial tensile force applied to the high strength bolt with turn-of-nut was measured by means of a load cell connected to the high strength bolt through the universal joints. Horizontal deflection at a mid span of the specimen was measured by the displacement meter with 50mm stroke capacity. Curvature of the cross section was measured by the post yield electric wire strain gages located at the mid span of the specimen.

3. Experimental Results. Solid curves in Fig. 2 (a-e) show the moment-curvature curves obtained from the experiments. In these figures, moment, M, and curvature, ϕ, are nondimensionalyzed by initial yielding moment, $M_y(=\sigma_y Z_e$, σ_y = yield stress, Z_e = section modulus), and corresponding curvature, $\phi_y(= M_y/EI$, EI = flexural rigidity), respectively. In Fig. 4 (a-e), maximum absolute values of the resisting moment of all specimens are plotted against number of repetition of loading reversals by solid curves. It is seen from these figures that; (1) The size and shape of a virgin curve are considerably different from those of separate hysteresis loops. (2) Influence of axial compression ratio, $n(= P/P_y)$, in increasing the maximum resisting moment of the cross section is quite evident from the figures. (3) Rate of increase of the maximum resisting moment to the number of cycles becomes remarkable as the axial compression ratio, n, becomes high. (4) Such increment of maximum resisting moment becomes gradually small with repetition of bending. (5) Elastic modulus of the moment-curvature hysteresis loops does not almost vary with cycles.

In Fig. 5 (a-e), average strain in the cross section, $\varepsilon_{\bar{o}}$, defined as the strain at the centroid axis of the cross section, is plotted against number of loading reversals by solid curves.

As is seen from the figures, when the specimen is subjected to constant axial compressive load, average strain in the cross section is increased gradually and is always accumulated to the compressive direction with repetition of bending. Under higher axial compressive load and curvature amplitude, accumulation of the average strain becomes progressively larger with each additional cycle. Therefore, it is seen from the experimental results that accumulation of the average strain in the cross section is closely related to the increase of the maximum resisting moment of the cross section due to repetition of cycles (Ref. 1).

4. Theoretical Analysis and Discussion. In Refs. 1 and 2, a simple analytical method to determine the moment-curvature relations for double symmetrical cross sections under constant axial compression and alternately repeated bending was proposed. Although this analytical method is based on trial and error technique, for a given hysteresis law between stress and strain, moment-curvature relation under any loading situation can be easily determined without simplification of the geometrical shape of the member section.

Experimental results were compared with theoretical ones obtained from the method of analysis proposed in Refs. 1 and 2, which were based on bi-linear and curved stress-strain relations, respectively. These stress-strain relations are shown in Fig. 3. In the analysis, values of strain hardening factor, μ, for bi-linear stress-strain relations are assumed as $\mu = 0.01$ and $\mu = 0.02$ (see Fig. 3), and values of the Ramberg-Osgood parameters for curved stress-strain relation shown in Fig. 3 are choosen as $\alpha = 1.5$, $\gamma = 9$ and $\alpha = 2.5$ $\gamma = 7$, which describe the stable region of the moment-curvature hysteresis loops under repeated pure bending (Ref. 3).

In Fig. 4 (a-e), relation between maximum resisting moment of the cross section at each cycle and number of loading reversals are compared with analytical results for all specimens. Analytical results based on bi-linear stress-strain relations with strain hardening factors, $\mu = 0.01$, and $\mu = 0.02$, are designated by open triangle, Δ, and solid triangle, ▲, respectively, and those based on curved stress-strain relations with Ramberg-Osgood parameters, $\alpha = 2.5$, $\gamma = 7$, and $\alpha = 1.5$, $\gamma = 9$, are designated by open square, □, and solid square, ■, respectively. It may be concluded from these figures that increase of maximum resisting moment due to repetition of loading cycles for some specimens can be explained approximately by the analysis based on curved stress-strain relations with parameters, $\alpha = 2.5$, and $\gamma = 7$ and based on the relation with strain hardening factor, $\mu = 0.01$, although all experimental results do not agree well with the theoretical results. Moment-curvature curves based on bi-linear relation with strain hardening factor, $\mu = 0.01$, are shown in Fig. 2 (a-e) by dashed curves. Although analytical results based on curved hysteretic stress-strain relation is seemed to be somewhat better than those based on bi-linear one to explain the experimental results, the bi-linear relation with strain hardening factor, $\mu = 0.01$, may be quite reasonable model for inelastic analysis of steel members from the engineering points of view.

In Fig. 5 (a-e), average strain in the cross section at each of reversal points for all specimens are plotted against number of loading reversals. Symbols used in the figure are the same as those in Fig. 4. It is note-worthy that cyclic change of the average strain in the cross section for all specimens can be explained quite well by the analytical results based on bi-linear stress-strain relation with strain hardening factor, $\mu = 0.01$.

From the facts described above, it is concluded that bi-linear stress-strain relation with strain hardening factor, $\mu = 0.01$, is sufficiently reasonable relation to simulate the inelastic behavior of steel members under constant axial compression and alternately repeated bending.

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SUMMARY

Experimental Studies on steel beam-columns which were subjected to constant axial compressive load and alternately repeated bending were performed. Experimental results were analyzed by a simple method of analysis to determine the cyclic moment-curvature relation of the members under constant axial compression on the basis of bi-linear and curved stress-strain relations.

Specimen Number	Axial Compression Ratio ($n=P/Py,\ Py=A\sigma y$)
WO	0.198
WP	0.406
WQ	0.402
WS	0.606
WT	0.604

Table 1

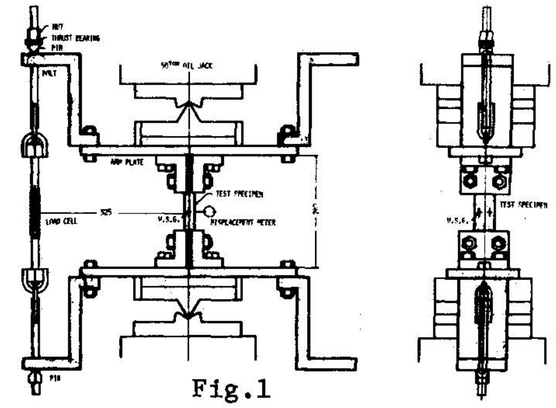

Fig.1

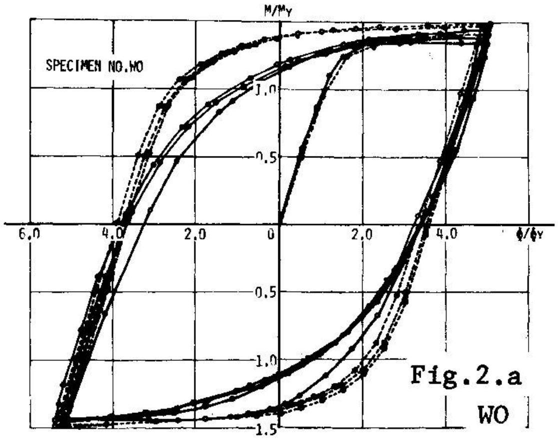

Fig.2.a
WO

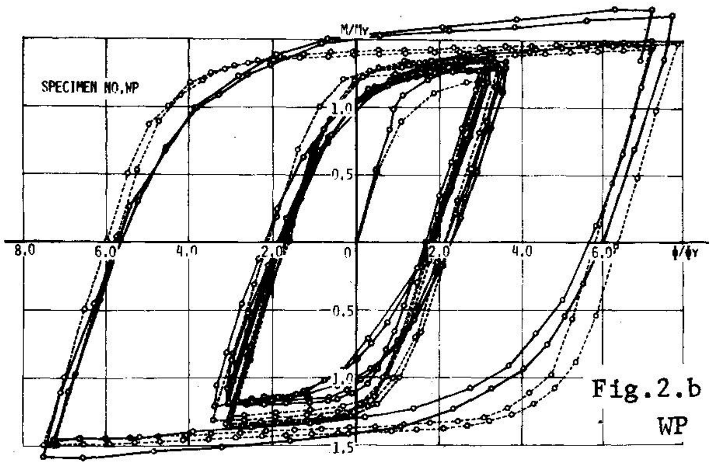

Fig.2.b
WP

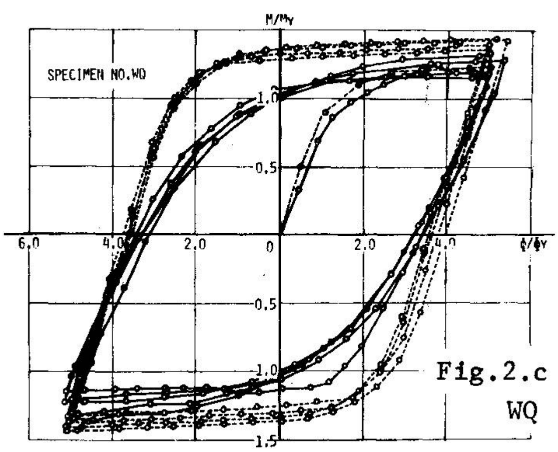

Fig.2.c
WQ

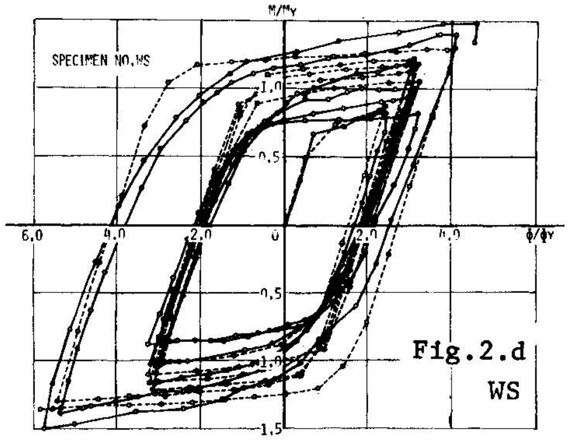

Fig.2.d
WS

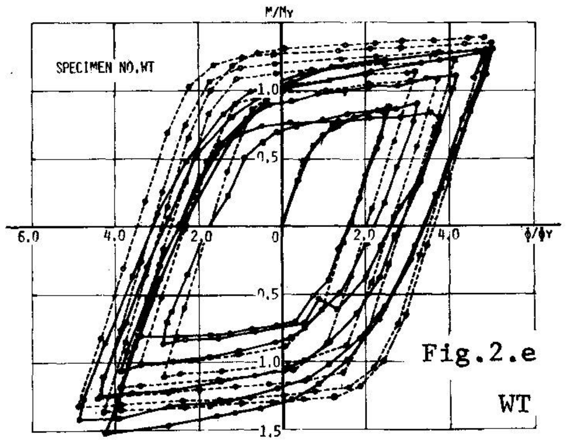

Fig.2.e
WT

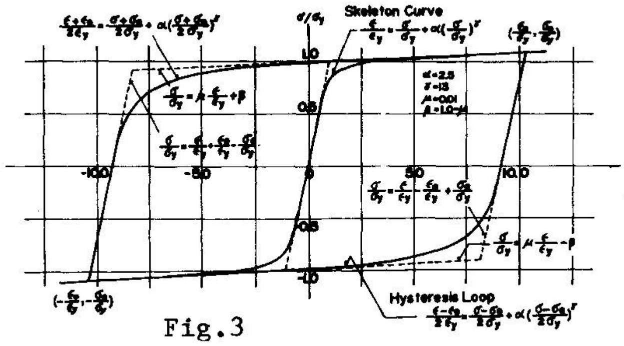

Fig.3

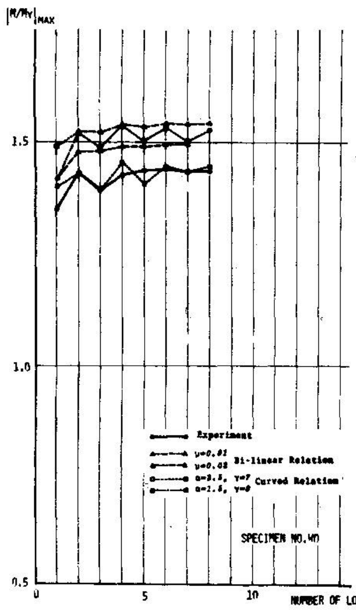

Fig.4.a
WO

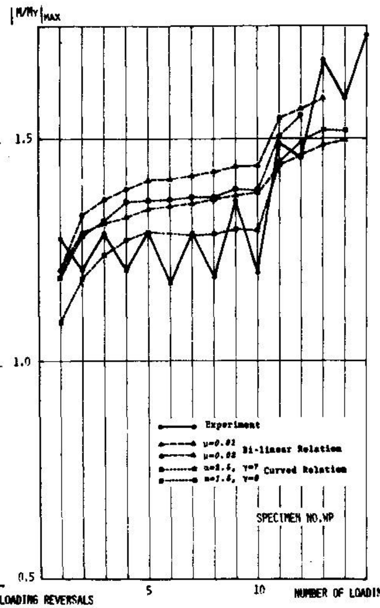

Fig.4.b
WP

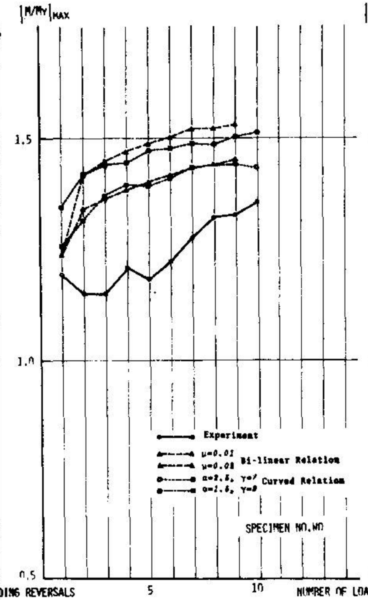

Fig.4.c
WQ

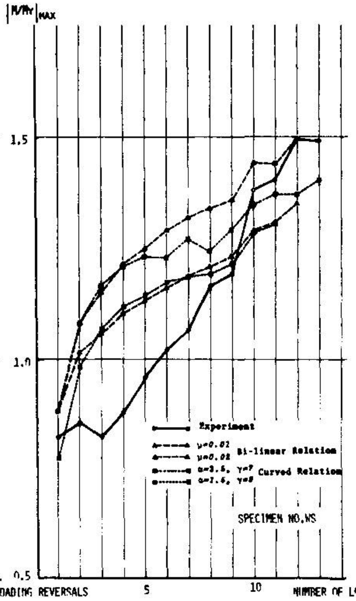

Fig.4.d
WS

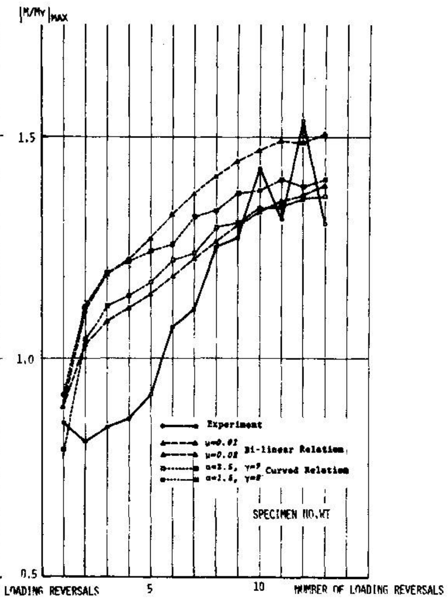

Fig.4.e
WT

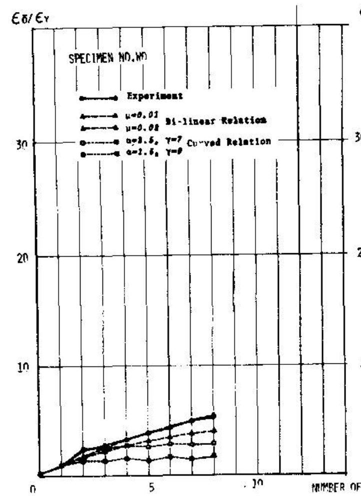

Fig.5.a
WO

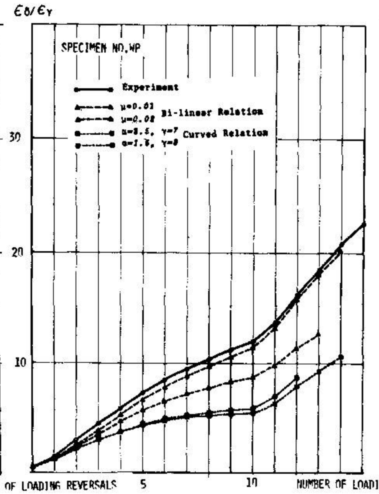

Fig.5.b
WP

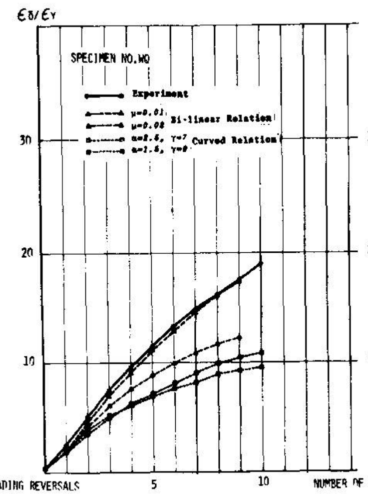

Fig.5.c
WQ

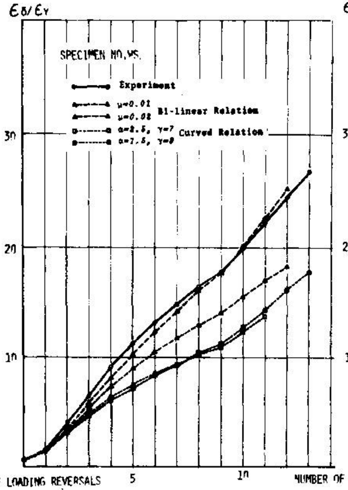

Fig.5.d
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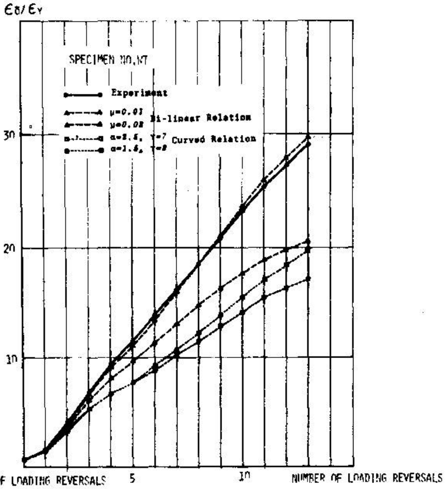

Fig.5.e
WT

RESUME

On a effectué des études expérimentales sur des colonnes en acier soumises à une compression axiale constante et à un moment de flexion alterné. On a traité les résultats par une méthode d'analyse simple afin de déterminer la relation moment cyclique-courbure des éléments soumis à une compression axiale constante, sur la base de relations tension-déformation bi-linéaires et courbes.

ZUSAMMENFASSUNG

Es wurden experimentelle Studien an Stahlstützen unter konstanter axialer Druckkraft und wechselseitiger wiederholter Biegung ausgeführt. Experimentell gewonnene Resultate wurden mittels einer einfachen Rechenmethode untersucht, um die zyklische Momenten-Krümmungs-Beziehung der Stützen unter konstanter Druckspannung auf der Basis der bi-linearen und der gekrümmten Spannungs-Dehnungs-Beziehung zu bestimmen.

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