NON-LINEAR BEHAVIOR OF REINFORCED CONCRETE MEMBERS OF HOLLOW CIRCULAR SECTION SUBJECTED TO MONOTONIC AND CYCLIC BENDING

Zamil A. Mokrin[I] and Wadi S. Rumman[II]

SUMMARY

Experimental investigations were made to determine the non-linear behavior of reinforced concrete members of hollow circular section subjected to both transverse and axial loads. Four specimens were tested monotonically to determine the ultimate moment and four other identical specimens were tested for reversed cyclic bending. All specimens were tested with the presence of an axial load. Specimens differed from one another in the value of the axial load and the amount of longitudinal steel. The effects of the axial load and the steel ratio on the strength, stiffness, cracking pattern, failure mechanism, curvature ductility and energy absorption were investigated.

EXPERIMENTAL SET-UP

All specimens were 128 inches long and 16 inches in outside diameter and with a wall thickness of two inches. The circumferential steel ratio in all specimens was .0038 and the bars were spaced at 4 inches center to center. The longitudinal steel ratios and other parameters for all eight specimens are given in Table 1.

Table 1 - Specimen designations, axial loads and longitudinal steel ratios

Test Type	Specimen Designations	Axial Load (kips)	$\frac{W}{rtf'_c}$	Longitudinal Steel Ratios ρ	$\frac{\rho f_y}{f'_c}$
Monotonic	A	3.0	.0315	.005	.0509
	B	32.3	.4807	.005	.0729
	C	8.3	.0996	.010	.1348
	D	33.0	.3315	.010	.1128
Reversed-Cyclic	E	8.8	.0987	.005	.0549
	F	33.0	.3461	.005	.0514
	G	9.4	.0998	.010	.1192
	H	33.7	.3405	.010	.1134

W=axial load, r=mean radius, t=thickness, f'_c=concrete strength, f_y=yield stress of steel

The general test set-up is illustrated in "Fig. 1". The transverse loading was applied at two points 40 inches apart. The center to center

[I]Instructor of Civil Engineering, Ph.D., University of Petroleum and Minerals, Dhahran, Saudi Arabia.

[II]Professor of Civil Engineering, University of Michigan, Ann Arbor, Michigan 48109, U.S.A.

distance between supports was 10 ft. The axial load was applied through a cable-hack arrangement as shown in the figure. Curvatures were measured by top and bottom dial gauges attached to steel bands wrapped around the specimens. Although measurements were taken in both the pure moment region and the shear span, inelastic deformations did not occur in the instrumented region of the shear span. For this reason the discussion will center on the behavior of the cross-section without shear effects. Because the test arrangement permitted delivering load in only one direction, specimens for reversed cyclic loading were rotated 180 degrees at each half cycle.

TEST RESULTS

"Fig. 2" gives a plot of the moment-curvature relationship of the monotonically loaded specimens. Also given in "Fig. 2" are theoretically computed values based on the work of Sun (1). For the cyclically loaded specimens, moment-curvature relationships are shown in "Figs. 3 and 4" for specimens G and H respectively. Both specimens have the same longitudinal steel ratio but differ in the amount of the axial load. Also plotted in "Figs. 3 and 4" are the theoretical monotonic curves. "Figs. 5 and 6" compare the last cycle of specimens G and H with Clough's Degrading Model (2).

CONCLUSIONS

1. The increase in the axial load ratio W/rtf'_c from 0.1 to 0.3 resulted in an increase in the strength at yield and ultimate by more than 25%, a reduction of the maximum curvature and ductility by more than 35%. an increase in yield curvature by 10% and an increase in the energy absorption by more than 30%.
2. The increase in the longitudinal steel ratio from .005 at .01 resulted in an increase in the yield and ultimate strength by more than 50%, in the yield and maximum curvature by 10% and in the energy absorption by more than 35%.
3. The shape of the moment-curvature diagrams is affected primarily by the magnitude of the axial load. Shapes similar to a parallelogram were exhibited with small axial loads while shapes of spindle-type diagrams were obtained with large axial loads.
4. It is reasonable to use Clough's model for specimens with small axial loads. However, for specimens with large axial loads a modification of Clough's model as suggested by Mokrin (3) is recommended.

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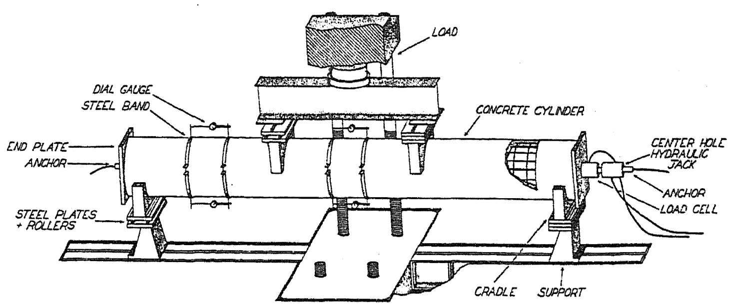

Fig. 1 Experimental Set-up

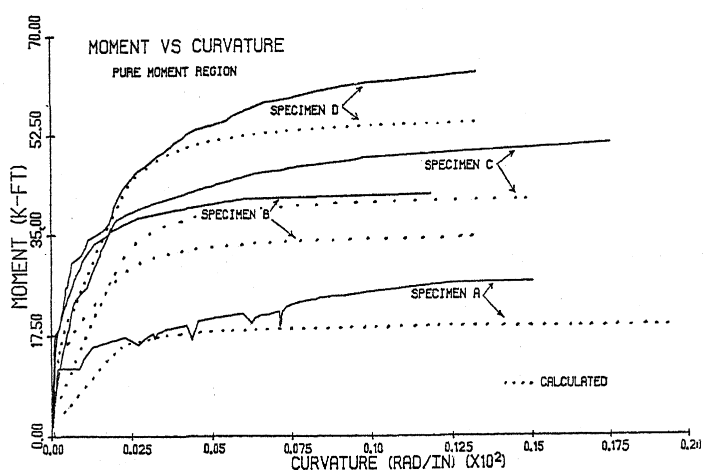

Fig. 2 Moment-curvature Diagrams of Specimens A through D

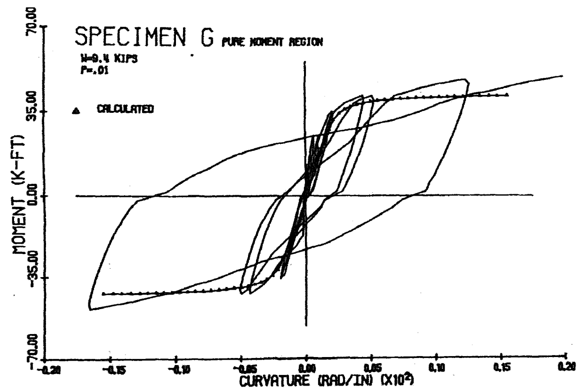

Fig. 3 Moment-curvature Diagram for Specimen G

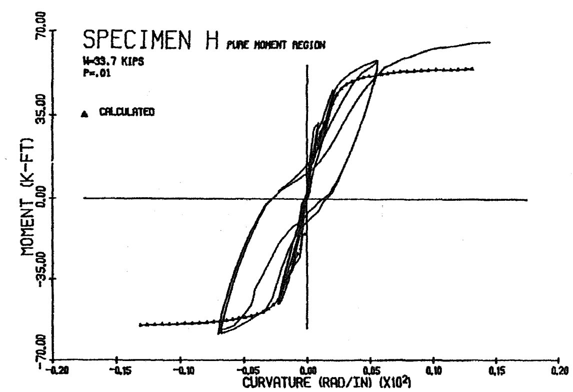

Fig. 4 Moment-curvature Diagram for Specimen H

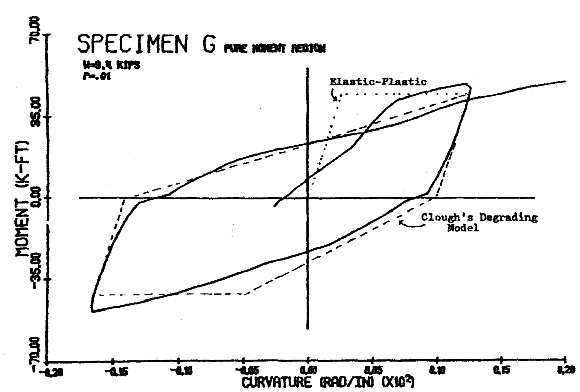

Fig. 5 Comparison of Last Cycle of Specimen G with Clough's Degrading Model

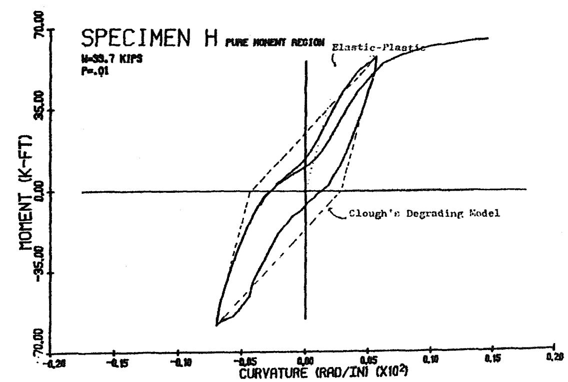

Fig. 6 Comparison of Last Cycle of Specimen H with Clough's Degrading Model