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# IV

## Hysteresis Loops of Reinforced Concrete Elements subjected to Reversed Cyclic Axial Loading

Boucles d'hystérésis d'éléments en béton armé soumis à l'inversion d'une charge cyclique axiale

Hystereseschleifen von Stahlbetonelementen unter Einwirkung zyklischer axialer Wechselbelastung


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### INTRODUCTION

The research presented herein was a by-product of a study dealing with moment-curvature hysteresis loops of reinforced concrete members having a hollow circular cross-section as shown in Figure 1. Members of this type are encountered in reinforced concrete chimneys and in bridge piers. As these members are subjected to an axial force and a cyclic bending moment, a longitudinal element such as A in Figure 1 will experience an alternating axial force that will fluctuate between compression and tension. Although it is possible to obtain hysteresis loops for such an element by using already established loops for concrete in compression and for steel in both compression and tension, it was felt that this approach neglects many factors such as the effect of the cracking of the concrete, the bond failure and the spalling of the unconfined concrete. To account for such factors it was decided to perform experimental tests on longitudinal elements subjected to axial cyclic loads. The purpose of this contribution is to present results of tests made on longitudinal elements 2 1/2" x 2 1/2" in cross-section reinforced with four longitudinal bars, and to compare the experimental results with hysteresis loops derived theoretically.

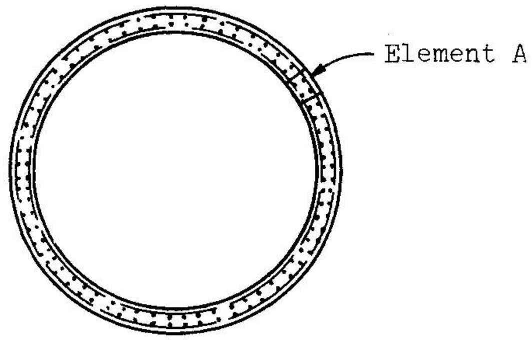


Figure 1

Hollow Circular Cross-section

### EXPERIMENTAL INVESTIGATION

Figure 2 shows the details of the specimens that were used in the experimental investigation. The size of the cross-section was limited to 2 1/2" x 2 1/2" because of the 50 kips capacity of the testing machine used. The specimens were reinforced by No. 2 reinforcing plain bars made of mild steel with a yield point of 55000 psi. The ties with a diameter of 0.0625 inches were made of iron wire with a yield stress of about 30000 psi. The concrete was made of regular Type I Portland cement and well-graded sand.

Two dial gages mounted between two rods that were placed in the concrete as shown in Figure 2 were used on two opposite sides of each specimen. The loading on the specimen was applied at such a rate as to allow for the continuous reading and recording of the load and of the displacement. It should be mentioned that the average reading of the two dial gages was used in plotting the results of the tests.

## THEORETICAL INVESTIGATION

Hysteresis loops for load versus strain on each element were established analytically by using hysteresis loops for steel [1,2] and concrete [3] that were previously established and used by many investigators. These hysteresis loops for steel and concrete are given in Figures 3 and 4 respectively. The hysteresis loops for plain concrete as given in Figure 4 include the factors $K_1$ and $K_2$ which are measures of the deterioration of the concrete when subjected to cyclic loading. The assumed value of $K_1$ that was used in the analytical investigation was primarily based on the results of the tests.

The modulus of elasticity of the concrete, $E_c$, was evaluated by using the ACI Building Code (ACI 318-71) formula:

$$E_c = w^{1.5}\, 33 \sqrt{f'_c}$$

where $f'_c$ = concrete strength as obtained from cylinder tests in lbs/sq. in.
and $w$ = weight of the concrete in lbs/cu.ft.

The theoretical hysteresis loops that were generated using a computer program, have the same controlled load values or controlled strain values at the turning points as those of the experiments.

## RESULTS

Although a total of nineteen elements were tested, only the results of three tests are given in this paper. The experimental results are given in Figures 5a, 6a and 7a and the corresponding theoretical results are given in Figures 5b, 6b and 7b. The results are plotted as the axial load on the specimen in kips versus the strain. The specimen of Figure 5a had a tie space of 1 inch while those of Figures 6a and 7a had a tie spacing of 2 inches.

The specimen of Figure 5a was subjected to controlled strain that fluctuated from .0015 in compression to .0068 in tension. In Figure 6a, the fluctuation of strain was approximately from .0016 in compression to .0100 in tension. The specimen of Figure 7a was tested with controlled loading that varied from about 35 kips in compression to about 11 kips in tension. Included in Figures 5a and 6a are additional diagrams that give the variation in the maximum compressive load as a function of the number of cycles. Similarly, an additional diagram giving the variation in the maximum compressive strain as a function of the number of cycles is plotted in Figure 7a. The dashed curves in Figures 5b, 6b, 7b represent the loops that would be obtained for all the cycles beyond the first if no deterioration in the concrete is assumed (i.e., $k_1 = k_2 = 1.0$).

## DISCUSSION AND CONCLUSIONS

In general, the experimental hysteresis loops were in good agreement with the analytical hysteresis loops. It should be mentioned, however, that the assumed deterioration factors in the concrete that were used in the analytical approach were derived mainly from the experimental data.

It can be stated that analytical procedures can be used to predict hysteresis loops of reinforced concrete elements subjected to cyclic axial loading if sufficient tests are performed to establish degradation coefficients.

REFERENCES

1. Agrawal, G. L., Tulin, L. G., and Gerstle, K. H., "Response of Doubly Reinforced Concrete Beams to Cyclic Loading," ACI Journal, Proceedings Vol. 62, No. 7, July 1965, pp. 823-836.

2. Singh, A., Gerstle, K. H., and Tulin, L. G., "The Behavior of Reinforcing Steel under Reversed Loading," Material Research and Standards, Vol. 5, No. 1, Jan. 1965, pp. 12-17.

3. Kent, D. C., "Inelastic Behavior of Reinforced Concrete Members with Cyclic Loading," Thesis presented to the University of Canterbury, Christchurch, New Zealand, 1969, in partial fulfillment of the requirement for the degree of Doctor of Philosophy.


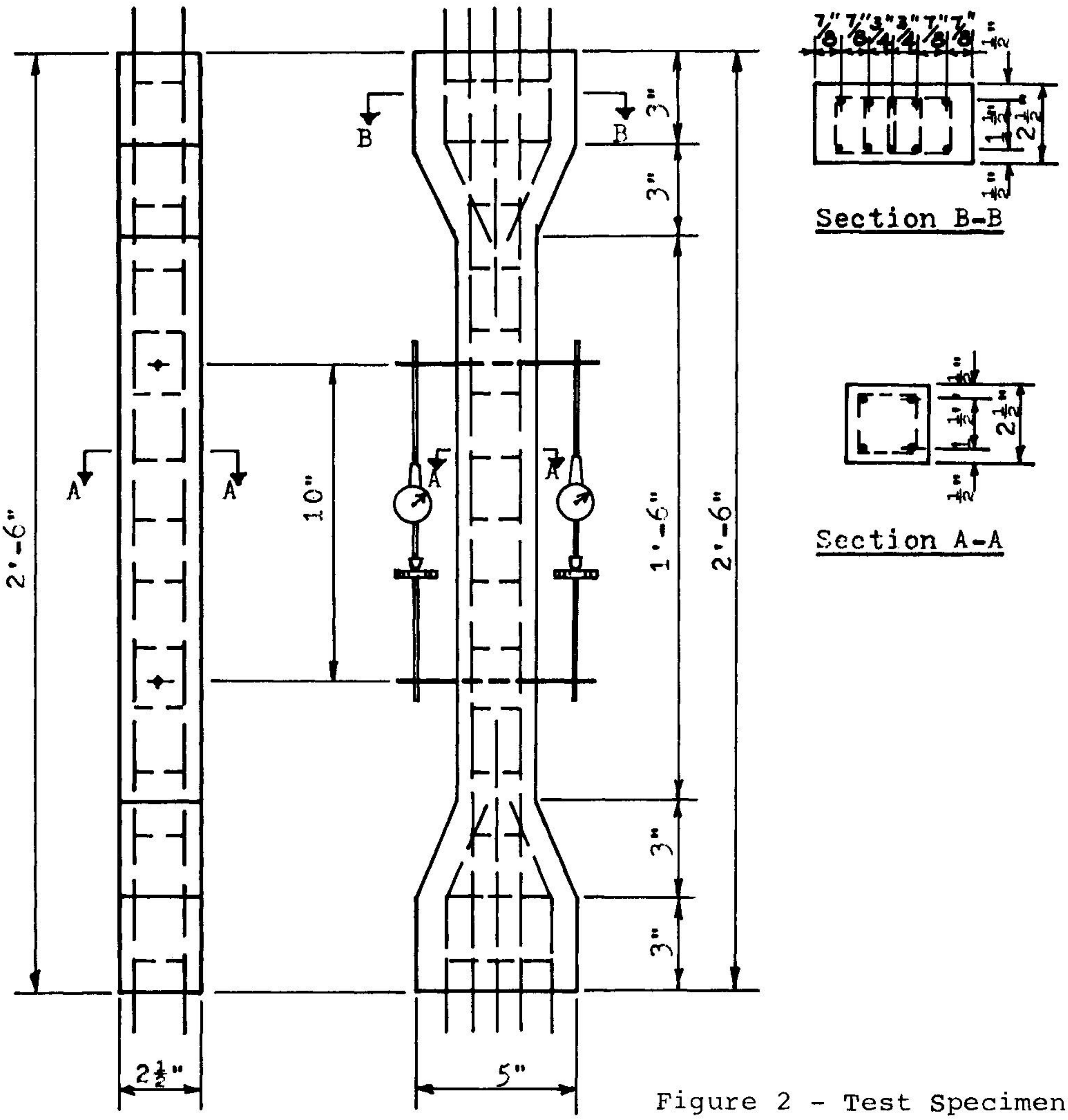


Figure 2 - Test Specimen

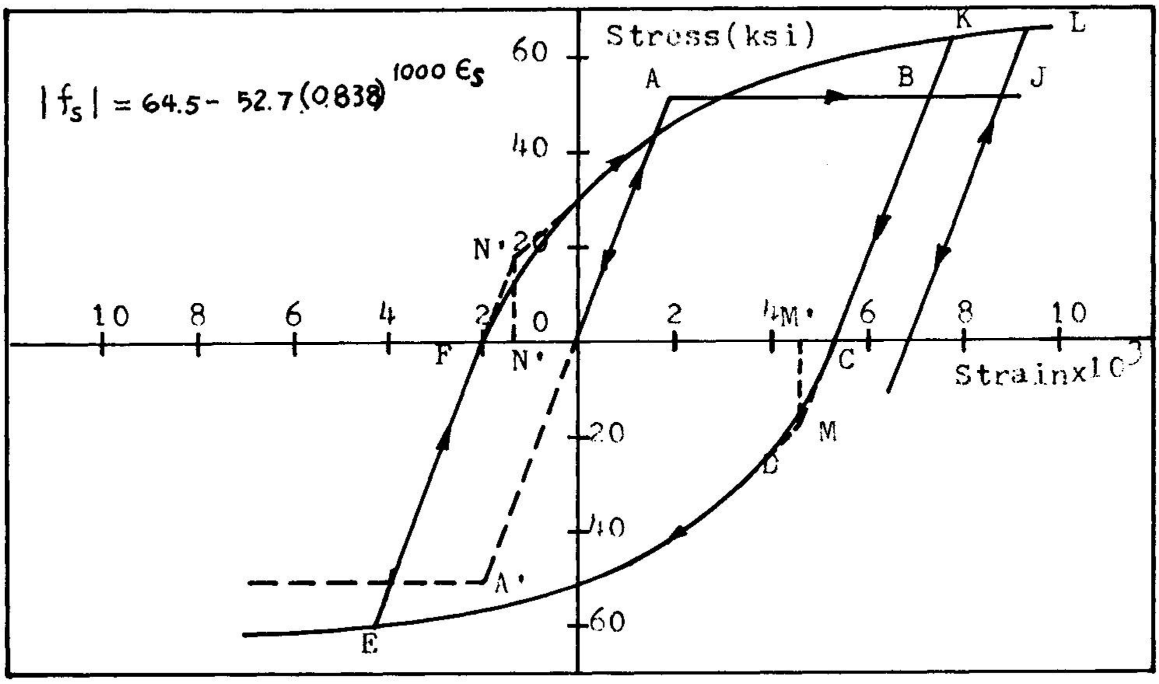


Figure 3 - Hysteresis Loops for Mild Steel

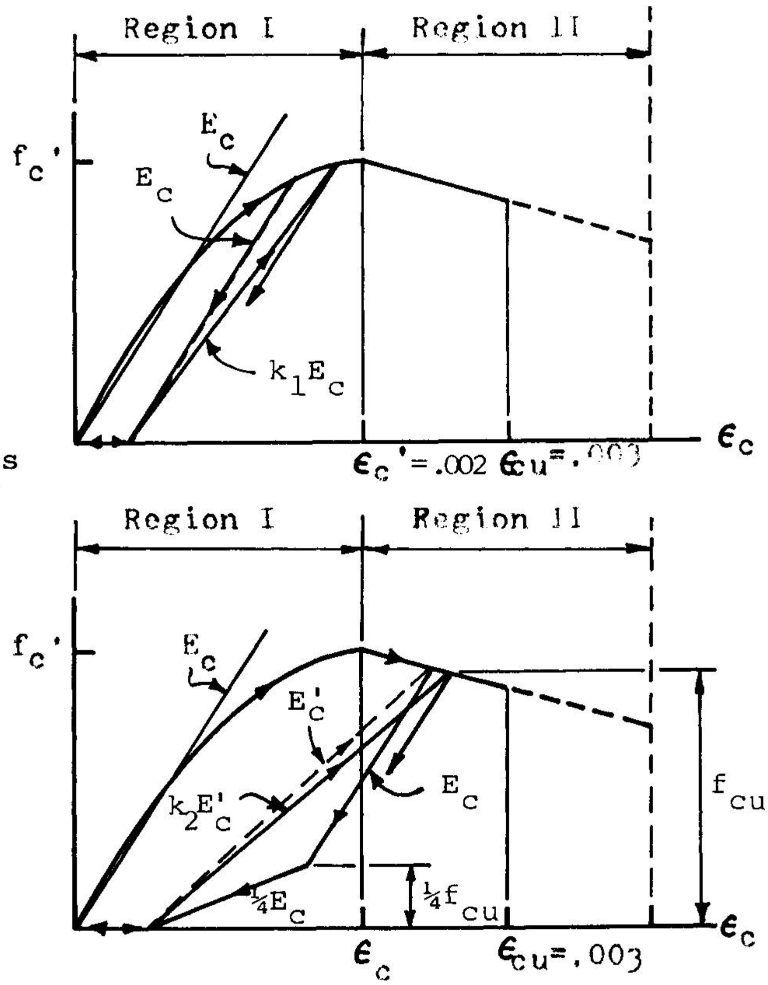


Figure 4 - Hysteresis Loops for Concrete

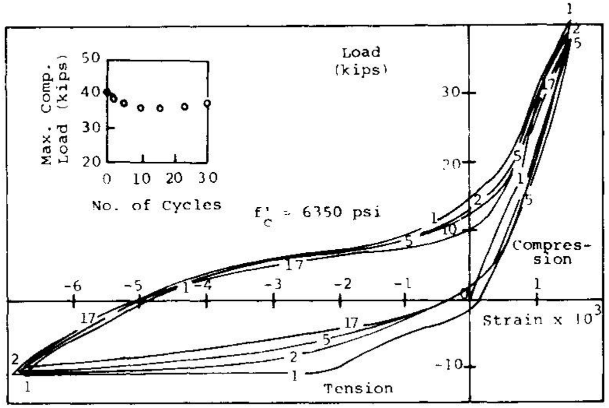


Figure 5a - Experimental Hysteresis Loops (Plain Bars-Controlled Strain)

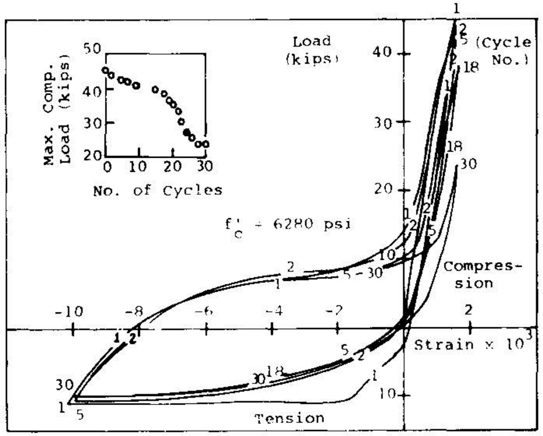


Figure 6a - Experimental Hysteresis Loops (Plain Bars-Controlled Strain)

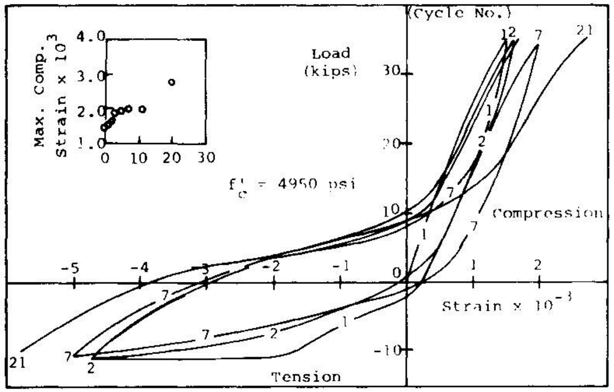


Figure 7a - Experimental Hysteresis Loops (Plain Bars-Controlled Load)

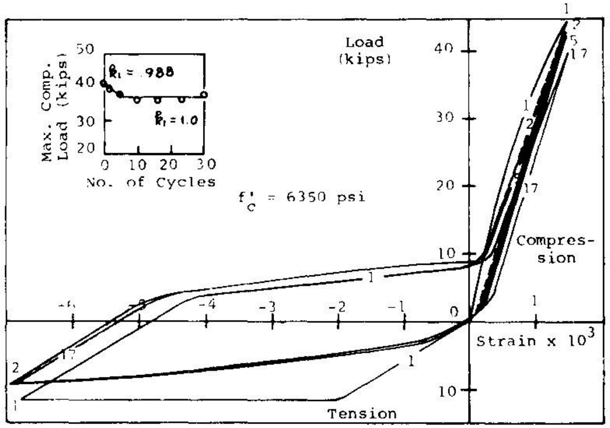


Figure 5b - Analytical Hysteresis Loops (Plain Bars-Controlled Strain)

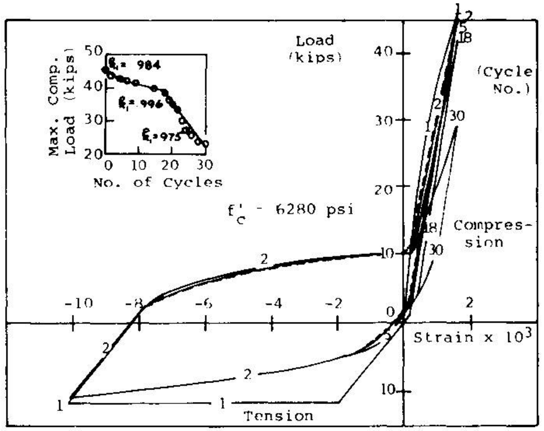


Figure 6b - Analytical Hysteresis Loops (Plain Bars-Controlled Strain)

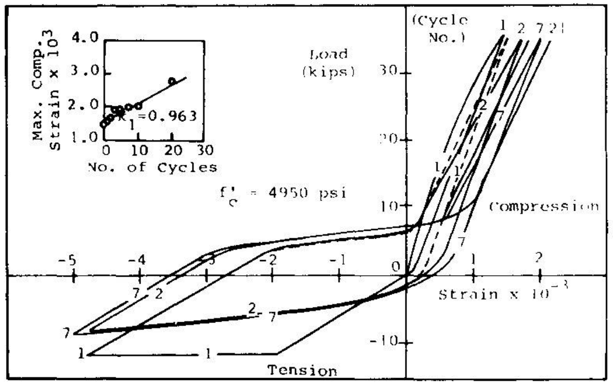


Figure 7b - Analytical Hysteresis Loops (Plain Bars-Controlled Load)

SUMMARY

This paper presents the results of tests made on longitudinal specimens of reinforced concrete subjected to reversed cyclic axial loading. These results are pletted as hysteresis loops giving the loads in kips versus the strain. Analytical hysteresis loops for the same element are also given in the paper and are compared with the experimental curves.

RESUME

Cette contribution montre les résultats d'essai sur éprouvettes longitudinales en béton armé sous l'effet de charges cycliques alternées. Les résultats sont reproduits par boucles d'hystérésis indiquant les charges en kilopound par rapport à la sollicitation. On montre également des boucles d'hystérésis analytiques pour le même élément et on les compare avec les courbes expérimentales.

ZUSAMMENFASSUNG

Der Beitrag vermittelt die Versuchsergebnisse an Längsprobestäben aus Stahlbeton unter Einwirkung wechselnder zyklischer Belastung. Diese Resultate werden als Hysteresekurven aufgezeichnet, welche die Belastung in Kilopound, bezogen auf die Beanspruchung angeben. Ebenfalls werden analytische Hysteresekurven für dasselbe Element gegeben und mit den experimentellen Kurven verglichen.