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BEHAVIOR OF RC FRAMES STRENGTHENED WITH INFILL PANEL UNDER DYNAMIC LOADING

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ABSTRACT

Increasing the lateral stiffness of the structure to limit the structure's drift is one of the strengthening techniques against seismic loads. This can be achieved by constructing reinforced concrete infill panels in existing frames. In this study, ¼ scaled RC frames strengthened with RC infill panels are tested on shake table to understand its behavior under sinusoidal load with different frequencies. Three specimens are constructed to see the location effect where infill panel is introduced to the existing frame. Connection between frames and infill panel is also investigated by considering the cases where infill panel is connected to the column and in fill panel is connected to beam only. Scaled frames are designed as one-bay, one-story, with minimum cross section requirements given in Turkish Earthquake Code-2007 (TEC2007). Fixed support is achieved by steel base plate, which is welded to the existing longitudinal steel bars of the column. Loading protocol is applied through a computer controlled shake table. Two accelerometers are placed on the top and the foundation of the frame. Accelerations are monitored during the test to observe the effectiveness of the infill panel. Acceleration records are integrated two times to calculate displacement time history of the frame. Maximum displacement value observed at the top level of the specimens are compared to explain the effectiveness of the strengthening method. It is found that placing infill panels decreases lateral displacement of the frame.

INTRODUCTION

Many of the existing reinforced concrete (RC) frame structures, which were not designed according to modern seismic codes, do not have enough strength, stiffness and ductility. Thus, they are vulnerable to earthquake loads with their current condition. Various strengthening techniques to upgrade strength, ductility and stiffness of the structural system are available to overcome this problem. One strengthening method is to limit the structure drift by increasing the lateral stiffness of the structure. Generally, introducing shear wall to the existing RC frames seems to be a solution to increase the lateral stiffness of the structure. However, constructing shear walls sometimes arises problems due to the existing architecture of the buildings. Another solution is to replace the shear walls with reinforced concrete infill panels.

Experimental studies on frames strengthened with reinforced concrete infill panels started with experiments conducted under monotonic loads (Ersoy et al., 1971- Benjamin et al., 1957). Then experiments completed under hysteresis load that simulates seismic loads (Klinger et al., 1976 and 1978, Kahn 1976, Kahn et al., 1979). Then, the effects of beam-column strength, shear strength of beams,

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material quality of the existing frames and the development length of anchorage on the behavior of infill panels are studied. In the researches completed on Middle East Technical University and Bogazici University, reinforcement details required for composite action of infill panel and existing RC frame are determined (Altın, 1990, Altın et al., 1992, Türk, 1998, Sonuvar, 2001, Sonuvar et al., 2004, Canbay, 2001, Canbay et al., 2003). In these studies anchorage details to achieve fixed foundation behavior and amount of increase in the lateral load carrying capacity are determined. None of these researches are conducted under base-induced motion.

This study focuses on tests that are completed on shake table. Sinusoidal excitation with different amplitudes and frequencies are applied. Two different test specimen constructed with two different infill panel location are investigated. Displacement results obtained from each test are compared to point out the effectiveness of the strengthening approach.

EXPERIMENTAL STUDY

Experimental specimens are designed by considering the capacity of shake table. Shake table can induce a maximum of ± 100 mm displacement in one direction. Maximum acceleration value of 2g can create a maximum linear velocity of 500 mm/s and a maximum horizontal force of 2.5 kN. Loading plane of the shaking table is a square with 1m x 1m dimension. Sinusoidal load can be applied in a frequency range of 1Hz-10Hz. With these limits of shake table test specimens are constructed with a scale of ¼. Shake table and general layout of the scaled specimen is given Figure 1.

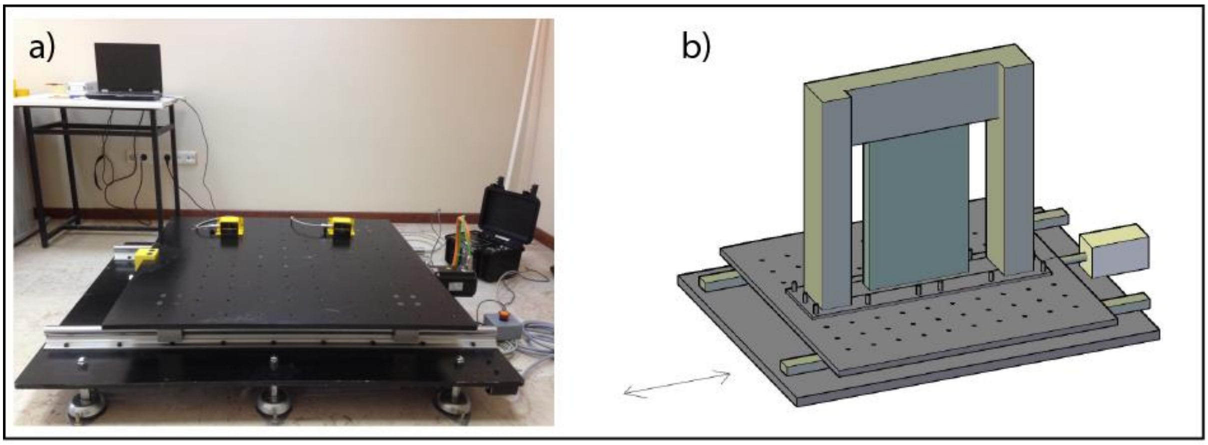

Figure 1. a) Shake table and instrumentation b) general layout of the scaled test-specimen

Three different test specimens are designed to investigate the effectiveness of the infill panels. A reference specimen is selected as a frame without an infill panel. Others are selected with different location of infill through the frame opening. Selecting such cases also made it possible to investigate the connection of the infill panel to the existing frame. In specimen 1 infill panel is connected to the column and to the beam (Figure 2b) while in specimen 2, it is connected to the beam only (Figure 2c). Dimension of specimens are given in detail in Figure 2.

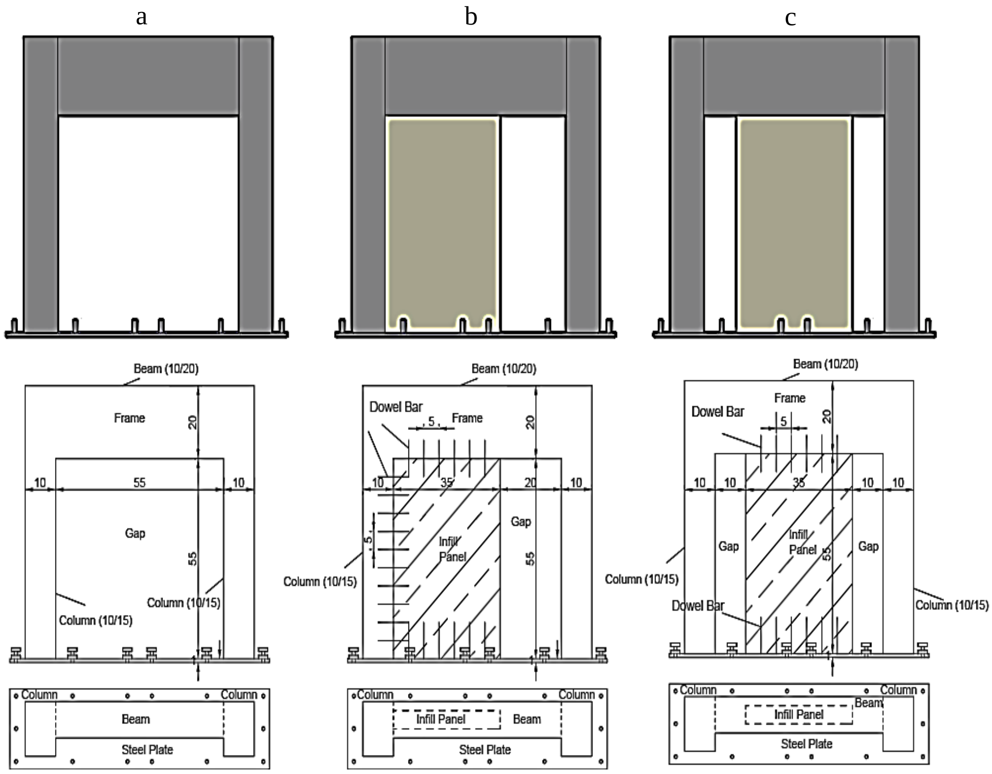

Figure 2. a) Reference specimen b) Specimen 1 (Spc 1) c) Specimen 2 (Spc 2)

Cross section dimensions and reinforcements are selected with the minimum design requirements of Turkish Earthquake Code-2007 (TEC2007). Minimum anchor diameter, depth and the widest spacing between anchors are modified for 1/4 scaled RC frames. To simulate the poor concrete quality concrete mixture to obtain C10 is created in the lab and axial compressive test is done over specimens to prove so. Reinforcement details, formwork plan and support details are given in Figure 3. To achieve the fixed support condition for the structure 14 bolts are used to connect the steel base plate to the shake table. Steel base plate is connected to the specimen with shear studs and the plate is welded to the existing steel bars of the columns and panels.

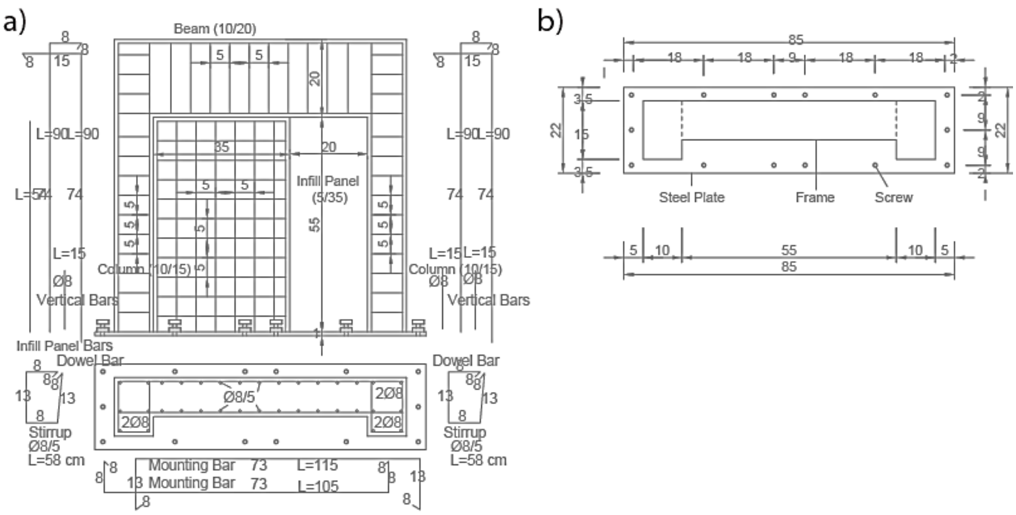

Figure 3. a) Reinforcement layout for Spc 2 b) Details of steel base plate

Formwork, reinforcement details and concrete pouring are completed in the lab (Figure 4). First timber formwork is constructed then steel reinforcement is installed (Figure 4a). Longitudinal bars of columns are welded to the base plate for achieving fixed support condition (Figure 4b). Before infill panel construction anchors are planted at the existing RC frame followed by steel reinforcement installation. Experiments are conducted after 28 days from concrete pouring.

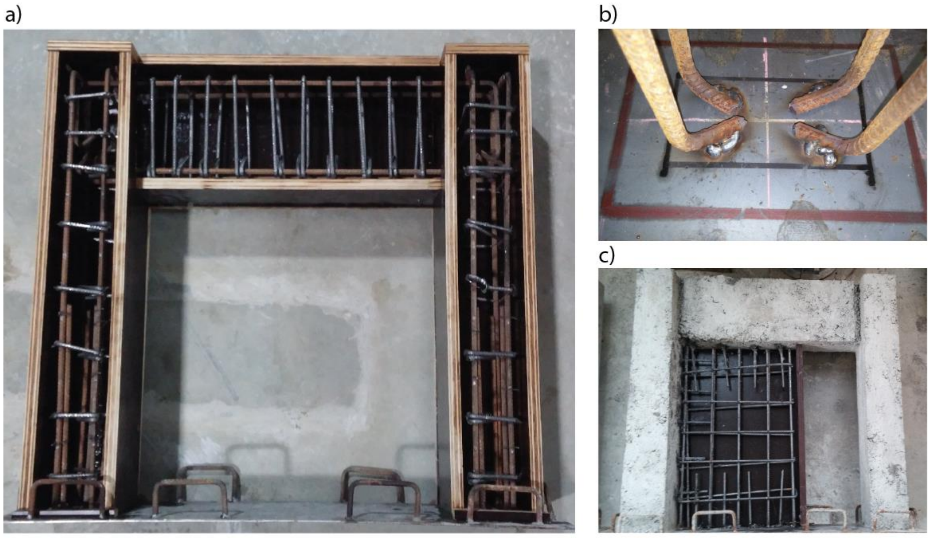

Figure 4. a) Formwork and steel reinforcement installation b) Connection of steel base-plate c-) installation of anchors and steel reinforcement of the infill panel

Specimens are instrumented with two accelerometers; one mounted on the top of the specimen and one on the shaking table. Dynamic data logger is used to collect the data (Figure 5).

Figure 5. Instrumentation of test specimens and general layout of the test setup

Dynamic behavior of a structure under base-induced motion is defined by Eq.(1) in which displacement of base is denoted by u_g, relative displacement between the mass and ground by u (Chopra, 2007). In this study test specimens are excited with sinusoidal loading protocol of $u_g=u_o sin(\omega t)$ where u_o and ω are the amplitude and frequency value of the induced vibration, respectively.

$$m\ddot{u} + c\dot{u} + ku = P_{eff}(t) = -m\,\ddot{u}_g(t) \quad (1)$$

RESULTS AND DISCUSSION

Total of 24 experiment records are obtained when three specimens are tested according to the loading protocol given in Table 1. Acceleration records are numerically integrated to determine the top displacement of the specimens. In order to determine the top displacement, records from accelerometer located at the base are subtracted from that located at the top of the specimen.

Relative displacement results are very small due to induced small motion. However, both strengthening method provides less displacement compared with the reference structure. When results of two strengthened frames are compared, Specimen 1 has less horizontal displacement. In Specimen 1, infill panel is anchored to both column and beam where as in Specimen 2, the infill panel is only anchored to the beam. Thus, lateral stiffness of Specimen 1 is greater than that of Specimen 2.

Table 1. Maximum relative displacement recorded during the tests

Name of Test	$u_g(t) = u_0 \sin \omega t$		**Maximum Relative Displacement, *u (mm)***		
	Amplitude u_o (mm)	**Frequency ω (Hz)**	**Reference**	**Specimen 1**	**Specimen 2**
Test 1	15	2	0.042	0.029	0.033
Test 2	15	3	0.094	0.071	0.089
Test 3	20	2	0.060	0.047	0.057
Test 4	20	3	0.115	0.100	0.108
Test 5	25	2	0.084	0.016	0.081
Test 6	25	3	0.192	0.128	0.176
Test 7	30	2	0.106	0.075	0.116
Test 8	30	3	0.258	0.201	0.208

A part of time history of acceleration records for all three specimens are given for two extreme cases, Test 1 and Test 8 (Figure 6). It is clear that decay of motion, which is also known as damping, is more rapid in strengthened specimens. Specimens encountered more acceleration as the amplitude of base motion increases.

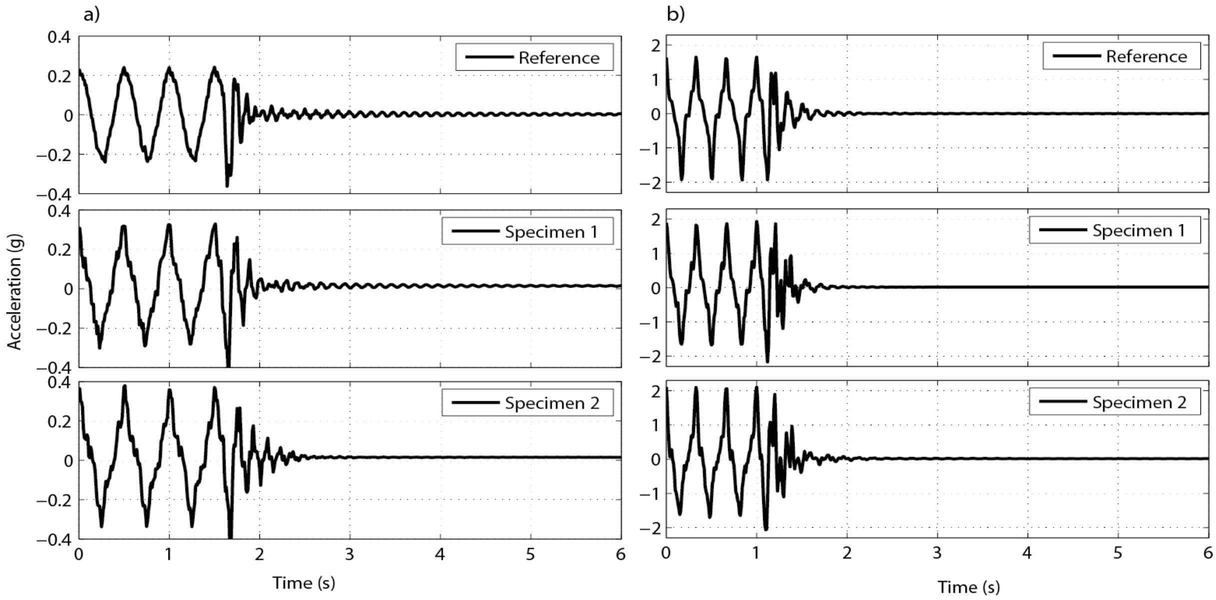

Figure 6. A part of acceleration history of test specimens under a base excitation of a) u_o =15 mm, ω=2 Hz b) u_o =30 mm, ω=3 Hz

CONCLUSIONS

Using infill panels as a strengthening tool, provides effective rehabilitation method for RC frames. However, location of infill panels can change the effectiveness of the strengthening method. Increasing the number of anchored edges of the infill panel decreases the lateral deflection of the frame. Decay of motion increases with added infill panels. More research must be conducted to investigate the damping ratio and energy dissipation of the frames strengthened with infill panels.

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