Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Seismic Vulnerability Assessment of Airport Terminal Building

Abhinesh Khatri [a], Prem Nath Maskey [b]

[a] *Department of Civil Engineering, Thapathali Campus, IOE, Tribhuvan University, Nepal*
[b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
Khatriabhinesh@gmail.com [a], pnmaskey@live.com [b]

Abstract

Terminal building is the important structure of the airport that should be serviceable during and after severe earthquakes. Seismic vulnerability of the terminal building is carried out to assess the seismic capacity of the building with the structural and non structural damages. The terminal building under the consideration is the Nepalgunj airport terminal building block B which is yet to be constructed, will be made of reinforced concrete structure with three stories and one semi basement has been designed with NBC105:2020 codal guidelines. The analysis of the structure is performed using ETABS V20 finite element program.Non linear Static(Push over) analysis is done to determine the seismic capacity of the structure and it reveals the formation of plastic hinge in the structural elements which is used to investigate the potential failures. The response of the terminal building in different earthquakes with different PGA value is determined using non linear dynamic analysis. This paper describes the seismic vulnerability of structure by using fragility curve based on the HAZUS Technical Manual guidelines. Peak ground acceleration is developed for different damage states .Probability of failure for different damage state for 0.4g hazard level are quantitatively calculated.

Keywords

Terminal building, Vulnerability Assessment, Push-over analysis, Time history Analysis, fragility curve

1. Introduction

Nepal lies in seismically active zone between Indian plate and Eurasian plate. Nepal has experienced great damaging earthquake with magnitude greater than 7.6 causing loss of life, properties and causalities. Airport transportation system is one of the lifeline infrastructure that should be in serviceable condition during and after the strong earthquakes. Terminal building is one the important facilities that affect the overall serviceability of the airport. 1989 Loma Prieta Earthquake caused damage to the airport and airport facilities [1].Similarly, Tacoma Seattle International airport lost its functionality due to non structural damage in the control tower [2].Past history of damage caused to the airport and its facilities show that airport is vulnerable to the earthquake event. Thus vulnerability assessment need to be carried out before the occurrence of an earthquake to know the actual condition of structures and suitable techniques should be used if found seismically deficient and insure their safety for future earthquakes. Seismic vulnerability of a structure can be defined as its susceptibility to damage by ground motion. Vulnerability assessment is the technique for assessing the vulnerability of structure in terms of damage states. Fragility curve is the technique for seismic risk assessment and estimation of structural and non structural losses.

Nepalgunj airport is located in the northern part of Nepalgunj City. It comes under 2nd busiest Domestic airports in western part of Nepal connecting urban and rural parts of nepal.There are the upgradation plan of airports. Upon the completion of upgrading project of the airport, it will have sufficient infrastructure to operate the international flights.Till date only Tribhuvan Airport has been serving for emergency works.Thus Nepalgunj Airport can also be used as the alternative airport for emergency response.The objectives of this study is to determine seismic capacity of structure using non linear push over analysis,the demand of structure using time history analysis and quantify the vulnerability of terminal building using fragility curves.

2. Methodology

2.1 Building Description

The RC Terminal building Block B is considered for the study purpose which is analysed and designed according to architecture plan as per NBC 105:2020.The building is modeled,analyzed and designed using ETABS V 20.0.0. The total height of airport terminal building is 18.221m.The Performance of the building is determined with the help of fragility curve in terms of probabilities for each damage state.

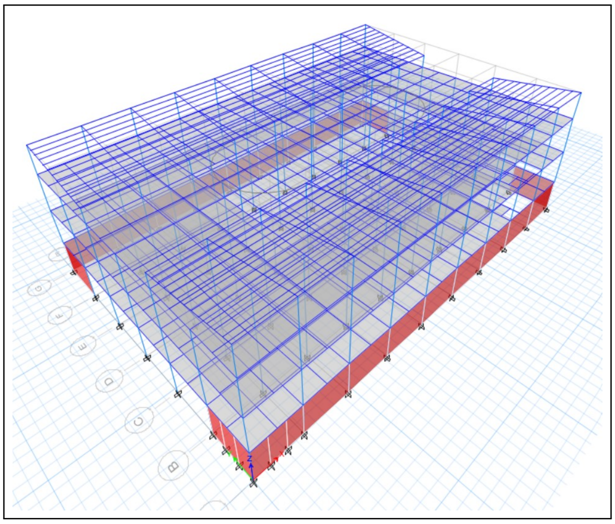

Figure 1: 3-D model of Study Airport Terminal building Block B

Table 1: Description of Building Model

Description	value
Number of Stories	3 storey and 1 basement
Height of storey	2 storey 5m each,3.721m at top storey
Height of Semi basement	4.5m
Grade of steel	Fe500
Grade of concrete	M30
Live load	0.75, 3, 4KN/m^2
Floor finish	1KN/m^2
Escalator load	as per ASME A17.1-2016
Number of bays in x direction	9
Number of bays in y direction	6
Bay width	6m

Table 2: Description of Section properties

Section	Size (mm)	Grade of Rebar	Grade of Concrete
column	Circular of 750 Dia	HYSD Fe500	M30
	Square of 800 X 800	HYSD Fe500	M30
Beam	MB-450 X 750 ,SB300X400	HYSD Fe500	M30
Slab	125	HYSD Fe500	M30
Basement Wall	400	HYSD Fe500	M30
D-ISMC	350	Fe250	-
ISMB	250	Fe 250	-

Table 1 describes about the dimension of building and loads applied on it. Table 2 describes about the section, grade of concrete and rebar of the structural elements used in the structure.

2.2 Spectral Analyses

The building is analysed and designed using Response spectrum method(NBC 105:2020).

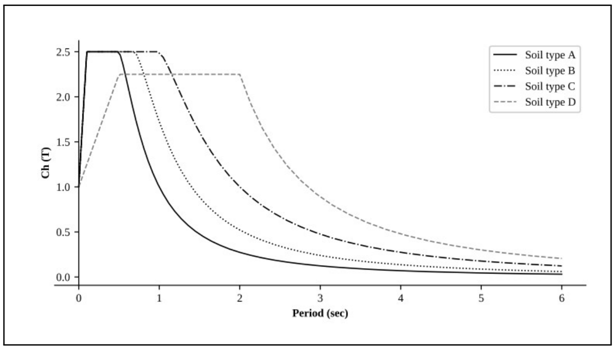

Figure 2: Response spectrum used in spectral analysis (NBC105:2020)

The time period calculated using empirical formula as per NBC is 0.56s .The spectral shape value Ch(T)=2.5 is obtained from graph of Response spectrum of soil type C for time period of 0.56s. Importance factor I=1.5, Zoning factor Z=0.4 for Nepalgunj City.

Elastic site spectra for horizontal loading C(T) = $C_h(T)*Z*I$ =2.5*0.4*1.5 =1.5 The Load combination used in the analysis are
1.2DL+1.5LL,

DL+0.3LL+ Rs,

DL+0.3LL- Rs

Elastic site spectra for Serviceability Limit State $C_h(T)$=0.3

Table 3: Base shear coefficient used for Response spectrum method

	Ultimate State	Serviceability State
Overstrength factor (Ω)	1.5	1.25
Ductility Factor (R)	4	1
Horizontal Base Shear coefficient ($C_d(T)$)	0.25	0.24

2.3 Pushover analysis

The Pushover analysis determines the strength capacity of structure upto the ultimate State. This method helps to determine the potential failure area of the structural elements.Plastic hinges are assigned to beam (auto M3 hinge) and column (auto P-M2-M3 hinge) as per

ASCE 41-13 [3] at relative location of 10% from the ends of length of structural elements.

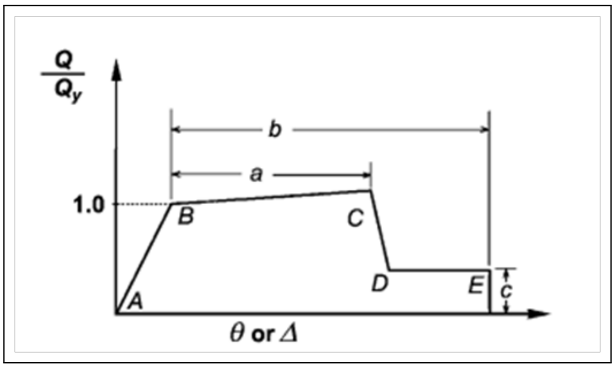

Figure 3: Generalized force deformation relations for concrete elements or components (ASCE 41-13)

where, A-B denotes the Linear response, point A is the unloading stage and point B is the effective yield point. B-C represents Linear response at reduced stiffness, C-D is sudden reduction in seismic force resistance and D-E is response at reduced resistance. And a,b,c are modeling parameters in which 'a' and 'b' are plastic rotation angle (radians) and 'c' is the Residual strength ratio.

Median Value of spectral displacement for reaching the threshold damage state is the important variable to develop the fragility curve is taken as listed in Table 4.

Table 4: Damage state threshold values [4]

Damage State	Damage State threshold
Slight Damage	$0.7S_{dy}$
Moderate damage	$1.5S_{dy}$
Extensive damage	$0.5(S_{du}+S_{dy})$
Complete damage	S_{du}

2.4 Time History analysis

The time history analysis gives the dynamic response of the structures subjected to loading which varies with time.This method requires the accelerogram data for the analysis to determine the demand of structure.According to NBC 105:2020 clause 9.3.2.1, time history analysis must include at least three ground motions.Non linear time history analysis has been performed using three earthquake accelerogram data to find the response of the structure during particular earthquake.The selection of earthquake data has been done considering amplitude,frequency content and duration of events.The three recordings examined in this investigation were linearly scaled to the desired PGA.The chosen ground motion must be scaled to fit target spectrum for soil type c defined according to NBC code.

Table 5: Earthquake Accelerogram data

S.N	Earthquake	Station	PGA
1	Imperial Valley 1940	EL centro Array	0.281g
2	Kobe Japan 1995	Kobe University	0.312g
3	Gorkha Earthquake 2015	Kirtipur	0.259g

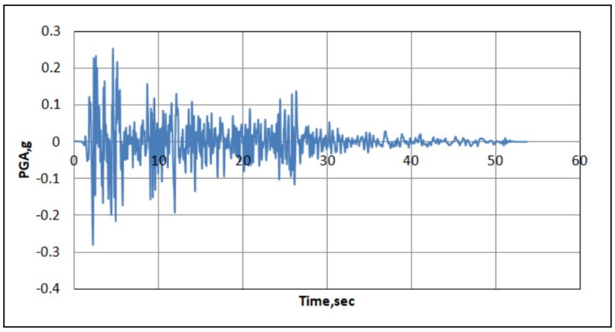

Figure 4: Accelerogram of Imperial Earthquake

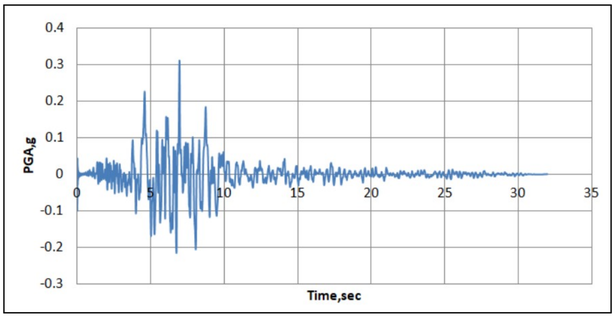

Figure 5: Accelerogram of Kobe Earthquake

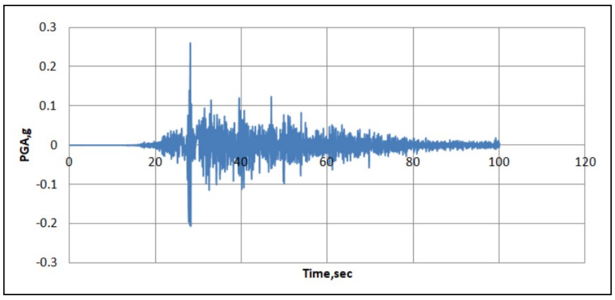

Figure 6: Accelerogram of Gorkha Earthquake

The above mentioned accelerograms data are used in this time history analysis. FEMA273 has explained the structural performance levels based on Drift % as 1% for Immediate Occupancy,1-2% for Life safety and 4% for collapse prevention [5]

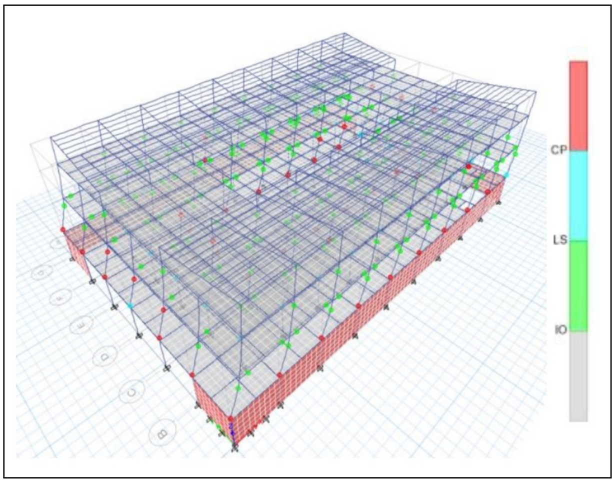

Figure 7: Plastic hinges at various performance level at 200 mm roof displacement

2.5 Fragility Function

Fragility curve is obtained as the lognormal distribution function of probability of failure for given PGA or spectral displacement. The fragility curve is plotted with median value of spectral displacement as a capacity and spectral displacement as the demand for each earthquake. The Probability of occurrence of particular damage state for given spectral displacement is given by [6]

$$P\left[d_s|S_d\right] = \phi\left[\frac{1}{\beta_{ds}}\ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right] \tag{1}$$

Where,d_s is damage state
S_d is spectral displacement
$\bar{S}_{d.ds}$ is median value of Spectral displacement for damage state threshold
β_{ds} is log-normal standard deviation whose value is taken as 0.64[6].

The fragility function obtained for different earthquakes are presented in figures 12, 13 and 14.

3. Results and Discussion

The modal analysis is carried out to the study of dynamic properties of structures under the excitation force.The fundamental period and modal participating mass ratios is 0.464s and 62.53 % along y direction respectively for the 1st mode and similarly fundamental period and modal participating mass ratios is 0.416s and 53.92% along x direction for the 2nd mode.

The base shear along x and y-direction given by response spectrum method are 18918KN and 19288KN.

The result shows that hinges in the beam and column are in various Performance levels.Figure 7 shows that more than 80% of the hinges are within the immediate occupancy level and remaining hinges are in Life safety and collapse prevention performance level at 200mm roof displacement.Most of the hinges are in immediate occupancy level within the target displacement due to stiffness of the frame is sufficiently high.Stiffness is reduced beyond the elastic limit in the Pushover curve which is due to the formation of cracks in the structural elements. Similarly slope of the curve is decreased and finally the ultimate strength of the structure is reached.

The Figure 8 and 9 is the result of Pushover analysis known as pushover curve which is the plot of base shear versus roof displacement of the structure.

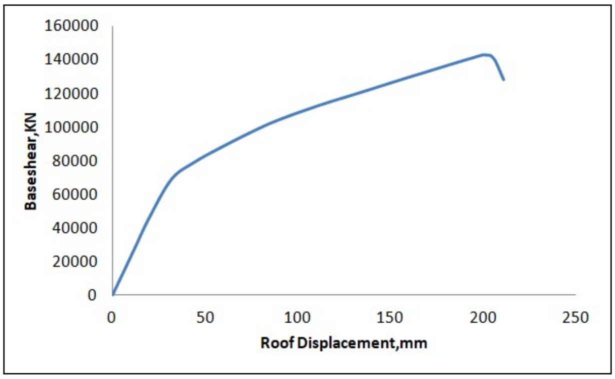

Figure 8: Pushover curve in x-direction

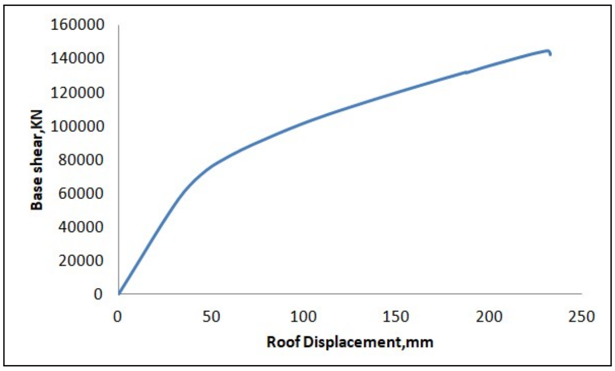

Figure 9: Pushover curve in y-direction

The pushover curve obtained from the Push Over analysis is converted into ADRS format using FEMA 440 equivalent linearization[7]. Figures 10 and 11 show plot of capacity curve of building.

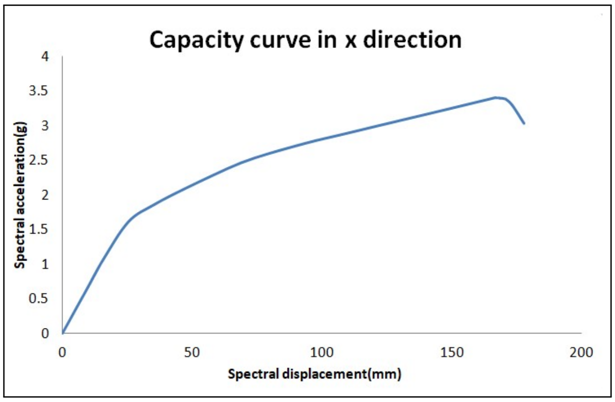

Figure 10: Capacity curve in x-direction

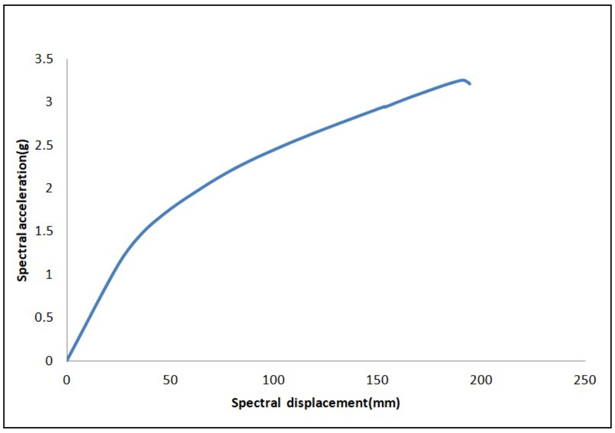

Figure 11: Capacity curve in y-direction

Yield Spectral Displacement is the displacement at which yielding starts to occur and Ultimate Spectral Displacement is taken corresponding to the maximum spectral acceleration. This two displacement value is obtained from the Plot of Spectral acceleration and Spectral displacement of the structure from push over analysis.

The value for yield spectral displacement and ultimate spectral displacement are obtained from capacity curve and is shown in table 7.

Table 6: yield and ultimate capacity control Points from capacity curve

Yield spectral displacement, S_{dy}	25mm
Ultimate spectral displacement, S_{du}	168mm

Table 7: Median Value for spectral displacement

Damage State	Damage State Threshold($\bar{S}_{d.ds}$)
Slight Damage	17.5mm
Moderate damage	37.5mm
Extensive damage	96.5mm
Complete damage	168mm

The time series data for roof displacement is obtained by performing non linear time history analysis and the maximum roof displacement is noted. Similarly,table 8 shows that the result of roof displacement is different for different earthquake at 0.4g hazard level.At the same PGA level, the response due to Kobe is higher compared to two other earthquakes.This is due to variation on duration and amplitude of the different earthquakes.Since drift % value for terminal building is less than 1% for all three earthquakes, shows that the terminal building is in immediate occupancy performance level according to FEMA 273.

Table 8: Roof Displacement for different Earthquake

Earthquake	Roof displacement at 0.4g	Drift
Imperial Valley 1940	20.74mm	0.143%
Kobe 1995	24.62mm	0.169%
Gorkha Earthquake 2015	20.81mm	0.144%

The maximum nodal displacement at roof level given by the time history analysis is converted into the spectral displacement by the use of modal shape and modal properties.The fragility function is developed using spectral displacement.

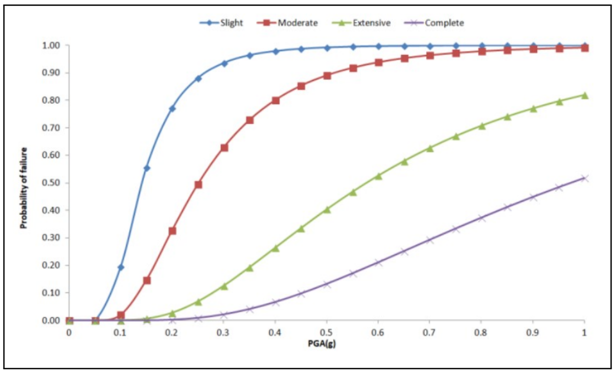

Figure 12: Fragility curve for Imperial Earthquake 1940

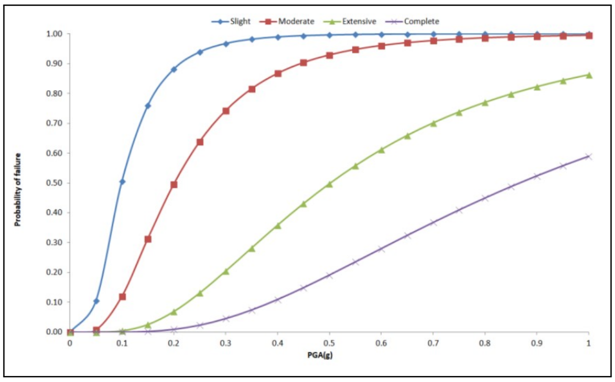

Figure 13: Fragility curves for Kobe Earthquake 1995

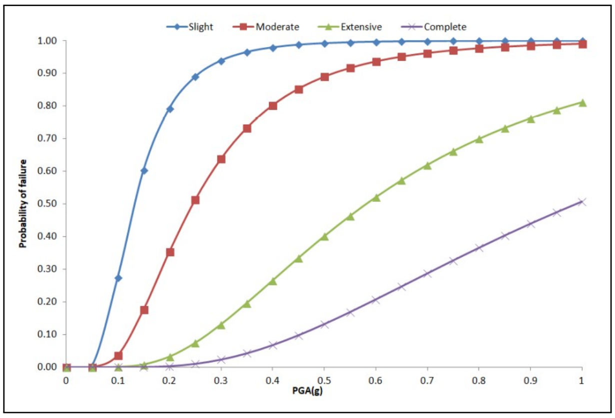

Figure 14: Fragility curve for Gorkha Earthquake 2015

The Peak ground acceleration value which is defined as seismic zoning factor for Nepalgunj city is 0.4g [8]. The probability of being or exceeding the different damages states for given 0.4g hazard level are presented in the table 9.

Table 9: Probability of occurrence of particular damage state at 0.4g

Earthquake	Slight	Moderate	Extensive	Complete
Imperial	97.91%	80.01%	26.37	6.71%
Kobe	98.94%	86.72%	35.81	10.94%
Gorkha	97.94%	80.24%	26.55	6.77%

At 0.4g PGA due to Gorkha Earthquake the building has 97.94%, 80.24%, 26.55% and 6.77% of slight, moderate, extensive and complete probabilities of failure. At 0.4g PGA due to Kobe Earthquake the building has 98.94%, 86.72%, 35.81% and 10.94% of slight, moderate, extensive and complete probabilities of failure.Similarly,at 0.4g PGA due to Imperial Earthquake the building has 97.91%, 80.01%, 26.37% and 6.71% of slight, moderate, extensive and complete probabilities of failure.

From the fragility curve developed for different earthquake,the Kobe earthquake have high probability of exceedence for all damage state.This is due to the PGA value for Kobe earthquake is higher than that of other earthquake considered.This shows that the building is more vulnerable at higher value of PGA.Because the chance of collapse at moderate damage is more than 80% in all three Gorkha earthquakes, the Imperial earthquake, and the Kobe earthquake, the terminal building is particularly sensitive to moderate damage.

4. Conclusion

Major conclusion of this study are

1. The probablity of exceedance for the building considering all three earthquake is 98.26%, 82.32%, 29.58% and 8.14% for slight, moderate, extensive and collapse damage state at PGA of 0.4g.
2. The result of Roof displacement is different for three earthquakes at 0.4g PGA.This is due to variation in frequency content and duration of earthquake events.

References

[1] Raymond B Seed, SE Dickenson, and IM Idriss. Principal geotechnical aspects of the 1989 loma prieta earthquake. *Soils and Foundations*, 31(1):1–26, 1991.

[2] Mark R Pierepiekarz, Donald B Ballantyne, and Ronald O Hamburger. Damage report from seattle. *Civil Engineering*, 71(6):78, 2001.

[3] American Society of Civil Engineers. *ASCE, Seismic evaluation and retrofit of existing buildings ASCE 41-13*. 2014.

[4] Sergio Lagomarsino and Sonia Giovinazzi. Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. *Bulletin of Earthquake Engineering*, 4(4):415–443, 2006.

[5] ATC, Redwood City. *ATC58-2 Preliminary evaluation of methods for defining performance.(2003).*

[6] Federal Emergency Management Agency (FEMA). Multi-hazard loss estimation methodology, earthquake model, hazus-mh 2.1, technical manual, 2013.

[7] U.D.H. Security and Federal Emergency Management Agency. *Improvement of Nonlinear Static Seismic Analysis Procedures: Fema 440*. Createspace Independent Pub, 2013.

[8] NepalM.O.U.D.GoN. *Nepal National Building Code,NBC 105:2020, singdurbar,Kathmandu, 2077.*