SECM/15/179

Seismic Assessment of School Building in Sri Lanka Using Fragility Curves

K.A.T.M. Abeysiriwardena[1*] , R.M.A. Buddika[2] and K.K. Wijesundara[3]

[1,2,3] Department of Civil Engineering, University of Peradeniya, Sri Lanka
*E-Mail: Malingathari@gmail.com, TP: +94711919135

Abstract: Considering the occupancy of future generation and the vulnerability of their lives in school time, it is considered being a timely requirement to assess the performance levels of school buildings for different return period earthquakes which happens without any advance notification. For this purpose, Fragility curves are developed using nonlinear finite element model of three storey type plan building developed in 'OPENSEES' computer program. The damage indices based on the inter-storey drift are evaluated for immediate occupancy and collapse prevention performance levels. Corresponding inter-storey drift ratios were obtained using static pushover analysis. Since the pushover analysis is a static analysis, it cannot take into account the effects of energy content, duration and frequency content of an accelerograme while development of fragility curves a dynamic analysis of structure under input accelerograme and then the effect of those parameters to the ultimate drift can be estimated. The corresponding drift ratios for immediate occupancy and collapse prevention performance levels are developed for past 30 earthquake records with different scale increments for each earthquake using the drift ratios obtained by resultant Pushover curves. The damage index which is close to the collapse prevention performance level is observed in the school building for an earthquake with the peak ground acceleration of 0.6g and immediate occupancy performance level for an earthquake with peak ground acceleration of 0.25g highlighting the importance of designing school buildings to resist the lateral load induced by earthquakes. According to the pushover curves, this building is weaker in longitudinal direction. By introducing a section with higher moment capacity for longitudinal beams but less than the moment capacity of the column in longitudinal direction in order to increase lateral storey stiffness, the failure of the structure can be delayed and the structure will be able to withstand higher magnitudes of earthquakes.

Keywords: Earthquakes, Fragility Curves, OpenSees, Pushover Curves.

1. Introduction

Historical earthquake records in and around Sri Lanka indicate that the two major earthquakes have been occurred in Manna basin (near Colombo) in 1615 and 1938 with a moment magnitude of 6.5 and 5.9 respectively. However, vulnerability assessment of important class of structures are not performed yet to evaluate the safety against the expected seismicity in the region. Furthermore, according to the census data published in 2014, approximately 20 percent of the total population in Sri-Lanka are school children and the staff. Therefore, considering all these factors and the occupancy of school children and the vulnerability of their lives in school time in Sri Lanka, it is considered being a timely requirement to assess the safety levels of school buildings for different return period earthquakes.

2. Literature review

2.1 Damage modes

When investigating the past failure modes of reinforced concrete frame buildings due to seismic activities, failure of the plastic hinges formed either at beam and column faces, anchorage failure at the beam column joint, diagonal shear failure at beam column joint, shear failure of short columns and the failure of non-structural components such as masonry infill walls were identified. Failure of plastic hinge is due to early crushing of concrete as a result of lack of confinement in concrete and bucking of longitudinal reinforcement. Diagonal shear cracks at the beam column joints and in short columns are due to lack of transverse shear reinforcements (stirrups). (Bralie 2003 [2])

2.2 Performance objectives and pushover curve

The assessment of school building is performed based on the two performance objectives. They are immediate occupancy and collapse prevention performance levels. Immediate occupancy performance level should satisfy the objective that

the building should be used for normal services immediately after an earthquake. The collapse prevention performance level should satisfy the objective that the structure should not be collapsed due to modes of failures discussed above after an earthquake. (Vona M. 2014 [3])
However, in this study, the limits of the two performance objectives are evaluated based on the inter storey drift as a damage index parameter. The limit values of inter storey drift for the two performance objectives are obtained from the pushover curve developed for the given structure. By a static analysis, pushover curve can be developed for a building. Importance of the developing pushover curve is to identify inter story drift values for each Performance objective, immediate occupancy and collapse prevention which are important to develop the fragility curves later. When developing the pushover curves triangular force distribution was applied to each story. (Borzi at el, 2007 [1])

2.4 Fragility curve

Fragility curves are the representation of the link between the probabilities of exceedence of damage levels reached at a defined specific performance level and the expected level of earthquake. In this study the fragility curves are developed by the cumulative probability distribution curve which is drawn to probability of exceedence versus the Peak Ground Acceleration (PGA) values.
Probability of exceedence is calculated by,

$$P[dsi / I H] = \Phi [(1/\beta dsi) \times \ln (IH / \mu ds)] \quad (1)$$

Where damage state is dsi, standard normal cumulative distribution function is Φ, μ is mean value for the damage state Ids , βdsi is standard deviation for the damage state and PGA(Intensity) values is I(h). (Vona M. 2014 [3])

3. Methodology

Figure 1: Selected typical school building

The selected school building is a three story reinforced concrete frame structure as shown in Figure 1: Selected typical school building, Typical gravity design school building's performance under an earthquake is assessed in this study. First all the elements were modelled using OPENSEES finite element software for analyse the structure for static pushover and time history analysis in a 3D right hand Cartesian coordinate system. In order to develop fragility curves, limit drift values of immediate occupancy and collapse prevention performance levels were obtained by pushover analysis. Next, time history analysis was performed to estimate the mean and standard deviation for different performance level. Finally, Fragility curves were developed for both performance objectives.

4. Validating section moment capacity

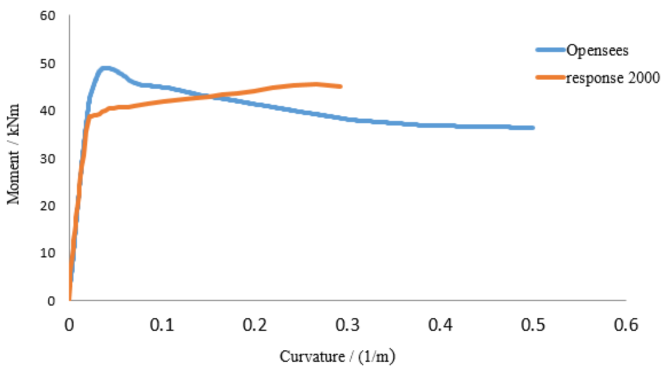


Figure 2: Moment-Curvature comparison of OpenSees and response2000 beam 39 section

Ultimate moment capacity obtained by OpenSees software and Response2000 of beam 39 is almost similar. In Response2000 software applies a fixed axial force for this analysis while in OpenSees software the beam is subjected to a variable axial force. But considering the ultimate moment capacity, the results obtained by OpenSees software is accurate.

4. Results and discussion

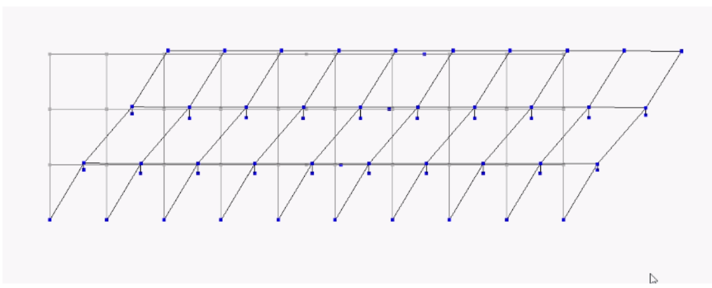


Figure 3: Deformed shape of the model due to triangular force distribution

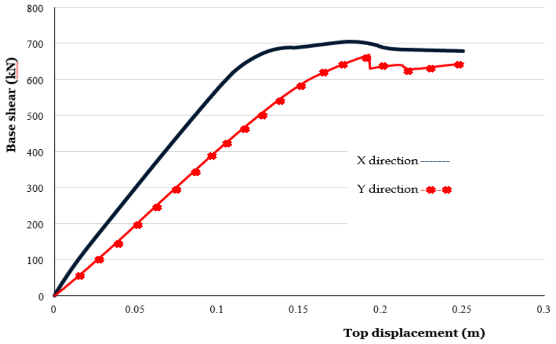


Figure 4: Pushover curves

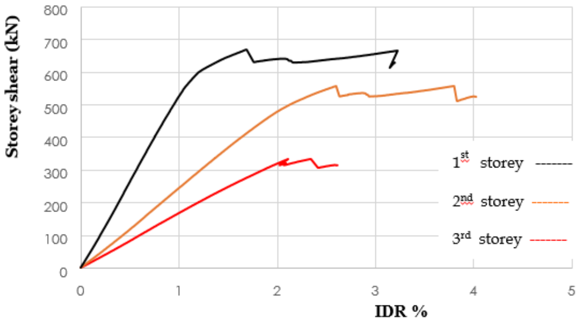


Figure 5: Story shear vs IDR% in transverse direction

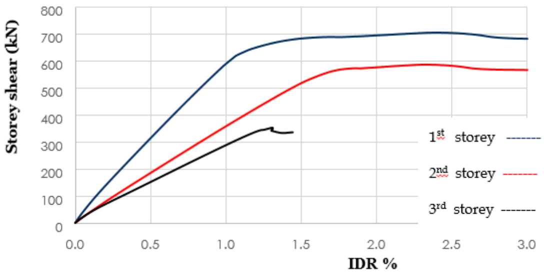


Figure 6: Story shear vs IDR% in longitudinal direction

Figure 4: Pushover curves shows that the three storey school building has base shear capacity of approximately 700 kN in both longitudinal (Y) and transverse (X) directions. However, it is observed that at the top displacement of 0.1 m in X direction, the building reaches to its elastic limit while it reaches to elastic limit at the top displacement of 0.14 m in the Y direction. Therefore, the stiffness in X direction is higher than the stiffness in Y direction. Figure 5: Story shear vs IDR% in transverse direction and Figure 6: Story shear vs IDR% in longitudinal direction shows that the three storey school building has storey shear capacities of 1st storey, 2nd storey and 3rd storey are approximately 700 kN, 600 kN, 350 kN respectively in transverse (X) direction and 670kN, 550kN, 330kN respectively in longitudinal (Y) direction. However, in X direction, it is observed that at the base, 2nd storey and in the top storey, IDR% of 1, 1.7 and 1.2 respectively the building reaches to its elastic limit while it reaches to elastic limit at the base, 2nd storey and in the top storey, IDR% of 1, 1.9 and 2 respectively in the Y direction. It can be observed that the stiffness of 1st storey and the 2nd storey are almost same for both transverse and longitudinal directions. However, the top storey in X direction compared to its Y direction.

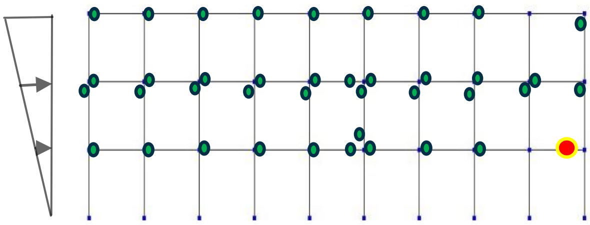


Figure 7: Plastic hinge formation in longitudinal direction

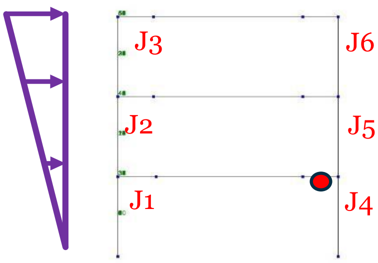
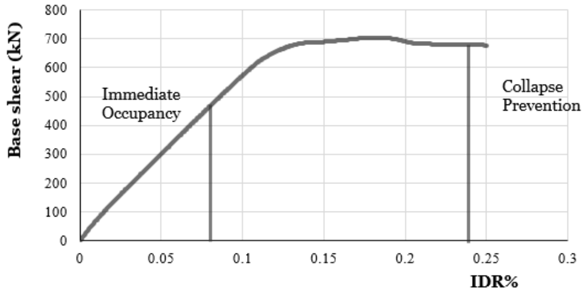


Figure 8: Plastic hinge formation in transverse direction

20% drop of moment of the member is considered as the failure of that element. Failure of one element can lead to collapse of whole building. Therefore, using the moment curvature diagrams of critical elements, load step corresponding to failure of that elements can be identify. Having found the critical load step for both x and y direction, collapse prevention performance level can be



identified in the 1st storey pushover curve.

Figure 9: Performance level limits in X direction

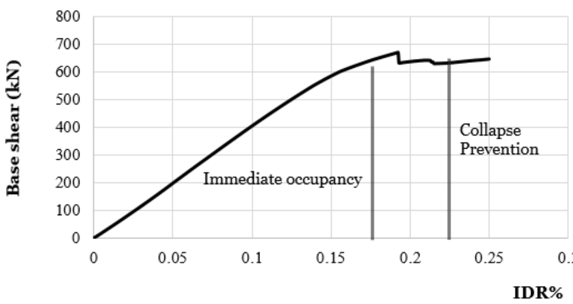


Figure 10: Performance level limits in Y direction

When a building is subjected to an earthquake, drift values of storeys are changing with the peak ground acceleration of the given earthquake. Fragility curves are drawn to show this relationship of drift values and return period/PGA values in corporate with probability. In order to develop fragility curves a data set of drift ratio percentage values are needed of the weak direction of the building which is global x direction. The building was subjected to 30 natural earthquakes consists of different PGA values and different wave forms.

5. Conclusions

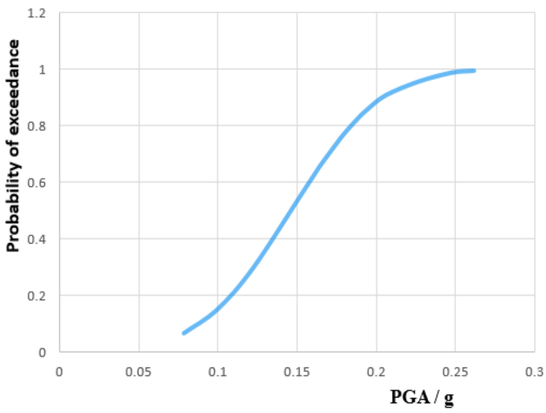


Figure 11: Fragility curve for immediate occupancy performance level

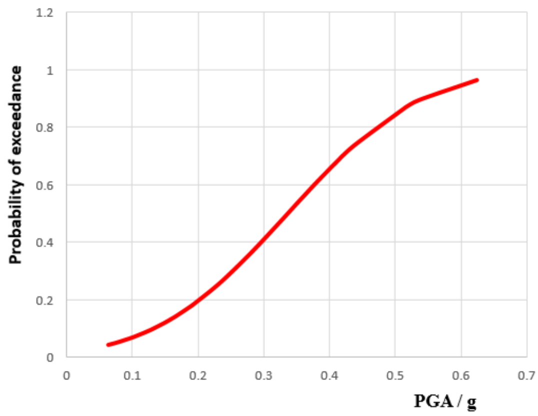


Figure 12: Fragility curve for collapse prevention performance level

According to the pushover curves, this type plan three storey school building is weak in longitudinal direction showing lower lateral storey stiffness and the moment capacity in longitudinal beams. However, the excessive rotation in the beam-column joints at the first storey level leads the failure of the longitudinal beams by forming of plastic hinges in the beam at the face of beam-column joint.

According to past studies, the expected PGA value for Sri Lanka is 0.15g. It is observed from the fragility curves that three storey 12 class room type plan school building displays 58% probability to building to get damage under an earthquake of PGA of 0.15g. And there is less than 10% of probability to get the building completely collapse under the level of PGA of 0.15g.

Figure 13: Walls with low flexural strength inside the building

Furthermore, it is important to highlight that some of the non-structural walls which have been used to separate class rooms are unconfined masonry infill walls there for it is strongly recommended that confine that masonry infill walls in order to prevent collapse due to the out of plane response of the masonry walls. By introducing a section with higher moment capacity for longitudinal beams but less than the moment capacity of the column in longitudinal direction, the failure of the structure can be delayed and it will be able to withstand higher magnitudes of earthquakes.

Acknowledgement

Deepest appreciation to all those who provided the possibility to complete this report. A very special gratitude to our final year project supervisor Dr. K.K. Wijesundara whose contribution in sharing spectacular knowledge, expertise, sincere and valuable guidance and encouragement helped to complete the project in due time and best manner.

References

[1]. Borzi B. et al., Pinho R. et al., Crowley H. et al.,2008, "Simplified pushover-based vulnerability analysis for large-scale assessment of RC buildings" Engineering Structures vol 30 pg. 804–820

[2]. Braile L., "Connections between failure modes observed in shake table testing of models in building contest and earthquake damage to actual buildings" Purdue University, October 2003

[3]. Marco Vona, "Fragility Curves of Existing RC Buildings Based on Specific Structural Performance Levels", Open Journal of Civil Engineering , vol. 4 ,pg 120-134