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Seismic Vulnerability of Hospital Building

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Abstract
Building should be designed as structural element to dissipate seismic energy well beyond their elastic limit and pre-constructed building should be strengthening according to their performance. Static nonlinear analysis is carried out to check the performance of building. After many damaging earthquake occur, many number of researches done in the field of building against earthquake. Most part of Nepal is seismically vulnerable area. In this research to access the vulnerability of the structure, development of fragility curve methodology is adopted. Fragility curve shows the probability of prescribed level of damage that on earthquake can causes in a structure for different range of PGA values. In this research building is consider as high code seismic design level according to HAZUS MH MR3 technical manual. Fragility curves represent the expected damage and observed damage have converted into probability for slight, moderate, extensive and complete damage state.

Keywords
Vulnerability, Fragility curve, Static nonlinear analysis, Damage state

1. Introduction

Natural disaster are originate from natural event, causes loss of life and property. The most common natural disasters are earthquake, flood, storm, tsunami etc. Nepal is the one of most seismic regions of the world. Nepal is located between Indian plate and Eurasian plate. Indian plate is compress 4mm every year so geologist predict major earthquake occur at every 70-80 years [1] . Which leads to the losses of life, damages on public and residential buildings. In nepal seismic record of region extend back to 1255 AD and suggest large magnitude earthquake like great bihar-nepal earthquake 1934 occur in approximately on 75 years [2]. Similarly gorkha earthquake 2015 occur on 79 years.

Developing countries like Nepal located in active fault zone have the most fatalities and damages causes by earthquake [3].According to the United Nations, Nepal is the 11th-most earthquake prone country [4]. Vulnerability is the susceptibility to damage the given society. Earthquake vulnerability in Nepal is great concern. Unplanned urbanization in city place, inappropriate construction technology and poor construction material are also the major reason for high vulnerability of Nepal. Implementation of code in the field is also causes of vulnerability. Considerable losses of property and life take place by past earthquake in Nepal. About 9,000 people died, many thousands people were injured and more than 6,00,000 structure in Kathmandu and other nearby towns were either damaged or destroyed by earthquake 2015 April 25 in Nepal [5]. Earthquake force is random in nature and cannot be predicted so proper design and analysis of structure is required.

Hospital are the healthcare institution where treatment is provided as per patient need with medicine and medical equipment. Due to the different causes like accident, natural disaster, pollution, food poisoning etc. different people suffer from different disease and goes to hospital for their treatment. People density at hospital is high. During natural disaster like flood, volcano, earthquake, tsunami, landslide immediate response and treatment is required. In the earthquake stored energy is released in the form of seismic wave which may damage, cracked the structural component of hospital building and it becomes nonfunctional. Injured people does not get the immediate treatment and may losses their life.

Due to earthquake medical facilities may be also damaged. San Fernando veterans administration hospital suffered extensive damage during 1971

February 9 Sylmar – sanfrancisco earthquake. At least 44 people were killed at hospital by structural damage [6].Emergency response of hospitals depends on not only coordination of medical resources and hospital staff it also depend on the structural strength of hospital building or reliability of hospital itself. To reduce the seismic risk of hospital building it must construct with better seismic design.

We cannot make earthquake proof building but we can make earthquake resistance. The process of making or designing earthquake resistance building is known as resilience. For existing building retrofitting technique is used to make earthquake resistance and for new construction building proper use of building code and analysis during design is done. Many researches are focused on seismic risk reduction. Main aim of these research are maintain and increase the resilience and sustainability. Pushover analysis is nonlinear static analysis. It is performance-based design. The analyses carried out in SAP 2000 version14, a commonly used finite element program by the structural engineering profession. SAP2000 can perform static or dynamic, linear or nonlinear analysis of structural systems.

Major objective is to determine the structural vulnerability of primary hospital model B type 3 building in terms of probability of failure obtained from the fragility curves for different values of ground acceleration.

2. Research methodology

Overall methodology is conducted on major four part as:

i. Model selection
ii. Pushover analysis
iii. Linear time history analysis
iv. Fragility curve development

Building is selected from the government template publish by ministry of health, Nepal. For modeling and analysis, SAP2000 program software version 14 is used. Frame structure with thin slab member model is constructed on SAP software. Fe 415 rebar and M20 garde concrete material is define on it. One and half story building with three meter story height. Plinth level is one and half meter above foundation base. Foundation is restrain in all direction and rotation. Is 875 (part 2):1987 is used for live load assign. According to the code hospital building categories as institutional building [7].

Nonlinear static analysis (pushover analysis) is perform to find out performance point. Hazus-MH MR3 technical manual gives the yield and ultimate capacity of structure. Demand of structure obtain from linear time history analysis. World Health Organization (WHO) collaborate with NSET of Nepal to study on seismic vulnerability assessment of hospital building in Kathmandu valley and made standard performance level [2].

Fragility function provides probability of exceeding of damage for wide range of ground motion intensity. There are four type of damages they are slight damage, moderate damage, extensive damage and complete damage.

The description of the damage states according to HAZUS-MH-MR3 for reinforced concrete moment resisting frame (C1) are [8].

Slight Structural Damage: Presence of Hairline crack of the flexural or shear kind in some beams and columns at or inside joints.

Moderate Structural Damage: Presence of Hairline cracks seen in the majority of beams and columns. Some of the frame members in ductile frames have attained yield capacity, indicate by greater flexural fractures and concrete spalling. Shear cracks and spalling may be more noticeable in nonductile frames.

Extensive Structural Damage: Presence of flexural cracks, spalled concrete, and buckled main reinforcement indicate that some of the frame elements have reached their ultimate capacity in ductile frames; nonductile frame elements may have suffered shear failures or bond failures at reinforcement splices, or broken ties or buckled main reinforcement in columns, resulting in partial collapse.

Complete Structural Damage: Structure is collapsed or in imminent danger of collapse due to brittle failure of nonductile frame elements or loss of frame stability. IT is predicted that Thirteen percentage (inlow-rise), ten percentage (in mid-rise) or five percentage (in high-rise) of the total area of C1 type buildings with Complete damage is expected to be collapsed. According to HAZUS-MH-MR3 guidelines, small cracks are assumed to be visible and cracks having less than a maximum width of 1/8th inch. For large cracks its width should be greater than 1/8th inch.

Table 1: Standard performance level

Designation	Description
Fully operational	There is presence of slight damage. Structure retains its original strength and stiffness. Non-structural component operate, and the building is available for normal use. Repairs, if required, may be instituted at convenience of building users. There is negligible risk of life threating and injury during earthquake.
Functional	There is presence of slight structural damage has occurred. Structure retains its original strength and stiffness. Non-structural component are secure, and if utilities are available, most would function. Life-safety system are operational. Repairs may be instituted at a convenience of building users. The risk of life threatening injury during earthquake is very low.
Life safety	Significant structural and non-structural damage has occurred. Building lost a significant amount of its original stiffness, but retains some lateral strength and margin against collapse. Non-structural components are secure, but may not operate. The building may not be safe to occupy until repaired. The risk of life-threatening injury during earthquake is low.
Near collapse	Limiting damage state in which substantial damage has occurred. Building lost most of its original stiffness and strength and has little margin against collapse. Non-structural component may become dislodged and present a falling hazard. Repair is probably not practical.

2.1 Building selection and typology define

According to the categorization of health facilities as per health infrastructure development standards 2074, publish by ministry of health, Nepal government different type of health post recommended. On the basis of location and population type of building varies as primary hospital type A1,A2,A3,B1,B2,B3 and healthpost type 1,2,3,4 [9].

There are 13 local level in dhading district. Among them following type of primary hospital and healthpost are purposed to construct.

Table 2: List Of Health Infrastructure In Dhading District

S.N.	Description	Number
1	Primary hospital A3	1
2	Primary hospital B1	1
3	Primary hospital B3	11
4	Health post type 2	1
5	Health post type 3	16
6	Health post type 4	22

Among them Health post are constructed on previous V.D.C. and primary hospital are constructed on one place of every local level. The study has been done on primary hospital type B3. Building was Reinforced concrete moment frame structure Because my research is taking place in Dhading district, where every local level has at least one primary hospital, primary hospital modal B type 3 was chosen to be studied. In comparison to other primary hospitals, the number of category B type 3 patients in dhading is high.

2.2 Representative building and Characteristics

Primary hospital type B3 is two stories building has simple rectangular plan dimension 48.9m * 17.40m. The story height is 3 meter. Number of grid in X direction and Y direction is 9 and 4 respectively. Spacing of grid in X direction is 6.5m and in Y direction is 4. Seismic gap 0.125m provided.

3. Building Modelling and Analysis

3.1 Modelling-SAP 2000-14

The representative primary hospital model B type 3 is modeled on SAP 2000v 14. The structure is subjected to earthquake load.

3.2 Material Properties

Table 3: Material Properties of concrete

Concrete M20	
Density (Kg/m3)	2451.53
Weight per unit volume (KN/m3)	24.99
Compressive Strength (N/mm2)	20
Mod. of Elasticity, E (N/mm2)	22360.68
Poisons ratio, U	0.2
Coefficient of thermal expansion (1/C)	0.0000055
Shear modulus, G(N/mm2)	9316.95

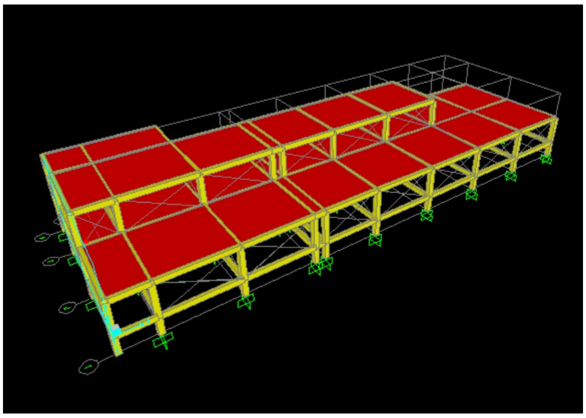

Figure 1: 3D Model

Table 4: Material Properties for rebar

Rebar (IS 883:1994) HYSD Fe415	
Density (Kg/m3)	7849.04
Mod. of Elasticity, E (N/mm2)	20 x10^5
Coefficient of thermal expansion (1/C)	0.000017

3.3 Sectional Properties

Table 5: Section properties

Beam	Column	Slab
3D Frame element	3D Frame element	Membrane element
B(300*450) mm2	C(450*450) mm2	150mm thick
M20 grade concrete	M20 grade concrete	M20 grade concrete

4. Results and Discussion

Primary hospital model B type 3 building pushover analysis is done on sap 2000 v 14. Pushover analysis is iterative analysis and design process continues until the design satisfies a pre-established performance criteria. The performance criteria for pushover analysis is generally established as the desired state of the building given a rooftop or spectral displacement amplitude.

In modal analysis, the time period and modal participation mass ratio is obtained. First mode time period is 0.394 sec and modal participation mass ratio is 81% along shorter direction (y direction). In second mode time period is 0.364 sec and 71% modal mass participation in longer direction (x direction). Similarly different mode time period and corresponding modal participation ratio as shown in table below. More than 90% modal mass participation obtain in mode eight.

Table 6: Modal participation mass ratio

Mode	Period(sec)	UX	UY
1	0.394	0.01	0.81
2	0.364	0.71	0.003
3	0.324	0.1	0.002
4	0.174	0.012	0.04
5	0.138	0.06	0.01
6	0.126	0.012	0.001
7	0.124	0.029	0.01
8	0.123	0.001	0.03
	Total	0.934	0.906

Pushover analysis is carried out by vertical loading (gravity load) followed by a gradually increasing displacement controlled lateral load in both +x and +y direction. The design base shear calculated as per IS specifications is compared with the overall capacity of the structure obtained from the pushover curve.

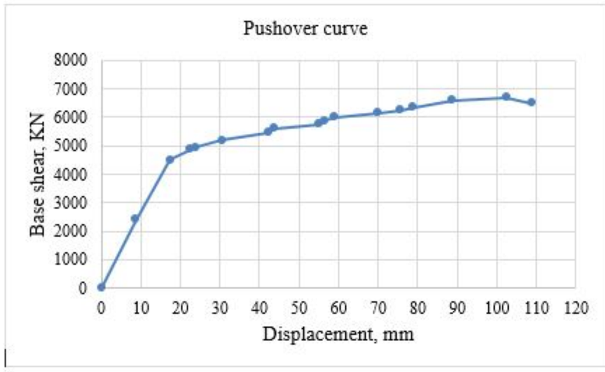

Figure 2: Push over curve of Model

Primary hospital building modal shows pushover curve as shown in above figure. In first stage roof displacement is 8.8 mm at 2400 KN base shear. Upto 6704 KN base shear and 102.45 mm roof displacement, pushover curve is in upward direction then it tends to downward direction as shown in figure. In this analysis 108.73 mm roof displacement obtained at 6493.82 KN base shear at final where curve tends downward.

Linear Time history Analysis of the hospital structures were performed using three earthquake accelerogram data in finite element modeling software sap to find their peak displacement demands.

Table 7: Earthquake with PGA

S.N.	Earthquake	PGA
1	Gorkha earthquake	0.177g
2	EI centro	0.348g
3	Kobbe	0.345g

Fragility curves are plotted for each linear time history analysis. The peak displacement demands has to be observed at the top of the structure being it the main structural element, thus the nodes are selected at the top of second storey. The observation node was selected as that node which provided maximum lateral deformation on the application of time history load. Before fragility curves, the results of the time history analysis due to the selected earthquake accelerograms done.

Result in terms of base shear and maximum roof displacement

Table 8: Roof displacement and base shear

S.N.	Earthquake	Bsae shear (KN)	Roof displacement (mm)
1	Gorkha earthquake	556.09	94.638
2	EI centro	706.78	106.342
3	Kobbe	561.46	101.28

EI centro, Kobe and Gorkha earthquake base shear and roof displacement on primary hospital are obtained as above.

4.1 Fragility Function

P[ds/Sd] = $\emptyset\left[\frac{1}{\beta ds}\ln\left(\frac{Sd}{\overline{S}d,ds}\right)\right]$ Where, Sd = Spectral displacement

βds = Standard deviation of the natural logarithm of spectral displacement of damage state

$\overline{S}d, ds$ = is the median value of spectral displacement at which the building reaches the threshold of damage state, ds.

The two contributors to damage state variability are assumed to be lognormally distributed, independent random variables and the total variability is simply the square-root-sum-of-the-squares combination of individual terms i.e $\beta_{(SPGA)}$ = 0.64.

From HAZUS-MH MR3 (Table 5.7a) yield displacement (d_y) = 0.39 inches = 9.39 mm

ultimate displacement (d_u) = 9.39 inches = 238.51 mm.

The capacity of the building in terms of yield displacement (dy) and ultimate displacement (du) as suggested by Giovianazzi and Lagomarsino 2006 after conducting a pushover analysis are

For slight damage capacity = 0.7d_y = 6.93 mm

Moderate damage capacity = 1.5d_y = 14.85 mm

Extensive damage capacity = 0.5 (d_y+d_u) = 124.21 mm

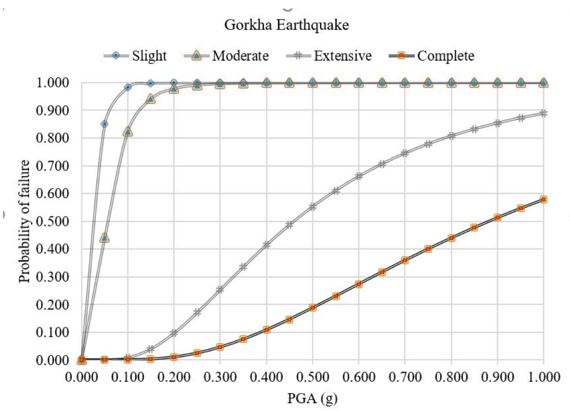

Figure 3: Fragility curve of building at gorkha earthquake

Complete damage capacity = d_u = 238.51 mm

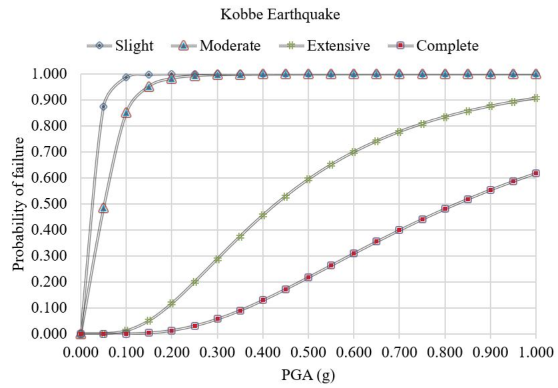

Figure 4: Fragility curve of building at Kobbe earthquake

Table 9: Probability of failure at PGA 0.35g

Earth-quake	Probability of failure (%)			
	Slight	Moderate	Extensive	Complete
Gorkha	0.999	0.998	0.335	0.014
EI centro	0.999	0.999	0.404	0.104
Kobbe	0.999	0.999	0.375	0.09

Probability of failure of primary hospital at Dhading on 0.35g PGA is summarized as above table. There is 99.9%, 99.9%, 40.4% and 10.4% of probability of slight, moderate, extensive and complete failure in EI centro earthquake at 0.35g PGA. There is 99.9%, 99.9%, 37.5% and 9.0% of probability of slight, moderate, extensive and complete failure in Kobe earthquake at 0.35g PGA. Similarly 99.9%, 99.8%, 33.5% and 7.4% probability of slight, moderate, extensive and complete failure in Gorkha earthquake at 0.35g PGA. Among these three earthquake probability of failure of structure is high in EI centro

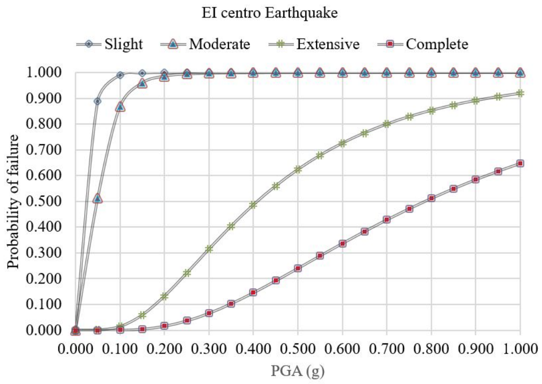

Figure 5: Fragility curve of building at EI centro earthquake

earthquake.

Since probability of failure of is more than fifty percentage at moderate damage state in all three Gorkha earthquake, EI centro earthquake and Kobe earthquake so primary hospital building is more vulnerable to moderate damage.

5. Conclusion

Three dimensional finite element model of primary hospital class B type 3 building was prepared and analyzed. The result obtained shows the dynamic behavior of building under research and identify seismic demand and capacity. From this study, we find out the mode of vibration, mode shape, time period, mass participation. During time history analysis seismic behavior of structure is understand in terms of displacement and base shear under different level of earthquake input. Main aim of this study is to develop the fragility curve of primary hospital class B type 3. Major conclusion of this research are:

1. 0.35g PGA Gorkha earthquake has 7.4% and 33.5% of complete and extensive probabilities of failure. Also 99.8% and 99.9% of moderate and slight probabilities of failure.
2. 0.35g PGA EI centro earthquake has 10.4% and 40.4% of complex and extensive probabilities of failure. Also 99.9% and 99.9% of moderate and slight probabilities of failure.
3. 0.35g PGA kobbe earthquake has9.0% and 37.5% of complex and extensive probabilities of failure. There is also 99.9% and 99.9% of moderate and slight probabilities of failure.
4. The developed fragility curve is useful to determine probabilities of damage and decision making to recommend the requirement of strengthen, retrofitting of existing hospital building.

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