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Retrofitting of Reinforced Concrete Frame Buildings

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Summary

Shaking table tests that were conducted on a single-storey, small scale, 4-column, 3-D reinforced concrete frame model building retrofitted by concrete jacketing are presented. It is concluded that concrete jacketing is a very effective seismic strengthening technique for reinforced concrete frame buildings, since stiffness, strength and ductility can be significantly enhanced. Moreover an undesirable column-sidesway failure mechanism can be transferred to a desirable beam-sidesway one.

1. The building model

A series of shaking table tests were conducted on a reinforced concrete (RC) frame building model. The specimen was a single-storey, 4-column, 3-D specimen with a RC slab at the top and one bay in each direction, simulating a real structure at 1:4 scale. The external dimensions of the plan of the model was 810mm by 1460mm and the height of the columns over the foundation beams was 640mm. The cross-section of the beams and the columns was 80mm x 80mm.

The retrofitting procedure involved the construction of RC jackets around the four columns. The thickness of the jackets was 25mm and they were cast from the foundation level up to the top of the column. The surfaces of the columns, were roughened by a pneumatic scrabbler prior the application of the jacket. The maximum aggregate size was 10mm. Jacket reinforcement consisted of four 6mm diameter longitudinal bars and 3mm diameter hoops fixed to the main bars at a spacing of 20mm. The hoops consisted of two L-shaped portions with 45° end hooks which overlapped in diagonally opposite corners which were alternated at each layer. The longitudinal bars were anchored into 60mm-deep holes which were drilled in the foundation beams and subsequently filled with epoxy adhesive. The other end of the jacket bars was welded on special steel plates already placed in the beam-columns joints of the initial model. No jacket hoops were provided in the beam-columns joints to avoid damaging the beams.

2. Shaking table tests

In the present work, shaking table motions were restricted along the longitudinal axis of the specimen. Since, simple sine motions ease the identification of model failure, sine dwell input motions with constant frequency were used. Thus, only the acceleration level and the frequency of the sine wave was changed at each test. It was desirable to shake the specimen at a frequency near to resonance. Therefore, the testing frequency was chosen about 10% lower than the natural frequency of the model since a frequency reduction was expected due to damage during testing. Moreover, a set of low level exploratory tests was conducted at the beginning of testing and after the main seismic tests to characterize the natural frequencies, mode shapes and damping parameters of the model. Accelerations, displacements and steel strains were measured at various locations.

Seismic tests were performed on the unretrofitted model with an additional load of 10 kN on the top of the specimen to increase the induced inertia forces. Testing was stopped just one step before total collapse of the specimen with severe damages at the top and bottom of the columns. The initial natural frequency of the specimen in the longitudinal axis was found to be 26.7 Hz. However, the natural frequency dropped to 8.7 Hz when a kentledge of 10 kN was positioned on the top of the model. Failure of the model occurred in a peak table acceleration of 2.5g, and the last seismic test was interrupted to prevent total collapse. Plastic hinges created in the columns resulted in the development of a column-sidesway failure mechanism as was anticipated. This, final shake was performed using a sine dwell input motion of 6.0 Hz. The natural frequency before the test was 6.75 Hz, and it dropped to 4.86 Hz after testing. In Fig. 1, acceleration time histories on the table and on the roof of the model are shown. It is clear that damage to the model initiated very early.

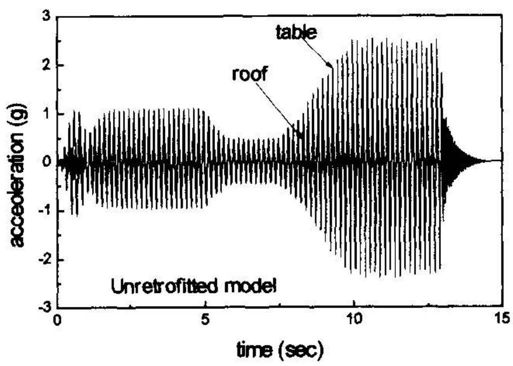

Fig. 1 Acceleration time histories on the table and on the roof of the unretrofitted model

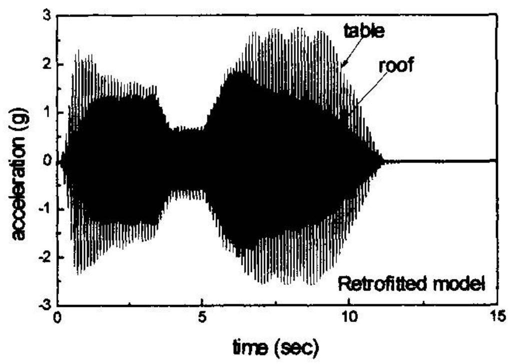

Fig. 2 Acceleration time histories on the table and on the roof of the retrofitteed model

The natural frequency in the longitudinal axis of the retrofitted specimen was found to be 47.3 Hz which dropped to 11.75 Hz when a kentledge of 10 kN was added at the top of the specimen. Eleven seismic tests were performed with a kentledge of 10 kN at the top in a range of 0.50g to 2.60g peak table accelerations. In Fig. 2 the acceleration time histories on the table and on the roof of the model are shown for the test with a peak table acceleration 2.60g where plastic hinges started to form at the bottom of the columns and beam ends. At the end of testing the natural frequency was measured to be 5.45 Hz. However, the natural frequency dropped to 4.25 Hz when the additional weight on the top increased from 10 kN to 30 kN. Finally, four more seismic tests were performed with a kentledge of 30 kN at the top up to a shaking table acceleration 1.65g. From the test series it was evident that the concrete jacket contributed significantly to the seismic resistance of the structure. High levels of strains were measured on the longitudinal reinforcement of the jackets while the strains were considerably lower in the respective bars of the original columns. Finally it is concluded that concrete jacketing is a very effective seismic strengthening technique for reinforced concrete frame buildings, since stiffness, strength and ductility can be significantly enhanced. Moreover an undesirable column-sidesway failure mechanism can be transferred to a desirable beam-sidesway one.