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

Seismic Vulnerability Analysis of Pagoda Temple

Girijesh Prasad Sah [a], Prem Nath Maskey [b]

[a] *Departmemt of Civil Engineering, Thapathali Campus, IOE, Tribhuvan University, Nepal*
[b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
girijesh.762539@thc.tu.edu.np [a] pnmaskey@live.com.np [b]

Abstract
The ancient buildings are constructed using masonry method. Construction techniques have improved over the years. However, there are still a lot of locally built, traditional brick masonry structures that were made of burnt clay bricks/sun dried bricks and mud mortar. Despite the fact that these structures have endured for centuries, they lack perfect seismic safety features to guard against potential severe earthquake threats. The goal of the research study in this area is to ensure the sustainability of the structures because of their historical and monumental importance as well as for the safety of the people. Linear time history analysis has been carried out using SAP2000 V24. Cosidering wall and floor as shell elements and the beam and column as frame element. The fragility curve has been generated using response of the building from analysis and capacity values obtained from HAZUS for URMM which define the probability of the building for slight to complete damage in an earthquake based on the different PGA. By generating the fragility curve one can ensure the damage state of the building during earthquake which the building can experience.At 0.35g the probability of damage for slight, moderate, extensive and complete are 99.73%, 98.29%, 89.75% and 63.06% respectively. Since the damage percentage is more than 89% there will be extensive damage in the 5 storied historic temple.

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

1. Introduction

There are many hazards all around like flood, seismic, tsunamis, etc. Seismic (earthquake) is one of the more occurrences and probably the most destructing due to the recurrence of it. Since, earthquake only is not the factor to cause the casualties but it destroys man made structure which cause casualties. Nepal lies in the sub-duction zone due to which it experience frequent seismic events. The occurrence of the greater magnitude earthquake in Nepal is like once in 70-80years which cause most of the destruction like earthquake of 1990 B.S(1934 A.D) of intensity 8.3 with the epicenter at chainpur of sankhuwasabha district which caused more than 8000 lives in which more than 4000 lives were registered only in Kathmandu valley, the earthquake of 2045 B.S(1988 A.D) with intensity of 6.6 magnitude with epicenter at Murkuchche of Udaypur district which caused fatalities of 721 people, and one of the most recent earthquake in 2072 B.S(2015 April) of magnitude 7.6 located in Gorkha district which cause 9000 dead and many high magnitudes of aftershocks had been recorded which caused more destruction like 23000 people got injured, thousands of family got homeless. In the 2015 earthquake, the top floor of Nyatapola temple had been damaged, which has been renovated recently.

Nyatapola is a five tiered temple situated at the central part of Bhaktapur, Nepal. The name Nyatapola means five-storyed, where Nyata means five and pola means roofs in Newari language. It is both the highest temple in the city and the tallest temple all over Nepal. Along with the temple of Bhairava and various other historical buildings, the Nyatapola temple forms the Tamarhi (Taumadhi) square, a culturally important area and popular tourist destination in Bhaktapur. Explaining its accessories, there are 5 Ganesha, 5 tiers, 5 plinths, 33 steps, 108 struts, and 360 battens used in the temple. While, tantric philosophy places a high value on all of these numbers. Moreover, it questionably demonstrates the tantric influence of the era. The temple was built in 1702-1703AD in the period of king Bhuptindra Malla, mainly of masonry structure which is held at different level with the wooden beams and lintels. The height of the temple is 33m (108.26 ft.) including plinth of the temple. In 214 days, the entire nyatapola structure was raised. Meanwhile, there was absolutely no high-tech building equipment back then. Since the soil of the kathmandu valley is having the high amplification factor of the earthquake magnitude also the destruction rate is very high which cause greater number of casualties. So, we have to be very careful about the design and the analysis of any structure at the Kathmandu valley. The structure Nyatapola is also situated in the Kathmandu valley (at Bhaktapur) so the earthquake can greatly affect the temple.

For the preservation of the monumental structure there has been growing interest for the past few years to ensure the life safety and damage of the property. With regard to the built heritage, masonry structure represent a major portion of the stock and they were often non engineered or not designed with reference to any specific code.

Since the Kathmandu Valley is renowned for the hub of the traditional buildings which were constructed centuries ago. These buildings were constructed when People were just learning how to construct a building which forces the building to lack some measures which results them seismically vulnerable. The demolition is not the option to remove seismic vulnerability but to retrofit it to withstand the upcoming earthquakes will conserve the example of our past generation works and also to conserve cultural history. The most of the traditional buildings are made up of mud mortar with the woods at the sill and lintel level with beam and column also made of wooden structure. So, by passing the age, the wooden structure gets deteriorated which made the structure more vulnerable. So, if we can generate the fragility curve for the old buildings, we can find out the level of the damage in the temple which helps to sort out the retrofit level required in the temple.

Since the temple is near about 400 years old[1] the upcoming earthquake may greatly affect it. so, we want to address the weak elements and how vulnerable it can be during the earthquake if it is not taken into consideration. Also, we want to generate the fragility curve which will address the damage point in the temple and will also help for the further study of temple.

2. Temple Description

Nyatpola was constructed during 18th century during which there was not the concept of concrete technology so it was constructed with mud masonry with timber beam and column. Nyatpola is unreinforced mud masonry (URMM) structure. Wall of temple are constructed with bricks in mud mortar. The slope roof of the temple is constructed with base of roof as timber while the roof is laid with jhingati tile. Table 1 shows the dimensions of the temple, table 2 shows the cross-sectional dimension of the structure and table 3 shows the material properties of the structure.

Table 1: Masonry Walls in Nyatapola temple[2]

Floors	LxBxH(mXmXm)
Ground Floor	6.65x6.66x3.103
First Floor	9.16x9.16x3.903
Second Floor	6.80x6.79x4.015
Third Floor	4.85x4.83x4.11
Fourth Floor	3.39x3.39x3.11
Fifth Floor	1.87x1.83x3.26

Table 2: Sectional Properties (mm)[2]

SN	Structural Element	Cross section (mm)
1	Masonry wall	630 to 1590
2	Timber strut	75X100
3	Timber strut	125X100
4	Timber Beam	125X125
5	Timber Beam	215X250
6	Timber Beam	260X300
7	Timber Beam	275X275
8	Timber Column	150X150
9	Timber Column	230X260

Table 3: Material properties [3]

	Mud Mortar Brick Masonry	Timber
Modulus of Elasticity(E) (KN/m^2)	$8x10^5$	$1.25x10^7$
Weight per unit volume (KN/m^3)	20	8
Poisson ratio (U)	0.1	0.12

3. Modelling of Structures

The effective modelling approach can be used to model the masonry structure accurately but also should be computationally efficient. The structure is modeled by using macro modeling in which macro-element model is represented by macroscopic element of continuous model in which mechanical properties of the masonry elements are directly correlated. Macro modeling is one of the powerful tools to reduce the number of equations to solve in finite element method.

The masonry walls are joined together to create the 3-dimensional model with the continous boundary. The horizontal floor elements transfer the horizontal actions to the walls based on their flexural behavior because macro-elements only take in-plane behavior into account.

Nyatpola temple is a five-story brick masonry structure which is modeled in SAP2000 24.0.0[4] with the masonry wall of variable thickness of 1590mm in ground floor, first floor second floor, 1200mm wall at third floor, 990mm wall at fourth floor and 650mm wall at top floor also the offset wall of 750mm at first floor as shown in figure 1. The column and beam are modeled with the frame elements made of timber. The roof is modeled with timber properties of slab with timber strut, purlin and rafter. The jhingati tile load and mud mortar load are applied in the roof slab of 0.708KN/m^2 and the live load of 0.75 KN/m^2 respectively.

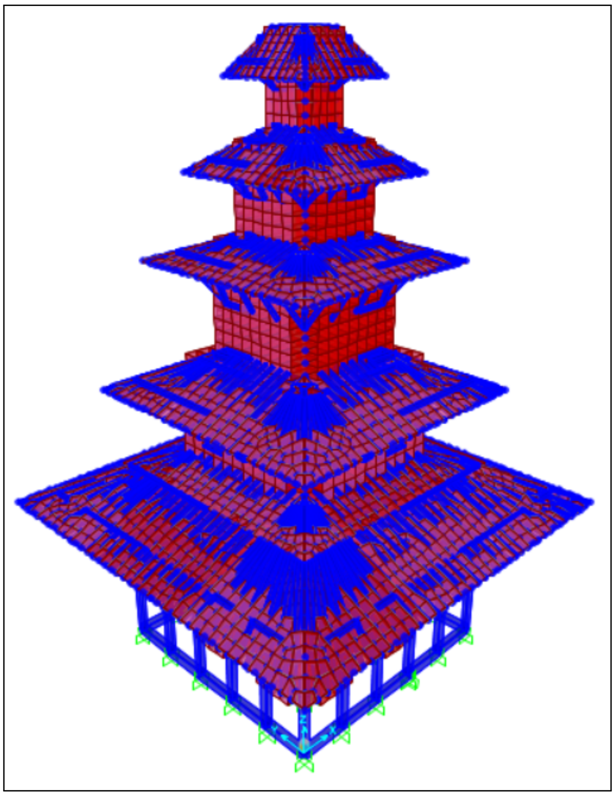

Figure 1: SAP2000 Model of Nyatapola Temple

4. Linear static analysis

Linear static analysis also known as equivalent static analysis is a design approach where equivalent static story forces, due to wind or earthquakes, are applied to the structure. This analysis is used to carryout to determine the natural time period, frequency, base shear, stresses, mass participation ratio's, etc. of the model. Linear static analysis requires density, modulus of elasticity and poisson's ratio of the structure. The static analysis is one of the fastest tools to analyze the structure as it only consider the linearity of the structure. The linearity will be either in material or in the geometry of the structure.

5. Linear Time history analysis

Time history analysis is a step-by-step examination of a structure's dynamic response to a given loading that may change over time. The seismic response of a structure to a representative earthquake's dynamic loading is ascertained through time history analysis. So, in this paper, time history analysis is done by considering the linearity. The earthquake is selected on the basis of different PGA value to see the response of the structure. For time history analysis 7 different earthquake of different PGA value is taken as presented in table 4. Figure 2-8 shows the accelerogram of gorkha, imperial valley, kobe, loma prieta, landers, trinidad and northridge earthquake respectively.

Table 4: Earthquake Data

SN	Earthquake Name	PGA(g)	Station
1	Gorkha 2015	0.154	Bhaktapur
2	Imperial Valley 1940	0.281	El Centro
3	Kobe 1995	0.3118	Kobe university
4	Loma Prieta 1989	0.44	Los Gatos Lexington Dam
5	Landers 1992	0.1354	Barstow
6	Trinidad 1980	0.1631	Rio Dell Overpass E Ground
7	Northridge 1994	0.067	Anacapa Island

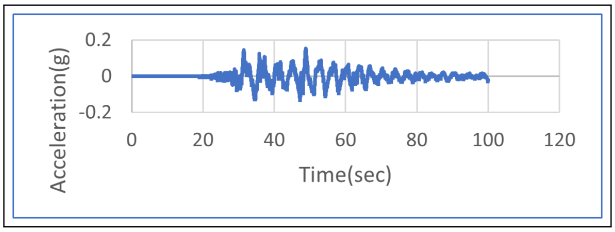

Figure 2: Accelerogram of Gorkha Earthquake 2015

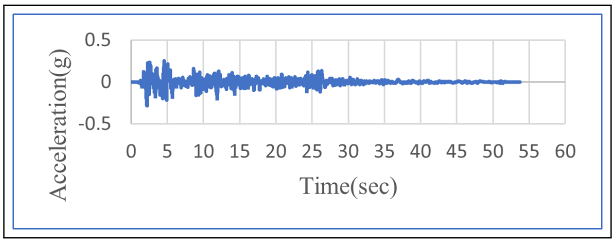

Figure 3: Accelerogram of Imperial Valley Earthquake 1940

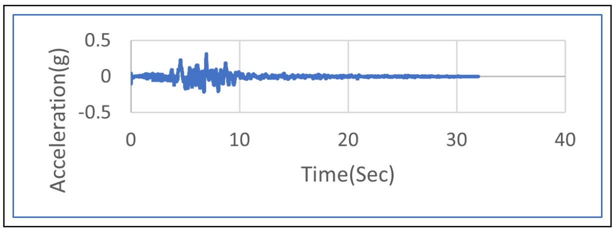

Figure 4: Accelerogram of Kobe Earthquake 1995

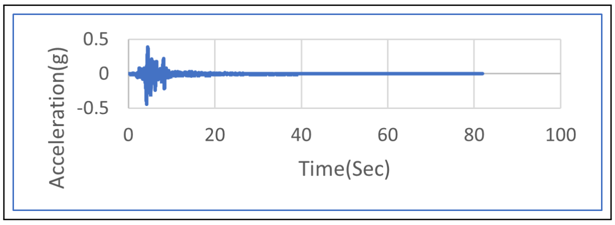

Figure 5: Accelerogram of Loma Prieta Earthquake 1989

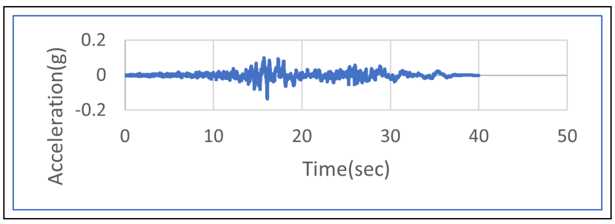

Figure 6: Accelerogram of Landers Earthquake 1992

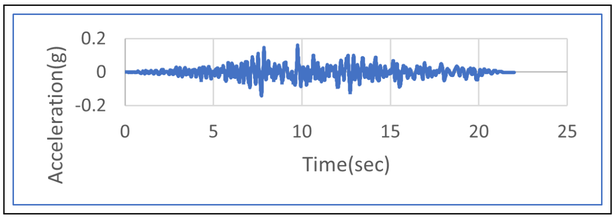

Figure 7: Accelerogram of Trinidad Earthquake 1980

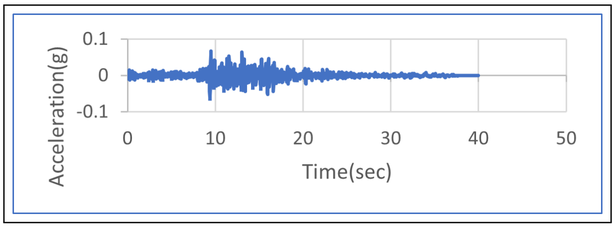

Figure 8: Accelerogram of Northridge Earthquake 1994

6. Development of Fragility Curve

The probability of being in or exceeding a given damage state is modeled as a cumulative lognormal distribution. For structural damage, given the spectral displacement, Sd, the probability of being in or exceeding a damage state, ds, is modeled as:

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

where, $\bar{S}_{\mathrm{d,ds}}$ is the median value of spectral displacement at which the building reaches the threshold of the damage state
β_{ds} is the standard deviation of the natural logarithm of spectral displacement of damage state
ϕ is the standard normal cumulative distribution function
The capacity of the structure is directly taken from the HAZUS Technical Manual 2.1 for URMM Building for Pre-code type as shown in table 5.

Table 5: Standard Deviation(Beta) and Median Value of Spectral Displacement[5]

Damage state	Median(mm)	Beta
Slight	12.7	0.99
Moderate	25.654	0.97
Extensive	64.008	0.9
Complete	149.352	0.88

Spectral displacement is found out by using regression method from the roof displacement found out from different earthquake at different scale factor.

To change roof displacement into spectral displacement FEMA440[6] conversion method is used.In uncertainty analysis, the first-order second moment (FOSM) method is frequently used. The function that connects the input variables and parameters to the output variables is linearized using this technique.By using normal distribution to spectral displacement and median value fragility curve is generated by using first order second moment method for the different PGA value as shown in figure 9.

Table 7: Earthquake Data

SN	Earthquake	PGA (g)	Roof Displacement (mm)
1	Gorkha	0.154	35.01
2	Imperial Valley	0.281	99.85
3	Kobe Japan	0.312	134.317
4	Loma Prieta	0.44	184.56
5	Landers	0.135	63.37
6	Trinidad	0.163	86.56
7	Northridge	0.067	30.21

7. Result and Discussion

7.1 Modeling Result

After modeling the Nyatpola temple in SAP2000, base shear, time period, frequency and roof displacement of the temple is found out as shown in table 6.

Table 6: Modal Analysis Result

Description	Xdirection	Ydirection
Base Shear(KN)	4877.576	4877.56
Time Period(Sec)	0.5723	
Frequency(HZ)	1.747	

As shown in the table, the time period is a little higher than that found from the empirical formula from NBC 105:2020 code (0.499sec)[7], as the time period depends upon mass, stiffness, and the strength of the structure. The time period is little higher because empirical formula only consider the height of the structure whereas in the SAP2000 it also consider the stiffness of the structure. Also, the frequency is nearly the same as the wood[8] (1.692 Hz). The maximum expected lateral force that will result from seismic ground motion at the base of a structure is estimated as base shear. The building with masonry will have a base shear much higher than that without masonry. So, the building with more seismic weight will have a high base shear and natural period.

7.2 Linear Time History Analysis Result

Linear time history has been run for the different PGA value of earthquakes from which the maximum displacement of roof is found out as shown in table 7.The base Shear and the interstory drifts between the floor is as shown in table 8.

The displacement is the outcome of the PGA of earthquake data. As we see that maximum displacement is due to the loma prieta earthquake, because the PGA of loma prita is greater than all of the earthquake taken for the analysis. Also, the displacement due to northridge is small because of less PGA value. It concludes that the displacement of the structure depends upon the frequency, earthquake duration and PGA of the earthquakes. The earthquakes with higher PGA affect the structure more than the lower PGA.

7.3 Fragility Analysis Result

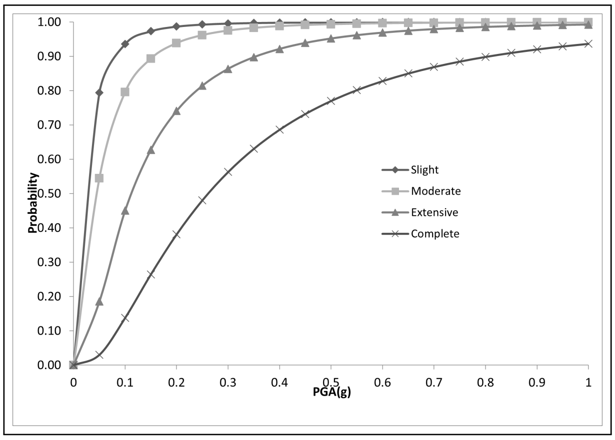

Figure 9: Fragility curve

Fragility curve is generated for the four-damage state by using median value as the capacity of temple and the spectral displacement as the demand of the structure. The fragility curve is generated as shown in figure 9. For Kathmandu valley, the seismic zone factor is 0.35g for the return period of 475 years according to NBC105:2020[7].

Figure 9 shows that at 0.35g, the probability of damage is 99.73%, 98.29%, 89.7%, and 63.06% for

Table 8: Base Shear(KN) and Inter Story-Drifts(mm)

Floor	Gorkha	Imperial	Trinidad	Loma	Landers	Kobe	Northridge
Base	0	0	0	0	0	0	0
GF	1.93	2.09	2.91	6.41	2.36	6.98	1.05
1st	2.46	2.82	2.55	7.06	2.68	7.74	0.81
2nd	3.58	4.61	4.342	9.58	3.62	10.34	0.72
3rd	9.04	12.54	9.45	33.44	6.96	21.3	2.55
4th	8.3	11.68	13.57	31.7	6.54	19.05	2.78
Top	10.49	15.23	20.45	42.117	13.15	24.71	3.25
Base Shear-X	1167.16	1714.38	2024.4	5740.65	1472.81	4390.39	818
Base Shear-Y	814.92	1939.17	2806.41	5929.6	1808.69	2484.61	447.799

slight, moderate, extensive, and complete damage, respectively. The probability of damage percentage is higher because of the structure being of masonry. Since the masonry structure is brittle in nature the less displacement will also lead the structure to high damage state. The probability of damage in the temple is more because the temple was constructed 400 years ago when there was not any building code in practice but it is analysed with the new building code NBC105:2020[7].

8. Conclusion

This study explores the seismic vulnerability of the existing URMM Nyatpola temple in Bhaktapur district as per revised NBC 105:2020. The linear time history analysis is done through the FEM modelling in SAP2000. The building's performance is done through modal analysis to determine the time period, base shear, and roof displacement. The fragility curve is also generated to determine the likelihood of building destruction during the future earthquake at various PGA's. At the PGA of 0.35g, which was given to the Kathmandu valley by NBC at 105:2020[7], there is a extensive chance of the destruction of the temple.

References

[1] Om Dhaubhadel. "gaganachumbi sānskritika dharōhara ngātāpōlah". *Ngātāpōlah jirnodvār*, (9789937086639):33–53, 2021.

[2] Rabina Shilpakar, Prem Nath Maskey, and Pramila Silpakar. Construction technology of multi-tiered temples and their rehabilitation after 2015 april earthquake in bhaktapur. *Progress in Disaster Science*, 10:100177, 2021.

[3] 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.

[4] Computers and Structures, University of Ave. Berkeley, 2009. *SAP Reference Manual*.

[5] Earthquake Committee, R. Whitman, Roger Borcherdt, D. Brookshire, R. Eisner, W. Holmes, R. Olson, M. O'Rourke, H. Lagorio, R. Reitherman, and Software Solutions. *HAZUS-MH 2.1 Earthquake Model Technical Manual*. 01 2013.

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

[7] Nepal National Building Code NBC: 105: 2020. *Seismic Design of Buildings in Nepal*.

[8] Richard L Wood, Mohammad Ebrahim Mohammadi, Andre R Barbosa, Linh Abdulrahman, Rajendra Soti, Chandra Kiran Kawan, Manjip Shakya, and Michael J Olsen. Damage assessment and modeling of the five-tiered pagoda-style nyatapola temple. *Earthquake Spectra*, 33(1_suppl):377–384, 2017.