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Seismic Vulnerability Analysis of Nuwakot Durbar

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Abstract

Nepal lies in highly seismic active zone, between Indian and Eurasian Plates, resulting in frequent earthquake of various magnitudes. Unreinforced masonry, being one of the oldest construction technologies, its behavior is still least understood. Historic structures typically include masonry walls made of bricks, stones, and mud or lime surkhi mortar as their main structural elements. Earthquakes are one of the threats to such monuments. These unreinforced structures are more vulnerable to earthquakes due of the lateral wave of the earthquake. Macro modeling has been performed using FEM modelling software, SAP 2000. This study evaluated seismic performance and vulnerability of historical monument seven storied Nuwakot Durbar. Different performance factors like time period, base shear, joint displacements are analyzed for evaluation of seismic performance of building. However masonry structures are highly nonlinear in nature, due to difficulty of nonlinear analysis and limited time, Linear time history analysis is carried out to determine demand of building. Fragility curve is developed for four damage states: slight, moderate, extensive and complete to find probability of failure for various damage states for various level strong ground motions for seismic vulnerability evaluation. For PGA value of 0.3g for area near Nuwakot Durbar as defined by NBC 105: 2020, the probability of exceeding the Slight, Moderate, Extensive and Complete states are 99.99%,99.66%, 89.13% and 64.34%.

Keywords

Seismic Vulnerability, Fragility Curve, Macro Modeling, Time History Analysis, Probability of Failure

1. Introduction

Nepal is a country with a significant seismic activity as it is located in a subduction zone. Most of the big earthquake occurs every 70 to 80 years based on past data. 1934 Jan 15 (1990 BS) earthquake of magnitude 8.0 was one of the most destructive earthquakes with casualties more than 8000. 1988 Aug 20 (2045 BS) earthquake of magnitude 6.6 was also destructive with around 1000 casualties. Most recent destructive earthquake was 2015 April 15 (2072 BS) Gorkha Earthquake of magnitude 7.8 recorded most casualties of around 9000 with many numbers of aftershock causing many injuries and loss of homes.

Nuwakot Durbar lies in Bidur Municipality, Nuwakot district, about 5 km ride from bidur bazar. The Palace is situated at the mid hills at elevation of 900m which was built during regime of Prithvi Narayan Shah and considered as the important landmark in history of Nepal. Nuwakot durbar area is composed of Malla Style palace [1].

Masonry is composed of masonry units (Stone or brick) and mortar [2]. During various earthquakes, unreinforced masonry buildings get severely damaged. Many of these buildings survived even in large earthquakes. In Nepal, they continue to make up a substantial portion of the remaining building stock in the form of historic cultural landmarks and residential structures even if they were often not designed with reference to any particular code. They still pose a significant seismic threat, not just in Nepal but for many other parts of the world. Understanding the actual behavior and response of these buildings in lateral loads, which is achievable by research and study in this area, is vital to preserve cultural heritages and prevent complications and property loss due to damage in masonry buildings during earthquakes. Due to growing interest in the preservation of the built heritage and consciousness that life and property must be protected, this issue has only recently come into consideration.

To lower the risk in the future, it is important to determine the seismic vulnerability and risk of existing structures. Historical masonry buildings' seismic performance evaluation informs us of its failure during seismic events. It might also be suggested that structures need to be retrofitted for seismic strengthening. It can help in controlling earthquake risk reduction. Additionally, it helps in loss estimation. One method for correlating demand and capacity is fragility analysis, which develops the probabilistic characterization of the demands with regard to certain limit states. Building fragility curves, which are often used to express the structural vulnerability of the building, are defined as the relationship between hazard intensity and the probability that a building will sustain damage greater than a particular limit. The probability of reaching or exceeding a particular damage state is expressed by the fragility curve, which is a log-normal function. The fragility curve is a very effective tool for estimating the probable extent of damage.

The main objective is to develop fragility curve of Durbar using linear time history excited by various earthquake ground motions and investigate seismic performance of the structure.

2. Need of Study

Many traditional, historical and cultural buildings are masonry buildings constructed centuries ago. Non-engineered masonry buildings are highly vulnerable to earthquake. Being vulnerable to damage, demolish is not an option, study of probability of damage and seismic performance can recommend options for structural strengthening measures like retrofitting to mitigate life and property risk. Less number of researches have been performed on historical buildings. Also, in case of Nuwakot Durbar no such kind of research is carried out so, this study encourage for further research of such kinds of historical monuments.

Nuwakot durbar being more than 300 years old monument, it is historically and culturally important building and Nepal being earthquake prone zone. Analyzing seismic vulnerability may help in many factors for historic monument. Knowing Seismic performance and fragility curve development may help in taking seismic considerations for preservation of Durbar.

3. Building Description

During 18th century, Malla king constructed Nuwakot Durbar. However, after capturing the Nuwakot district from the Malla monarchs, King Prithvi Narayan Shah erected the current seven-storied Nuwakot Durbar. The adopted durbar is unreinforced lime-surkhi masonry building. Walls of building are composed of bricks with lime-surkhi mortar of thickness from 450mm to 2000mm. Floor slabs consists of timber planks of 50mm over which lime-surkhi mortar and flat bricks are placed which rests on numbers of timber joists of 100 X 100mm spaced at 100mm . Sloped slab also consists of timber plank of 50 mm over which lime-surkhi and jhingati tile are placed on sloped timber joists of 100 X 100mm.

4. Material Properties

The mechanical material qualities of brick masonry and timber buildings are taken into consideration from related literatures due to a lack of material testing data and equipment. Few studies in Nepal are focused on monumental structures, and the input variables, particularly for masonry's elastic modulus (Em), compressive strength (fm), and mass density are determined based on these probabilistic distributions

Table 1: Material Properties

SN	Material	Young's Modulus of Elasticity, MPa	Poisson Ratio	Mass density, kg/m ^{3}
1	Lime Surkhi Masonry [3]	1708	0.15	2100
2	Timber [4]	12500	0.12	800
3	Lime Surkhi Mortar [5]			1620.4
4	Jhingati Tile			2080

5. Methodology

5.1 Modelling

Modeling methods based on the effective modeling approach, an accurate but computationally efficient modeling tool, have been used to study the behavior of masonry. The macro-element model is a macroscopic representation of a continuous model [6] in which the parameters are correlated to the mechanical characteristics of the masonry elements. The macro-element parameters should be regarded as an average representation of masonry panel behavior. The masonry walls are joined to create the three-dimensional model. The horizontal floor elements transmit the horizontal actions to the walls based on their flexural behavior because macro-elements only take in-plane behavior into consideration. The timber floors are modeled as two-way equivalent timber shell element. Timber floor is rested on timber joists which acts as frame element. Timber joists are connected on wall as simply supported frame element. Equivalent timber floor is obtained as floor depth of 0.05m. Masonry wall is modeled as bi-dimensional thin shell element of thickness 0.45 to 2 m according to building sample plan. Gravity load was calculated on the basis of unit weight of material and live load was taken as 4 KN/m2. The 3D macro element modelling in SAP2000 is shown in Figure 1.

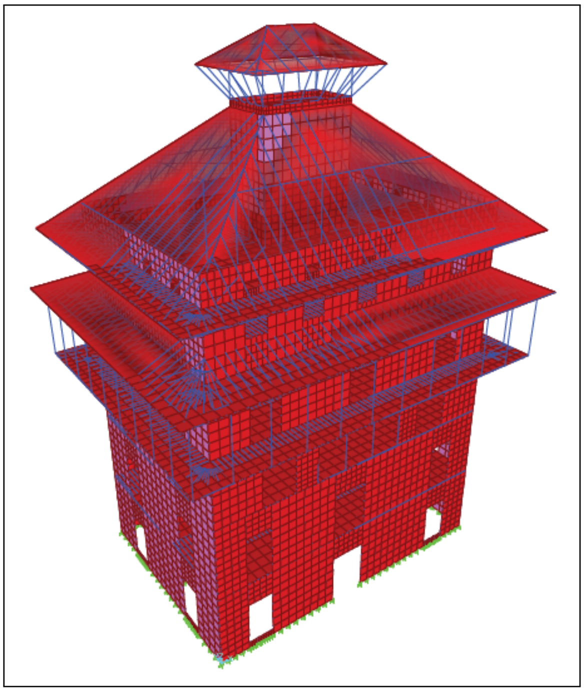

Figure 1: 3D macro element model in SAP2000

5.2 Linear Time History Analysis

Linear time history analysis is performed to determine demand of structure at an arbitrary time using the dynamic properties of the structure and applied loading when a dynamic load is applied. The ground motions are selected from the PEER ground motion database of previously recorded earthquakes with a range of magnitude and PGA values. Selection of these seven earthquake data are done because of different amplitude and frequency content of particular earthquake. High to low range of PGA value are taken for linear time history.

The following time history data of seven different earthquakes taken are shown in Table 2 and accelerograms are shown in Figure 2 to Figure 8.

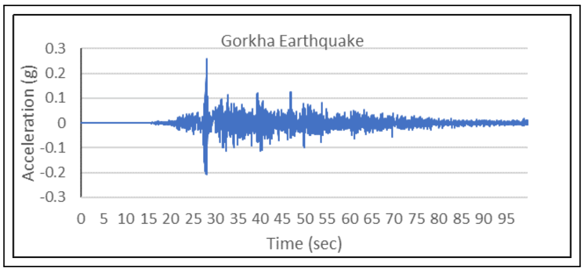

Figure 2: Accelerogram of Gorkha Earthquake (2015)

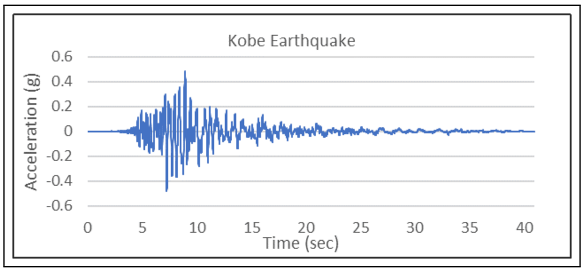

Figure 3: Accelerogram of Kobe Earthquake(1995)

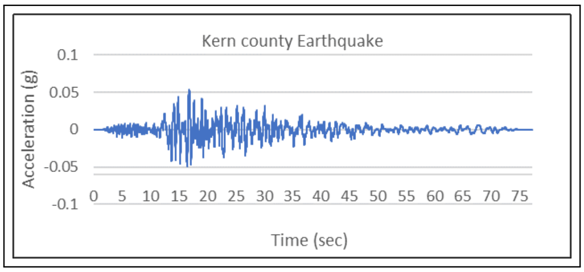

Figure 4: Accelerogram of Kern County Earthquake(1952)

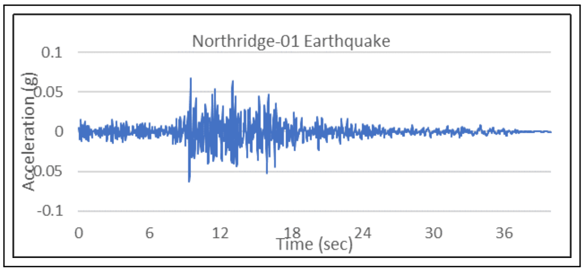

Figure 5: Accelerogram of Northridge-01 Earthquake (1994)

Table 2: Earthquake Data

SN	Description of Earthquake	Magnitude	Station	PGA
1	Gorkha Earthquake (2015)	7.6	Kirtipur	0.26g
2	Kobe Earthquake (1995)	6.9	Nishi-Akashi	0.483g
3	Kern County Earthquake (1952)	7.36	Pasadena - CIT Athenaeum	0.053g
4	Northridge-01 Earthquake(1994)	6.69	Anacapa Island	0.067g
5	Loma Prieta Earthquake (1989)	6.93	Los Gatos - Lexington Dam	0.443g
6	Trinidad Earthquake (1980)	7.2	Rio Dell Overpass, E Ground	0.163g
7	Landers Earthquake (1992)	7.28	Lucerne	0.789g

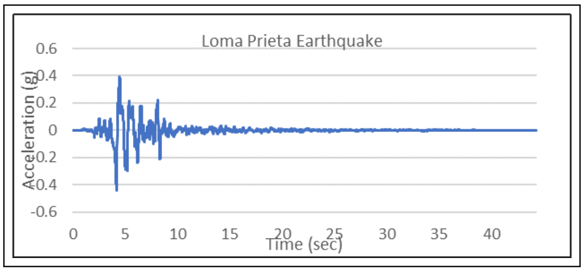

Figure 6: Accelerogram of Loma Prieta Earthquake (1989)

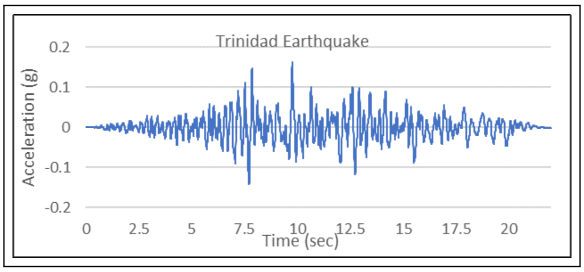

Figure 7: Accelerogram of Trinidad Earthquake (1980)

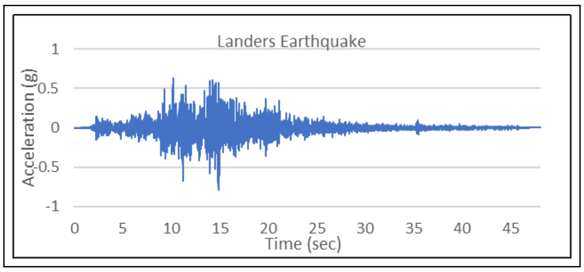

Figure 8: Accelerogram of Landers Earthquake (1992)

5.3 Development of Fragility Curve

Seismic vulnerability is a measure of how vulnerable a structure is to damage when the ground shakes severely. The two most largely utilized formulations to describe the vulnerability are damage probability matrices and vulnerability/ fragility curves [7]. The seismic fragility of a structure is the probabilistic chances of the structure reaching a predetermined limit state in accordance with a particular value of the selected seismic intensity parameter. An accumulative log-normal distribution is used to determine the probability of being in or exceeding a given damage state. First order second moment (FOSM) method, which is easy and reliable method, is adopted for development of Fragility Curve. Fragility curve for spectral displacement demand, Sd, the probability of bring in or exceeding a damage state ds, is described by the following log normal probability density function [8].

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

where, $\bar{S}_{\mathrm{d,ds}}$ is the median value of spectral displacement at which the building reaches the threshold of damage, ds
Median values for four Damage States as specified by [9]:
(1) Slight damage, capacity = 0.7dy
(2) Moderate Damage, capacity = 1.5dy
(3) Extensive Damage, capacity= 0.5 (dy + du)
(4) Complete Damage, capacity = du
where, dy = yield displacement = 0.27 inch and du= ultimate displacement =1.81 inch [8]
β_{ds} is the standard deviation of the natural logarithm of spectral displacement of damage state, ds. It is an estimate that takes into consideration additional unknown aspects that have an impact on the functions' accuracy and on the determination of the median PGA while generating the fragility curves. Simply, it is the square root sum of the squares of all the individual variability factors equals to 0.64 for URMM [8].
ϕ is the standard normal cumulative distribution function.
After calculating median and standard deviation of natural logarithm of spectral displacement, Probability of being or exceeding damage state is calculated for each variable and fragility curve is plotted between probability as ordinate and peak ground acceleration

as abscissa.

6. Results and Discussion

6.1 Model Results

Macro modelling of building is done in SAP2000 v24. Seismic Performance parameters like time period on first mode of building, base shear, maximum roof displacements are shown in Table 3.

Table 3: Model Results

SN	Parameters	X-direction	Y-direction
1	Base Shear (KN)	11862.37	11862.37
2	Maximum Roof Displacement (mm)	295.5	514
3	Time Period (sec)	0.611	

Table 3 shows maximum roof displacement in y direction is more than x direction. As width of building in x direction is more than that of y, stiffness in x direction is more. So, for equal amount of lateral load, it is more likely to deflect in less stiff direction.

Time Period of building in FEM modelling is found to be 0.611 sec while, as per NBC 205-2020, using empirical formula, time period is calculated as 0.538 sec. The amount of variation in time period may be due to value of constant taken while calculating using empirical method ($T = K_t H^{3/4}$). The constant value, K_t , is generalized for value 0.05 for all other structural systems is considered not specified for masonry building.

Also, variable of Height only is considered in empirical method, while in modelling other many factors are considered for time period.

6.2 Capacity of Building

For dy = yield displacement = 0.27 inch (6.858mm) and du = ultimate displacement = 1.81 inch (45.974mm) as specified in for URMM building as nonlinear static analysis is not performed in our case. Median values of spectral displacement for four Damage States adopted are,
(1) Slight damage, capacity = 0.7dy = 0.27 X 6.858 = 4.801mm
(2) Moderate Damage, capacity = 1.5dy = 1.5 X 6.858 = 10.287mm
(3) Extensive Damage, capacity= 0.5 (dy + du) = 0.5 X (6.868+45.974) = 26.416 mm
(4) Complete Damage, capacity = du = 45.974mm
Capacity of building is generally calculated using non-linear static analysis i.e., Pushover Analysis.As in our case, nonlinear pushover analysis is not carried out, capacity of building for four damage state is calculated using [6] where values of yield and ultimate displacement are considered as yield displacement equals to 0.27 inch and ultimate displacement equals to 1.81 inch for masonry building as specified in [8].

6.3 Fragility Curve

For above mentioned seven earthquakes, roof displacements are determined using linear time history analysis. Maximum value of roof displacement for scaled value (0.1g to 1g) is then converted into spectral displacement which is also called demand of building. Linear regression is performed for spectral displacement of all scaled seven earthquake as equation 2.

$$Sd = 0.1939 * (PGA) \tag{2}$$

Then, with the value of capacity and demand, probability of failure is calculated and plotted to obtain fragility curve as shown in Figure 9.

From Figure 9, we can observe, at 0.6g PGA, building have nearly 100% probability of exceedance of the Slight state, Moderate state, Extensive state and about 92% probability of exceedance of the Complete state. For 0.3g PGA, that corresponds to the peak seismic zoning factor of 0.3g with return period of 475 years for area near nuwakot durbar as defined by NBC 105: 2020, the probability of exceeding the Slight, Moderate, Extensive and Complete states are 99.99%,99.66%, 89.13% and 64.34%. And at 0.4g PGA, the probability of exceedance of Collapse state reaches near 80%. It is seen that at PGA 0.3g, the building has high probability of complete failure, thus building is susceptible to collapse during 0.3g earthquake. In figure 9, we can see that there is high probability of failure for all damage state. The reason is, building considered for analysis is masonry building which tends to displace more in earthquake. With high value of roof displacement, probability of failure also increases for all damage states.

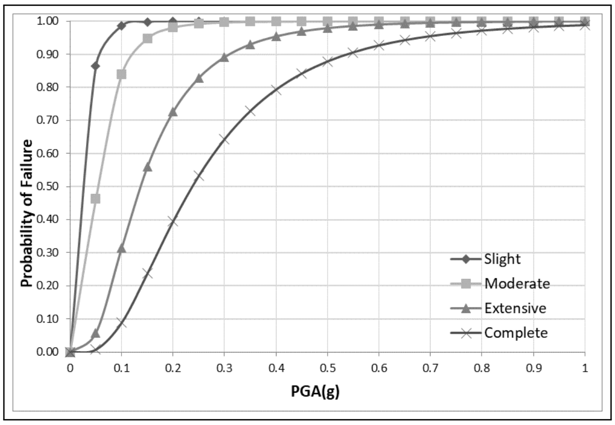

Figure 9: Fragility curve of Nuwakot Durbar

7. Conclusion

Nuwakot durbar is taken into consideration to explore seismic vulnerability as per revised NBC 105:2020. The building was modelled in finite element software SAP2000 v24 and seismic performance is evaluated using linear static and dynamic analysis. The major conclusions of the result are summarized as:

The seismic fragility curve developed for four damage states (slight, moderate, extensive and complete) shows that even in very low value of PGA probability of failure in slight and moderate damage is maximum whereas near 0.3 PGA, about 90% probability of failure can be observed and for complete state it can be achieved near 0.55 PGA. So, from fragility curve, it can be concluded that Nuwakot Durbar is more vulnerable to seismic force. Different safety measures like retrofitting, renovation can be done with further study can be done for safety for monument.

For peak seismic zoning factor of 0.3g with return period of 475 years for area near nuwakot durbar as defined by NBC 105: 2020 mentioned in result section, it is thus evident that the building taken into consideration is in risk for damage.

References

[1] Srijana Gurung Shrestha. *Seismic Vulnerability Analysis of Traditional Brick Masonry Buildings*. PhD thesis, 11 2013.

[2] Meera Chikanbanjar, Gokarna Bahadur Motra, and Dev Kumar Maharjan. Non-linear static analysis of unreinforced masonry building. In *Proceedings of IOE Graduate Conference*, 2019.

[3] Shyam Sundar Khadka. Seismic performance of traditional unreinforced masonry building in nepal. *Kathmandu University Journal of Science and Technology*, 9(1):15–28, 2013.

[4] Bijaya Jaishi, Wei-Xin Ren, Zhou-Hong Zong, and Prem Nath Maskey. Dynamic and seismic performance of old multi-tiered temples in nepal. *Engineering Structures*, 25(14):1827–1839, 2003.

[5] Rukshana Shrestha, Sristi Koju, and Rameswor Shrestha. Performance of lime mortar in reconstruction of monuments of bhaktapur.

[6] Luigi Gambarotta and Sergio Lagomarsino. On dynamic response of masonry panels. In *Proceedings of National Conference on Masonry Mechanics between Theory and Practice, Messina, Italy*, 1996.

[7] Barbara Borzi, Rui Pinho, and Helen Crowley. Simplified pushover-based vulnerability analysis for large-scale assessment of rc buildings. *Engineering structures*, 30(3):804–820, 2008.

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

[9] 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.