STRUCTURAL BEAM SHAPES UNDER CYCLIC INELASTIC LOADS

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SUMMARY

Structural shapes have been found to become unstable due to accumulated permanent strain under cyclic inelastic loads. The paper describes a programme in which 10 small rolled I-beams are subjected to fully reversed strains at the outer fibres ranging from ±0.11% to ±0.45% under pure bending conditions. The material softens under cyclic straining leading to premature flange instability when the control strain exceeds 3 times the yield strain of the material. In contrast, under static loading, the beam does not exhibit any instability even though the strain may exceed 10 times the yield strain. Moment-strain relations have been developed for predicting behaviour of simple structures under alternating deflections.

1. Introduction

Considerable work has been done on the behaviour and life of structural components under cyclic loading conditions [1,2]. These studies are on rectangular beam specimens, the dimensions of which are such that the instability is not a factor. Structural shapes, however, have been found to become unstable [3,4] due to accumulation of permanent strain under cyclic inelastic loads.

The study reported in this paper describes a programme in which structural I-shapes were investigated experimentally under fully reversed cyclic inelastic deformations to assess the influence of changing material behaviour on instability. The I-beams are subjected to fully reversed cyclic strains under pure bending conditions. Moment-strain relations also have been developed to predict behaviour of simple structures under alternating deflections.

2. Experiments

A special fixture shown in Figure 1 is designed to apply pure bending on the specimen. A closed-loop servo-controlled testing machine is used for the work.

The specimen used in the tests is sketched in Figure 2. The test beams are used as-received without any heat treatment. The specimens are monitored at critical locations of maximum moment and deflection for strain measurements. The yield strain, yield stress and Young's Modulus of the material are 0.15 per cent, 43×10^3 psi, and 30×10^6 psi respectively.

The specimen is installed in clamps and the desired displacement (strain) range is preset on the control mechanism, the deflected shape, under its own weight, being the reference state for fully reversed cycling. The first quarter cycle of each test is loaded manually in the downward direction before automatic cycling takes over.

The change in load (bending moment) is monitored continuously together with periodic strain readings. The curvature (strain) is computed from the displacement and the geometry of the deformed beam. Tests are curtailed when either instability or fatigue crack reduces the stiffness of the beam to a minimum. A total of 10 I-beams are subjected to fully reversed maximum strains ranging from ±0.11 per cent to ±0.45 per cent under pure bending conditions. The maximum strain imposed is about 3 times the yield strain of the material and the testing frequency is about 1 cycle per minute. The cyclic variation of bending moment for typical tests is plotted in Figure 3.

3. Analysis of Test Results

Initially the material softens as indicated, by a decrease in the bending moment, before reaching a stable state which is generally independent of the control strain. The rate of softening, however, is a function of the control strain. When the control strain exceeds ±0.43 per cent, the beams exhibit flange instability before failing due to material deterioration. For example, when the control strain is ±0.45 per cent, the flange instability occurs at about 50 cycles significantly reducing the total life of the beam. Under static loading, however, the beam does not exhibit any instability even after a strain well in excess of 1.5 per cent. The evidence clearly indicates that material softening under cyclic loading accelerates flange instability in I-beams.

By cross-plotting from Figure 3, pseudo-static moment-strain curves can be developed for various cyclic states as shown in Figure 4. The experimental points can be represented by a function of the form

$$\varepsilon = A(M)^{B} \qquad \text{eq. (1)}$$

where ε = per cent strain, M = moment amplitude (ft lbs) and A and B are constants which can be computed from test data. It is seen, from the 95% confidence limits curves of Figure 4, that the proposed function better fits the data in the high cycle range. Because of its simplicity in further structural applications, however, and because it facilitates structural computation by retaining uniqueness between moment and maximum strain at any given cyclic state, the function of equation (1) is chosen to represent material behaviour under all incidence of load. The moment-strain relationships for various cyclic states are combined in Figure 5.

In Figure 6, the strain ranges, ε, are plotted against the number of cycles to failure, N_f, for I-beams. Flange instability is observed in two beams when the control strain exceeds ±0.43 per cent.

4. Conclusions

An experimental programme is described for studying I-beams under fully reversed cyclic inelastic strains. The change in material behaviour under cyclic straining and its effect on the stability of I-beams are examined. The failure of the beams was also observed. Cyclic moment-strain curves have been developed for predicting behaviour of simple structures under alternating deflections.

Under fully reversed cyclic straining the material is found to soften, the rate of which is a function of the control strain. When the control strain exceeds a limit of approximately 3 times the yield strain of the material, flange instability sets in, significantly reducing the stiffness of the beam. This contrasts with static loading where much higher strains can be tolerated. If premature flange buckling under cyclic loading is therefore to be prevented, it is essential to consider the change in material response as part of the analysis.

5. Acknowledgement

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References

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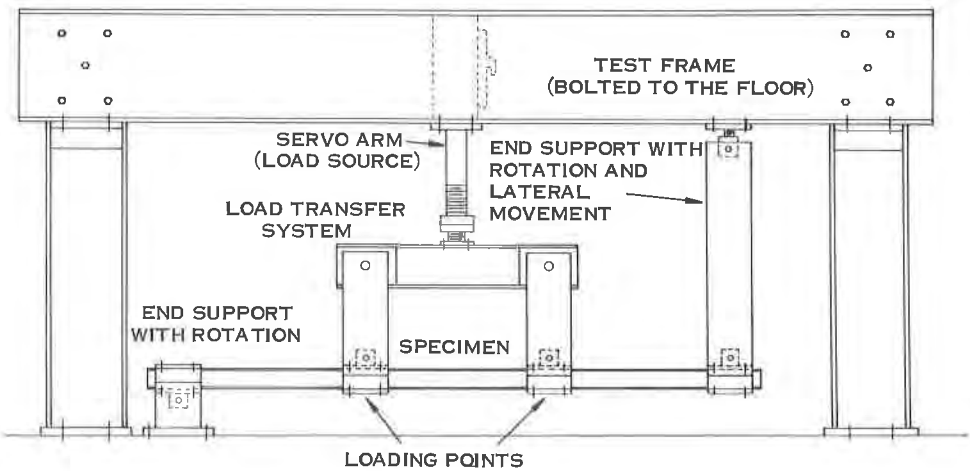


FIGURE 1. TEST SET—UP

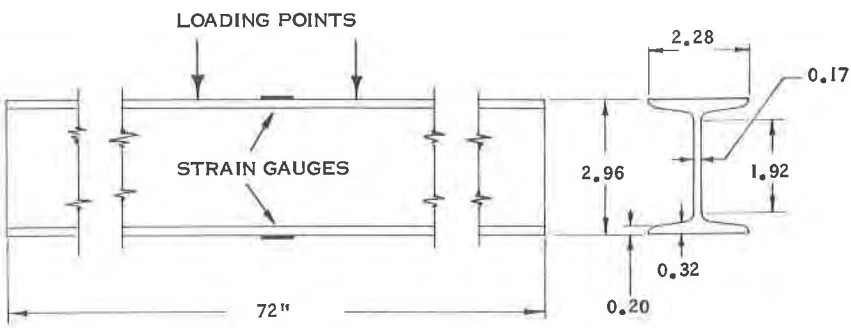


FIGURE 2. TEST SPECIMEN

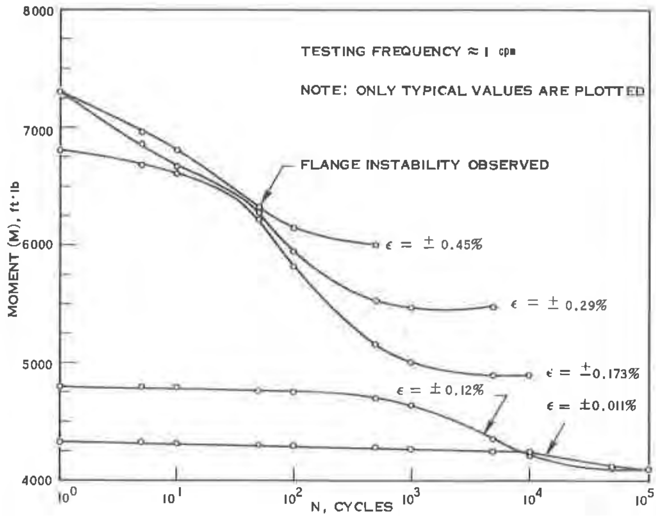


FIGURE 3. CYCLIC VARIATION OF MOMENT AMPLITUDE

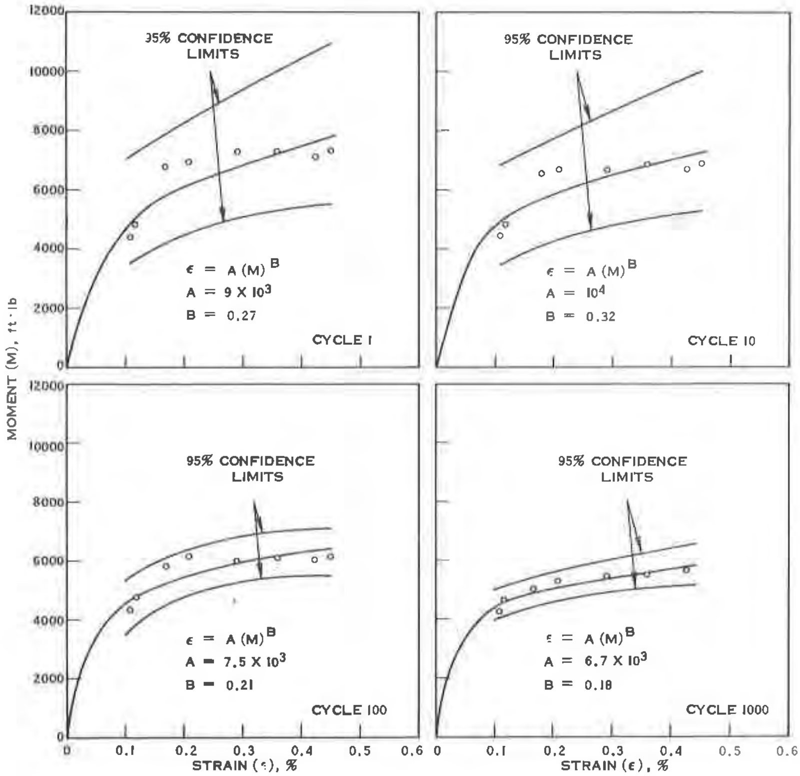
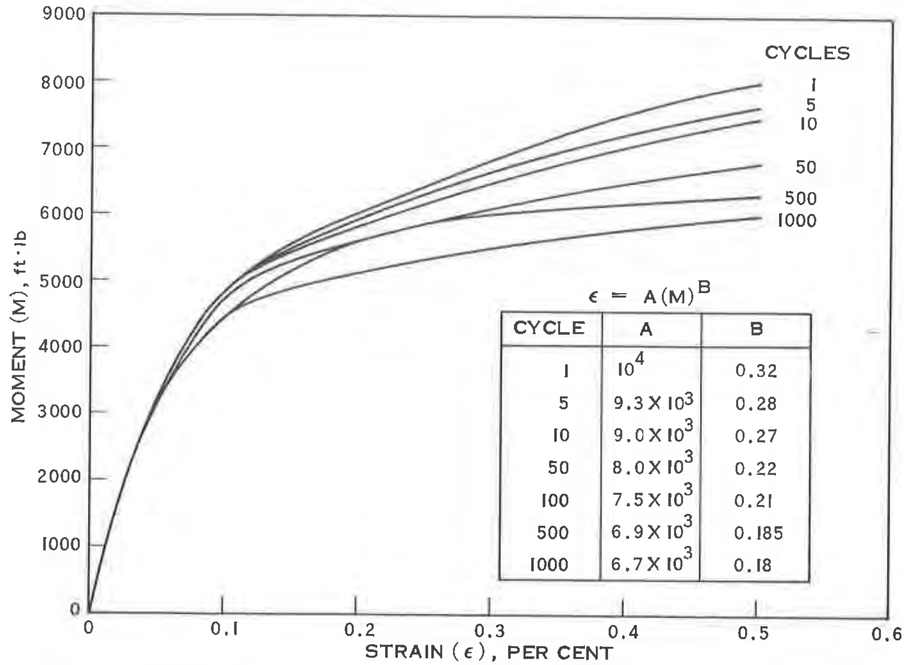


FIGURE 4. CYCLIC MOMENT—STRAIN CURVE FOR TYPICAL CYCLIC STATES



CYCLE	A	B
1	10^4	0.32
5	9.3×10^3	0.28
10	9.0×10^3	0.27
50	8.0×10^3	0.22
100	7.5×10^3	0.21
500	6.9×10^3	0.185
1000	6.7×10^3	0.18

FIGURE 5. COMBINED CYCLIC MOMENT–STRAIN CURVE FOR VARIOUS CYCLIC STATES

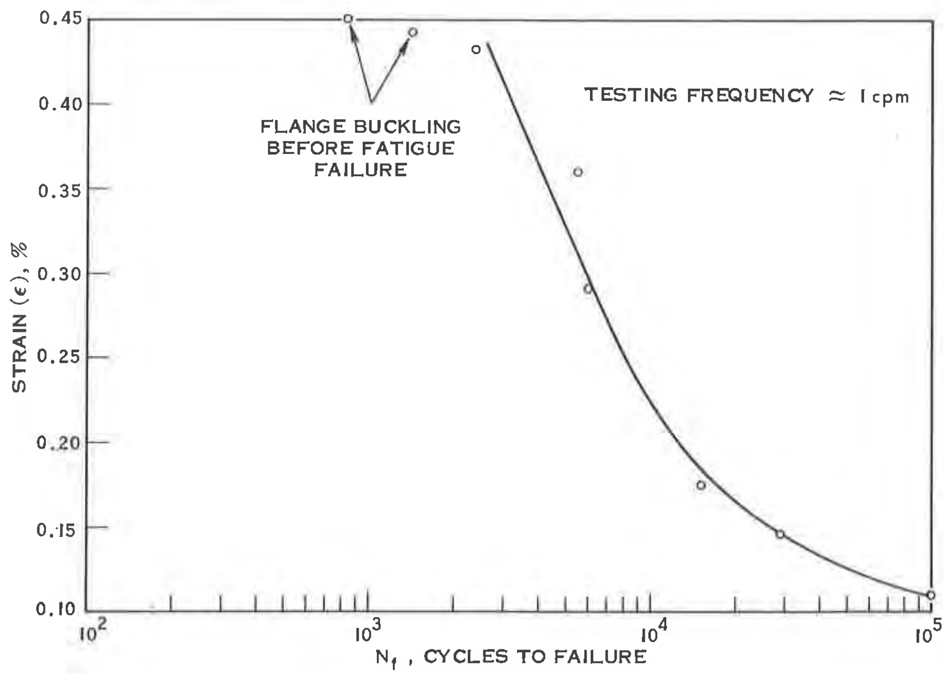


FIGURE 6. STRAIN VS CYCLES TO FAILURE