Paper Number: 19

Evaluation of Period of Vibration and Vulnerability Assessment of a Historical Masonry, Sama Center: A Case Study

Pooja Amatya[1],[2] Rohit Ranjitkar[2],[3]

Lochan Rijal[2], Prachand Man Pradhan[1],[4]

[1]Kathmandu University Department of Civil Engineering, Dhulikhel, Nepal

[2]Kathmandu University Department of Music, Tripureshwor, Nepal

[3]Kathmandu Valley Preservation Trust, Patan, Nepal

[4]Manmohan Technical University, Morang, Nepal

pooja.amatya@ku.edu.np, rohit.ranjitkar@kvptnepal.org,
lochan.rijal@ku.edu.np, prachand@ku.edu.np

ABSTRACT

The restoration of 'Kathmandu University Bal Krishna Sama *Saichik Guthi*[1] (Sama Center)'; the birthplace of the foremost Nepali playwright and artist Bal Krishna Sama; is being carried out by Kathmandu University with the vision of the amalgamation of tangible and intangible heritage in Nepal. This historically important Rana-period[2] architectural heritage will be ultimately transformed into an academic discourse center and a hub for music, theatre and literature. This paper analyzes the old structure of the Sama Center through contemporary approaches in order to create a practical database for future conservation of archaic, diverse and valuable Nepalese heritage sites. Despite the Finite element analysis of masonry buildings being very difficult to be considered feasible for analysis of the traditional unreinforced masonry structures due to the deficiencies faced during the modeling of the building in the computer program, it is widely used for the analysis of masonry due to the ease in studying the global seismic response of the structure. The primary objective is to study the structural performance of the building using a preliminary method of linear static analysis during the earthquake. The seismic coefficient and response spectrum method are adopted to analyze the dynamic nature of the building. The assumptions of materials have been considered with a similar review of the structures in Kathmandu valley whereas the connections and behaviour of elements are assumed and need to be refined in further analysis since the seismic inputs need proper care with the professional experience in how the building reacted to the earthquake. The time period of the existing building was measured using the ambient vibration method which was checked with the model in the computer program and further proposed building was studied in axial and shear stresses. Finite Element Modeling of the building is performed in CSI ETABS.

---

[1] Educational Trust
[2] Neoclassical buildings were built when Rana rulers were leading Nepal in the mid-19th – mid-20th century

Keywords: Linear Analysis, Ambient Vibration Test, Finite Element Method, Historical Masonry Building, Tangible and Intangible Heritage

1. INTRODUCTION

Masonry is one of the oldest construction methods known to human beings (NBS building science series 106. 1976). It is an art of creating a structure with bricks or stones laid one above the other with a binding component, mortar. The masonry can be used as both structural and non-structural units. The architectures during the Rana period in Nepal were Unreinforced Masonry (URM) structures, load-bearing structural units with walls made up of bricks in mud mortar and plastered in lime surkhi and timber in lateral load-resisting elements at the floor level.

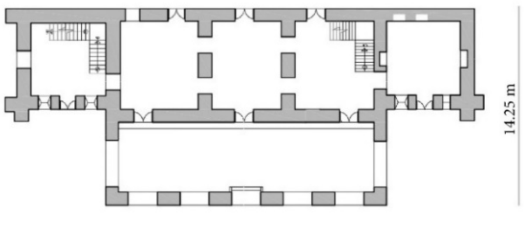
Sama Center, the birthplace of the then-playwright of Nepal, Bal Krishna Sama, is one of the magnificent architecture of that time. It is located at Latitude 27°42'36.5"N and Longitude 85°19'45.4"E. The building was built around 120 years ago. It has thick walls, and columns made up of masonry and arches to bear the load of the structure. The lateral support to the structure is given by the pinewood and Mild steel I section beams. The floors are made up of wooden joists planked with pinewood for flooring. It consists of a huge balcony in the main façade which is a point of attraction. These balcony columns extend vertically from the first floor up to the second floor. There is an open terrace above this balcony which is accessible from the third floor. The roof sections are covered with Galvanized Iron sheets.

1.1 Foundation

The foundation of the main building seemed stable since the walls of the ground floor and above were in a plumb line and no such settlement was seen in the walls above. From the conversation with the owner, the foundation of the building is around 10 feet deep. We could dig 7 feet deep to check the foundation until which the foundation bricks were seen, but due to the water level rise during the rainy season, further excavation was not possible.

1.2 Wall structures

The external dimension of the building is as shown in 'Figs 1 and 2'. The ground floor structural walls are 1 meter in width. There are huge arch openings on the ground floor whose crown sections have suffered damage to an extent, due to the installation of mild steel I sections right above the crown area without any wall plates during the initial repair of the building. Some arch sections are partially and some are filled with walls for partition. The insertion of I-sections and concrete to rest it in the wall has damaged the portions of the walls. The non-load-bearing partition walls were built in cement mortar and were about 23 cm in thickness. The northern wall seemed to be out of plumb by a few cm. Some wooden shores have been provided to the north façade walls of the building after the 2015 earthquake to support the building from further damage.



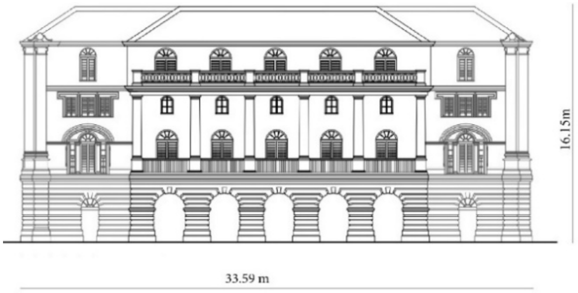


Figure 1. Typical Floor Plan of the Building
Figure 2. South elevation of the building

2. AMBIENT VIBRATION TEST

'A microtremor is a sophisticated instrument with a tri-axial velocity sensor, used to analyze the natural frequency and damping ratio of a building. The main advantages of microtremor analyses are simple, efficient, and quick, yielding reliable, accurate, and temporarily stable estimates of frequency and damping of the building's vibration modes from small amplitude excitation. '[1] It is also called the ambient vibration method to measure the motions generated due to wind, traffic, human activities, industrial machinery, etc. using highly sensitive instruments. This is a non-destructive vibration measurement technique for obtaining modal parameters of large structures. The identification of modal parameters through in situ analysis has been used to study buildings' seismic response and detect damages. The ambient time histories are recorded from the building, which further helps obtain the Fourier spectrum of each signal, resulting in the structure's natural frequency.

The fundamental properties need to be known for a proper design or analysis of any structure. For a seismic analysis, the fundamental time period of the structure is important. Micro tremor measurement gives the dynamic characteristics of buildings that play an important role in predicting their seismic behavior and in selecting the appropriate retrofitting approach in case of damage.

The fundamental vibration period of a building can be found in various codes.

Data Collection

For the measurement of the 3D geophone, a laptop with data acquisition software and a camera was used. For the building, one vertical and two horizontal measurements (east and north) were recorded, with a sampling rate of 100 Hz and a duration of 5 minutes for each location. The instrument was placed on each story wall. The topmost level of the existing building was reached as shown in 'Fig 3'.

The measurements' collected data were transferred to the Geopsy software for further processing. The software processed the time domain data into the frequency domain by a fast fourier transform algorithm as in 'Figs 4 and 5'. The frequency spectrum of the result was observed. Since clear peaks were obtained with less noise, usage of filter was not required.

From the frequency spectrum, frequency for peak amplitude in both east-west and north-south directions were found for each sample. Vertical vibration was not considered. The time period were calculated for the frequencies obtained in both directions. The experimental time period was compared with the existing building in the modelling software.

Figure 3. Data Collection at site. The highest point accessible in the mid longitudinal wall

---

[1] Gullapalli V.L., R RaghuNandanKumar , Reddy G.R., Assessment of Antenna Mounting Building Structural Strength using Micro tremor Analysis

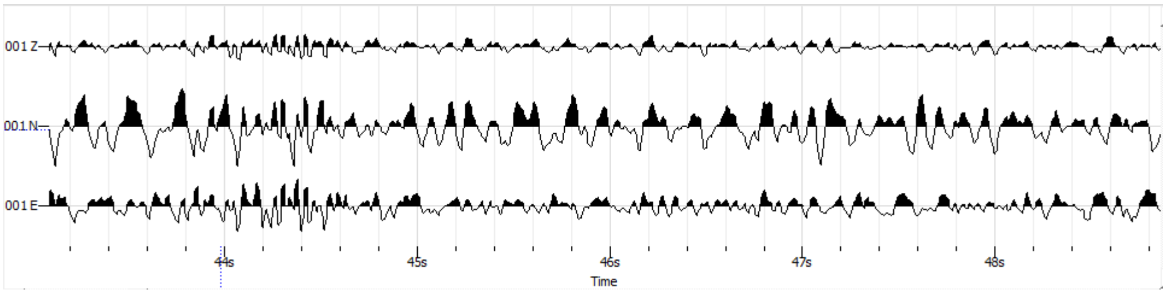
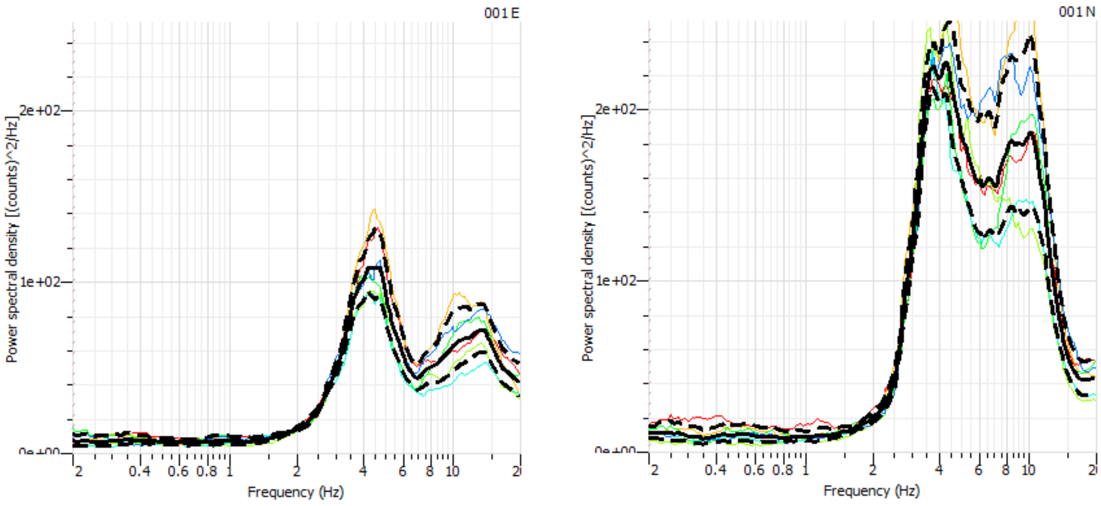


Figure 4. Sample of time domain data measured by micro tremor



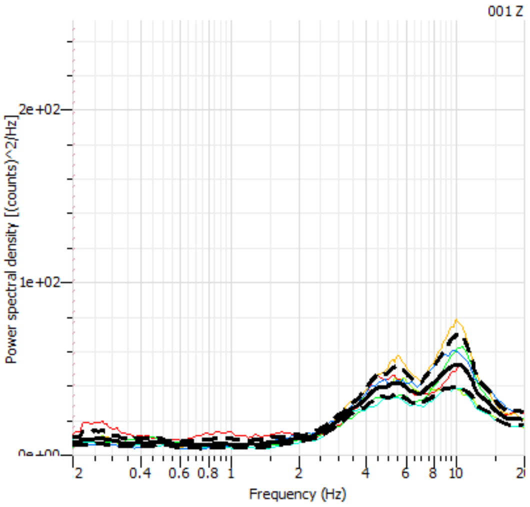


Figure 5. Frequency Spectrum of the building

The north-south direction of the building plays a fundamental role in the determination of the time period of the building. From the above graph in north direction, the frequency of the building can be taken as 4 Hz.

$$\text{Time period} = \frac{1}{\text{Frequency}} = \frac{1}{4} = 0.25 \text{ sec}$$

Comparison with that obtained from the results of highest Mass participating ratio from ETABS, gives the time period of 0.237 sec in a north-south direction. Since, the time period calculated by the building's model in ETABS matches 94% to the real structure, the model in the software is reliable

Table 1. Time period comparison

From Micro tremor	From ETABS model
North - South 0.25 sec	Y - Direction 0.237 sec
East – West 0.22 sec	X - Direction 0.196 sec

The ambient vibration test has been performed on the existing three-story building to check one of the parameters i.e. time period of the building and compared to the one generated by the software for analysis.

3. GENERAL DESIGN CRITERIA

3.1 Unit Weight and Material Properties

Unit weight of Brick Masonry in mud mortar: 19.61 kN/m^3 (Wood et al. 2017)
Compressive Strength of Brick Masonry in mud: 1.82 N/mm^2 (Shakya et al.)
Poisson's Ratio Brick Masonry in mud: 0.12 (Shakya et al)
Modulus of Elasticity Brick Masonry in mud, E=550 f_m : 800 MPa (FEMA 273)
Shear Modulus Brick Masonry in mud, G=0.4 E: 322.58 MPa

The mechanical properties from (Phajiu, S., and Pradhan, P.M., 2018.) have not been taken for masonry since the masonry used new bricks and cement mortar whereas we required values for existing bricks in mud mortar for analysis.

(IS 883: 1994)
Unit weight of Pinewood: 5.05 kN/m^3
Compressive Strength of Pinewood: 1.30 N/mm^2
Modulus of Elasticity Pinewood: 6800 MPa
Shear Modulus Pinewood: 2833.33 MPa
Poisson's Ratio Pinewood: 0.20

3.2 Earthquake Design Load as per NBC 105:2020

Soil Type : Type D-Very Soft Soil Sites
Seismic Zoning Factor, Z: 0.35 for Kathmandu
Importance Factor, I : 1.25
Ductility factor, Rμ : 1
Over strength factor, Ωs : 1.1
Fundamental time period, T, Sec : 0.237
Spectral Shape factor, Ch (T) : 1.625 for soil type D
Elastic site spectra C (T) = Ch (T) Z I : 0.71
Design Horizontal Base Shear coefficient : 0.646
Wall thickness (mm) : 1000, 860 and 300
Beam size (mm) : 200 X 150, 250X 150
Live Load : 3 kN/m^2, in general

4. ANALYSIS OF STRUCTURE

4.1 Assumptions

A Three-dimensional finite element analysis is prepared on the ETABS software, produced by CSI, California Berkeley, as per actual dimensions shown in 'Figs 1 and 2'.

The sizes of structural components are kept as per the real dimension on site of the existing structure and the new ones are as per the drawing.

Seismic loads will be considered acting along the two principal horizontal directions and not along the vertical direction.

The design seismic force has been applied automatically in different floor levels by the software.

Beams are modeled as rectangular frame elements whereas the masonry wall is modeled as a thick shell element.

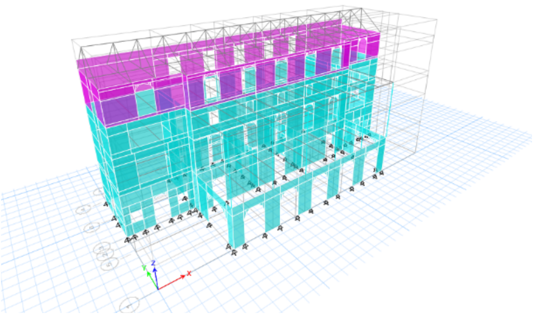
The diaphragm has not been assumed at floor level to be flexible in the horizontal direction.

The principal lateral load-resisting system in both longitudinal and transverse directions is a shear-resisting frame. The detailing shall be done as per the requirement of the shear-resisting frame.

4.2 Finite Element Modeling

The finite element model has been prepared in ETABS Ultimate 19.1.0. Beams were modeled as frame elements while walls were modeled as shell elements. The mechanical properties and loads were assigned as mentioned above. '**Figure** 6.' shows the finite element model of the building. Analysis of the building was prepared based on NBC 105:2020 code.

Whenever was necessary to check ETABS results, manual calculations were also performed. The walls have been taken as shell elements and the timber beams as frame elements. The connection of the building with the foundation has been taken as a pinned joint. The linear static analysis was first done followed by a linear dynamic analysis.



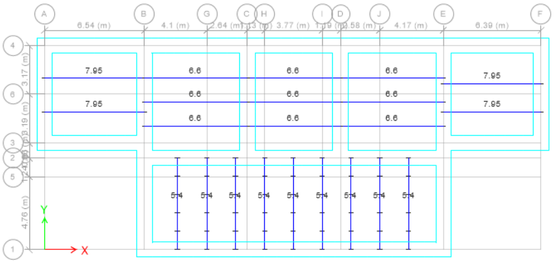


Figure 6. Finite element model of the building in ETABS
Figure 7. Floor Dead Load (kN/m^2) in plan

4.3 Analysis Results

4.3.1 *Axial Stress*

The axial stress patterns in the two elevations are as shown in 'Figs 8 and 9'. The average compressive stress is 0.5N/mm^2 which is within the limit whereas the tensile stress is exceeded in some openings as recorded after the earthquake in the building as shown in 'Fig 14'. The foundation of the building was checked for its bearing capacity for four story which resulted safe.

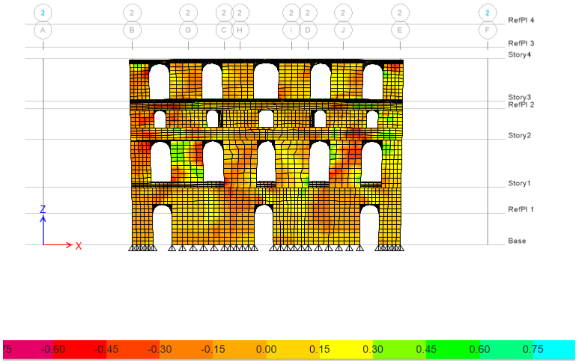


Figure 8. Axial Stress Diagram for Grid 2

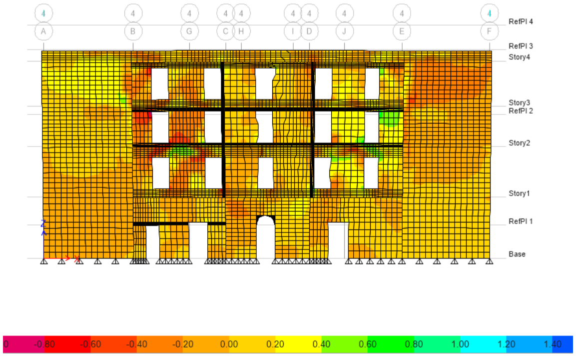


Figure 9. Axial Stress Diagram for Grid 4

Table 2. Axial Stress in Compression and Tension

(N/mm^2)	Calculated from ETABS	Permissible	Remarks
Compressive	0.5	0.67	Safe
Tensile	0.6	0.1	Exceeded near the openings

4.3.2 Shear Stress (Walls parallel to Y axis)

The shear stress from the model is recorded as 0.04 N/mm^2 which is within the permissible limit as shown in 'Figs 10 and 11'.

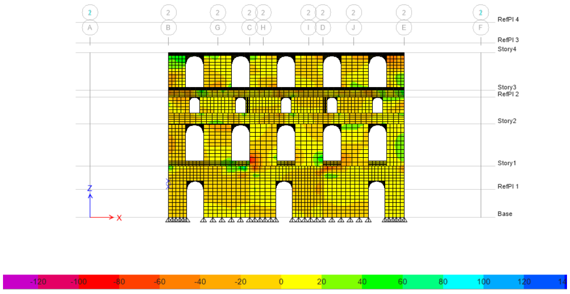


Figure 10. Shear Stress Diagram for Grid 2

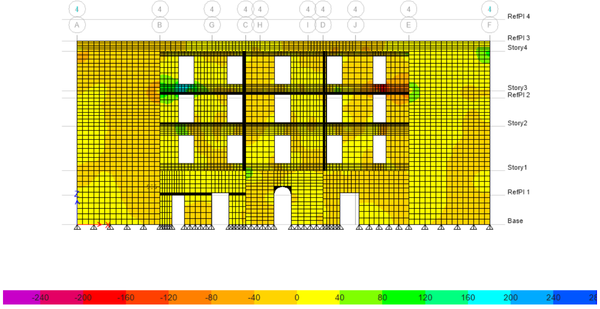


Figure 11. Shear Stress Diagram for Grid 4

Table 3. Shear Stress from ETABS in comparison to permissible stress

	Calculated shear from ETABS	Permissible shear stress	Remarks
(N/mm^2)	0.04	0.10	Safe

4.3.3 Out-of-plane Horizontal Bending

The out-of-plane bending seems to be between 0 to 40 kN-m/m avoiding the local stresses near the openings as shown in 'Figs 12 and 13'. The second-floor central portion seems to have maximum horizontal bending stress. This might have occurred since the floor is of the smallest height which makes its stiffness higher compared to other floors and a huge balcony in the third floor that rests on the columns in the first floor which makes the section flexible resulting the maximum displacement compared to other floors.

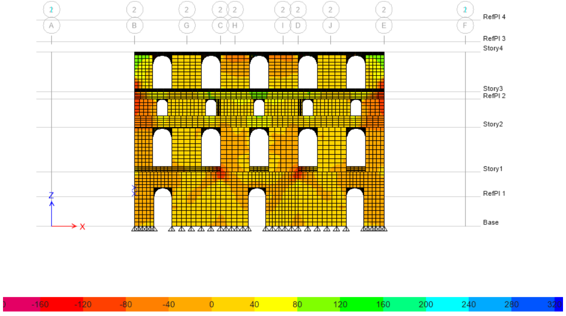


Figure 12. Out-of-Plane Horizontal Bending for Grid 2

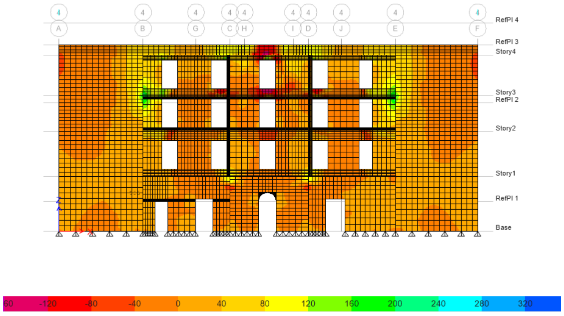


Figure 13. Out-of-Plane Horizontal Bending for Grid 4

Figure 14. Photographs of the cracks in the openings and the arches after the 2015 earthquake

5. CONCLUSION AND RECOMMENDATION

This paper discussed the vulnerability of a load-bearing Rana period architecture which in its current state is a 3 story building but needs to be built to its original state ie four stories as per the monument act since it has been listed as a heritage building according to Department of Archaeology. The time period of the existing state of the building (3 stories) was measured at the site and compared with that in the ETABS model. The time period was 94% close to the real-time period of the structure. Hence, ETABS was further used for the analysis of the proposed building with four stories. The walls have been taken as shell elements whereas the timber beams have been taken as frame elements. The joists and planking in the flooring have not been considered except few cases. The connection of the building with the foundation has been taken as a pinned joint. And the properties for the masonry were adopted from papers that analyzed existing buildings.

The stresses of the building have been observed through the finite element method. The building acts well in compression and shear since the walls are thick. Certain local stresses have been seen in the horizontal bending when analyzed using the Dynamic Analysis Method on the third floor which is due to the presence of a balcony that rests on tall columns and fewer cross walls. A diaphragm should be created to increase the stiffness of the balcony and the third floor whereas the local stresses in the corners of the openings can be strengthened using some wire mesh inside the plastered surface.

6. ACKNOWLEDGEMENTS

We are grateful to the Kathmandu University Department of Music for funding the research through Rebuilding Bal Krishna Sama Educational Guthi. Similarly, the researcher would like to thank Er. Sudip Karanjit, Khwopa College of Engineering for their support in microtremor analysis and Er. Ravi Sharma Bhandari for software analysis.

7. REFERENCES

[1] Shakya, M., 2013. Seismic Sensitivity Analysis of the common structural components of Nepalese Pagoda Temples
[2] Yeomans, D.T., 1995. The behaviour of structures in Nepal: with recommendations for remedial work to the structure of Sundari Chowk, Patan Durbar Square
[3] Betti, M., Galno, L., Seismic Analysis of Historic Masonry Buildings: The Vicarious Palace in Pescia (Italy)
[4] Shrestha, S., Shrestha, B., Shakya, M., Maskey, P.N., Investigation and Analysis of damages in the heritage structures: An aftermath of 2015 Gorkha (Nepal) Earthquake

[5] Phaiju, S., Pradhan, P.M., 2018 Experimental work for mechanical properties of Brick and Masonry Panel
[6] Nienhuys, 2003. Options for reconstruction and retrofitting of Historic pagoda temple
[7] Sabatino, R., Rizzano, G., A simplified Approach for the Seismic Analysis of masonry Structures
[8] Wood et al., 2017. Structural Damage Assessment of a Five-tiered Pagoda Style temple in Nepal
[9] Lourenco, P. B., 2002. Computations on historic masonry structures
[10] NBC 105:2020, Seismic Design of Building in Nepal.
[11] IS: 875 (Part1) -1987, Code of practice for design loads in Building and structure- Dead Loads, Bureau of Indian Standards, New Delhi
[12] IS: 875 (Part1) -1987, Code of practice for design loads in Building and structure- Imposed Loads, Bureau of Indian Standards, New Delhi
[13] IS 883: 1994: Design of Structural Timber in Building, Table 1: Safe Permissible Stresses for the Species of Timber
[14] Gullapalli V.L., R RaghuNandanKumar , Reddy G.R., Assessment of Antenna Mounting Building Structural Strength using Micro tremor Analysis
[15] FEMA 273, 1997. Seismic Rehabilitation Guidelines, USA.