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16. Abstract (Limit: 200 words)
Earlier tests on half-scale beam-column subassemblages representing the third floor of a typical 20-story ductile moment-resisting frame have clearly demonstrated the possibility of a severe cyclic bond degradation at the interior joints. The design of these subassemblages was based on the conventional approach of the strong column and weak girder. In that series of experiments, the beam reinforcement was continuous, consisting of four #6 bars at the top and three #5 bars on the bottom of the beam. In these experiments the plastic hinges were formed in the beams at the faces of the column, corresponding to the locations of maximum moment. After repeated displacements into the inelastic range, the cracks in the beams at the column faces became very large and the bars extending through the column began to lose their bond. Eventually, at large ductility ratios the bars slipped completely through the column causing a large drop in stiffness and eventual failure. The experimental work reported in this paper addresses this problem of bar slippage in the column. Two different techniques for solving this problem were studied. Cyclic bond tests, the first technique, were directed toward a study of the anchorage characteristics of bars of sizes frequently encountered in practice. The novel feature of these experiments was an arrangement where a bar was being simultaneously pulled from one side and pushed from the other. This condition corresponds to the one observed in the columns in the earlier tests. The other technique was to design the beam so that the plastic hinge forms away from the face of the column thereby increasing the anchorage length.

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Recent studies at Berkeley of the behavior of interior joints in moment-resisting reinforced concrete ductile frames developed in two different directions. Because of the observed severe cyclic bond degradation in the interior of beam-column subassemblages in earlier tests, one of the studies was directed toward cyclic bond degradation of individual bars with different embedment. In the other study, the design of the reinforcement was modified to avoid cyclic bond degradation in the joint. The National Science Foundation sponsored the work.

Introduction

Earlier tests on half-scale beam-column subassemblages representing the third floor of a typical 20-story ductile moment-resisting frame have clearly demonstrated the possibility of a severe cyclic bond degradation at the interior joints [1, 2]. The design of these subassemblages was based on the conventional approach of the strong column and weak girder. In that series of experiments the beam reinforcement was continuous, consisting of 4 #6 bars at the top and 3 #5 bars (50% of the negative steel) on the bottom of the beam. As to be expected, in these experiments the plastic hinges were formed in the beams at the faces of the column, corresponding to the locations of maximum moment. After repeated displacements into the inelastic range, the cracks in the beams at the column faces became very large and the bars extending through the column began to lose their bond. Eventually, at large ductility ratios the bars slipped completely through the column causing a large drop in stiffness and eventual failure.

It was to their problem of bar slippage in the column that subsequent experimental work addressed itself. Two different techniques for solving this problem were studied. One program was directed toward a study of the anchorage characteristics of bars of sizes frequently encountered in practice. The novel feature of these experiments was an arrangement where a bar was being simultaneously pulled from one side and pushed from the other. This condition corresponds to the one observed in the columns in the earlier tests. The other technique was to design the beam in such a manner that the plastic hinge forms away from the face of the column thereby increasing the anchorage length. In this manner the slippage of the bars in the column could be delayed until very large displacements or may be entirely eliminated.

Cyclic Bond Tests

The arrangement for determining the bond characteristic of bars is shown in Fig. 1. The specimens in the form of a rectangular block simulating a part of a column are tested in a horizontal position. The specimens are reinforced with longitudinal bars as well as stirrup-ties. The thickness of these blocks is uniformly maintained at 10 in.;. their depths vary to provide different lengths of embedment for the bars. The bar sizes employed are #6, #8 and #10, and the depths of embedment used so far are 15 in., 20 in. and 25 in. The specimens are securely positioned with tie-down straps and rigid horizontal supporting arms. Hydraulic jack C is capable of applying an axial force simulating a column load.

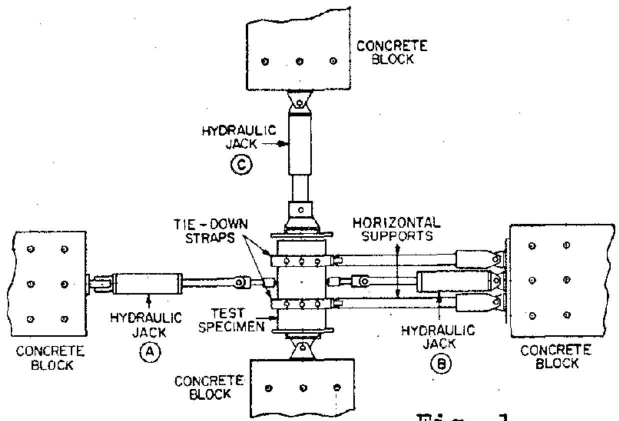

Fig. 1

Hydraulic jacks A and B are displacement controlled and can apply any prescribed ratio of the two forces; one being tensile, the other compressive. The direction of the two forces can be simultaneously reversed on command. Most of the test bars have a number of electronic gages along their length of embedment. These gages are placed into a machined groove and are carefully protected by a plastic material and a metal cap. The results of a monotonic experiment with a #6 bar in a 15 in. wide block are shown in Fig. 2. The bar was simultaneously pulled and pushed with forces of equal magnitude. The need for a longer embedment length of the bar for tension in comparison to that in compression is clearly brought out. Fig. 3 shows the bar stress vs. slip from the column face. Note particularly the decaying part of the curve, which defied measurement by previous investigators. The large loss of bond on the return stroke is noteworthy.

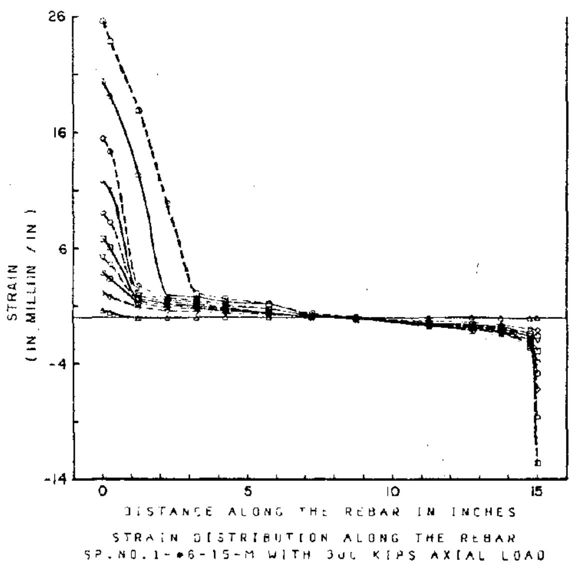

Fig. 2

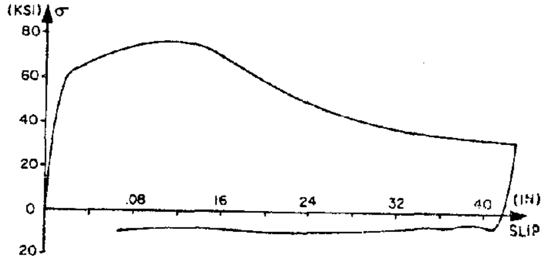

Fig. 3

Plastic Hinge Away From Column

In this series of experiments two beam-column subassemblages, BC5 and BC6, were designed to have the plastic hinges form away from the column faces. The details are shown in Fig. 4; in both designs 100% of negative steel was placed on the bottom of the beam. In BC5 the plas-

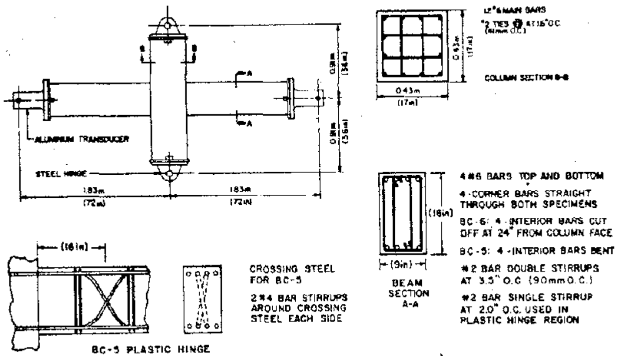

Fig. 4

tic hinge was located at 16 in. away from the column face by bending and crossing the middle bars of the top and bottom reinforcement. In BC6 the plastic hinge occurred at the cut-off points of the two middle bars 24 in. away from the column face. As in the earlier experiments, the top hinge of the specimen was held in position, the beam hinges were permitted to move only horizontally; the lower hinge was moved cyclically in the horizontal direction. A constant 470 kip axial force was maintained throughout each **experiment** giving rise to a large P-δ effect.

The most important results of these cyclic experiments are summarized in the plots of the equivalent horizontal force H_{eq} vs. δ, the horizontal movement of the bottom hinge. These are shown in Figs. 5 and 6. To obtain H_{eq}, the applied horizontal force H was increased by $P\delta/h$, where h is the height of the column.

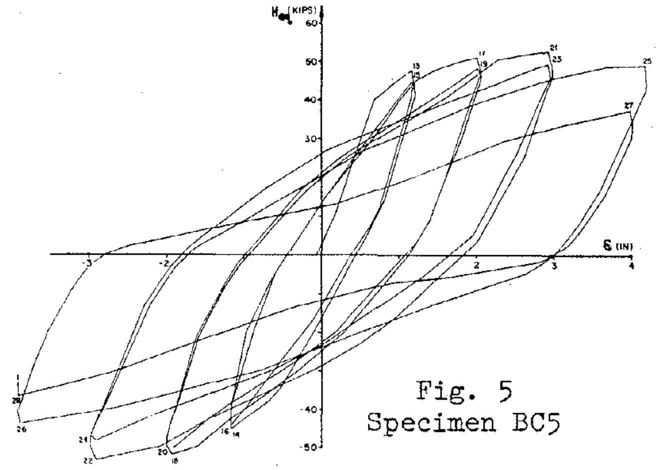

Fig. 5
Specimen BC5

Excellent results were obtained from the model BC5 in terms of overall member performance as well as in solving the problem of anchorage loss. Slippage of the bars through the column was completely eliminated, and also stable smooth hysteretic curves were recorded throughout the duration of the experiment. The steel at the face of the column yielded at approximately a ductility ratio of 4.5. Slippage of the bars through the column was also eliminated in BC6; however there was a large amount of shear deformation. The plastic hinge formed as expected at the cutoff point, but later began to move toward the face of the column as the bond at the end of the cutoff bars deteriorated and the moment capacity of that section decreased. Under repeated application of load reversal in the inelastic range the diagonal cracks at the top and bottom of the critical section of the beam increased until they crossed so that the concrete section became very weak in resisting the shear force, except for the frictional resistance between the two faces, and the dowel action of the steel.

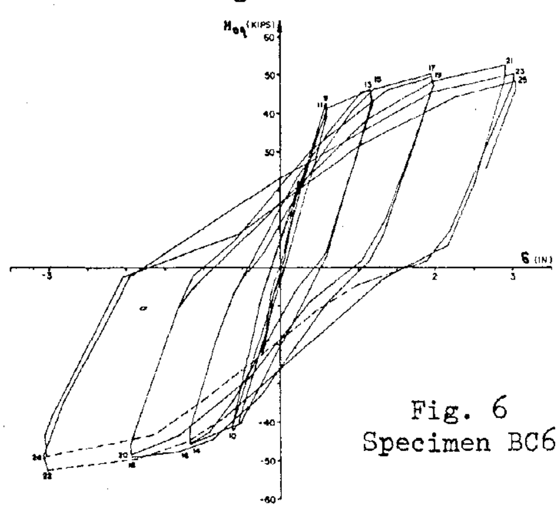

Fig. 6
Specimen BC6

<u>References:</u> [1] and [2] V.V. Bertero and E.P. Popov, EERC 75-16 and 5ECEE.