2024. 20(2). 120–133

СТРОИТЕЛЬНАЯ МЕХАНИКА ИНЖЕНЕРНЫХ КОНСТРУКЦИЙ И СООРУЖЕНИЙ

STRUCTURAL MECHANICS OF ENGINEERING CONSTRUCTIONS AND BUILDINGS

ISSN 1815-5235 (Print), 2587-8700 (Online)

HTTP://JOURNALS.RUDN.RU/STRUCTURAL-MECHANICS

СЕЙСМОСТОЙКОСТЬ СООРУЖЕНИЙ
SEISMIC RESISTENCE

DOI: 10.22363/1815-5235-2024-20-2-120-133
UDC 699.841
EDN: JNAYFF

Research article / Научная статья

Seismic Fragility Analysis of Existing Old Newari Brick Masonry Building in Pokhara Valley

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Article history
Received: January 16, 2024
Revised: March 28, 2024
Accepted: April 5, 2024

Conflicts of interest

The authors declare that there is no conflict of interest.

Authors' contribution

Undivided co-authorship.

Abstract. Most of the building stock in Nepal is based on masonry construction, which includes monumental, administrative, and residential structures. These structures are vulnerable during earthquakes, as evidenced by the massive structural damage, loss of human life, and property damage due to a lack of proper assessment and appropriate strengthening measures. An analysis of the seismic vulnerability of existing old Newari brick masonry buildings in the Pokhara Valley is presented. These buildings were built using indigenous knowledge and technology. The investigation is based on analytical studies, with some material properties obtained from field tests. Proper modeling of a masonry structure is crucial for reliable seismic resistance and structural design. However, modeling a real masonry structure is a challenging and computationally demanding task due to its complicated framework, requiring in-depth knowledge, realistic material properties, and relevant information. The aim of this research is to assess the seismic performance of old Newari masonry buildings using stress level and fragility curves. The research issues are addressed analytically through linear time history analysis using the finite element program-based software Sap 2000 v20. In dynamic analysis, numerical building models were subjected to three synthetic earthquakes. The performance status of the building based on various stress levels is evaluated, and weak regions are identified. The fragility curve of the structure is assessed, considering the ground motion parameters in the locality. The fragility function is plotted with the probability of failure at an interval of 0.10 g. The results of the analysis highlight that the studied structure is vulnerable compared to the codal provisions and standard recommendations.

Keywords: Brick masonry, Fragility analysis, Finite element analysis, Old masonry structure, Mechanical characterization

For citation

Chapagain K., Chaulagain H. Seismic fragility analysis of existing old Newari brick masonry building in Pokhara valley. *Structural Mechanics of Engineering Constructions and Buildings.* 2024;20(2):120–133. http://doi.org/10.22363/1815-5235-2024-20-2-120-133

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Анализ сейсмической устойчивости старого кирпичного здания в стиле Ньюари в долине Покхара

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История статьи

Поступила в редакцию: 16 января 2024 г.
Доработана: 26 марта 2024 г.
Принята к публикации: 5 апреля 2024 г.

Заявление о конфликте интересов

Авторы заявляют об отсутствии конфликта интересов.

Вклад авторов

Нераздельное соавторство.

Аннотация. Большинство сооружений в Непале, включая административные и жилые здания, выполнены из камня. Их конструкции уязвимы во время землетрясений, о чем свидетельствуют масштабные повреждения и человеческие жертвы из-за отсутствия надлежащей оценки и соответствующих мер по укреплению. Представлен анализ сейсмической уязвимости существующих зданий из кирпича в традиционном стиле Ньюари, находящихся в долине Покхара. Эти здания были построены с использованием методов и технологий коренного населения. Исследование основано на аналитических расчетах, при этом некоторые свойства материалов были получены в результате полевых испытаний. Эффективное моделирование каменной кладки имеет решающее значение в проектировании надежной и сейсмостойкой конструкции. Однако моделирование реальной каменной конструкции является неординарной и затратной в вычислительном плане задачей из-за сложной структуры, требующей углубленного анализа, реалистичных свойств материала и актуальных данных. Целью данного исследования является определение сейсмических характеристик старых кирпичных зданий в стиле Ньюари с использованием кривых пределов напряжений и сейсмоустойчивости. Задачи исследования решаются с помощью линейного динамического анализа с использованием программного обеспечения на основе конечных элементов Sap 2000 v20. Конечноэлементные модели зданий были испытаны на трех землетрясениях. Дана оценка эксплуатационного состояния здания на основе различных уровней нагрузки и выявлены слабые участки. Проанализирована кривая предела сейсмоустойчивости конструкции с учетом параметров движения грунта в данной местности. Функция предела сейсмоустойчивости построена с вероятностью разрушения с интервалом 0,10 g. Результаты расчетов подтверждают, что исследуемая конструкция уязвима в сравнении с положениями строительных норм и правил.

Ключевые слова: кирпичная кладка, расчет предела сейсмоустойчивости, конечно-элементный анализ, старая каменная конструкция, механическая характеристика

Для цитирования

Chapagain K., Chaulagain H. Seismic fragility analysis of existing old Newari brick masonry building in Pokhara valley // Строительная механика инженерных конструкций и сооружений. 2024. Т. 20. № 2. С. 120–133. http://doi.org/10.22363/1815-5235-2024-20-2-120-133

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1. Introduction

Most of the historic, administrative, and residential building structures in Nepal are based on masonry construction. To date, more than 60 % of buildings in Nepal are masonry, which have heavy mass and low compressive strength, and these structures are normally up to four stories tall. They have a flexible diaphragm system both in the roof and floor levels. Basically, masonry structures are built with mortar and masonry units. The mortar is made with lime-cement, clay, and bitumen, while mud, stone, and fire clay are used as masonry units. However, the majority of the masonry buildings in Nepal are constructed without adopting proper engineering guidelines. In past seismic events, the masonry structures have failed due to inadequate brick units, poor quality of mortar, irregularities in plane and vertical direction, inadequate load-bearing walls, lack of vertical confinement, weak bottom storeys, wall openings, improper section and dimension, wall connections, etc. [1]. In fact, unreinforced masonry buildings are more vulnerable to earthquakes due to their heavy mass, insufficient deformation capacity, and lack of integrity between the structural elements [2]. These types of structures have a brittle failure mode during earthquakes (see Figure 1).

a *b* *c*

d *e* *f*

Figure 1. Failure mode in masonry building during earthquake:
a — separation of short wall at cross section; *b* — complete collapse of short wall; *c* — collapse of gable wall;
d — out of plane bulging; e — in plane damage with opening; *f* — shear damage

S o u r c e: photos by R.K. Adhikari, D.D'Ayala [3]

Researchers [4; 5] studied the importance of compressive strength in conventional design practices, while in [6] highlighted the necessity of characterizing the mechanical behavior of masonry bond. Costigan et al. [7] and Parajuli and Kiyono [8] experimentally characterized the mechanical properties of masonry walls. Endo et al. [9] conducted an experiment on a brick masonry wall composed of fired bricks and mud mortar. Parajuli et al. [10] studied the behavior of the monumental brick masonry wallet through in-situ tests. The analysis of masonry structures is a challenging and computationally demanding task due to their complicated framework. It requires in-depth knowledge, realistic material properties, and relevant information. It is difficult to extract the structural and material properties of the structure built with indigenous technology in the absence of information and data concerning the behavior of their primary frameworks. The appropriate modeling technique is essential to extract the realistic response of old masonry structures. Creating a feasible model for a contemporary structure made of new industrial materials is easier, as materials and member properties are more uniform and largely clear. However, accounting for the multiple uncertainties of the problem that arise during the analysis and design of the structure requires more work. Nevertheless, there is negligible study found in the literature that covers both the characterization of the mechanical properties of masonry and performance assessment of such a historical building structure based on those properties.

In the Pokhara valley, most of the masonry structures have existed for three to four generations without proper damage assessment, which ultimately leads to the loss of life and property. Proper strengthening measures can restore the existing buildings, which will have a greater impact on the overall performance of the structure. Realistic seismic performance evaluation methods should be followed for this purpose. To this end, this research focuses on the performance assessment of existing old historical building structures based on field data. The research objective is achieved through the analysis of numerical models. The numerical models are subjected to three earthquakes of Kobe, El-Centro, and Gorkha. Finally, the results are based on the stress level and fragility curves in different ground motions, and these are compared with standard codal provisions and recommendations.

2. Study of existing old Newari building

2.1. Description of building under study

The prototype building structure is a traditional building in the locality that was constructed in the 17th century using original local technology. Most old Newari buildings in the area have traditional architecture. The building is three to four stories high with a floor height ranging from 1.8 to 2.3 meters and a larger opening ratio in the lower stories. The building typically has a simple rectangular floor plan with a breadth of over 6 meters and a length between 10 to 16 meters. The substructure uses shallow foundation with stones, and the superstructure is built with locally available clay burnt brick and mud mortar. The design is supported by three walls, two external walls, and one spine wall in the middle. In the upper story, the spine wall is sometimes replaced by a timber column frame system for creating a bigger continuous space. Wood joists uphold the floors and rooftop, over which wooden sheets or boards with a thick layer of mud topping are applied. The rooftop is typically doubly pitched and covered with traditional stone in the past, but nowadays, they are replaced by CGI sheets to make it waterproof. The brick masonry wall's typical thickness is about 60 cm and consists of a bricklayer in mud mortar and timber planks and beams.

During fieldwork, general information about the building, such as its length, breadth, height, number of stories, the thickness of the masonry wall, position and size of doors and windows, dimension of timber beams and columns, and material properties, was measured. The dead and live load in the building model is applied based on IS 875-1 (1987) and IS 875-22 (1987) codes.[1] The load of the timber staircase is calculated manually, and its loads are distributed to the supporting wall. The mechanical properties of brick, mortar, and wallet are taken from previous literature [11]. The old Newari building and corresponding plan, front and side elevation, and sectional view of the studied building are presented in Figures 2 and 3. The structural and geometrical properties of the case study building are summarized in Table 1.

[1] IS 875-1. Code of Practice for Design Loads (Other Than Earthquake) For Buildings and Structures. Part 1: Dead Loads — Unit Weights of Building Material and Stored Materials. New Delhi: Bureau of Indian Standards; 1987; IS 875 (Part 2):1987Code of Practice for Design Loads (Other Than Earthquake) For Buildings and Structures. Part 2: Imposed Loads. New Delhi: Bureau of Indian Standards; 2008.

Figure 2. Old Newari building
S o u r c e: Photo by K. Chapagain, H. Chaulagain

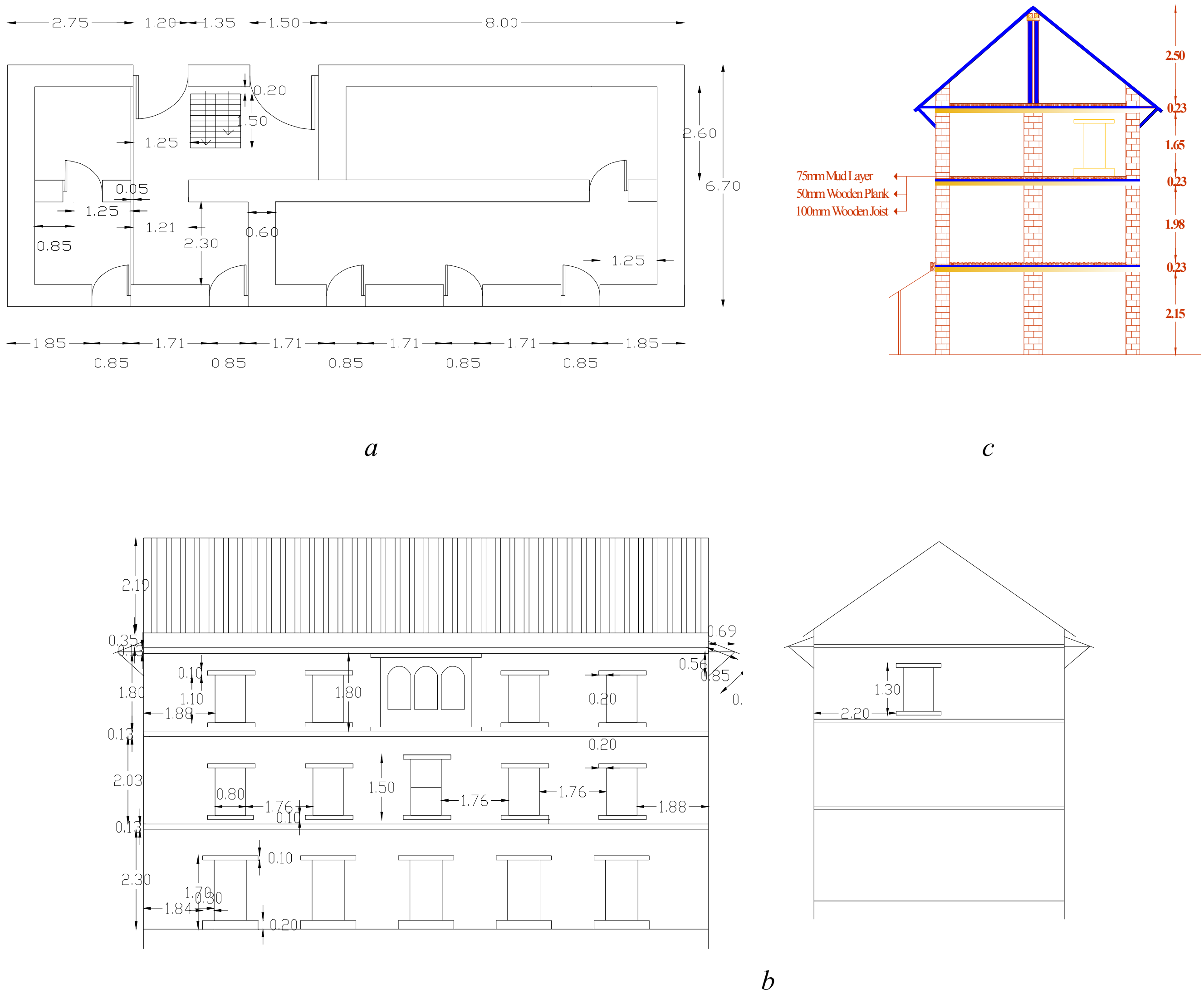

Figure 3. Details of studied building structure:
a — plan; *b* — front and side elevation; *c* — cross section
S o u r c e: made by K. Chapagain, H. Chaulagain

Table 1

Geometrical and structural properties

Description	Properties	Description	Properties
Area of building	14.8 m×6.70 m	Unit weight of brick in mud mortar (ϒ)	17.68 kN/m^3
Building Height	9.06 m	Modulus of elasticity (E)	509 N/mm^2.
Floor height	GF = 2.30 m, FF = 2.16 m, SF = 1.93 m, TF = 2.68 m (at attic)	Modulus of elasticity of Sal (E)	12600 N/mm^2
Earthquake Zone	V	Shear modulus (G)	204 N/mm^2
Subsoil type	II	Unit weight of mud-topped	1.47 kN/m^3
Timber column	0.14 m×0.14 m	Imposed load for Floor	2 kN/m^3
Timber beam	0.14 m×0.10 m	Imposed load for roof	1 kN/m^3
Slab thickness	0.125 m	Unit weight of Sal (ϒ)	8.03kN/m^3
Wall thickness	0.60 m	Poisson's ratio (ν)	0.25

S o u r c e: made by K. Chapagain, H. Chaulagain

2.2. Determination of compressive strength of brick units of building model

The old Newari building that exists today was constructed 265 years ago in 1814 B.S and is still being used as a residential space. Despite being exposed to various earthquakes in the past and recent times, the building remains in good usable condition. The masonry walls of the building are made of brick units constructed using local cohesive soil without the addition of any binding materials. In order to assess the strength of the bricks, a sample was taken from the building and tested using a Compression Testing Machine (CTM), and the results of this experiment are provided in Table 2. Additionally, Figure 4 depicts the testing process for the brick units.

Figure 4. Testing of brick samples in lab

S o u r c e: photo by K. Chapagain, H. Chaulagain

Table 2

Determination of Compressive Strength in Lab CTM

Sample	Dimension and area			Yield Load, kN	Strength of brick unit, N/mm^2	Average strength, N/mm^2
	Length	Breadth	Area, mm^2			
1	118	90	10620	115	10.83	11.06
2	120	88	10560	120	11.36	
3	145	97	14065	155	11.02	
4	132	88	11616	130	11.19	
5	122	88	10736	115	10.71	
6	121	88	10648	120	11.27	

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2.3. Seismic Input

The ground motion parameters of displacement, velocity, and acceleration can occur separately or in combination. Acceleration is usually the measured quantity, and the other parameters are derived from it. However, due to limitations in technology and instrument setup, there is a lack of precise earthquake data. To meet the research objectives, appropriate time history data must be arranged. This study considers three recorded earthquakes, which are presented in Table 3. The peak ground acceleration (PGA) has been scaled to an interval of 0.05 to 1 g. The El Centro, Gorkha, and Kobe earthquakes are analyzed in two orthogonal components in the *x*- and *y*-directions, as their magnitudes, fault distances, and source mechanisms correspond to the seismic hazard at the study location. Figure 5 shows the earthquakes examined in this study.

Table 3

Peak ground acceleration used for the dynamic analysis

Name of earthquake	Peak Ground Acceleration (PGA)
Kobe earthquake	0.379 g
El Centro earthquake	0.365 g
Gorkha earthquake	0.4 g

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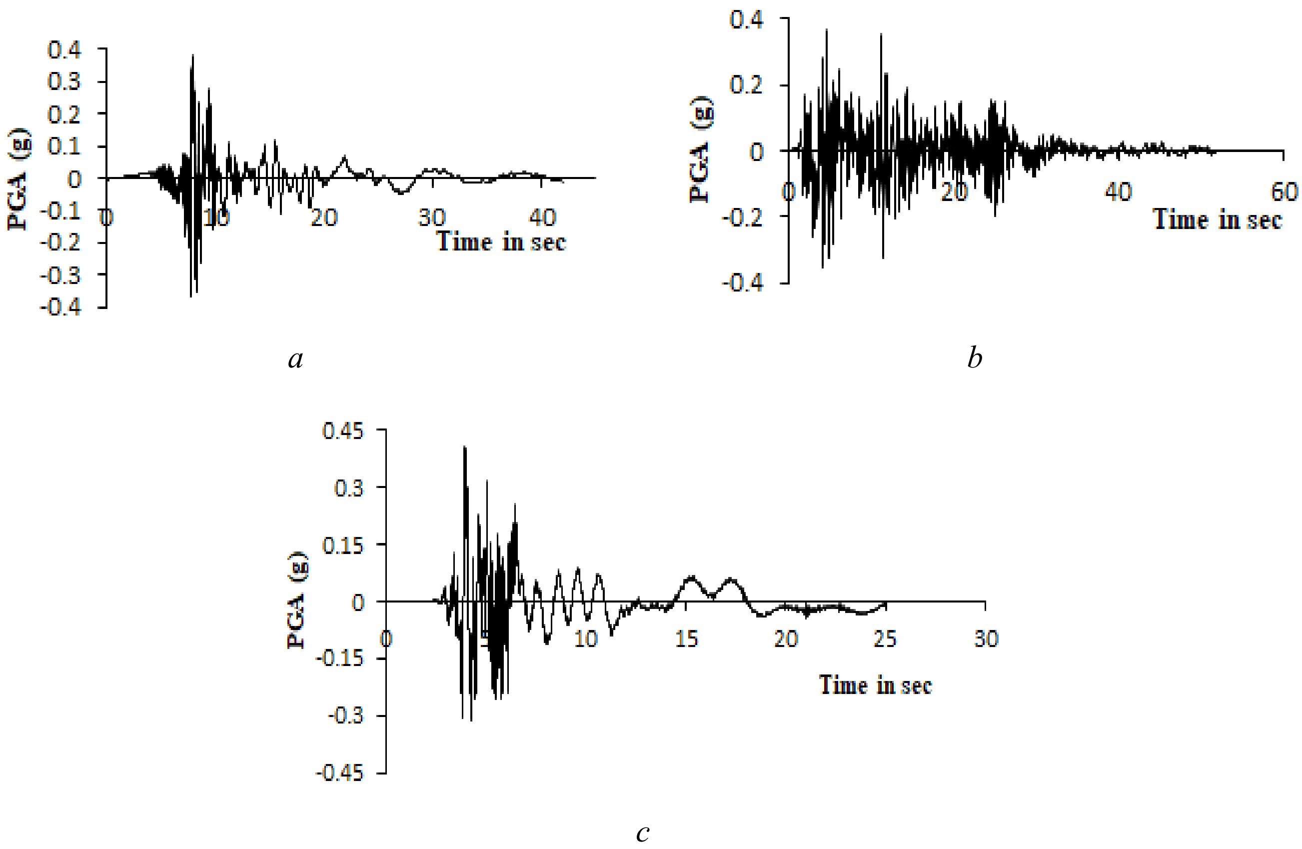


Figure 5. Time history data:
a — Kobe earthquake; *b* — El-Centro earthquake; *c* — Gorkha earthquake

S o u r c e: made by K. Chapagain, H. Chaulagain

2.4. Linear time history analysis

The analysis of masonry structures using nonlinear methods is a complicated and time-consuming process. Therefore, linear analysis, which is a simpler approach, is more commonly used. This method involves studying the structural behavior within the linear range of the stress-strain curve, assuming the brick masonry as a homogeneous material. Many researchers utilize linear time history analysis to determine the real performance of the structure. In time history analysis, loading and response history is analyzed in progressive time increases using a step-by-step technique. It is assumed that the structural characteristics remain constant and the structure behaves linearly throughout the loading history. Each natural mode of vibration is estimated as a function of the building period for a given time history and damping, and is expressed in terms of pseudo-spectral acceleration, displacement, and velocity.

2.5. Damage state criteria and fragility analysis

The study of a structure's behavior can be achieved by examining damage thresholds, also known as limit states, which represent the point at which different levels of damage occur. Various researchers have recommended different damage states, based on criteria such as drift ratio, yield displacement, and ultimate displacement of the structure, for example in [12] established light, moderate, and severe damage levels based on maximum drift ratio, while Dumova-Javanoska [13] proposed five damage levels (none, minor, moderate, severe, and collapse) based on damage index. Kircil and Polat [14] developed yielding and collapse damage levels for studying the performance of existing structures, while Jiang et al. [15] suggested maximum inter-storey drift ratio and global damage index for fragility assessment. Ahmad [16] focused on slight, moderate, extensive, and incipient damage levels to study reinforced concrete structures in the Himalayan region.

Lagomarsino and Giovinazzi [17] employed four damage grades — slight damage (0.7 dy), moderate damage (1.5 dy), extensive damage (0.5 (dy + du)), and complete damage (du) — by considering ultimate (du) and yield displacement (dy) for the fragility analysis of existing structures. After reviewing the limit states proposed by various researchers, it was found that the most commonly adopted limit states are slightly damage, moderate damage, extensive damage, and complete damage. Therefore, Lagomarsino and Giovinazzi's [17] four limit states were used in this study to construct a fragility curve that describes the performance level of the study building.

Fragility curves are typically generated through a fragility analysis of structures. Specifically, they are obtained by deriving a probability of failure relation from the following expression:

$$P(f) = \varnothing\left[\frac{\ln\left(S_d / S_c\right)}{\beta}\right].$$

Where, $\varnothing(\ldots)$ represents a standard cumulative normal distribution function, S_d and S_c are the demand displacement and medium of damage state. For this study, the demand displacement of the building structure was determined through linear dynamic analysis using three different ground motions. The medium damage states were determined using the damage grade proposed by Lagomarsino & Giovinazzi [17]. The total uncertainty is represented by the log standard deviation, denoted by the symbol β, as per HAZUS-MH-MR4.[2]

[2] HAZUS-MH-MR4. Multi-hazard Loss Estimation Methodology. Technical Manual. Department of Homeland Security, Emergency Preparedness and Response Directorate, Federal Emergency Management Agency, Washington, D.C. 2003.

3. Finite element modelling

3.1. Structural Modeling

There are two main approaches to model masonry structures: micro modelling and macro modelling. In micro modelling, masonry is considered as a single-phase material, while macro modelling involves modelling the masonry structure as two or three phase materials. However, the macro modelling approach cannot address the mortar joints acting as a plane of weakness. Therefore, this study adopts the micro modelling approach due to its higher level of accuracy and simplified methodology. Figure 6 presents the different modelling approaches, including macro modelling, simplified micro modelling, and detailed macro modelling with two-phase and three-phase materials. Brick Element Mortar Element

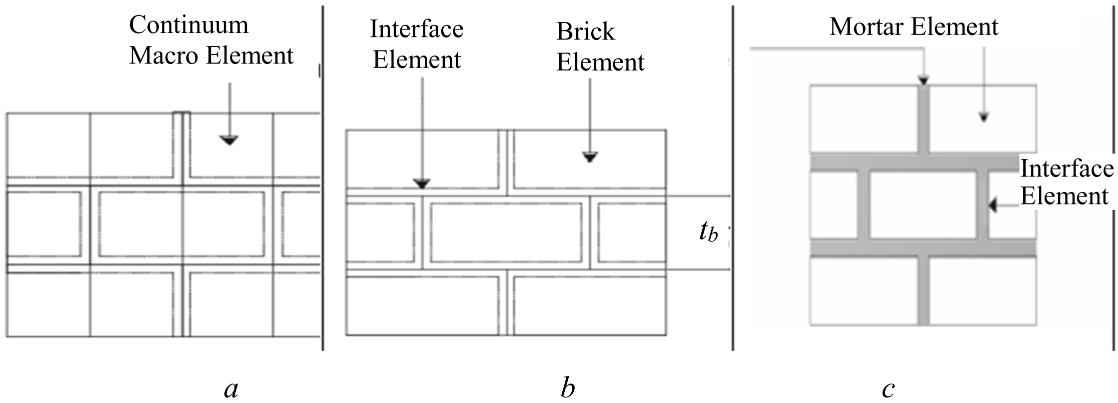


Figure 6. Masonry modeling strategies:
a — macro-modeling; *b* — simplified micro-modeling; *c* — detailed micro-modeling
S o u r c e: Asteris et al. [18]

3.2. Foundation

The strip foundation of the old Newari traditional building is constructed with larger stones at the base and has a depth of at least 175 cm for buildings with three to four stories. The construction follows a stepped fashion and has a width greater than 1 m.

3.3. Masonry walls

The walls are made of mud mortar and unreinforced brick masonry, typically consisting of three layers of bricks in the vertical direction. The brick units are handmade using locally available soil for the mortar.

3.4. Floor System

The traditional Newari building's flooring is typically constructed with timber material. Wooden or timber joists with an average dimension of 0.10 m width and 0.14 m depth and a center-to-center dimension of 0.35 m to 0.45 m are used to support the floor from party wall to party wall. The floor is supported by closely spaced timber joists with a layer of wooden planks. The subfloor is finished with a mud-topped layer that is 10 cm thick.

3.5. Roof system

In the past, the roof structure of the building was made of stone slabs and was supported by timber purlins and rafters. However, nowadays, the stone slabs have been replaced by CGI sheets. The rafters and purlins are supported by the brick masonry walls.

3.6. Masonry construction

Masonry structures are characterized by continuous bearing walls instead of framed structures. When subjected to vertical loads, these walls exhibit excellent mechanical behavior and high resistance to impact or accidental loads. However, when subjected to horizontal loads such as earthquakes, masonry structures tend to have low stability due to the low tensile strength of masonry materials. Thus, in masonry structures, all walls contribute significantly to structural function. It should be noted that masonry structures typically have structural walls with constant transverse dimensions and experience only modest compressive loads [19].

3.7. Timber in masonry

Besides using wooden ring beams at the top of load-bearing walls, timber elements can also be employed as horizontal reinforcement along the wall's height, creating a building technique known as “timber-laced masonry.” This method not only enhances the wall-to-wall connection but also provides stability through the systematic insertion of timber pieces along the wall’s height. The use of timber elements is advantageous due to their superior tensile strength. The confined masonry wall sections improve the walls' compressive strength and deformability. The timber-laced masonry technique is distinct from ring beams and has been examined separately [20].

3.8. Modelling of contact surfaces

Typically, wooden beams and columns are modeled as either fixed or hinged joints, but in reality, their behavior doesn’t match either of these assumptions. In the software SAP2000 v20[3], frame elements are represented by single center lines to model timber elements such as joists, beam-columns, and posts. These center lines come into contact with adjacent masonry walls, which are modeled as thick shell elements. In actual designs, the surface of wooden elements contacts the adjacent masonry wall, and this contact issue is resolved by introducing link elements between the wooden elements and the surface of the thick shell element. When the joint moment of the rafter and masonry is fixed, a two-point link must be applied to bring it closer to a simple support. To satisfy bending moments closer to pin joints, two-point link elements are used during modeling.

3.9. SAP 2000 v 20

Computers and Structures developed the SAP2000 v20 software which offers a user-friendly interface for modeling, analysis, design, and reporting. Users can customize window layouts and toolbar configurations. As a finite element program, SAP2000 v20 has gained popularity for its versatility in designing and analyzing various structures such as buildings, bridges, dams, and industrial plants. Its practical and object-based modeling environment allows for easy to complex calculations in 2D and 3D models. SAP2000 v20 also provides a wide range of structural analysis techniques, including linear and

[3] SAP2000. Computers & Structures, Inc., Berkeley, California, USA, 1978-2016. 2016.

nonlinear analysis, static and dynamic analysis, seismic analysis with ground excitations, response spectrum analysis, and other types of dynamic analysis under time-varying constraining conditions.

A FEM model was created using SAP2000 v20 to evaluate the response of the structure to different levels of seismic activity. The isotropic elastic behavior was assumed, ignoring the effect of mortar joints as planes of weakness. These assumptions were useful in predicting low-level stress deformations but not higher-level stress deformations that result from nonlinear material behavior and local failure. Material models based on average properties and ignoring the effect of mortar joints were used, but including the possibility of local failure [21]. Brick masonry walls were modeled using isotropic surface members, i.e. shell elements, and wooden joists, beams, and posts were represented by isotropic linear members, i.e. frame elements [18]. The building model created in SAP2000 v20 is depicted in Figure 7.

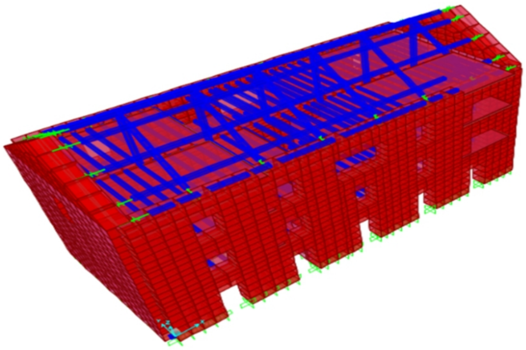


Figure 7. Building model in Sap 2000 v20
S o u r c e: made by K. Chapagain, H. Chaulagain

4. Results and discussion

4.1. Stress level in structure

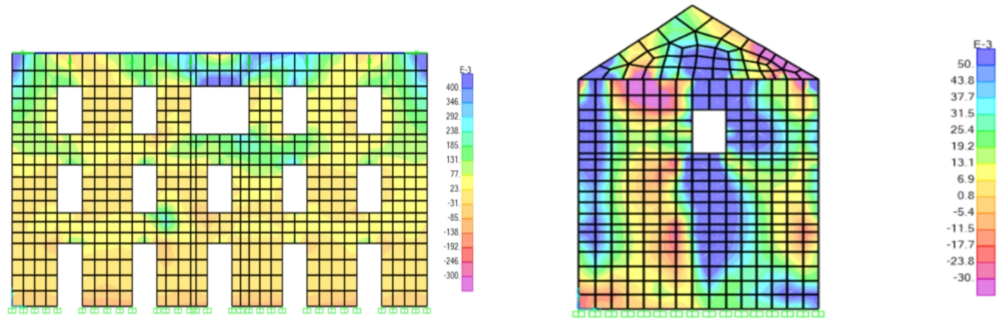
Table 4 shows the stress contour map of the building model generated by the finite element software SAP2000 v20 under the load combination of *DL+LL+THx* and *DL+LL+Thy*. The highest stress values were observed at the openings and the base of the building model, while the tensile stress was concentrated at the gabion. At a PGA of 0.30 in the three different considered earthquakes, the maximum compression stress (S11), stress in the perpendicular direction (S22), and shear stress (S12) were 0.564 MPa, 1.313 MPa, and 0.988 MPa respectively. Conversely, the maximum tension stress (S11), stress in the perpendicular direction (S22), and shear stress (S12) were 3.287 MPa, 3.436 MPa, and 2.0 MPa, respectively. Based on the permissible allowable stress of a masonry structure for compression, tension, and shear, the building model is safe in compression but not in tension and shear. The results also indicate that the structure performs better under loading in the y direction. Figure 8 shows the maximum compression shear stress (S11 and S12) in the building model.

Table 4

Stress on the building due to three different earthquakes MPa

Combination	Type of stress	El Centro			Gorkha			Kobe		
		S11	S22	S12	S11	S22	S12	S11	S22	S12
DL+LL+THx	C	0.434	1.294	0.673	0.469	1.302	0.646	0.336	1.228	0.453
	T	1.229	1.368	2.611	1.023	1.272	2.237	2.938	3.436	1.57
DL+LL+THy	C	0.564	1.313	0.988	0.378	1.304	0.576	0.491	1.251	0.872
	T	0.972	1.397	1.115	1.682	1.475	2.321	3.287	2.092	1.90

S o u r c e: made by K. Chapagain, H. Chaulagain



a *b*

Figure 8. Maximum shear stress:
a — S11; *b* — S12 in the building in compression (S12)
S o u r c e: made by K. Chapagain, H. Chaulagain

4.2. Fragility analysis

Fragility curves are useful tools for structural engineers and experts to assess the seismic vulnerability of buildings. In this study, fragility curves were generated for four damage states for three earthquakes: El Centro, Kobe, and Gorkha. The peak ground acceleration (PGA) values ranged from 0.10g to 1g with an interval of 0.05g, and the probability of failure for the structure was determined. From Figure 9, it is evident that the building model has a higher probability of failure for slight, moderate, extensive, and collapse damage levels in the Kobe earthquake at a PGA of 0.30g than in the El Centro and Gorkha earthquakes. Previous studies have highlighted a peak ground acceleration of 0.40g for Pokhara with a 10 % probability of exceedance in 50 years [22]. Therefore, the probability of failure at a PGA of 0.30 to 0.40 is significant in this study.

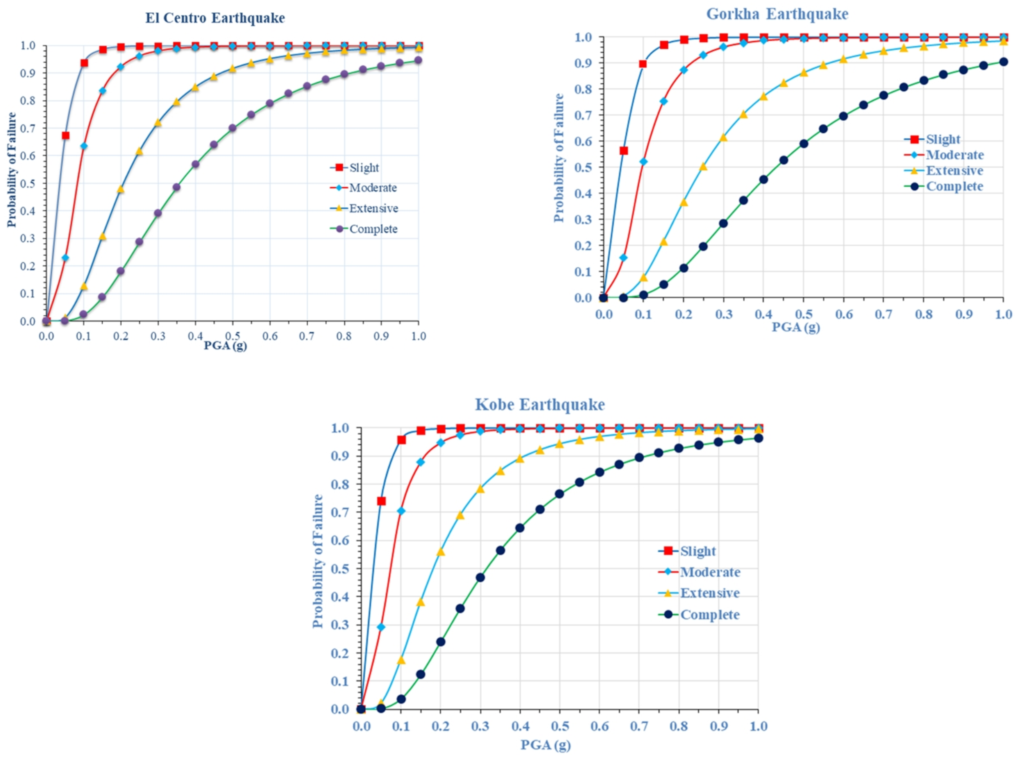
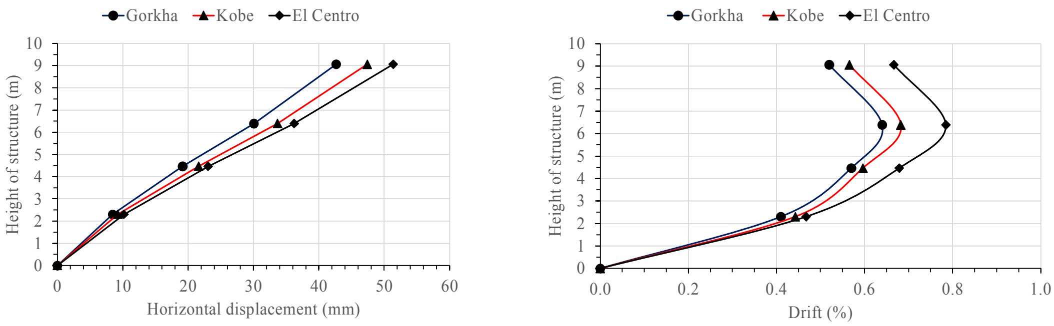


Figure 9. Fragility Curve of Old Newari Building for various Damage States at El Centro Earthquake
S o u r c e: made by K. Chapagain, H. Chaulagain

4.3. Inter-storey drift

Based on the results of the linear static analysis, it can be observed that the building model exceeds the standard drift limit proposed by the code (FEMA, 2008)[4] in all three earthquakes — Kobe, El Centro, and Gorkha. The displacement of the building is found to be the highest in Kobe earthquake, followed by El Centro and Gorkha earthquakes. Additionally, the displacement of the structure does not meet the prescribed limit, indicating its vulnerability in terms of displacement (Figure 10). This may be attributed to various factors, including the parameters associated with the time history function such as frequency content and duration (Table 5).



a *b*

Figure 10. Storey displacement and drift of building structure in different earthquakes:
a — Storey displacement; *b* — Storey drift
S o u r c e: made by K. Chapagain, H. Chaulagain

Table 5

Probability of failure at PGA = 0.3g for Centro, Gorkha and Kobe Earthquake

Earthquake	Slight	Moderate	Extensive	Complete	State of damage
El Centro	99.94	98.05	72.26	39.15	Extensive
Gorkha	99.85	96.19	61.78	28.56	Extensive
Kobe	99.97	98.79	78.46	46.94	Extensive

S o u r c e: made by K. Chapagain, H. Chaulagain

5. Conclusion

This research paper presents a case study of an existing 265-year-old Newari building made of brick masonry in mud mortar. In the numerical analysis, a masonry wall is modeled as a thick shell homogeneous element and timber is modeled as isotropic linear members frame element. Three earthquakes, namely El Centro, Kobe, and Gorkha earthquakes, with different peak ground acceleration values are considered as seismic input parameters. Based on the stress level and the fragility status of the building structure, the following conclusions are drawn:

1. The stress level of the building structure is within the allowable permissible limit in compression, while the tension and shear stress levels exceed the allowable limit, indicating the vulnerability of the structure to shear and tension.
2. The probability of failure of the building is higher in Kobe earthquake at the same peak ground acceleration value as compared to El Centro and Gorkha earthquakes. This may be due to the variation in model frequencies and predominant frequencies of the ground motion.
3. The displacement of the building model is maximum in Kobe earthquake followed by El Centro and Gorkha earthquakes, and the displacement of the structure is not within the same limit. Thus, the studied

[4] Federal Emergency Management Agency (FEMA). (2008). Disaster Program Information. Washington, DC: FEMA.

building is vulnerable in displacement parameter, which may be attributed to the parameters associated with time history function like frequency content and duration. Moreover, the building model has higher inter-story drift level as compared to the standard drift limit in all three considered earthquakes.

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