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Forced Vibration Test on Damaged Reinforced Concrete Structure

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Abstract — *This paper presents research carried out on damaged reinforced concrete structure using forced vibration technique. Half scaled model of reinforced concrete special moment resisting frame (SMRF) was investigated, which was designed as per Building Code of Pakistan for seismic zone 4. This structure has been tested already dynamically that caused minor damage in the structure columns. The present study now focusses on measuring the dynamic characteristics of damaged reinforced concrete structure in order to understand how the pre-existing cracks and damage in the structure affects the elastic dynamic properties (frequency and elastic damping).*

Keywords- *Forced Vibrations, Damping, Frequency, Damaged RC Structure, Eccentric Mass Vibrator component*

I. INTRODUCTION

Pakistan lies at the collision boundaries of Indian, Eurasian and Arabian tectonic plates [1]. This region is more vulnerable to earthquakes [2]. Quetta earthquake of 1935 having magnitude of 7.7 Mw was the first devastating earthquake in this region which had killed about 30,000 and 60,000 people [3]. In 2005 Kashmir earthquake of magnitude 7.6 Mw, due to damage of 450,000 buildings, more than 80,000 people were killed and about 2.8 million people became homeless [4]. Pakistan is a developing country and 6th most heavily populated country of the world [5]. In most cities of Pakistan including Islamabad, Karachi, Peshawar, and Lahore, RC structure with brick masonry infills is a popular form of construction. It is a common practice that the provided infill masonry walls are not considered in the analysis and design process of designing RC structures, which may cause several effects during a seismic activity. Research regarding this type of construction is the need of day. Therefore, keeping in view local construction practice a two-story half scale reinforced concrete model was constructed on six degree of freedom shake table at Earthquake Engineering Centre (EEC) of University of Engineering and Technology Peshawar (UET). The model was tested and it was found that the damage of RC frame was very minimal while the masonry infill walls were severely damaged. This research focusses on the frequency and damping characteristics of the damaged RC bare frame after extraction of remaining infill walls, using forced vibration technique.

II. MODEL DESCRIPTION

RC frames structures are normally infilled with brick masonry to resist the surrounding moisture, temperature, fire and noise. In these structures the infilled walls are intended as nonstructural elements and usually neglected in structural design and analysis because of a large number of variables such as relative infill to frame stiffness, strength and geometry of infills, position of openings etc. However, under lateral loading the infilled walls can change the failure pattern and load resisting mechanism and of RC frames. In failure pattern and load resisting mechanism of URM infilled wall openings (door and window) play a very important role, therefore a half-scaled RC model was constructed on shake table, in which infilled walls with different combination of window and door openings. The scheme of construction of the model is shown in Figure 1.

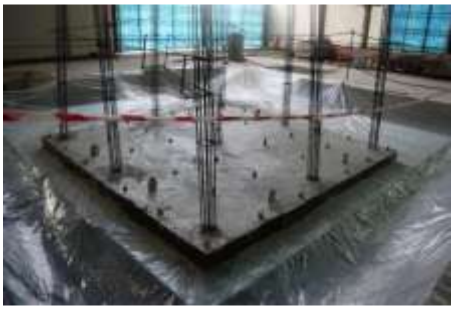

Figure 1: Scheme of construction of test mode

After the construction of the model, the model was left for curing process to gain strength. Additionally, it was white washed in order to capture good picture of damages, which may occur during the test.

III. SHAKE TABLE TEST OF MODEL

The model was subjected to sinusoidal seismic excitation of varying frequencies and displacements to push the structure from elastic state on inelastic state in a progressive manner. In order to capture response of the model during the test, several accelerometers and displacement transducers were installed on the model at different locations. The damage observations revealed that RC frame members were slightly damaged however, the infill walls were severely damaged as depicted in Figure 2.

IV. FORCED VIBRATION TEST

In order to compute seismic parameters of damaged RC bare frame, the damaged infill panel walls were removed from the model. Earthquake Engineering Center of University of Engineering and Technology Peshawar is blessed with diverse instruments and experienced staff for conducting various seismic tests. Eccentric Mass Vibrator (EMV) was used for forced vibration test of the model.

A. ECCENTRIC MASS VIBRATOR

MK-138 eccentric mass vibrator system owned by the Earthquake Engineering Center, University of Engineering and Technology Peshawar was used as a source of harmonic excitation imposed on the model structure. The particular mass vibrator system is a portable, omnidirectional rotating shaker that can produce a maximum horizontal force of 10 tons and can be operated from 0.1 to 25 Hz. During the forced-vibration tests at Earthquake Engineering Center, the motor drive was operated manually adjusting the operating speed of the shaker to the desired excitation frequency. Pictorial image of the EMV is shown in Figure 3.

Figure.2: Damage photos of test model

Figure 3: Eccentric Mass Vibrator at Earthquake Engineering Center, UET Peshawar

B. INSTRUMENTATION OF MODEL

At the initial stage, EMV was transported to the top slab of the model using 60 tons weighing capacity crane of EEC. The EMV was mounted to slab using nut and bolts, in the already drilled holes as shown in Figure 4 (left). In order to capture the seismic response during the test, the model was instrumented with three accelerometers, one on top floor (A1), one on first floor (A2) and one on base slab (A3), as shown in Figure 4 (right).

Figure 4: EMV mounted on model (left), instrumentation of model (right

C. TESTING OF MODEL

The model was tested with increasing frequencies, ranging from 0.1 Hz to 3.5 Hz. As the frequency was increased, the model showed different behavior, and at resonant frequency, the model showed resonance i.e. the frequency of excitation matched with the model frequency which caused maximum amplitude vibrations. Beyond the resonance, the model vibrated with lower amplitudes.

D. DATA PROCESSING

DADiSP (Data Analysis and Display) software was used for data processing. It includes programming language which is used to implement custom alogrithms, called as Series Processing Language (SPL). Logrithmic decay procedure was followed to compute damping and from Power Spectral Density, frequency was computed.

E. OUTCOMES OF THE TEST

a. Damping

The decay function for the time history of the response acceleration as proposed by Chopra (2003) is used to calculate the model damping:

$$z = \frac{1}{2np} Ln\left(\frac{A_1}{A_n}\right)$$

where ζ represents elastic damping coefficient; A_1 represents the peak amplitude of response displacement at reference point 1; A_n represents the peak amplitude of response displacement at reference point after n cycles; and n represents the number of cycles between the peaks. From the acceleration decay, using the above equation, damping of the model was calculated out to be 7.41 %. Decay in the acceleration is shown in Figure 5.

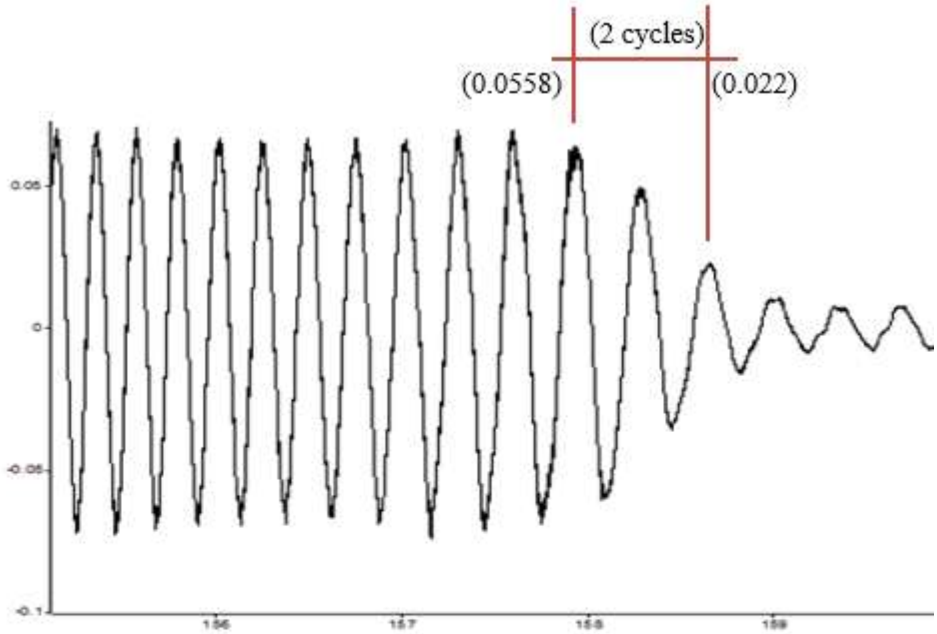

Figure 5: Response history of the test

b. Frequency

Frequency of the model was calculated from the available data of the accelerometer. After performing filtering and base line correction to the data, power spectral density (PSD) was calculated in which a clear peak was observed as shown in Figure 6. This peak corresponds to resonant frequency of the model, calculated as 2.59 Hz.

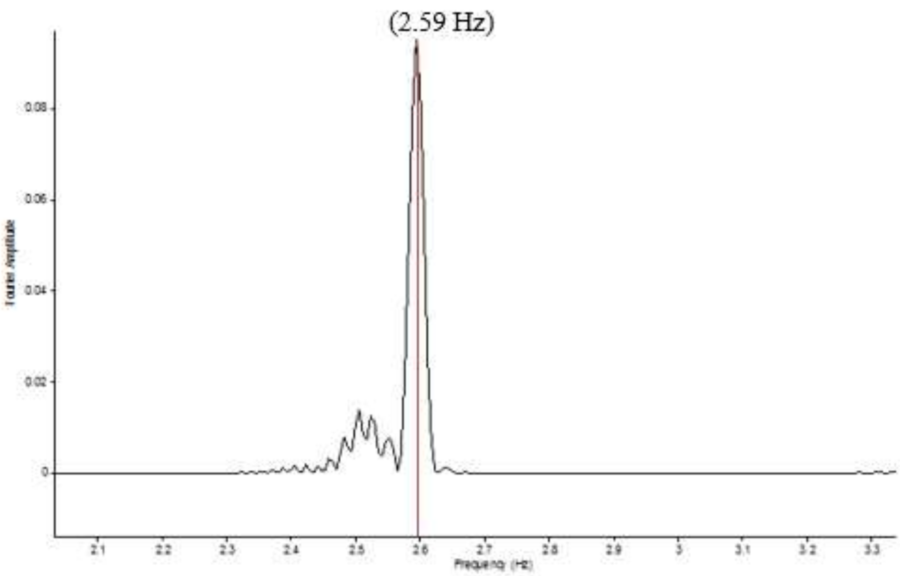

Figure 6: Power Spectral Density Plot

V. CONCLUSIONS

The present study has shown that frequency decreases with structure damage i.e. in this case from 6.45 Hz (undamaged RC structure with masonry infills) to 2.59 Hz (damaged RC structure), which is 40% less than the undamaged structure. This is due to structure damages which causes reduction in stiffness and softening of the structure. Also, in the case of undamaged RC structure the damping ratio was calculated to be 2.92% when the structure was behaving elastically without any cracking, however, in this study the calculated damping ratio is 7.41% which is 253% more than the undamaged structure. One of the reasons in experiencing such large increase in damping is the possibility of structure rocking as the model was not connected to the strong floor completely. The change in frequency and damping significantly affects the seismic behavior of a damaged RC structure.
This research signifies the importance of due considering the effect of cracking and damage in the analysis and design of retrofitting of a damaged RC structure.

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