Integration of Modern Earthquake Resistant Techniques into Traditional Bhutanese Architectural Buildings for Enhanced Seismic Resilience

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Abstract

The project titled Integration of Modern Earthquake Resistance Techniques into Traditional Bhutanese Architectural Buildings for Enhanced Seismic Resilience explores the seismic vulnerability of traditional Bhutanese buildings and aims to enhance their resilience through the incorporation of modern base isolation techniques. Traditional Bhutanese buildings, while architecturally significant, are at considerable risk during seismic events due to their design and materials. This study employs ETABS-Extended 3D Analysis of Building Systems software to conduct detailed structural analyses, simulating seismic conditions and evaluating retrofitting interventions. A comparative analysis between fixed-base and base-isolated buildings reveals that base isolation significantly reduces displacements, accelerations, and inter-story drifts, thereby minimizing structural damage and preserving cultural heritage. The research enhances the essential of incorporating traditional construction methods with contemporary engineering solutions, which facilitates critical perceptions for seismic retrofitting strategies. The results of this project provide valuable directions for those who are involved in decision-making, engineers, and the public of Bhutan, problem solvers, and the heritage preservation of the region.

Keywords— Earthquake, resistant, Bhutanese, architectural, simulation

1 Introduction

Bhutan, known as a landlocked kingdom in the Himalayas zone, is renowned for its rich culture and natural beauty but has a high prediction of earthquakes due to its closeness to major tectonic plates. The traditional Bhutanese buildings which are constructed of stone, rammed earth, and wood were designed with exceptional seismic resilience, including the slopes of roofs and robust load-bearing walls [1]. On the other hand, rapid urbanization and changes in construction technology threaten the old practices and high prediction of extinct heritage culture [2]. Nevertheless, there are ways to offer a solution to enhance earthquake resilience as well as preserve the cultural heritage by applying a base isolation technique that incorporates bearings to decouple structures from the ground [3]. They used different isolators, viz. elastomeric and rigidity components, since it has properties to damp the seismic disturbance, whereby they control the forces that directly impact on the system [4]. Applying the isolator regulates the critical issues and analyzes the base isolation in traditional buildings to asses them effectively. Besides this device, the researchers also used software called ETABS to simulate the earthquake [5]. For future reference, the authors had recommended that although Bhutan is towards the Himalayas, it can preserve the architectural building methods and bring community safety by implementing base isolation with the traditional techniques [6]. The Bhutanese traditional buildings significantly threaten both public and cultural heritage, especially in earthquake regions due to seismic weakness. Even though these structures are intended to resist seismic isolations, there is an emergent requirement for a comprehensive evaluation of the structural integrity, so that it can identify the need for improvement and action to be taken as a retrofitting measure. The weakness of systematic assessment approaches and retrofitting strategies increases the risk of earthquake resistance as well as endangering human life and results in the loss of unique cultural heritage. For these reasons, it is critical to evaluate and implement successful base isolation techniques to enhance the seismic resilience of Bhutanese traditional buildings. This study intends to develop a corrective measure for retrofitting to ensure the structural safety and preservation of culturally significant.

Figure 1: Past earthquake damages on traditional Bhutanese structures

Upon the results and recommendations from the multiple papers on seismic retrofitting for traditional Bhutanese buildings, it was observed that a significant research gap is with the lack of base isolation systems in heritage structures. The purpose of base isolation is not only to strengthen the structure, it also adds the value of safeguarding against architecture, but another reason with the traditional structure is the lack of documentation on the uses of base isolators for retrofitting. This gap offers a chance to find out the benefits and challenges of integrating base isolation technology to improve seismic resilience. With this, it will assist in the control of seismic resilience on the traditional Bhutanese buildings, and gauge the effectiveness and compatibility of base isolation with the local construction materials by conducting a comparative study between fixed-base and base-isolated structures. Moreover, this study creates an opportunity to validate the challenges and opportunities for implementation as researchers. This topic aims towards seismic retrofitting so that it preserves historical heritage, and promotes safety to sustain Bhutan's built environment. With the above context, this project focused on integrating modern earthquake resistance techniques, explicitly on base isolation into traditional Bhutanese architectural buildings, hoping that this technique resolves to preserve cultural heritage and enhance seismic resilience. In addition, it also assists the seismic susceptibility of the home by comparing structural responses with and without the base isolation for seismic retrofitting. With the mentioned objectives of the project, it is likely to protect Bhutan's cultural heritage, ensure community safety against seismic hazards, and preserve Bhutan's architectural legacy.

2 Literature Review

Bhutan is located in a high seismic active zone (Zone V per Indian seismic code IS1893: 2002) and experienced high earthquake frequency as Bhutan lies close to the subduction of the Indian plate. In the year 1941, the people of Bhutan were a heart-wrenching experience, helpless, and momentous seismic forces in their life of history, which hit a 6.75 magnitude. According to the authors, in those days all the seismic data of Bhutan were recorded through the Indian seismic code as Bhutan did not have a standard code to record the earthquake frequencies. Moreover, the data recorded for those days are not sure of a perfect and accurate figure to address the specific seismic risk of Bhutan [1]. Upon the history of significant events dating back to the 18th century, Bhutan will be exposed to be of high seismic susceptibility to earthquakes. In the years 2009 and 2011, considerable damage was done to the rural homes. In continuation to the above incident, the investigation team observed that the failure of the structure is due to insufficient wall connections and delamination of wall wythes, and was not incorporated in developing an effective mitigation strategy [2]. In the line to the above statement, the authors recommended to work on the seismic retrofitting technique for traditional rammed earth house, viz. foundation reinforcement, wall reinforcement, bracing systems, shear wall construction, foundation isolation, damping devices, roof diaphragm strengthening, and seismic brackets to improve the structural integrity, control the seismic issue effectively, and enhance the safeguarding resilience against earthquakes [3][1]. In the year 2009, a group of researchers surveyed the impact of the earthquake in Bhutan and found that the maximum susceptibilities of earthquakes will be impacted to traditional stone and timber buildings due to weak masonry walls and lack of proper wall bonding. In this regard, the team highlighted the importance of seismic design and proposed mitigation techniques, viz. tapered wall, minimized opening, and improved mortar mix ratio to address the issues. In addition, it added that raising awareness and developing a regional seismic code will assist in enhancing the resilience [4][12]. The other solution to improve the damage of the structure is by applying the base isolation systems, which work by decoupling the structures from the ground to provide effective protection for the buildings against seismic forces. In this system, it absorbs and dissipates the seismic energy, thereby reducing the building vibrations, and enhancing stability, but it is likely to be a high initial cost, besides offering long-term cost savings, versatile, durable, and minimally disruptive during installation [5] [13]. Similarly, the group of authors had experimented on the base-isolated structures, and observed that by implementing a lower maximum drift and acceleration, it provides better performance than the fixed base structures. It is not too useless, the base isolation is valuable for low to medium-height unreinforced masonry buildings, including historic structures, that have the potential to reduce the building acceleration thereby enhancing seismic resilience [6][14]. With these findings, it ensures to continue to preserve, promote sustainability, and maintain a unique heritage culturally, and architecturally, besides the complex design of traditional Bhutanese architecture, which is made of different materials like woodwork, sloping roofs, rammed earth, and mud with stone. These are taken as Bhutan's cultural and spiritual traditions [7][15]. To address the problem and to fill the research gap, it worked on numerical solutions, viz. calculation of load for traditional Bhutanese buildings to ensure structural integrity. With this, it understands that the distribution and magnitude of dead and live loads are considerably considered. Nonetheless, it can also investigate and optimize the building designs of seismic resilience and sustainability using software [8]. To give more clearly and visually results, the team designed a model building of traditional Bhutanese rammed earth houses using ETABS software to determine the detailed analysis and behavior under various loads including seismic events. Finally, it observed that this approach helps in assisting the structural integrity and seismic resilience of those buildings, contributing to preserving and enhancing the modern engineering challenges [9][16].

3 Methodology

To enhance seismic resilience, it begins with exploring and gathering the literature review from multiple sources. The information from the various research papers, academic journals, and relevant subject topics gives comprehensive concepts on design, how it integrates the systems, and technological advancement to solve the issues. With these concepts, it gathers an approach to work on the Integration of Modern Earthquake Resistance Techniques with Traditional Bhutanese Architectural Buildings for Enhanced Seismic Resilience. The dataset was compiled after analyzing and synthesizing from multiple literatures, subsequent design calculations, and simulations. The collected data points include parameters, viz. types of rammed earth houses, load calculation, different types of retrofitting techniques, types of base isolators, and relevant factors that impact the integration and performance of the base isolator. This extracted data serves as valuable input for the subsequent stages of the design process, including conceptual design development and simulations. Based on this gathered information, the analysis method begins with 3D modeling of the Bhutanese traditional building in ETABS software, ensuring fidelity to architectural drawing and structural specifications. Material properties of mud and timber are defined with parameters such as density, modulus of elasticity, Poisson ratio, and coefficient of thermal expansion. Loading conditions are applied considering seismic excitation and stimulated earthquake scenarios based on Bhutans seismic zone factor [10]. The analysis is carried out in two phases: the first simulation is done on the structure without the base isolator, that is, a fixed base, followed by the simulation on the same structure with fixing the LRB isolator. The comparative analysis of the result is measured on parameters, viz. maximum displacement, maximum drift, fundamental period, and base shear.

3.1 Data collection

Traditional Bhutanese building is built mostly using damped mud and timbers. The walls are constructed out of rammed earth wall mostly painted in white or in stone masonry. The ground floor has thick earth walls with minimal, and small openings with a door. The upper floors are enclosed with mud walls and timber frame structure with in-fill of plastered bamboo weaving (ekra). [8]. The buildings have pitched timber roof shingle. The roof is pitched for quick water discharge during excessive rainfall during summer monsoon. It is made of wooden shingles over which laths run across. The technical drawings of common traditional Bhutanese buildings are given below:

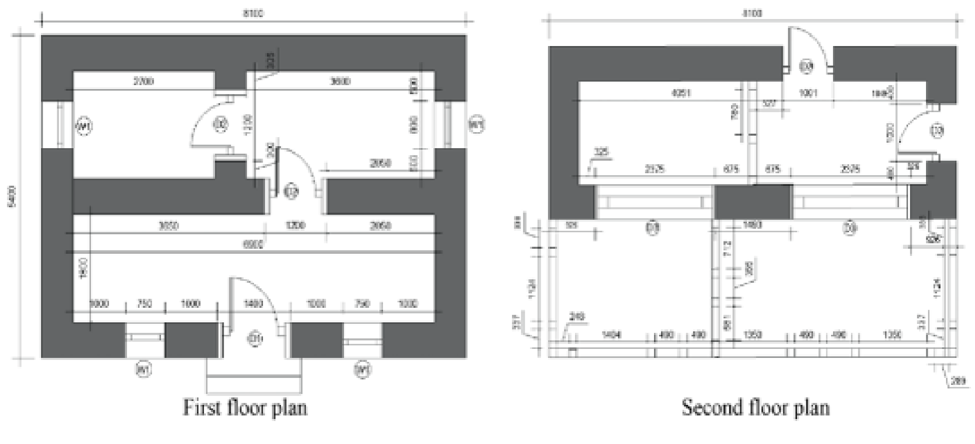

Figure 2: Drawing using AutoCAD showing layout plan for first and second floor

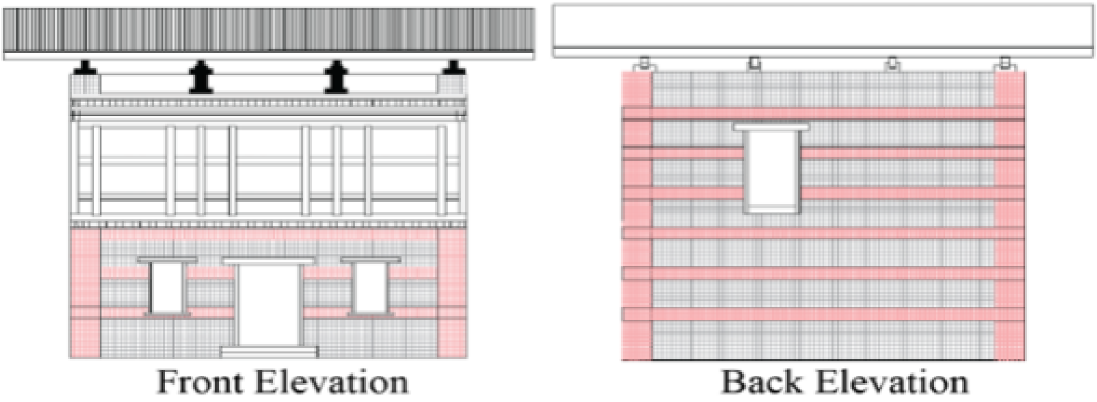

Figure 3: Drawing of Front and back view of Traditional Bhutanese building using AutoCAD

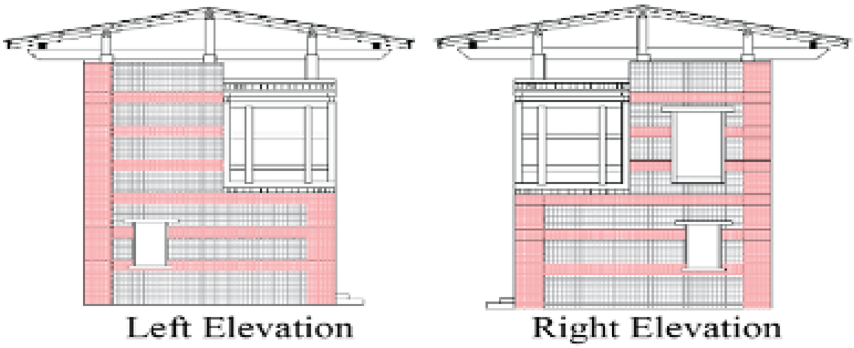

Figure 4: Drawing of Side views of Traditional Bhutanese buildings using AUTOCAD

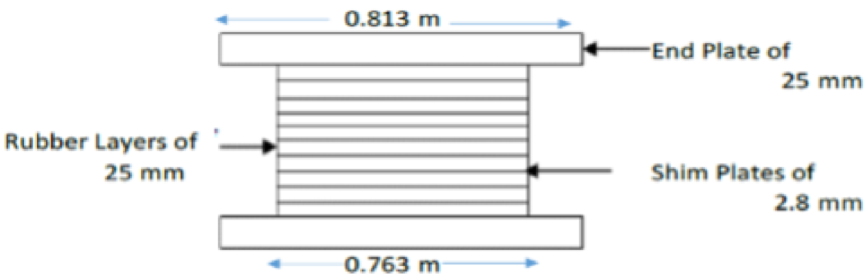

Figure 5: Design of LRB isolator by DECODE BD

Seismic isolation tools are called lead rubber-bearing isolators, which are frequently applied in civil engineering to shield the building from damage by earthquakes [6]. They are made up of rubber layers with a lead core embedded in the rubber, sandwiched between steel plates. Because of its design, the bearing can flex under lateral loads during an earthquake, absorbing and dispersing seismic energy while still being able to support vertical loads. In earthquake-prone areas, lead rubber bearing isolators are useful for minimizing damage, lowering structural vibrations, and guaranteeing the stability and safety of bridges, buildings, and other infrastructure [17]. Universal, they are the preferred option for both new construction projects and seismic retrofitting due to their strength and adaptability. Figure 5 shows the drawing of the LRB isolator which has the capacity of a maximum vertical load of 1825.5 kN.

Table 1: Salient features of proposed traditional Bhutanese building

Particulars	Values
Type of building	Masonry building
height of each story	3 m
thickness of walls	609.6 mm
Total height of building	8.2 m
Seismic zone	5
Support conditions	Fixed
Dead load	1523.903 kN
Live load	112.23 kN
Size of timber beam	180 mm by 200 mm
Size of timber column	180 mm by 200 mm
Thickness of timber slab	60 mm

Table 2: Materials properties used for constructed building

Materials	Density (kN/m^3)	Modulus of Elasticity (N/mm^3)	Poisson Ratio	Coefficient of Thermal Expansion ($(10^{-6})/°C$)
Mud	19.6	45	0.22	6.0
Timber	6.3	11850	0.30	5.6

Table 3: Properties of LRB Isolator

LRB isolator properties	Values
Rotational Intertia	0.016603 ($kN\text{-}m^2$)
For U1 Effective Stiffness	1175418.57 kN/m
For U2 and U3 Effective Stiffness	1175.42 kN/m
For U2 and U3 Effective Damping	0.05
For U2 and U3 Distance from End-J	0.00318 m
For U2 and U3 Stiffness	10831 kN/m
For U2 and U3 Yield Strength	34.70 (kN/m^2)

3.2 Load Calculation of the Designed traditional Building

Formula used for the calculation of loads: -

3.2.1 Dead Load

Volume = length * width * thickness
Dead Load = Volume * density or unit weight of the element
Total vertical load = Dead load + Live load

3.2.2 Live Load

live load =Standard loading Œarea

The total dead load of the proposed traditional Bhutanese building was calculated to be 1733.9591 kN. As for the live load, the table below gives the standard live loads of a residential building according to the IS-875.

Table 4: Calculated dead load of first floor and roof

Wall Elements	Unit Weight (kN/m^3)	Height (m)	Length (m)	Thickness (m)	Volume (m^3)	Qty	Weight (kN)
G Floor Slab (All Beam)	6.3	0.2	4.8	0.2	0.192	13	15.72
G Floor Slab (All Plank)	6.3	1.8	6.9	0.508	0.631	2	7.94
Back Facing Wall	19.6	3.0	8.1	0.6096	14.81	1	290.34
Right Facing Wall	19.6	3.0	2.39	0.6096	4.372	1	85.68
Left Facing Wall	19.6	3.0	1.39	0.6096	2.542	1	49.85
Central Partition Wall	19.6	3.0	2.715	0.6096	4.965	1	147.20
Door 1	6.3	2.0	2.375	0.15	0.712	1	4.48
Door 2	6.3	2.0	1.8	0.15	0.54	1	3.40
Door 3	6.3	2.0	1.0	0.15	0.3	1	1.89
Front Facing Rabsel	6.3	3.0	8.1	0.15	3.645	1	22.96
Left Facing Rabsel	6.3	3.0	2.25	0.15	1.0125	1	6.38
Right Facing Rabsel	6.3	3.0	2.25	0.15	1.0125	1	6.38
Steps	6.3	1.5	4.2	0.152	0.9	1	6.05
All Roof Sheet	6.3	3.46	9.8	0.51	1.72	2	21.70
Roof Thrust	6.3	-	-	-	-	9	25.67
F Floor Slab (All Beam)	6.3	0.2	4.8	0.2	0.192	13	15.72
F Floor (All Plank)	6.3	1.8	6.9	0.508	0.631	2	7.94
					Total Dead Load		719.3091

Table 5: Live load for residential building

Occupancy	Loading (kN/m^2)
All rooms and kitchen	2.0
Toilets and bathrooms	2.0
Corridors, passage, and staircase	3.0
Balconies	3.0

Table 6: Calculated dead load of ground floor

Wall Elements	Unit Weight (kN/m^3)	Height (m)	Length (m)	Thickness (m)	Volume (m^3)	Qty	Weight (kN)
Back Facing	19.6	3.0	8.1	0.6096	14.81	1	290.34
Right Facing	19.6	3.0	3.4	0.6096	6.30	1	145.87
Left Facing	19.3	3.0	3.4	0.6096	6.02	1	121.78
Front Facing	19.3	3.0	5.2	0.6096	9.51	1	243.72
Central Partition	19.6	3.0	5.7	0.6096	10.43	1	204.33
Room Partition	19.6	3.0	0.6	0.6096	0.108	1	2.14
Windows	6.3	1.0	0.8	0.15	0.12	4	3.02
Doors	6.3	2.0	1.2	0.76	0.182	3	3.46
					Total Dead Load		1014.65

3.3 3D Model Development and Simulation in ETABS

After the required properties were defined, it was proposed the traditional Bhutanese building using all the information provided above. Firstly, the foundation was set, on which the mud walls were drawn for the first floor. The doors and windows opening were drawn after which the timber beams were laid to hold the timber plank as a slab for the second floor. Half a section of the second floor was constructed using the timber frame and the other half section was mud wall. The roof structure was constructed after the completion of the second floor. The figure below illustrates the model of the proposed traditional Bhutanese building in ETABS.

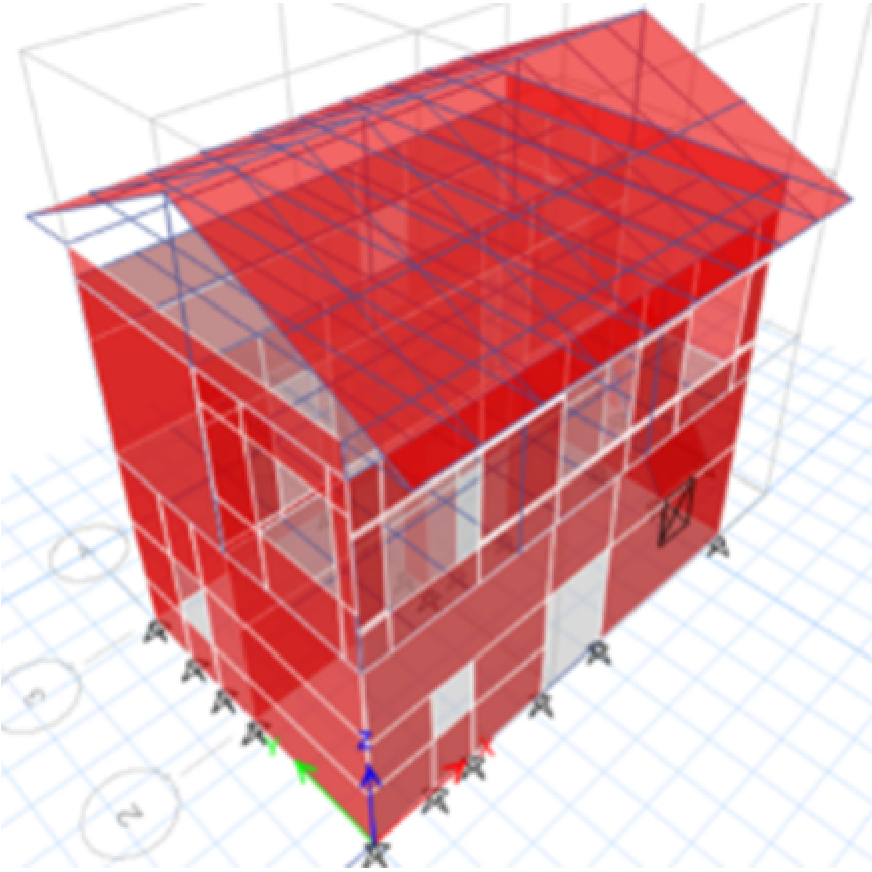

Figure 6: 3D model of building in ETABS

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The figure 7 shows the 2D diagram of the base of the building with LRB isolators. The LRB isolators were placed automatically by the ETABS software such that the isolators were fixed around the mud wall and observed there with maximum vertical load due to the structure. The cross marked on the plan view shows the base of the building, where the LRB isolators are placed.

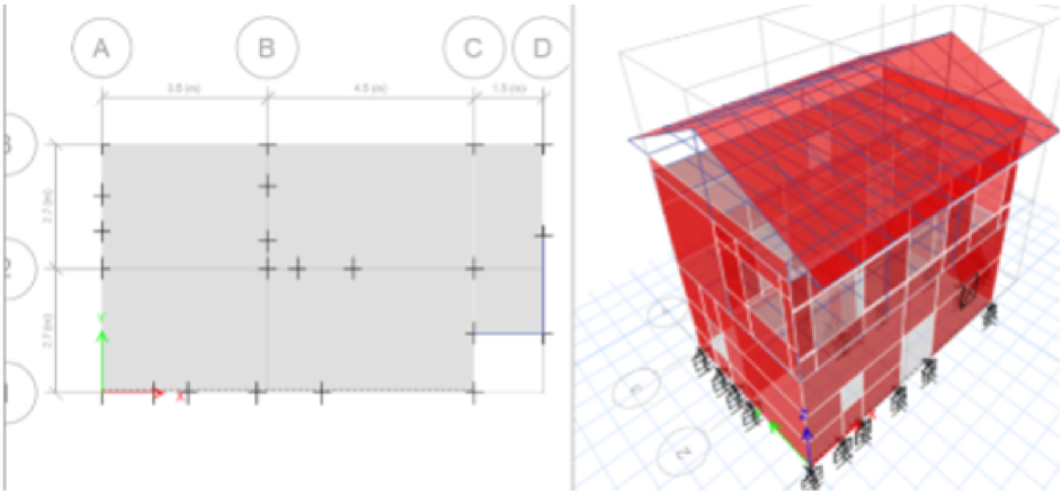

Figure 7: Location of the LRB isolator

Since Bhutan lies in a proactive earthquake region, the simulation was done by giving the seismic load of zone 5, where zone 5 encompasses the regions that are most susceptible to earthquakes with an intensity of MSK IX (Destructive) or higher. The zone 5 has a zoning issue of 0.36 according to the IS code. This problem is used by structural engineers to design structures in Zone 5 for earthquake resistance. The zone issue of 0.36 is indicative of effective (zero periods) level earthquakes.

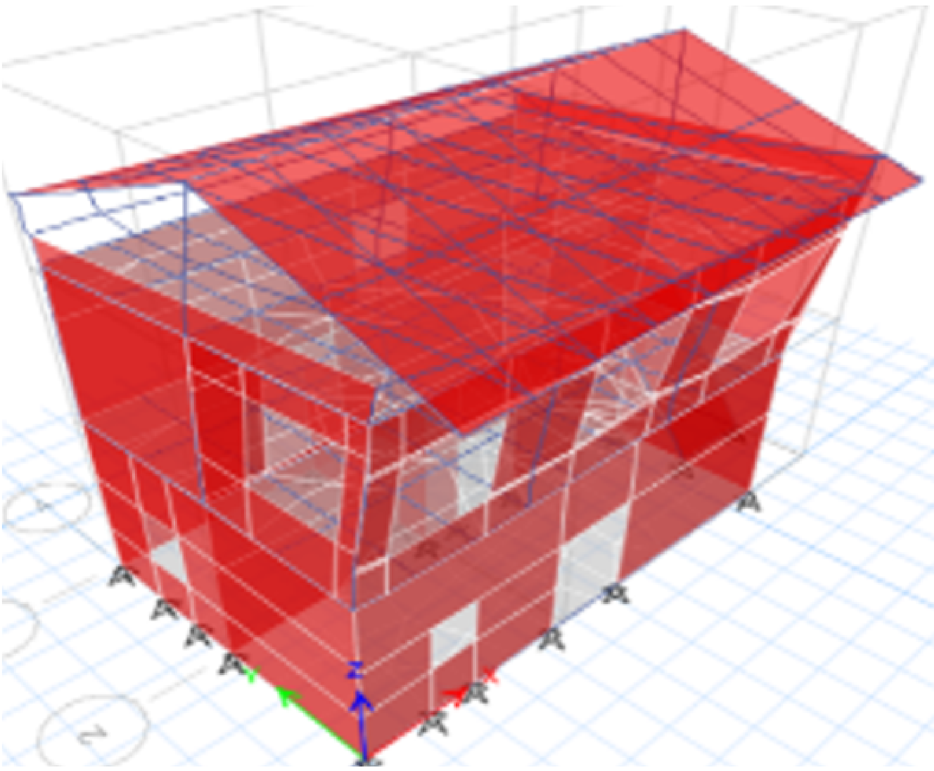

Figure 8: Deformed structure of building after applying seismic load

4 Result and Discussion

4.1 Results

Table 7: Values obtained from ETABS after simulation

	Building with Fixed Base	Building with Isolators
Maximum Displacement	10.22 mm	16.619 mm
Maximum Drift	0.001587 mm	0.001381 mm
Fundamental Time Period	0.611 s	1.23 s
Base Shear	926.73 kN/mm^2	217.0087 kN/mm^2

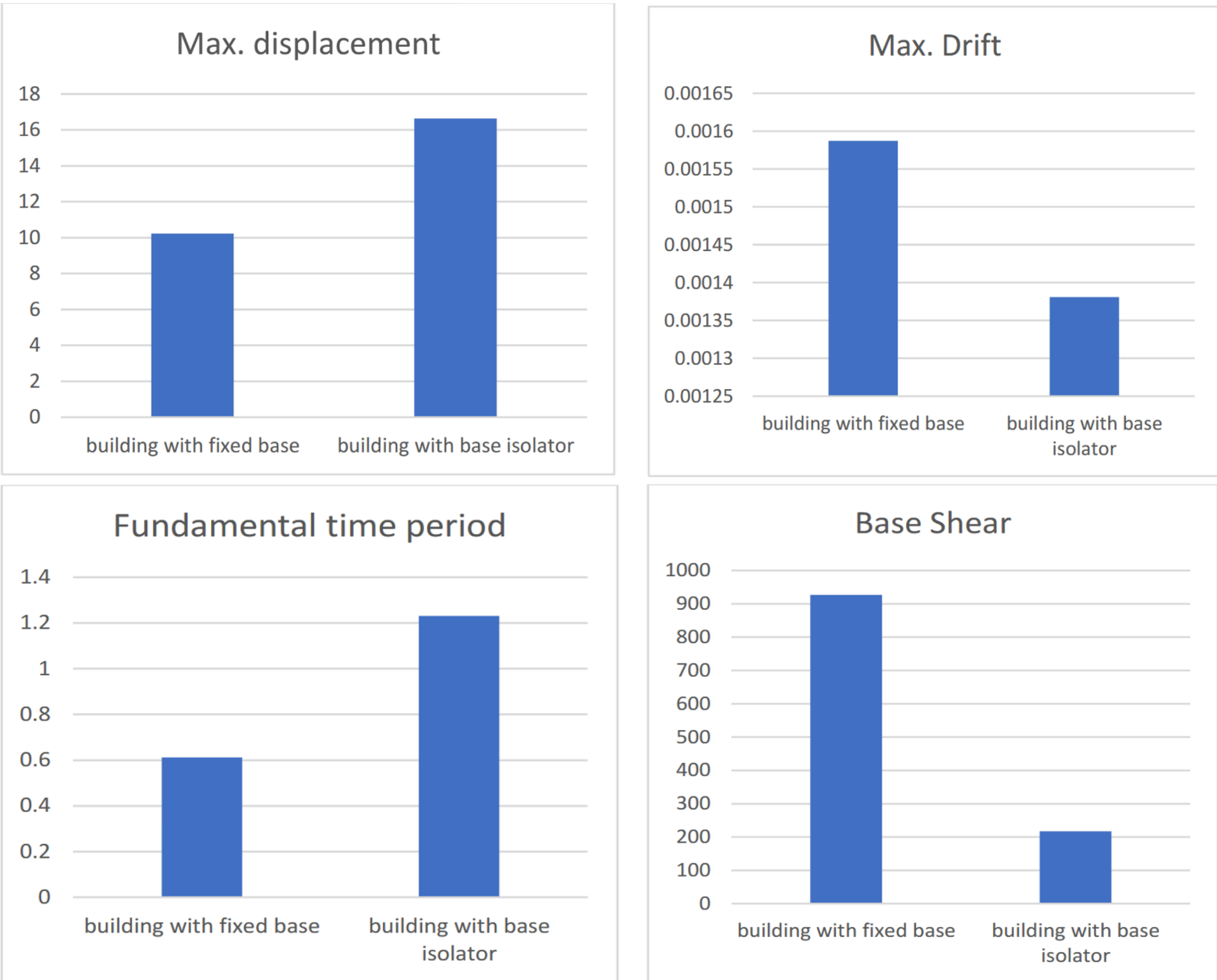

Figure 9: Displacement, drift, time period and base shear of building

4.2 Discussion

The comparison and analysis of the structure with and without base isolation is examined based on the characteristics, viz. maximum displacement, maximum drift, fundamental time, and base shear as shown in Figure 9. It observed that the base isolation generally performs better in terms of reducing movement and forces during seismic events. To provide better and clearer information, it is illustrated by breaking down the elements as follows.

4.2.1 Maximum displacement

The maximum displacement of a building with a base isolator is typically higher compared to a building with a fixed base. This indicates that

- The base isolator system effectively reduces the seismic forces transmitted to the building, which allows it to move more freely during an earthquake.
- By allowing the building to move with the ground motion, base isolators dissipate seismic energy and reduce the forces transferred to the structure, thereby increasing its resilience to earthquakes.

4.2.2 Maximum drift

The building with a fixed base is observed higher maximum drift as compared to the base isolator and the following are its functions.

- The base isolator system has the potential energy to reduce the lateral movement or sway of the building at the time of seismic.
- For these reasons the building with base isolators there is less deformation and structural damage, whereby there is a possibility to improve the seismic performance and lower maintenance costs.

4.2.3 Fundamental time-period

It observed that the maximum displacement is generated by a building with a base isolator as compared to a building with a fixed base. This indicates that

- The base isolator system has the potential energy to reduce the seismic forces that are transmitted to the building and allows it to move more freely during an earthquake.
- This is done by movement of the base building to ground motion, and the base isolators dissipate seismic energy and reduce the forces transferred to the structure, thereby increasing its elasticity to earthquakes.

4.2.4 Base shear

The base shear for a building is less in the base isolator as compared to a building with a fixed base which specifies;

- It reduced the seismic forces transmitted to the structure.
- The reduction of base shear advocates that it minimizes the damage imposed on the building during an earthquake.
- This base isolator helps to protect and improve the structures by absorbing and dissipating the seismic forces.

5 Conclusion

In conclusion, this comparative study will provide better and strengthened traditional buildings with information to improve the seismic resilience of traditional Bhutanese buildings and the efficacy of base isolation techniques. With the comparative, it also conducted alternative approaches to measure the comprehensive structural analysis and dynamic simulations using ETABS software. The simulation was done for both the traditional Bhutanese building models with and without base isolators on the response to the seismic. It was observed that there was a positive signal in preserving and retrofitting traditional Bhutanese buildings to mitigate the influence of seismic energy as well as preserve the cultural heritage. The results show the base isolation techniques significantly reduce the structural response of traditional Bhutanese buildings to seismic of displacements and accelerations. By decoupling the structure from the ground motion, the base isolators dissipate seismic forces and mitigate the risk of structural damage, thereby enhancing overall resilience. With the experience from this analysis, it is recommended that seismic retrofitting strategies be tailored to aiming to strike a balance between preserving cultural heritage and ensuring structural safety. The seismic controlling can be done by the implementation of base isolation systems, reinforcement of critical structural elements, and augmented traditional construction techniques with modern engineering principles. Hoping that this study will contribute fundamental knowledge on seismic resilience and heritage preservation, which offers valuable insights for the policymakers, engineers, and communities of Bhutan as well as seismic-prone zones. In fact, integrating traditional wisdom with innovative retrofitting approaches has tremendous advantages in longevity, and the safety of traditional Bhutanese buildings, in which it preserves the significance of culture for future generations.

6 Recommendations

To bring seismic resilience, it is essential to adopt tailored retrofitting solutions to address the unique structure safety and characteristics of weakened areas. Before it hence, it must have comprehensive capacity building and training for local stakeholders, providing financial incentives and support mechanisms. In this, it is important to develop and enforce the updated building codes and policies that integrate modern earthquake resistance. With these mechanisms, it is important to reach public awareness, campaigns, and educational initiatives on the benefits of retrofitting. The system must have robust monitoring and evaluation systems to ensure the effectiveness and durability of interventions.

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