SEISMIC ANALYSIS OF REINFORCED CONCRETE FRAME USING SHAKE TABLE TEST

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ABSTRACT:

Recently, the reinforced cement concrete (RCC) frame has been one of the most commonly used structural systems for buildings in the high seismic region due to its inherent earthquake-resistant property. However, there is still a deficiency in understanding the RCC building structural system dynamic behaviour during significant earthquakes. A 1/4th scaled RCC framed building structure has been tested on the shake table in the present study. The response in terms of engineering parameters like natural time period, damping, story acceleration, and damage pattern have been reported. The 1940 EL-Centro (NS component) time history has been used for the study. The failure patterns were observed within the column-beam joints. The difference between the input signal and the output signal has been noted and found to be in good agreement with each other.

1. INTRODUCTION

Recently, the reinforced cement concrete (RCC) frame has been one of the most commonly used structural systems for buildings in the high seismic region due to its inherent earthquake-resistant property (Arastu and Moin, 2018). However, there is still a deficiency in understanding RCC building structural system dynamic behaviour during significant earthquakes (Arastu and Moin, 2018). The Indian subcontinent has a history of earthquakes. The intensity and high frequency of earthquakes is the Indian plate driving into the Asian region at approximately 47 mm/year (Bendick et.al., 2002). Significant earthquakes like the Jabalpur earthquake (1997), Chamoli earthquake (1999), Bhuj earthquake (2001), and a recent Nepal earthquake (2015) have highlighted the need for an extensive study to understand the behaviour of Reinforced Cement Concrete (RCC) structures under seismic inputs (Arastu and Moin, 2018). Most RCC structures were built before revising the latest Indian Standard of Earthquake Resistant Design of Structures-2016 (Bureau of Indian Standards, 2016). Hence, the performance of such RCC structures needs to be assessed experimentally and numerically under moderate/severe earthquakes. The seismic response of structures substantially differs from the systems designed and built to meet aseismic design provisions as per the latest codes of Indian Standard.

The present study aims to assess the engineering parameters such as the natural time period, damping, story acceleration, velocity and displacement, and damage pattern of 1/4th scaled RCC building structures against the horizontal forces produced by scaled El-Centro earthquake using a shake table (Li, H., Liu, J. K., Chen, W. H., Lu, Z. R., Xia, Y., & Ni, Y. Q., 2015, Lu, X. L., Wang, B., Jiang, H. J., Li, J. B., & Lu, W. S. 2013, Lu, X. L., Zhou, B., Zhao, B., & Lu, W. S. 2015). One bay and four stories, three-dimensional RCC building structure has been considered for the present study.

2. METHODOLOGY

2.1 Scaling and Geometry of Structure

A cast-in-situ RCC building structure has been scaled down on a 1/4th scale as per the factors obtained from similitude consideration for earthquake loading (Deyuan and Zhou Changtuan, 2016, Li, C. S., Lam, S. S. E., Zhang, M. Z., & Wong, Y. L. 2006, Lu, Z., Chen, X. Y., Lu, X. L., & Yang, Z. 2016).). The summary of these scale factors is given in Table 1. The structure's overall dimensions have been chosen based on the limitation of the sizes and capacity of the shake table (2m x 2m plan dimensions) (Zhou, Y., Lu, X. L., Lu, W. S., & Qian, J., 2011).

Item	Parameter	Dimension	Gravity Force Neglected Prototype Material
Loading	Force	F	S^2
	Pressure	FL^{-2}	1
	Acceleration	LT^{-2}	S^{-1}
	Gravitational acceleration, g	LT^{-2}	Neglected
	Time	T	S
Geometry	Linear dimension	L	S
	Displacement	L	S

	Frequency	T^{-1}	S^{-1}
Material Properties	Modulus of Elasticity	FL^{-2}	1
	Stress	FL^{-2}	1
	Strain	-	1
	Mass Density	$FL^{-4}T^{2}$	1
	Poison's ratio	-	1

Table 1. Summary of Scale Factors for Earthquake Response of the Structure

The general layout plan of the scaled models is shown in Figure 1 (a & b).

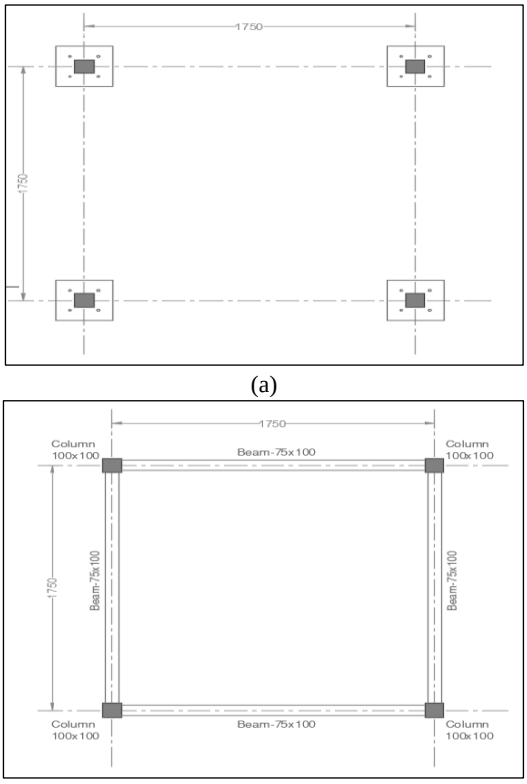


Figure 1. (a) Base Plan; (b) Beam Plan

The column centre-to-centre dimensions were 1750 mm in both directions. Columns were cast with RCC footing of 300x300x100mm. The model was fixed at the base with a shake table using a 300x300x8mm base plate and 4 number of M12 high-strength bolts under each column, as shown in Figure 2.



Figure 2. Base Plate Connection with Shake Table

The column and beam details have been done as per the earlier version of the Code of Practice of Indian Standard. The 75mm wide and 100mm deep beam with 2 bars of 8mm diameter at the top and bottom were used at all levels and in both directions. The stirrups of 2mm diameter wire were used at 25mm c/c at the edge (from the face of the column to 2 times the beam depth) and 50mm c/c for the rest of the central part of the beam. The 100mm x100mm columns with 4 bars of 8mm diameter (one at each corner) and 2mm diameter wire were used as stirrups at 25mm c/c near the beam-column junction and 50mm c/c near the mid-height of the column.
The story height was kept at 750mm c/c of the beam on all floors. Column-beam reinforcement arrangement and the final model are shown in Figure 3 (a & b).

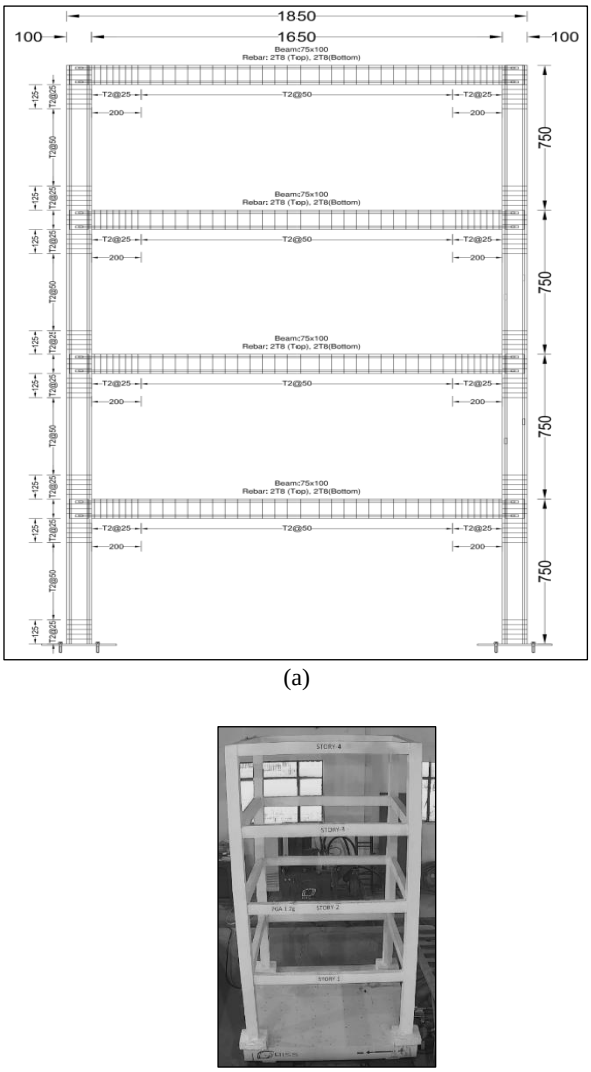


Figure 3. 1/4th Scaled RCC Model mounted on Shake Table, (a) Elevation; (b) Final Model

2.2 Mechanical Properties of Material

All material properties were tested in the laboratory before the shaking table test. The yield strength of the longitudinal and transverse bars was 500N/mm^2 and 250N/mm^2, respectively. The average tested compressive strength of micro concrete used was 25 MPa at seven days (IS:456-Bureau of Indian Standards, 2000).

2.3 Input Ground Motion

The 1940 El Centro earthquake (or 1940 Imperial Valley earthquake) time history was used to shake the table at

different PGA values (T.K. Datta, 2010). This earthquake was used because it was one of the most catastrophic earthquakes in history and was used by many researchers for their research. The original El-Centro (NS Component) time history is shown in Figure 4.

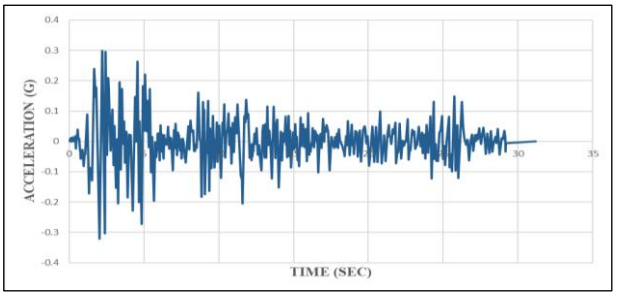


Figure 4. 1940 El Centro earthquake Time-History

The acceleration response spectrum of the El-Centro earthquake, response spectrum for maximum considered earthquake (MCE), design basis earthquake (DBE), and design level earthquake as per IS-1893 for 5% damping and medium soil category are shown in Figure 5.

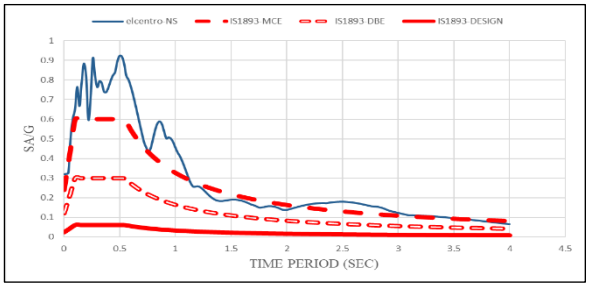


Figure 5. Acceleration Response Spectrum

The displacement time histories (shown in Figure 6) were generated from scaled El-Centro (NS Component) time histories and were used for shaking the table. The five different scaled PGA El-Centro earthquake time histories are shown in Figure 7.

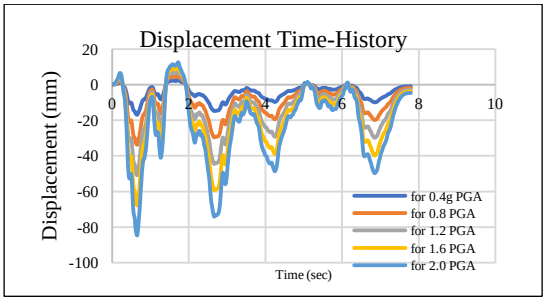


Figure 6. Scaled Displacement Time-Histories for different El-Centro PGA values

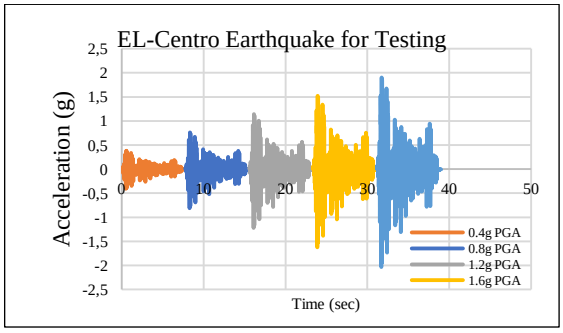


Figure 7. Scaled El-Centro Time-Histories for five different PGA values

3. RESULTS AND DISCUSSION

The free vibration was given to the model by pulling with the help of a rope, and top-story acceleration was recorded, as shown in Figure 8. The Fast Fourier Transform of records was carried out using the standard software, as shown in Figure 9.

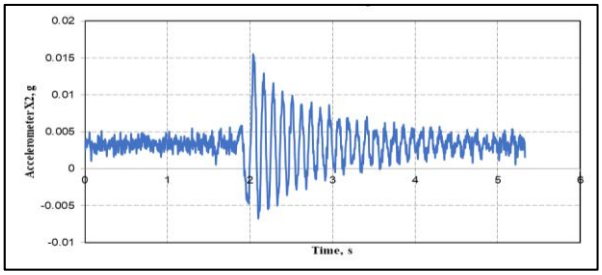


Figure 8. Records of top story acceleration after free vibration before EQ testing

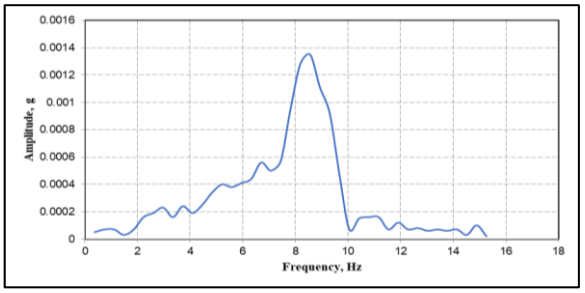


Figure 9. Fast Fourier Transform of acceleration record of free vibration before testing

Before conducting the shake table test, the natural frequency of the structure in the first mode was evaluated experimentally as 9.80 Hz and damping considered is 0.0518. The ground input motion was given with increased PGA values, and a free vibration test was carried out after each cycle test to calculate the natural frequency of the structure after each excitation results of the free vibration test are reported in Table 2.

Parameters	0.4g	0.8g	1.2g	1.6g	2.0g	Unit
Natural Frequency:	8.10	7.94	7.69	7.69	7.440	Hz
Damping Ratio:	0.0391	0.036	0.0455	0.0477	0.040	

Table 2. Dynamic properties of the model after each cycle of testing

The tabletop and top story acceleration record PGA values are given in Table 3. It was observed visually that the cracks developed within the column-beam joints shown in Figure 10.

Parameters	0.40g	0.80g	1.20g	1.60g	2.00g
Tabletop measured PGA	0.34g	0.67g	0.90g	0.98g	1.34g
Top Story measured PGA	1.09g	2.03g	2.77g	2.98g	3.77g

Table 3. Dynamic properties of the model after each cycle of testing

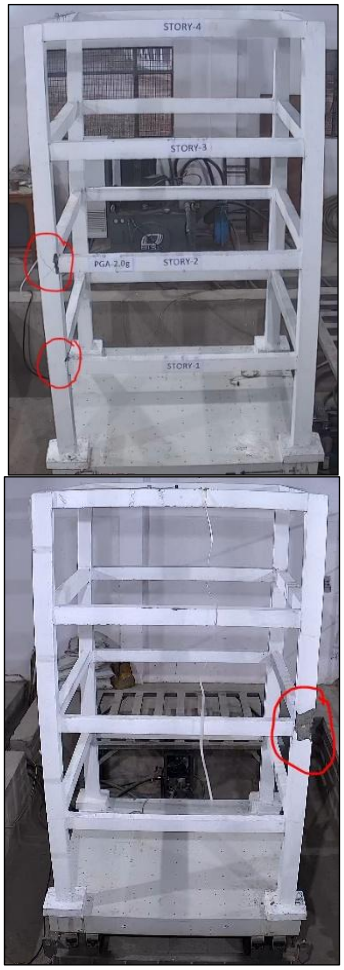


Figure 10. Cracks after the last cycle

4. CONCLUSION

The two accelerometers were used to measure the table acceleration and the top story acceleration. The measured acceleration at the shake tabletop differs from the input acceleration, probably because of the energy dissipation of the actuator internally. It was observed visually that the cracks were developed within the column-beam joints, the stiffness of the structure reduced after each cycle of the test, and the top story acceleration increased.

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