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Seismic Risk Assessment of Vertically Irregular Buildings

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Abstract

The construction of the vertically irregular buildings are almost inevitable due to the functional as well as aesthetic requirements. However, Post-Earthquake damage assessment shows that the structural irregularity plays vital role in the seismic performance of the buildings. Sudden change in the strength, stiffness as well as load path discontinuity increase the seismic demand of the building which increase the vulnerability of the buildings. Seismic risk assessment in certain geographical area requires the fragility model of the different archetype of the buildings. In this research, a humble effort is made to comprehend the analytic seismic fragility estimate of the existing types of the vertically irregular reinforced concrete buildings in Nepal.

Keywords

Verical Irregularity, Seismic risk, Reinforced Concrete, Pushover Curve, IDA curves, Fragility curves

1. Introduction

On 25th April 2015, a strong earthquake of moment magnitude Mw 7.8 hit central part of Nepal causing over 8000 casualties and nearly 23000 injuries. About 7 lakhs plus residential buildings, 4000 government offices and 8200 schools were damaged due to this earthquake. 14 districts were severely affected by this 2015 Gorkha Earthquake followed by several aftershocks[1].Various post damage assessment studies were made to assess the seismic performance of the existing buildings in Nepal so as to provide valuable insight to the seismic risk and future opportunities for retrofit and mitigation.

Reinforced concrete (RC) buildings construction has increased drastically over the last few decades in the capital as well as other major urban centers of Nepal. According to the National census of 2011, about 10% of the buildings construction in Nepal is RC type, with more than 40% of the total RC construction are concentrated in the Kathmandu valley[2] . Recent field investigation shows that majority of the RC construction does not comply with the building code provisions.Majority of the buildings lacks gradual reduction of the stiffness as well strength reduction due to the absence of the infill at the ground story as well as load path discontinuity. These structural deficiencies increase the seismic vulnerability of the buildings[3].

In this context, present study focuses on the seismic fragility estimate of the existing RC vertically irregular buildings which helps to develop the vulnerability model for these type of the buildings. The demand estimate of the buildings has been done by the static pushover analysis of the buildings at the every floor level. Using the modal analysis results and pushover curves, fragility curves at the different limit states are evaluated using MATLAB code based tool SPO2FRAG[4]. To be structure-specific estimate of the fragility, the intensity measures are spectral acceleration Sa (T1) at the fundamental time-period of the buildings and the structural demand as Engineering demand parameter (EDP) which is inter-storey drift capacities at any story level.

2. Development of Analytical fragility estimate

The next generation seismic design and assessment procedure for buildings within the performance based framework are radical departure from the traditional seismic design practice and performance assessment[5]. The performance bases seismic design and assessment approach, in which the building is expected to satisfy certain performance requirements in its lifetime, make a paradigm shift from traditional design and assessment procedure.The uncertainty and randomness in the building performance and seismic hazard will be captured and quantified in each steps in design and assessment procedure.Finally the performance will be measured in terms of direct and indirect economic losses and causalities [6].

Perhaps the most notable example is the problem of the estimating the rate of the earthquakes leading the structure to exceed the different limit states which can be computed using total probability theorem[4]

The methods used to derive the fragility function can be classified as empirical, analytical or hybrid[7]. In recent years, a considerable effort has been made to compute the analytical fragility which is based on the numerical model, especially for the structure specific fragility function. Analytical method rely on the advanced numerical model of the structure subjected to nonlinear dynamic analysis.These nonlinear dynamic analysis (NDA) can be used to build the relationship between the demand and the spectral acceleration or Peak ground acceleration (PGA), which are type of IMs. Some of the widely used NDA are cloud analysis [8], multiple stripe analysis (MSA)[9], Incremental dynamic analysis (IDA)[10]. IDA seeks to map the seismic structural response statistically, from the first sign of nonlinear inelastic behavior up to eventual collapse. However the main disadvantage of this method (including CA and MSA) is the computational burden and the amount of the effort that has to go into the modelling of the highly nonlinear behavior. Combination of the selection of adequate ground motion history, numerical model complexity, required number of the runs and the elaborate post processing motivates the engineers to seek the simplified, approximate procedures. Simplified procedure which is based on nonlinear pushover analysis and MATLAB code based tool (SPO2FRAG) to convert pushover curves to fragility curves are used in this research work.

3. Fragility functions for considered Nepalese RC buildings

The seismic risk assessment can be described using vulnerability or fragility functions. Fragility functions provide the probability of exceeding different damage states for a set of levels of ground shaking whereas the vulnerability functions are related to the probability of loss given a level of shaking.

In this research study, two typical types of the vertical irregularity along with their regular counterpart are considered, first type is Open ground storey (OGS) and second type is load path discontinuity (floating columns) which are faulty RC construction prevalent in the urban centers.

Analytical fragility curves are derived based on the results of the static pushover curves and SPO2FRAG software.SPO2FRAG (Static Pushover to Fragility), a MATLAB coded software tool for estimating structure specific seismic fragility curves of buildings, using the results of static pushover analysis.

The SPO2FRAG tool helps to avoid the computational demanding dynamic analyses by simulating the results of the incremental dynamic analysis via SPO2IDA algorithm[11] and an equivalent single-degree-of-freedom approximation of the structure.

The step by step process of constructing the fragility functions are as follows

Step 1: Appropriate numerical modelling of the selected buildings for nonlinear analysis.The computer software SeismoStruct[12] was used to define the numerical models where use is made of the so-called fiber approach to represent the cross-section behavior.Each fiber is associated with a uniaxial stress-strain relationship; the sectional stress-strain state of beam-column elements is then obtained through the integration of the nonlinear uniaxial stress-strain response of the individual fibers (typically 100-150).

Nonlinear material model (Menegotto-Pinto and Mander model) defined in Seismostuct are used to define the nonlinear behavior of the material. Infilled masonry walls are modelled,which takes into account of the stiffness and strength degradations in each cycle, which is implemented in SeismoStruct(2018).

The reinforcement details of the Beam (230*355) and Columns (300*300) are as per Ready to use guidelines for detailing of low rise reinforced buildings NBC 205:2012.Slab thickness and details are also based on same document for all selected buildings

Step 2: Derive the Static Pushover (SPO) curves at different floor levels which relates the inelastic seismic response of the structures to that of some equivalent SDOF system.

Step 3: Define the SDOF backbone of the equivalent SDOF system using piece-wise linear idealization of the SPO curve. In this case bilinear fit in the spirit of FEMA 356 displacement coefficient method[13].

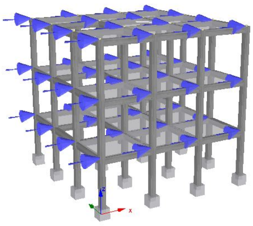

Figure 1: Bare frame Building(BF)

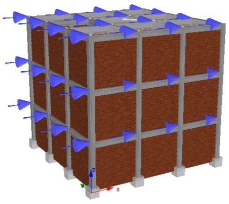

Figure 2: Infilled frame Building(FF)

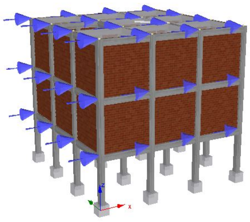

Figure 3: Open ground story Building(OGS)

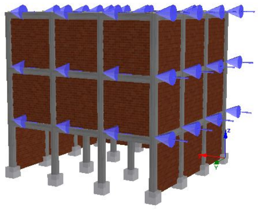

Figure 4: Open at one side building(OGS1)

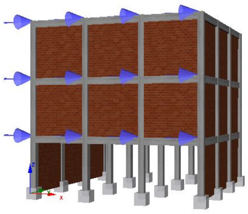

Figure 5: Open at two side Building(OGS2)

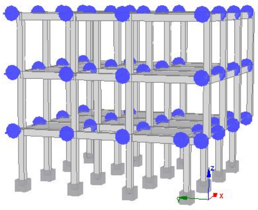

Figure 6: floating columns Building(FC)

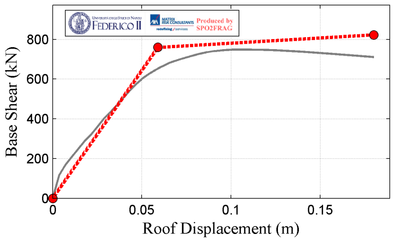

Figure 7: SPO-BF

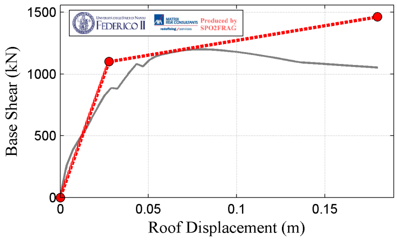

Figure 8: SPO-FF

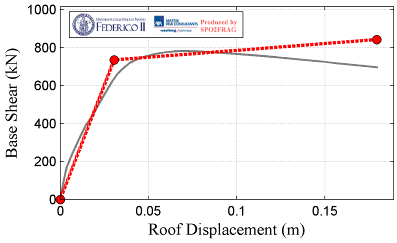

Figure 9: SPO-OGS

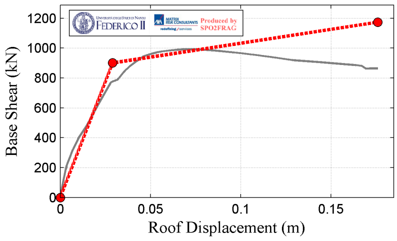

Figure 10: SPO-OGS1

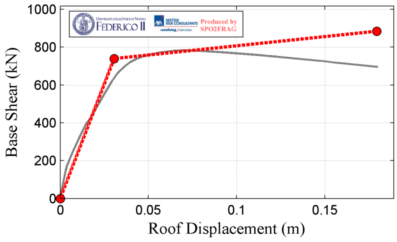

Figure 11: SPO-OGS2

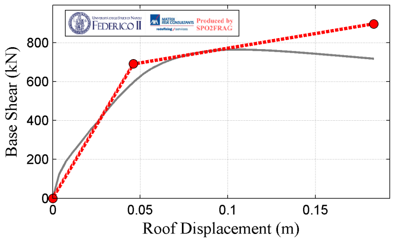

Figure 12: SPO-FC

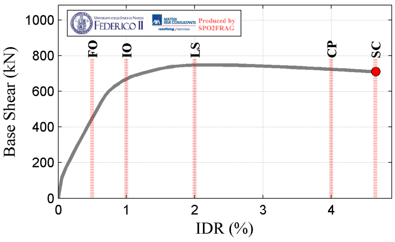

Figure 13: Limit state thresholds

Step 4: Input the dynamic characteristics which includes the no of storey, floor masses and modal characteristics. In this study, multistory pushover are performed which helps to calculate the modal properties automatically by treating the displacement vector at the elastic limit as the first mode eigenvector.

Step 5: Using the SPO2IDA algorithm, generate an analytical prediction of the 16%, 50%, and 84% IDA fractile curves. In this study, IM is 5% damped spectral acceleration at the period of the equivalent SDOF and the engineering demand parameter (EDP) is automatically set to inter-storey drift ratio (IDR) when multistory SPO curves are available.

Step 6: Define the limit state thresholds as per FEMA 356 or other similar documents in terms of the EDP. In this case, for the fully operational level (FO), immediate occupancy (IO), Life safety (LS), collapse Prevention (CP), the IDR thresholds are 0.5%, 1%, 2%, 4% respectively.

Step 7: Up to this step, the sufficient parameters required to generate the fragility curves are already generated. One can update the IDA curves using additional variability at the nominal yields and modelling uncertainity. However in this research study, no such modifications are made.

4. Analysis and Results

The pushover curves of the buildings at every storey level is obtained so as to obtain model characteristics of the buildings. The equivalent SDOF backbone curve along with pushover curves for each types of buildings are as shown for each types of buildings are as shown in figure as SPOs.The generated 16%,50%,84% fractile curves for each types of buildings are shown in figure as IDAs.

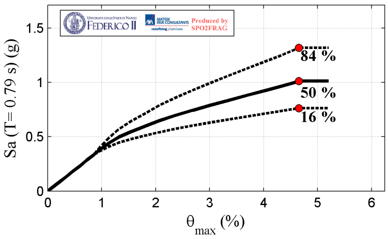

Figure 14: IDA-BF

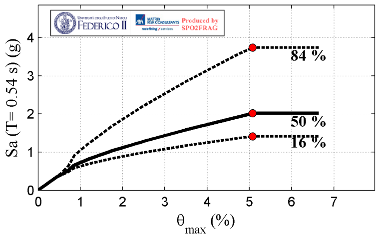

Figure 15: IDA-FF

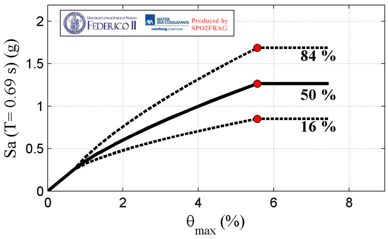

Figure 16: IDA-OGS

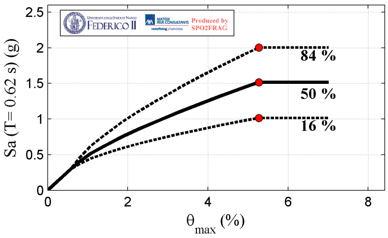

Figure 17: IDA-OGS1

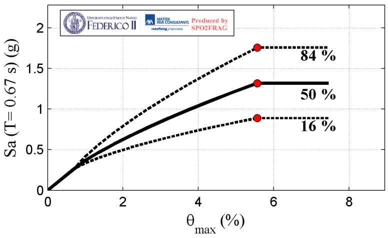

Figure 18: IDA-OGS2

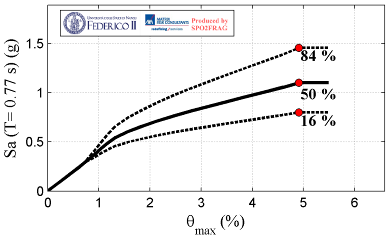

Figure 19: IDA-FC

Finally the fragility curves for each defined limit states are plotted

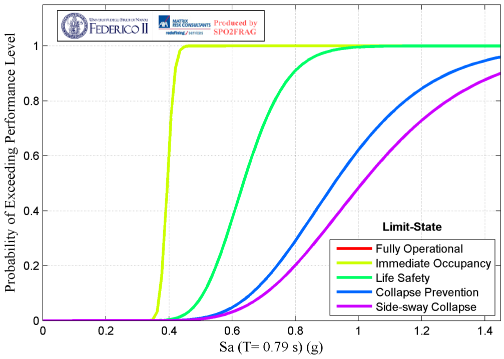

Figure 20: Fragility-Bare frame Building

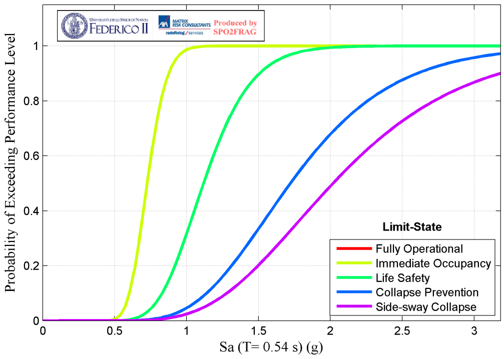

Figure 21: Fragility-Infilled frame Building

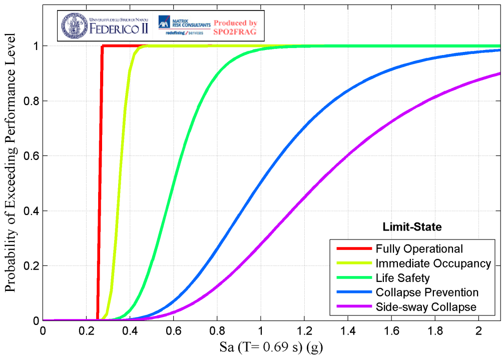

Figure 22: Fragility-OGS Building

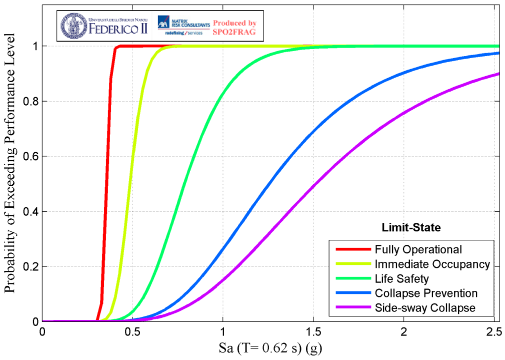

Figure 23: Fragility-OGS at one side Building

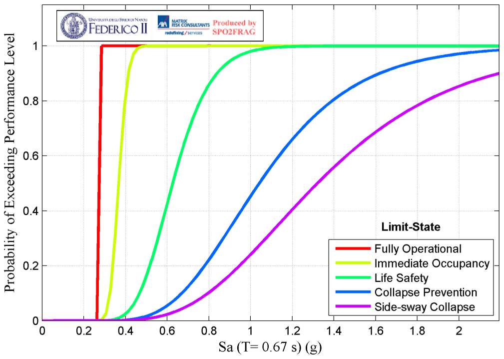

Figure 24: Fragility-OGS at two side Building

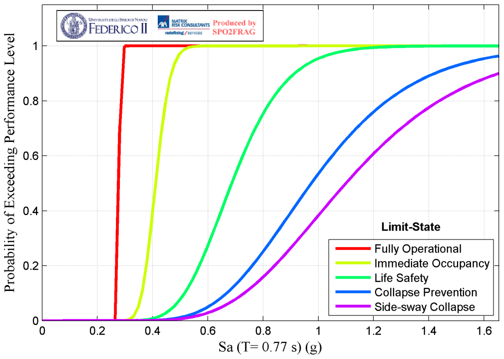

Figure 25: Fragility-Floating Column Building

5. Conclusions and Recommendations

In order to study the performance of selected vertically irregular buildings, the fragility curves are developed for all the buildings for each performance limit states (FO,IO, LS, and CP as per FEMA 356).The fragility curves shows that the effect of the infill helps to reduce the vulnerability of the buildings in some extent. However sudden change in stiffness and strength due to open ground storey suggest that the performance of the building is also worse than fully infilled case.Also the discontinuity in load path of the column increases the vulnerability of the buildings than its regular counterpart.From the fragility curves above,the Open ground storey buildig and load path discontinous type buildings are vulnerable than their regular counterpart.

The zero slope of the IDA fractile curve shows that open ground building as well as floating column buildings reaches the dynamic instability relatively at lower intensity measures than their regular counterpart.

Fragility functions obtained from this study can be integrated with probabilistic seismic hazard analysis to compute the mean annual rate of exceedance of different limit states.

Loss analysis can be performed after the formulation of the fragility functions, which are more meaningful to the stakeholders to know about the decision variables such as fatalities,economic losses and repair duration.

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