Loading Tests of Strengthened RC Beams

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Abstract. In this study the gravity load resisting capacity of a RC beam-column subassemblage with and without strengthening was investigated. Total of five specimens were tested; two unreinforced specimens, the one designed as gravity load-resisting system and the other as seismic load-resisting system, and three specimens reinforced with: i) bonded strand, ii) unbonded strand, and iii) side steel plates with stud bolts. Monotonically increasing load was applied at the middle column of the specimens and the force-displacement relationships were plotted. It was observed that the gravity load-resisting specimen failed by fractures of re-bars in the beams. In the other specimens no failure was observed until the maximum displacement capacity of the actuator was reached. Highest strength was observed in the structure with unbonded strand. The test result of the specimen with side steel plates in beam-column joints showed that the force-displacement curve increased without fracture of re-bars.

Introduction

Researches have been conducted on the collapse behavior of moment-resisting frames caused by sudden loss of columns. Milner et al. [1] and Sasani and Kropelnicki [2] carried out experiments to investigated the behavior of a scaled model of a continuous perimeter beam in a reinforced concrete frame structure following the removal of a supporting column. Yi et al. [3] carried out static experimental study of a three-story RC frame structure to investigate progressive failure due to the loss of a lower story column. In those experiments it was observed that after the plastic mechanism formed, the concrete strain in the compression zone at the beam ends reached its ultimate compressive strain, and the compressive re-bars were gradually subject to tension with increasing displacement. Choi and Kim [4] investigated the collapse resisting capacity of RC beam-column subassemblages designed with and without seismic load.

In this study monotonic loading tests of strengthened RC beam-column subassemblages were carried out to investigate their collapse resisting capacity and to observe the effect of the reinforcement methods. The two-span subassemblage specimens were designed as part of an eight-story RC moment resisting framed building. Three specimens were reinforced with: i) bonded strands, ii) unbonded strands, and iii) side steel plates, and their relative effectiveness in enhancing collapse resisting capacity was addressed.

Design of specimens

To evaluate the collapse resisting capacity of a structure when subjected to sudden removal of a column, beam-column subassemblages, which are parts of an exterior frame, were manufactured for tests. Total of three specimens, scaled to 37% of the prototype structure, were constructed for the loading tests specimens. The subassembly test specimens are composed of three columns and two beams located between the columns. The longitudinal bars were anchored to the columns with the tail extension of the hook. The D10 re-bars with nominal diameter of 9.53mm were used for main reinforcing steel for beams and columns, and 6 steel bars were used for stirrups and tie bars in the
specimens. From coupon tests it was observed that the yield strengths of the main re-bars and stirrups/tie bars are 457 MPa and 325 MPa, respectively. To increase the progressive collapse resisting capacity, the specimen out of the gravity load-resisting system was strengthened by either high strength strand or steel side plates welded with stud bolts. Figure 1 shows the test specimen for gravity load-resisting system strengthened with a wire strand with diameter of 12.7mm. The strand was placed along the center of the cross-section of the beams before casting of concrete without prestress, and was anchored at the exterior surfaces of the two end columns using an anchorage as shown in Figure 4. To compare the effects of bonded and unbonded strands, one specimen was prepared with a bonded strand and another specimen was prepared with an unbonded strand located within a sheath pipe. For existing structures the high strength tendons can be installed at both sides of the beams similarly to the external prestressing used to retrofit old structures. The other strengthening scheme is to attach steel side plates at both sides of beam ends as shown in Figure 2. To increase the flexural strength of a beam for gravity load, steel plates are generally attached in the middle of the beam where bending moment is maximized. In this study, for resisting progressive collapse caused by loss of a column, they were placed at the ends of the beams in the form of side plates. Thirteen high strength bolts with diameter of 8mm were welded in two rows to the 5mm-thick side plates as shear connectors to ensure composite action of the plates and the specimen.

![Figure 1. Specimen strengthened with high-strength strands.](image1)

![Figure 2. Specimen strengthened with steel side plates.](image2)

**Test Setup**

Figure 3 shows the test setup for the specimens. The right- and left-side-columns were fixed to the jigs and the actuator was connected to the middle column. It was assumed that the center column was suddenly removed by accident, and displacement-controlled monotonic pushdown force was enforced at the middle column of the specimens using a hydraulic actuator with maximum capacity of 2000 kN and maximum stroke of ±250mm. The tests were carried out horizontally, and to prevent vertical deflection of the specimens due to self weight, rollers were placed beneath the beam-column joint during the. Strain gages were attached on the longitudinal re-bars and strands located at the ends of girders.
The force-displacement relationships of the specimens strengthened by bonded and unbonded strands are shown in Fig. 4. The force-displacement curve for the unstrengthened specimen was also plotted in each figure for comparison. The specimen reinforced with bonded strand showed similar force-displacement relationship to that of the unstrengthened specimen, except that the maximum strength increased by 56% and the specimen did not fail completely when the test was over. The number of re-bars fractured was seven, which is the same with that observed in the test of the unstrengthened specimen. In the specimen with unbonded strand, the maximum strength turned out to be 145% higher than the maximum strength of the specimen without the strand. It was also observed that two re-bars fractured at the displacement of 350mm, and the force was reduced for about 50 kN. As displacement further increased the force increased again until the strength reached the maximum value of 84 kN at the displacement of 436mm. The number of fractured re-bars was reduced to three. It can be observed from the figures that the specimen with an unbonded strand showed superior catenary action to that of the specimen with bonded strand.

Summary

Highest strength was observed in the structure with unbonded strand. The test result for the specimen with side steel plates in beam-column joints showed that the force-displacement curve increased without fracture of re-bars. Compared with the performance of the specimen strengthened with the high strength strands, the specimen reinforced with side plates showed slightly smaller strength but more stable behavior. Considering the higher expanse involved in the prestressing of members, the side plate strengthening scheme seems to be more practical means of enhancing progressive collapse resisting capacity of RC moment frames. Based on the test results it was concluded that the progressive collapse resisting capacity of a RC frame could be significantly enhanced using unbonded strands or steel side plates in the beam-column subassemblages exposed to abnormal loads.
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References


