AN EXPERIMENTAL STUDY ON INELASTIC BEHAVIOR OF STEEL MEMBERS SUBJECTED REPEATED LOADING

by

Toshiro SUZUKI[I] and Tetsuro ONO[II]

SYNOPSIS

The objects of this paper are to explain the deformation capacity of steel members under monotonic and repeated loading with experiments. Deformation capacities of members under repeated loading are quite different from that under monotonic loading. This causes based on increasing of the lateral and torsional deflection after local buckling. It is worth to be noted that the critical deformation capacity for repeated loading are lower than a half of the value for monotonic loading. Some data on the capacity of steel members as energy dissipators in plastic range are given.

1. INTRODUCTION

The safety of the steel structures, for the strong ground motion during earthquake, depends on the load-carring capacity and the deformation capacity of structures in the plastic range. For the antiseismic design of the steel structures, therefore, it becomes indispensable to explain the inelastic deformation capacity of structural members that formes the basis of the hysteretic characteristic of the steel frames. In the past, these problems of steel structures have studied under the ideal and simple conditions that out-plane deformation and local buckling might not arise. For instance, the repeated loading tests on the cantilever beams conducted by Popov[1] et al., gave the conclusion that hysteresis loops keep remarkablly stable shapes and the onset of local buckling on compression flanges does not imply an important loss of moment capacity, when out-plane deformations are prevented. In the practical structures, however, it is difficult to prevent completely the lateral deformations of members. In such cases, lateral or torsional buckling are considered to occur, after the local buckling of flanges. Therefore, it is necessary to explain the effects of these instabilities on the deformation capacity in order to understand the safety of the practical structures.

This paper chiefly deals with the monotonic and repeated loading experiments in order to explain the relationships between the local and lateral buckling and the deformation capacity.

I. Associate Professor of Architecture, Tokyo Institute of Technology. Tokyo, Japan.
II. Assistant of Architecture, Tokyo Institute of Technology. Tokyo, Japan.

2. DEFINITION OF THE LIMITED DEFORMATION CAPACITY

It is difficult problem to definite the limited deformation capacity of steel members. In this paper, the critical points are definited with the following method. For the beams under monotonic loading, the critical point is the maximum moment point and for the beam-columns, it is the point that moment level reduces 10% of maximum moment. Under repeated loading, the critical deformation capacities of members are definited with maximum deformation, within which the hysteresis loops are still stable.

3. DEFORMATION CAPACITY OF STEEL MEMBERS AND MONOTONIC LOADING

In this section, the rotation capacity of steel beams and beam-columns under monotonic loading which forms basis of hysteresis loops are discussed. The typical load-deflection curves obtained from the experiments are shown in Fig.2. These load-deflection curves are influenced by moment distribution, material, wide-thickness ratio, and bracing spaces etc.. In general, the plastic behaviors of these results are divided into three categories. On the beams under moment gradient, local buckling is limited the deformation. On the other hand, the capacity of beams under uniform moment is determined by lateral buckling. On the beam-columns, this plastic behaviors are different each other with the value of axial force. On the low axial force, the local buckling occurs firstly. Fig.3 and Fig.4 show the rotation capacity and slenderness ratio relationships of steel beams. The scatters of experimental values are large at the each slenderness ratio. Fig.5 and Fig.6 show the relationships between the rotation capacity and the following nondimensionalized factora.

Under uniform moment

$$R = K_1 \frac{1}{\lambda y^2} (\sigma_{yo}/\sigma_y)^2 \sqrt{\frac{B}{H}} \qquad (1)$$

Under moment gradient

$$R = K_2 \frac{1}{\lambda y^2} \rho (\sigma_{yo}/\sigma_y) (\frac{t_f}{B}) \qquad (2)$$

$R = \theta_{max} / \theta_p - 1$
ρ = end moment ratio
σ_{yo} = yield stress (ss41)
σ_y = yield stress of material
K_1, K_2 = proporsional constant
B, t_f, H = Crosssection of member

These equations are obtained from the analysis, assuming two models which are based on the inelastic behavior obtained from the experimental results. The relationships between these equations and rotation capacity are shown by linear functions and the experimental results agree with the theoretical results. Fig.7 and Fig.8 show the rotation capacity of beam-columns. The curves in these figures are obtained by the numerical analysis. The rotation capacity increases as slenderness ratio is smaller. However, the relations between the deformation capacity and the axial force are not monotonic increasing function. This relationships have an extremum at near $P=0.4P_y$

4. DEFORMATION CAPACITY OF STEEL MEMBERS UNDER REPEATED LOADING

Fig.9, 10, and 11 show the typical hysteresis loops of beams and beam-columns. The hysteresis loops of beams under uniform moment become unstable near the point of $V/V_p=2.0$, as shown in Fig.9. This value is very different from the deformation capacity under monotonic loading. The cause for the unstable of the hysteresis loops in this experiments due to incrasing of torsional deformation. The hysteresis loops of beam under moment gradient show the stable shapes as compared with the loops of the beams under uniform moment. The value of critical deformation capacity is $V/V_p=6.0$, when the loops become unstable. However, the deformation capacity is small comparing the deformation capacity of beams under monotonic loading is $V/V_p=12$, as shown in Fig.10. In this cases, local buckling is not the largest cause for the reduction of moment capacity. Lateral deflections that are given rise by local buckling are significant. Fig.11 shows the hysteresis loops of the beam-columns under the repeated moment and constant axial force. The size of hystersis loops develops into a large size affected by the axial force, on the inelastic range of stable loops. Onsets of local buckling on the compression flanges imply an important loss of moment capacity. The decreasing rate of loops is larger than that of beams. It is cause that the axial force gives rise the lateral and torsional deflections. Fig.12 shows the relationships between the accumulated energy ($\Sigma\Delta W/H_{pc}.V_{pc}$) and the accumulated deflection ($\Sigma\Delta V/V_{pc}$), in order to understand the energy absorption capacity.
In general, the areas enclosed by loops described above represent dissapated energy, these loops provide information on the energy absorption capacity of members. This relationships are shown with the linear function, when the hysteresis loops are stable. In case of the unstable loops, relations between these two factors are shown with the nonlinear functions.
The members which have the large deformation capacity under monotonic loading secure the large energy absorption capacities. Fig.13 and 14 show the experimental results of rotation capacity. The defferences in the test results between the monotonic loading and repeated loading are easily recognized from Fig.13 and 14. From Fig.14, it can be considered that is not effect of the value of axial force on deformation capacity on the beam-columns under repeated loading.

5. CONCLUSION

In this paper, the deformation capacities of steel members are explain from experimental results. The influences of the instability on the hysteresis loops are significant. However, it is not easy to determine quantitatively the deformation capacity of steel members under repeated loading considering the effects of the instabilities, because there are so many influencing factors as these expermental results. Furthermore, it is necessary to study the hysteresis loops of steel members from the point of this view.

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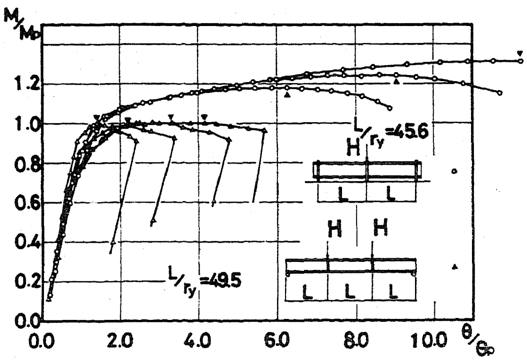

Fig.1 M-θ Relationships of Beams

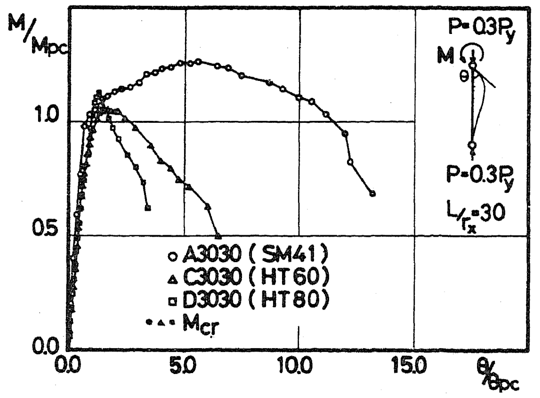

Fig.2 M-θ Relationships of Beam-Columns

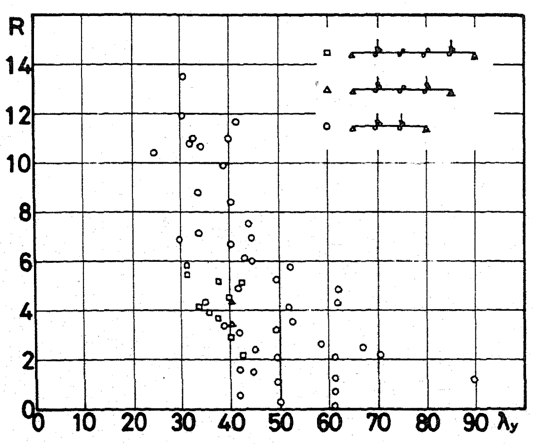

Fig.3 Rotation Capacity - Slenderness Ratio of Beams under Uniform Moment

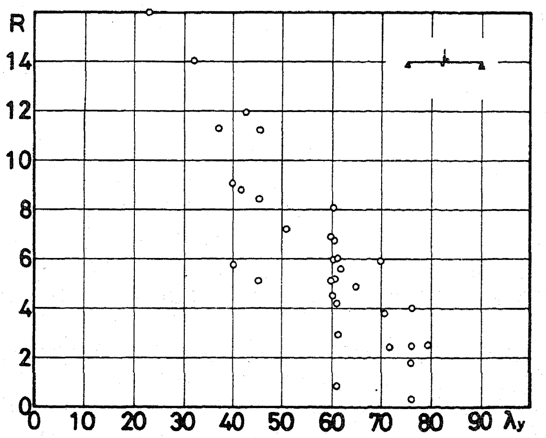

Fig.4 Rotation Capacity - Slenderness Ratio of Beams under Moment Gradient

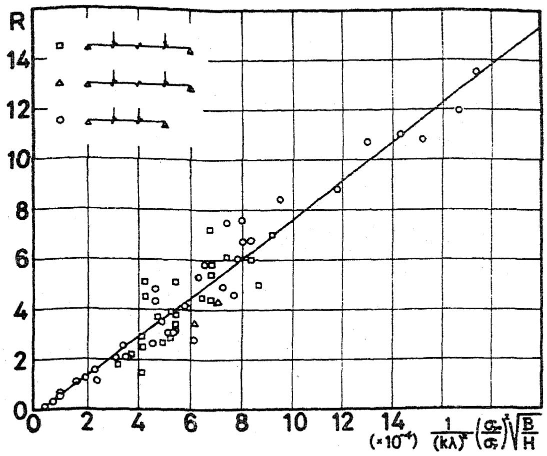

Fig.5 Least-Square Approximation of Experimental Results

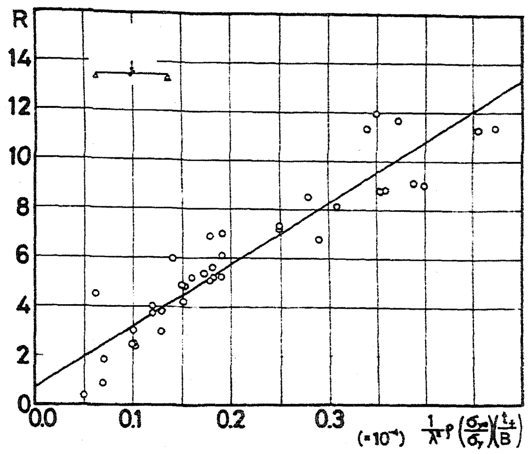

Fig.6 Least-Square Approximation of Experimental Results

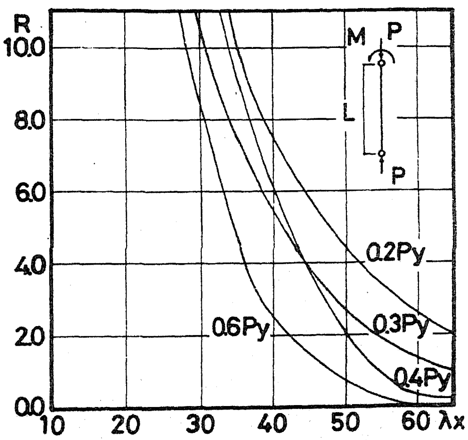

Fig.7 Rotation Capacity - Slenderness Ratio of Beam-Columns

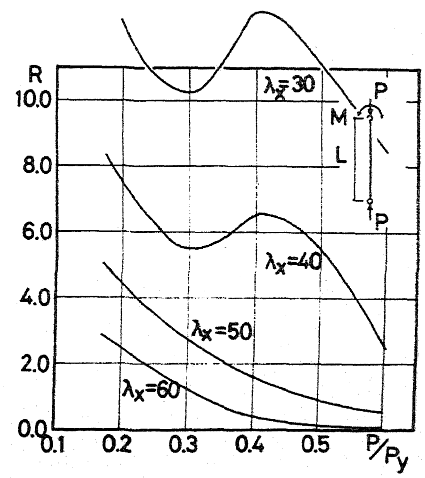

Fig.8 Rotation Capacity - Axial Force of Beam-Columns

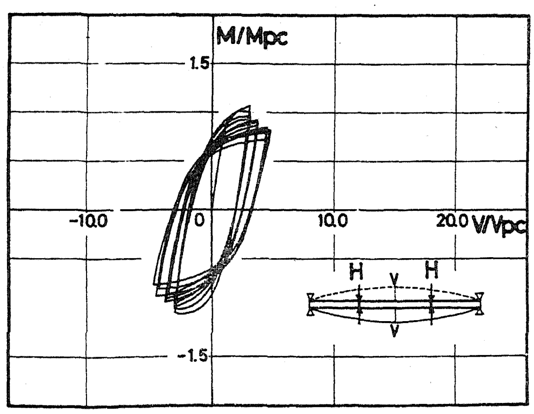

Fig.9 Hysteresis Loops of Beams under Uniform Moment

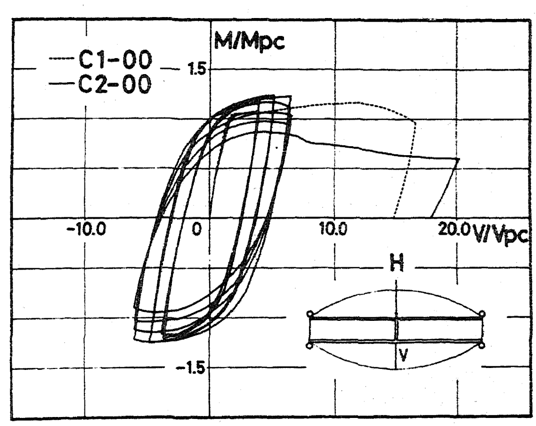

Fig.10 Hysteresis Loops of Beams under Moment Graduent

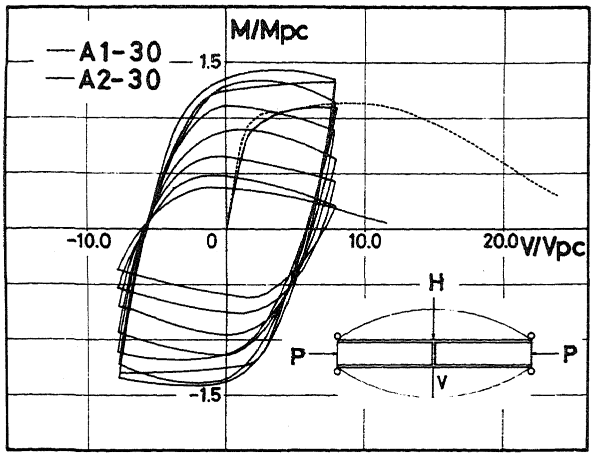

Fig.11 Hysteresis Loops of Beam-Columns

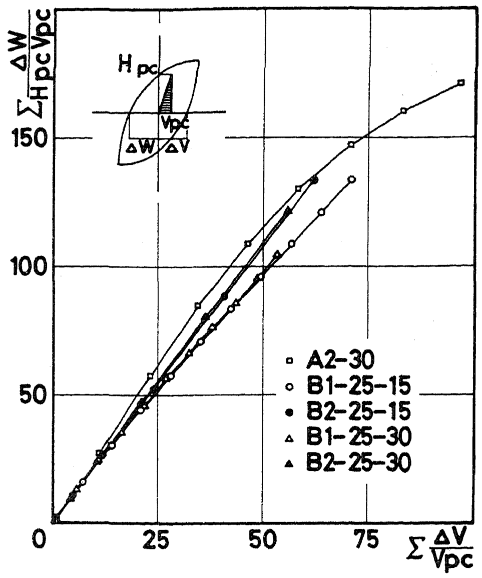

Fig.12 Accumulated Energy - Accumulated Deflection

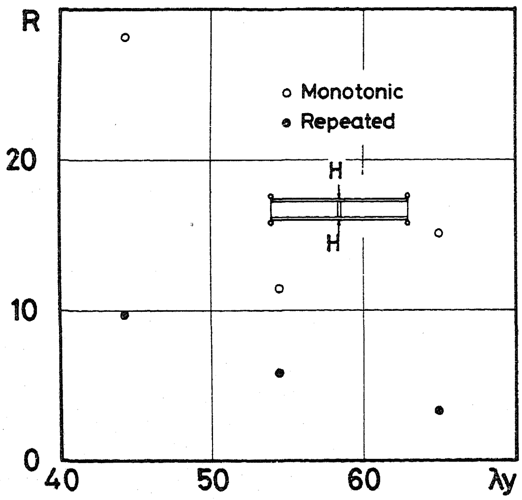

Fig.13 Rotation Capacity of Beams

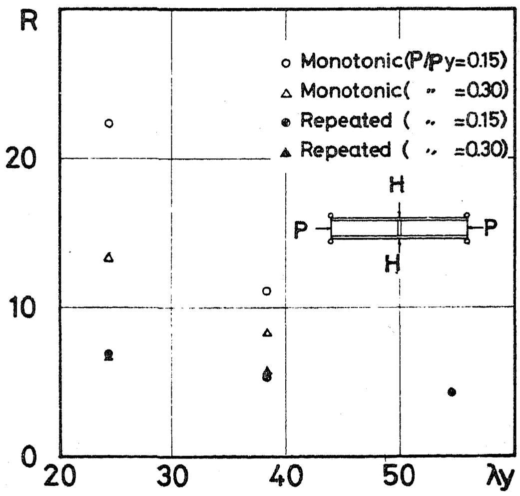

Fig.14 Rotation Capacity of Beam-Columns