INFLUENCE OF LATERAL BEAMS ON THE BEHAVIOR OF BEAM-COLUMN JOINTS

by
Marisol Abad de Aleman,[I] Donald F. Meinheit,[II] and James O. Jirsa[III]

SYNOPSIS

One of the most difficult problems associated with the design of frame structures for seismic loads is the design of the beam-column joint for shear. Current design procedures are based on tests of planar frames and little consideration is given to the influence of lateral beams (beams which frame into the joint normal to the direction of the primary shear force or deformation). The object of this paper is to examine the behavior of beam-column joints with and without lateral beams.

TEST PROGRAM

The tests reported herein are part of an investigation of factors influencing the shear strength of beam-column joints. The entire program consisted of 14 tests, some of which have been reported previously (1). The results of 9 tests listed in Table 1 will be discussed.

Test Specimen. The test specimen is shown in Fig. 1. The column cross section (13X18 in.; 33X46 cm) was kept constant in all tests; however, for 6 tests the large dimension was in the direction of bending (strong axis) and in 3 the short dimension was in the direction of bending (weak axis). In all cases the beam reinforcement consisted of of three #10(32mm) bars top and three #8(25mm) bars bottom, so that the ultimate flexural capacities of the beams remained about constant. Transverse reinforcement through the joint consisted of #4(13mm) or #5(16mm) closed hoops. Clear cover was 1½ in.(38mm) in all cases. The lateral beams were of varying width, as indicated in Table 1 and Fig. 1. The lateral beams were 15 in. (38cm) deep and 24 in.(61cm) long and were not loaded during testing. The longitudinal reinforcement ratio in the lateral beams was about 0.012 for both top and bottom steel. No transverse reinforcement was provided in the lateral beams. The column reinforcement ratio was 0.043 for all tests.

Materials. Concrete strengths for the tests are listed in Table 1. The specimens were cast in an upright position (column vertical) in two lifts. The first lift completed the bottom column and the beams and the second lift completed the top column. Grade 60 (414 MPa) reinforcement was used throughout.

Test procedure. The specimens were tested in a horizontal position, as shown in Fig. 2. Column loads were applied prior to beam loads and held constant throughout the test. The column load was the same for all the tests discussed here and produced an average compressive stress on the column of 1500 psi (10 MPa) or about 0.2 of the axial capacity. Beam loads, column loads, and reactions, steel strains, beam deformations, and joint shear deformations were recorded at all stages of loading.

Loading History. The specimen was subjected to racking loads with beams loaded in opposite directions and subjected to equal deflection increments at the load points. Typical load-deflection curves are shown in

---

[I] Structural Engineer, Panama, Republic of Panama.

[II] Assistant Professor of Civil Engineering, University of Notre Dame, South Bend, Indiana.

[III] Professor of Civil Engineering, The University of Texas at Austin, Texas.

Fig. 3. Load-deflection curves are plotted for each beam and identical points in the load history lie in opposite quadrants (see load stage 33 for example). In most tests three cycles of load were applied:

(1) A cycle in which the specimen just reached diagonal cracking in the joint in each direction.

(2) A cycle in which maximum loads were reached on both beams and produced maximum shear on the joint.

(3) A final cycle in which large deformations were imposed.

In cycles 2 and 3, the deformation limit varied between tests because the deformations were increased until maximum shear on the joint was realized, as shown in a typical joint shear-shear strain curve (Fig. 4).

TEST RESULTS

The influence of lateral beams on the performance of the joint can be seen by comparing joint shear-shear strain curves for cycles 2 and 3. Figure 5 shows a comparison for five tests (strong axis bending). Shear forces on the joint V_j have been reduced to average shear stresses on the joint by dividing by bd, the effective joint area carrying shear, and normalizing with respect to $\sqrt{f'_c}$, a measure of concrete shear strength. Only specimens VIII and XII developed a flexural hinge at some point in the load history (see Table 1 for mode of failure). The remainder failed in shear at the joint. In the second cycle the lowest strength was exhibited by specimen II, no lateral beams and large spacing of transverse reinforcement through the joint. Note that the shear deformations imposed on all five specimens were comparable in the second cycle. In the third cycle, it is clear that the specimen with large lateral beams performed very well. It carried a shear stress equal to the second cycle value, whereas the other specimens showed reductions in capacity which were very substantial in the last half of the third cycle. Similar curves were obtained for specimens loaded about the column weak axis. The average joint shear stress reached at the peak of each cycle is summarized in Fig. 6.

Figure 7 shows the appearance of four specimens after testing was completed. Specimen II, which had no lateral beam, rapidly lost the entire side cover and a close examination of the transverse steel indicates it was bent outward as a result of the lateral expansion of the concrete in the joint. Specimen VIII, with a large beam (15x15 in.), lost only a very small amount of side cover. Specimens IX and X, with smaller beams, suffered increased damage because the lateral beams confined only about half as much of the side face of the joint as was confined by the beam in Specimen VIII. Although the lateral beams were not loaded during testing, they suffered extensive cracking and damage during the racking test on the specimen. Therefore, it would be expected that under racking loads on the specimen in both directions, the performance might be considerably different.

CONCLUSIONS

Considering specimens II and IV, which had no lateral beams and a small amount of transverse joint reinforcement as standards against which to compare the effectiveness of lateral beams and transverse reinforcement, the following trends are apparent.

(1) Lateral beams are generally more effective than transverse reinforcement in improving both shear capacity and cyclic load performance. With a large lateral beam (15x15 in.) covering about 70 percent of the

side face of the joint (specimen VIII), the beams developed yield hinges in both directions of loading. With the inclusion of a large amount of transverse steel (#5 @ 2 in.) in specimen XII, the shear capacity was substantially improved; however, with cycling the strength decreased rapidly. Even with smaller beams covering only about 40 percent of the side area of the joint (specimens IX, X, XI), the shear strength was improved. Increasing transverse steel from #4 @ 6 in. to #4 @ 2 in. (specimens XIII and XIV) had little effect on performance.

(2) The shear strength of the joint is improved by about 20 percent with lateral beams covering 70 percent of the side face of the joint and about 10 percent with lateral beams covering 40 percent of the side face. These increases are consistent with values reported by Higashi and Ohwada (2) for joints with intersecting beams.

(3) The ultimate shear stress reached in all specimens exceeded $22\sqrt{f'_c}$. Even with the imposition of severe deformations during cycling, the capacity did not fall below $15\sqrt{f'_c}$ for joints without lateral beams and about $18\sqrt{f'_c}$ for joints with lateral beams. These values are considerably greater than values currently used in design. However, the joints were subjected to deformation in only one direction and under bidirectional loading the shear strength may be reduced.

ACKNOWLEDGMENTS

This investigation was sponsored by the National Science Foundation under Grant GK-40289 and was conducted at the Civil Engineering Structures Research Laboratory of The University of Texas at Austin.

REFERENCES

1. J. O. Jirsa, D. F. Meinheit, and J. W. Woollen, "Factors Influencing the Shear Strength of Beam-Column Joints," Proceedings of the U. S. National Conference on Earthquake Engineering - 1975, Earthquake Engineering Research Institute, June 1975.

2. Y. Higashi and Y. Ohwada, "Failing Behaviors of Reinforced Concrete Beam-Column Connections Subjected to Lateral Loads," No. 19, Memoirs of Faculty of Technology, Tokyo Metropolitan University, 1969.

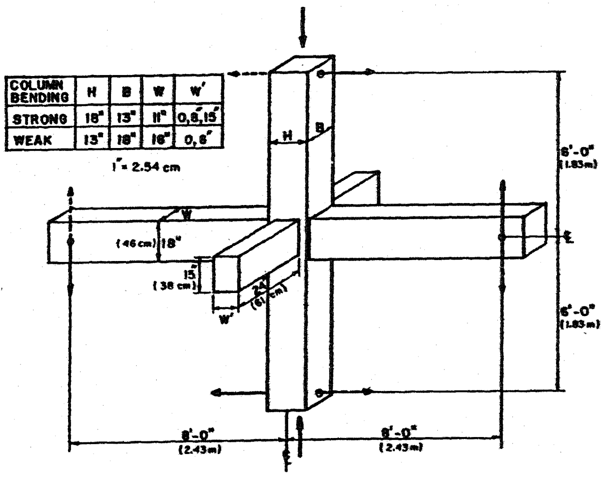

Fig. 1. Test specimen

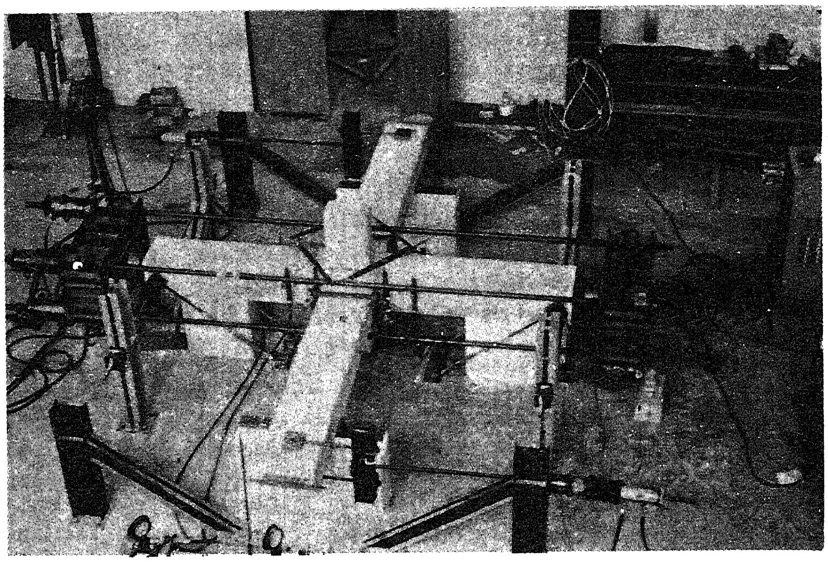

Fig. 2. Test setup

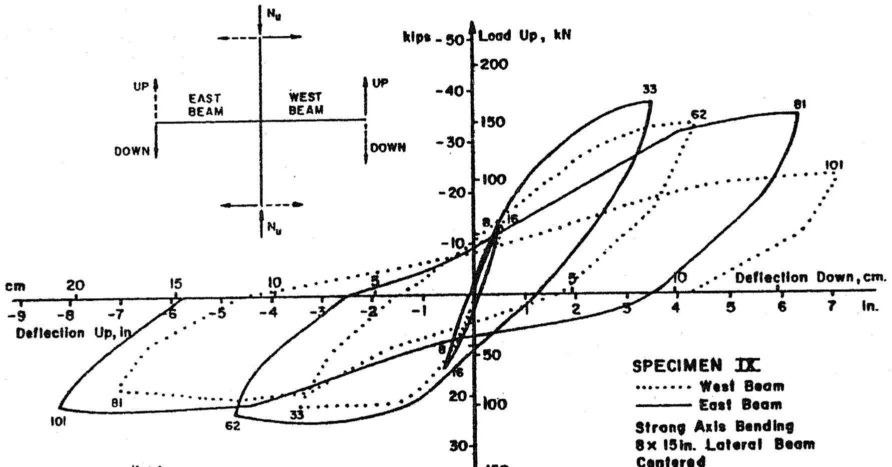

Fig. 3. Load-deflection curves--Specimen IX

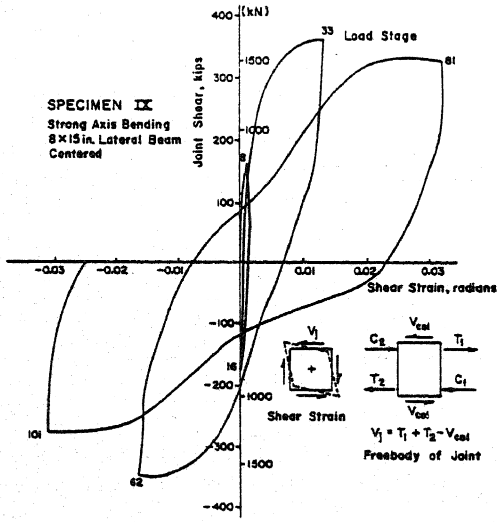

Fig. 4. Joint-shear versus shear strain--Specimen IX

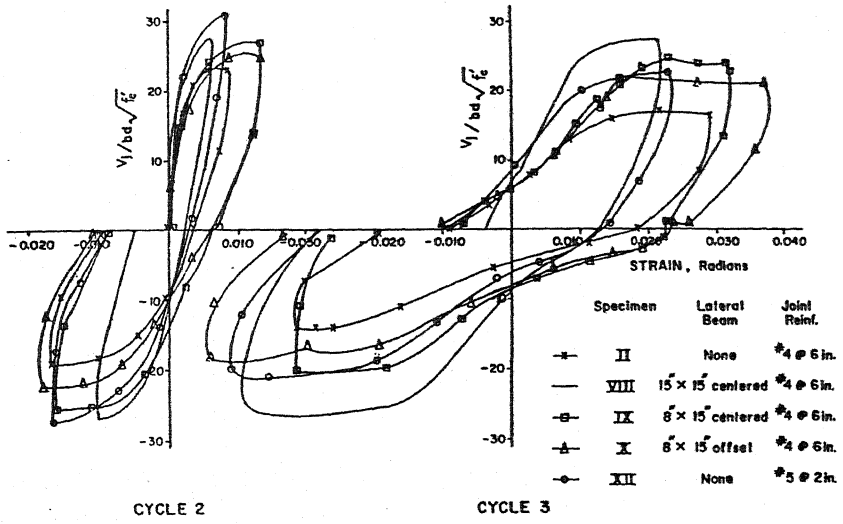

Fig. 5. Influence of lateral beams on behavior

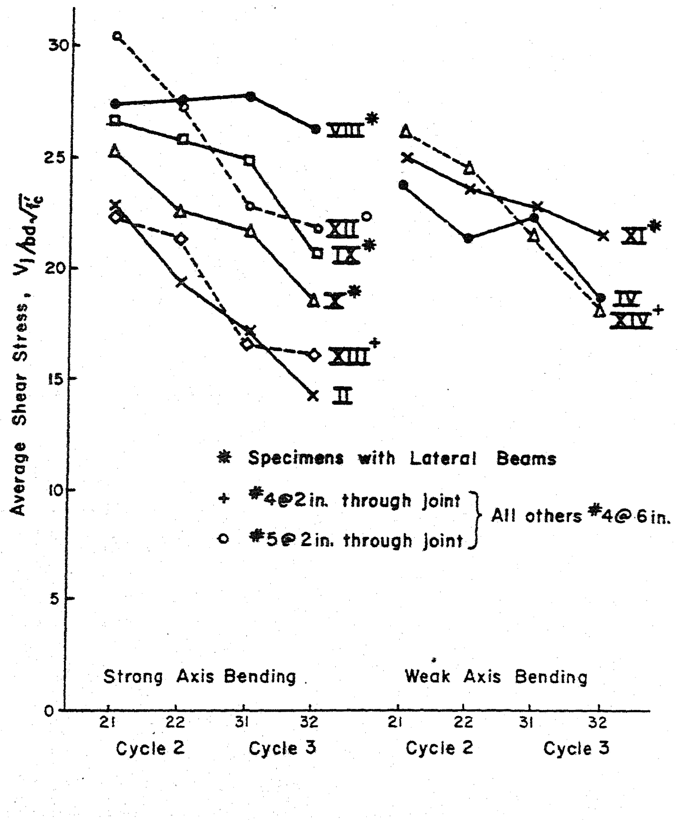

Fig. 6. Average joint-shear stress at peak of cycle

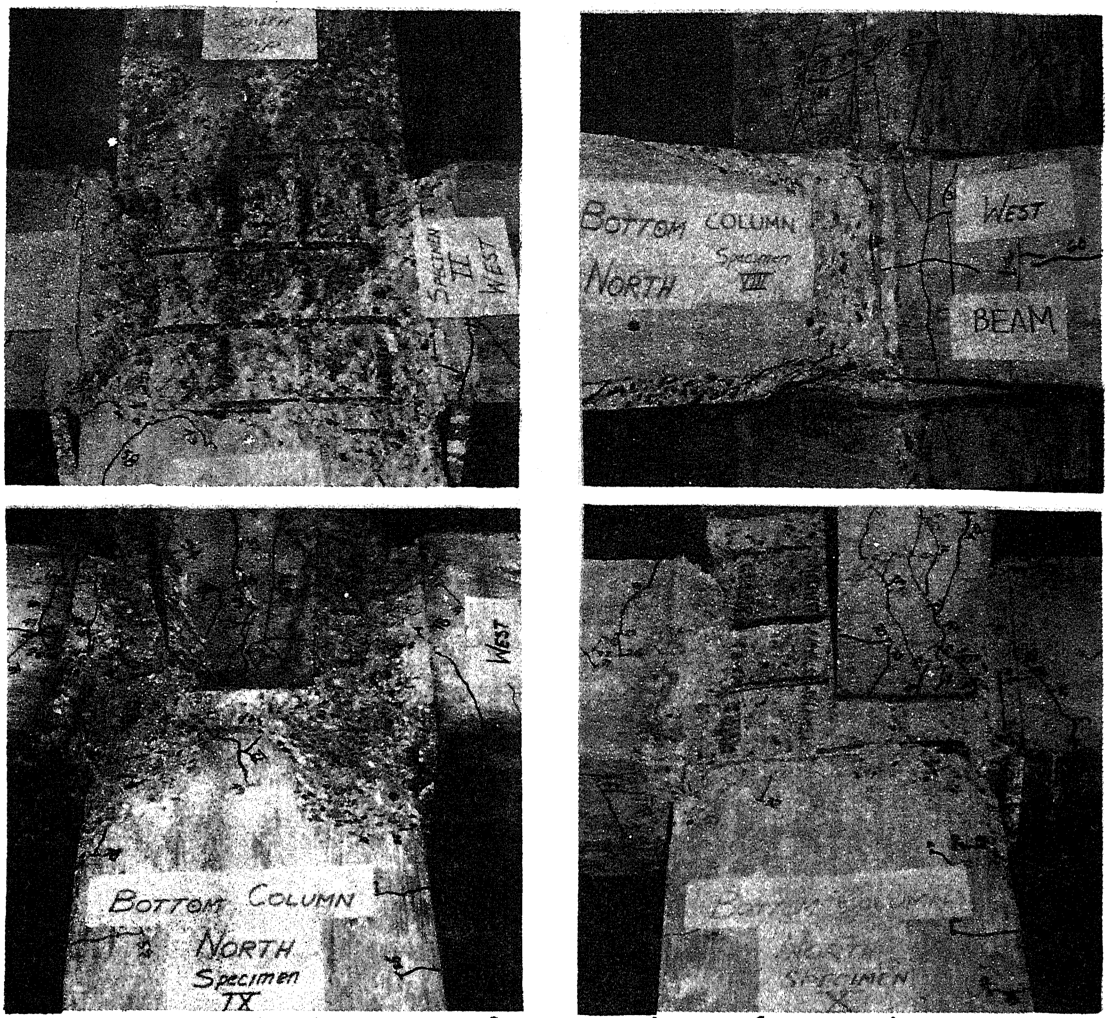

Fig. 7. Appearance of test specimens after testing

TABLE 1 DETAILS OF TEST SPECIMENS

Specimen	Column Bending	Lateral Beam Width and Placement	Joint Reinforcement	f'_c psi	Mode of Failure
II	Strong	None	#4 @ 6 in.	6060	Joint Shear
VIII	Strong	15 in., centered	#4 @ 6 in.	4800	Yielding
IX	Strong	8 in., centered	#4 @ 6 in.	4500	Joint Shear
X	Strong	8 in., offset	#4 @ 6 in.	4290	Joint Shear
XII	Strong	None	#5 @ 2 in.	5100	Yielding
XIII	Strong	None	#4 @ 2 in.	5990	Joint Shear
IV	Weak	None	#4 @ 6 in.	5230	Joint Shear
XI	Weak	6 in., centered	#4 @ 6 in.	3720	Joint Shear
XIV	Weak	None	#4 @ 2 in.	4810	Joint Shear

Note: 1000 psi = 6.9MPa, #4 bar = 13mm, #5 bar = 16mm, 1 in. = 2.54cm.