INELASTIC LATERAL BUCKLING OF STEEL BEAMS SUBJECTED TO REPEATED AND REVERSED LOADINGS

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Synopsis. Repeated and reversed loading tests at constant deflection amplitudes are conducted on the steel beams with H-shaped sections. The results of these tests show the quite different behaviors of the lateral buckling from the behaviors under loads increased monotonously. There was the upper bound of deflection amplitude for each specimen, within which a stable hysteresis loop can be established. Beyond the bound, however, no stable hysteresis loop is obtained and the force recorded reduces each cycle. It is worth to be noted that these critical amplitudes have much lower values than the values evaluated from static and monotonous loading tests.

Introduction. The reversed bending tests on the cantilever beams conducted by Popov et al. (1) gave the conclusions that load-deflection hysteresis loops keep remarkably stable shapes and the onset of local flange buckling does not imply an immediate loss of moment capacity, when closedly braced compact members are used. The beams of actual frame structures, however, can not be always braced closedly even though uncountable restraints are provided by floors. In such cases, lateral buckling is considered to occur. Therefore, the investigation of lateral buckling of steel members must be required. The specifications for plastic design, say, AISC Spec. and AIJ Spec., recommend that lateral bracings shall be provided within the distance of the specified values. Unfortunately these provisions are based on the analysis for the structural members subjected to monotonously increasing loadings.

Specimens and Reversed Loading Test Procedures. Specimens tested were fabricated from rolled H-shaped sections. They are summarized in the Table. Specimens of DG series were made of JIS SS41 steel, which yield stress was evaluated 2.9 t/cm^2 by coupon tests. Specimens of DGH series were made of JIS SM50 steel which yield stress evaluated 4.5 t/cm^2. All specimens were not annealed.

The rig employed to subject the beam specimens for reversed loading tests is shown in Fig.1. Reversed loads were applied cyclically by the hydraulic actuator at the center of the span, where a guide preventing lateral displacement and torsion was provided. At the both ends lateral displacement and torsion were prevented also. This loading arrangement was intended to simulate the behaviors of a beam in a structure under a lateral load in spite of disregarding the torsional stiffness of a column which restrains the flanges to buckle sideways. A half length of span of each specimen denoted by l was chosen in order to make the slenderness ratio about weak axis l/r_y plotted in the vicinity of 65 which is recommended by AISC Spec.

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As shown in the Table, some specimens were statically applied monotonously increasing loads. The results of these tests are added to the previous static test results and are compared to the results of reversed loading tests. Throughout of these series of tests the vertical displacement of the center of a beam was controlled by the servo controller. The sequences of amplitudes were summarized in the Table. Each amplitude is divided by the yield deflection of the specimen, although in the Table the calculated end rotations defined by Fig.2 are adopted. The amplitudes were increased to the next step in each 10 cycles. The number of cycles in each step was determined by the reason that the stable hysteresis loops might be obtained in several cycles and the transient instability of material property must be excluded as well as possible for buckling problem. In all cyclically reversed loading tests except DG-130-5, the applied deflection were so controlled that they were sinusoidal functions of time t. The frequency of the cyclic deflection was 0.03 Hz or 0.05 Hz. This very low frequency was inevitable from the capacity of the power supply, but it was convenient for measurement. Moreover, the validity of using static measurement to predict dynamic behavior was already established by Hanson (2) and Rea et al.(3).

Experimental Results. The typical moment-rotation hysteresis loops obtained are shown in Fig.4 and Fig.5. Failure by buckling is defined in these series of experiments as follows: In 10 cycles, the value of moment, namely load, reduces more than 5 % of the first attained value at each amplitude and moreover the value of moment does not asymptotically approach to the lower value. The differences in the test results between monotonous loadings and cyclic reversed loadings are easily recognized by Fig.3. The rotation capacity R was calculated by $R=(\theta/\theta_p)_m-1$ where $(\theta/\theta_p)_m$ is defined by the value at the maximum load on the monotonous curve obtained. In the cyclic tests $(\theta/\theta_p)_m$ was determined to be equal to the maximum amplitude where the hysteresis loops were still stable.

Conclusions. The following conclusions were drawn out from the experiments. 1) Stable moment-rotation hysteresis loops can not be obtained after severe lateral buckling occured by monotonously increasing load. 2) There exists the some critical magnitude of amplitude, within which the hysteresis loops are stable under cyclically reversed loadings. Once the amplitude is beyond this magnitude, the moment capacity of beam reduces each cycle. 3) This critical magnitude mentioned above is considerablly low compared to the rotation capacity observed at monotonous loading tests. It is worth to be noted that the critical values for cyclic loading are lower than a half of the values for monotonous loadings. 4) For SM50 steel which has higher yield stress than SS41, more severe bracing requirements for lateral buckling must be provided in the structures subjected to both monotonous loadings and cyclically reversed loadings.

References

1) Popov, E.P. et al., "Cyclic Yield Reversal in Steel Building Connections", Proc. ASCE, Vol.95, No.ST 3, 1969 2) Hanson, R.D., "Comparison of Static and Dynamic Hysteresis Curves", Proc. ASCE, Vol.92, No.EM 5, 1966 3) Rea, D., et al., "Damping Capacity of a Model Steel structure", Proc. 4WCEE Chile, 1969

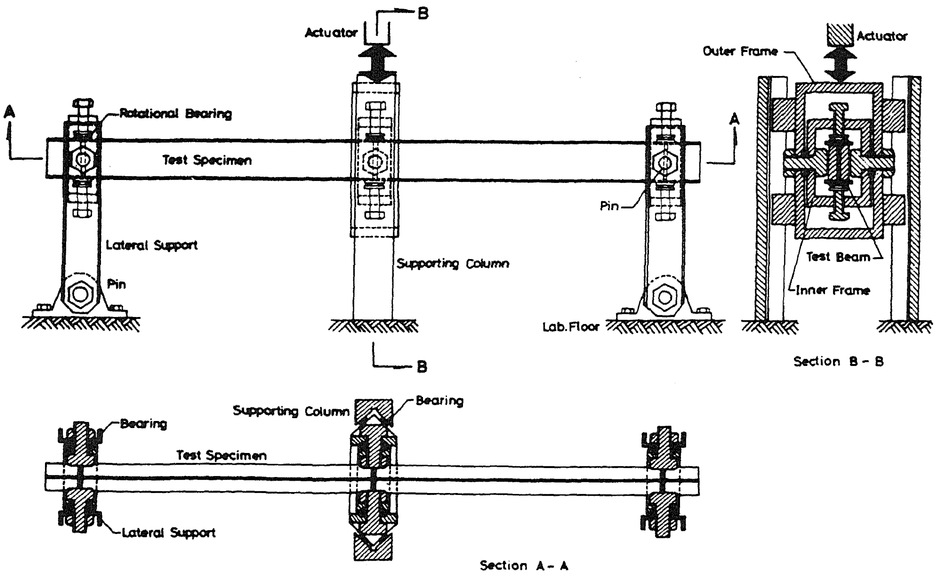

Fig. 1 GENERAL VIEW OF TEST SETUP

Fig. 2 DEFINITIONS OF MOMENT AND ROTATION

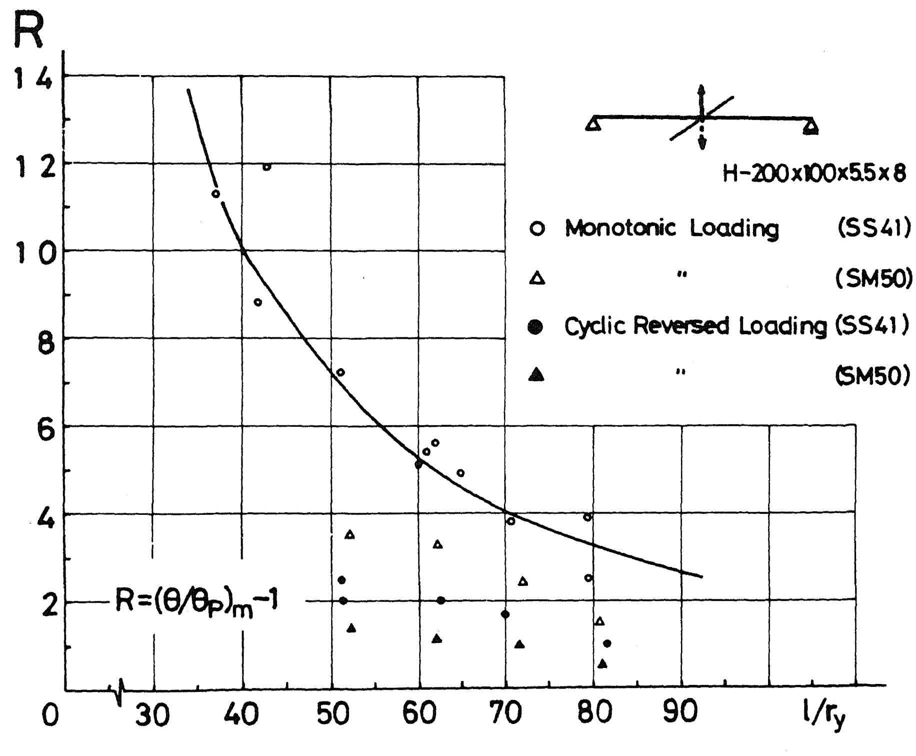

Fig. 3 ROTATION CAPACITY-SLENDERNESS RATIO

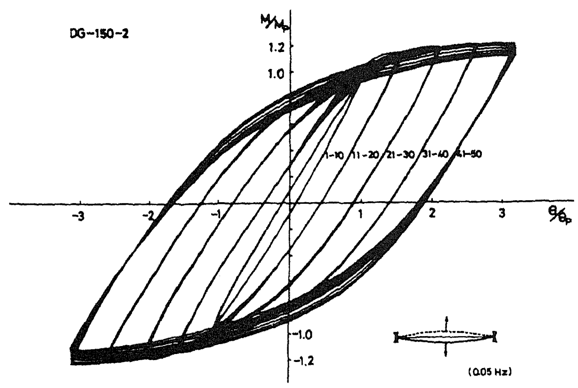

Fig. 4 HYSTERESIS LOOPS

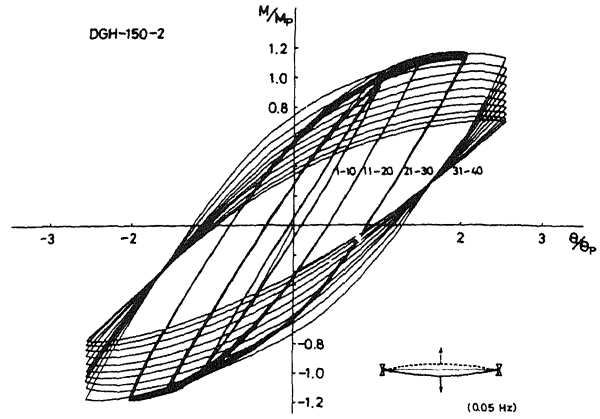

Fig.5 HYSTERESIS LOOPS

Table SUMMARY OF TEST RESULTS

Specimen	Slenderness Ratio	Loading Condition	Frequency (HZ)	Cyclic Program θ/θp Amplitude (Number of Cycles)	Rotation Capacity (R)
DG-110-1	51.2	Cyclic	0.03	1.0—2.0—2.5—3.0—3.5 (10) (") (") (") (15)	2.5
DG-110-2	51.3	"	"	1.0—1.5—2.0—2.5—3.0—3.5— (10) (") (") (") (") (") 4.0—4.5 (10) (5)	2.0
DG-130-1	60.9	Monotonous	——		5.4
DG-130-4	62.5	Cyclic	0.03	1.0—2.0—2.5—3.0—3.5 (10) (") (") (") (")	2.0
DG-130-5	"	Earthquake Response 1)	0.067 2)	1.0—2.0—2.5—3.0—3.5—4.0— (1) (") (") (") (2) (") 3.5—3.0 3) (1) (")	
DG-150-2	70.0	Cyclic	0.05	1.0—1.5—2.0—2.5—3.0—3.5 (10) (") (") (") (") (5)	1.7
DG-170-1	79.4	Monotonous	——		3.9
DG-170-3	81.7	Cyclic	0.03	1.0—1.5—2.0—2.5—2.75—3.0 (10) (") (") (40) (10) (5)	1.0
DGH-110-1	52.2	Monotonous	——		3.5
DGH-110-2	52.3	Cyclic	0.03	1.0—1.5—2.0 (10) (") (")	1.3
DGH-130-1	62.2	Monotonous	——		3.3
DGH-130-2	61.9	Cyclic	0.05	1.0—1.5—2.0—2.5—3.0 (10) (") (") (") (6)	1.1
DGH-150-1	72.0	Monotonous	——		2.4
DGH-150-2	71.6	Cyclic	0.05	1.0—1.5—2.0—2.5 (10) (") (") (")	1.0
DGH-170-1	80.7	Monotonous	——		1.5
DGH-170-2	80.9	Cyclic	0.03	1.0—1.5—2.0—2.5 (10) (") (") (3)	0.5

1) Response of deflection calculated with acceleration of ground motion recorded at Hachinohe 1968 earthquake

2) Mean frequency of response waves

3) Ratio of maximum response of rotation to θ_p